Electricity Advisory Committee

TO: **Honorable Patricia Hoffman, Acting Assistant Secretary for Electricity Delivery and Energy Reliability, U.S. Department of Energy**

FROM: **Electricity Advisory Committee**
Susan Tierney, Chair

DATE: **June 7, 2017**

RE: **High Penetration of Energy Storage Resources on the Electricity System**

Purpose and Approach

Over the past twenty years, numerous studies have focused on the impact of a high penetration of renewables on the electric grid. These studies informed the work undertaken to enable the increasing adoption of wind and solar installations in the industry today. Very few comprehensive studies of a similar nature have been conducted for energy storage. However, with significant grid storage already installed and active procurements underway throughout the United States, a similar approach could be beneficial for investigating how the transition to a high penetration of energy storage (HPES) future might affect grid design or operations. In recognition of this research gap, and because of many future uncertainties, the U.S. Department of Energy's (DOE) Electricity Advisory Committee (EAC) utilized a scenario planning process to investigate the question and develop a set of recommendations for how DOE might further explore the implications of an HPES future. This paper reflects the outcomes of using scenario planning to envision and understand possible grid effects from a significant penetration of energy storage.

Scenario Planning Process Overview

To help develop scenarios of how the future electric grid may look given a high penetration of energy storage, the EAC Energy Storage (ES) Subcommittee chose two "independent" variables from among a number of highly variable drivers that would significantly impact grid and utility operations. This led to four distinct scenarios as depicted in the graphic below. The first driver is whether *public policy* or *competitive markets* shape the evolution of the electricity delivery system. Policy-driven scenarios reflect a society that, for various reasons, leans toward a preference for decisions made by policy makers and government support, perhaps in the form of subsidy, regulation or mandates, focused on achieving societal goals. Market-driven scenarios on the other hand, reflect a society leaning toward market-based decisions where competition drives innovation and promotes its adoption by market participants.

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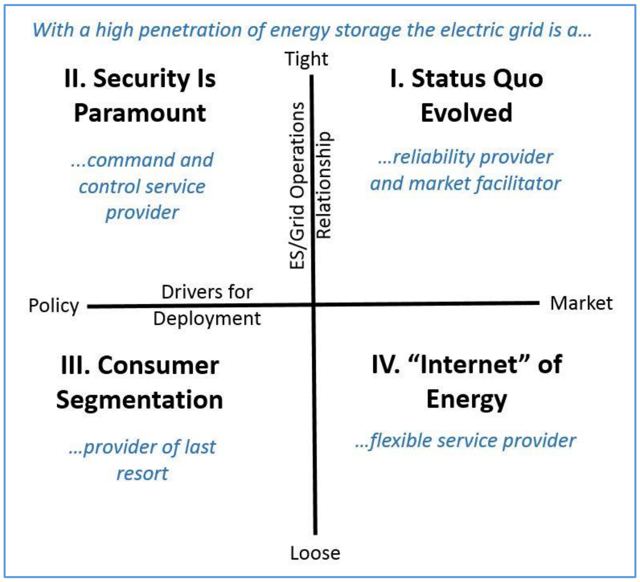
The second driver focuses on whether energy storage in the future scenario is tightly integrated or loosely integrated with electric grid operation, design, and planning. In a tightly integrated future, the electric grid institution—e.g., the utility or Independent System Operator (ISO)—tightly controls dispatch, deployment, or design of energy storage that interfaces with the electric grid. In a loosely integrated future, the electric grid institution loosely controls dispatch, deployment, or design—or may not at all. While other drivers were considered, the policy landscape and the structure of grid operations were deemed the most critical factors in producing disparate scenario outcomes. By evaluating the grid characteristics and energy storage impacts in each scenario, the ES Subcommittee developed recommendations on the type of analysis and other research that is needed to understand fully the challenges and opportunities facing an electric grid with HPES.



For reference, the matrix to the right outlines the four scenarios positioned along the axes that represent the two variable drivers impacting the future scenario outcomes. A summary of the scenarios is below, followed by an overview of the resulting impacts and recommendations, which are aggregated across scenarios. More detailed discussion of each scenario can be found in the Appendix.

Scenario Descriptions

All four scenarios developed by the EAC ES Subcommittee members share the overarching assumptions listed in the box below. However, variations both in drivers of storage deployment and in the structure of the relationship between storage owners and grid operators led to divergent scenario outcomes.

Scenario I: Status Quo Evolved (Tightly Integrated, Market Driven)

In Scenario I, the future grid is, much as today's is, a reliability provider and market facilitator. A notable characteristic is that there is less use of traditional generation for ancillary services and congestion mitigation. Storage has become the low-cost solution in the market for flexibility and is being deployed throughout the electric power sector as a result of careful system planning and efficient price signals. Storage is well integrated with markets as a market participant and is directly managed/operated by either the load- serving entity (LSE) and/or the ISO.

Grid operators primarily use distributed storage resources more so than central station thermal resources to provide grid-balancing services, while long-term planning accounts for a combination of generation and storage to meet resource adequacy needs. High levels of Distributed Energy Resources (DERs)—including storage—also increase grid resiliency against natural disasters and other outage scenarios. This structure limits rate-based energy storage to specific transmission and distribution applications, but utilities rely on storage to meet local service and reliability responsibilities. Overall, a more efficient market supports a wider range of low-cost storage products and services available to customers, including behind-the-meter storage.

Scenario II: Security Is Paramount (Tightly Integrated, Policy Driven)

In Scenario II, the grid is a command-and-control service provider. A key characteristic is that societal concern about reliability, security, and resiliency in the wake of natural and man-made disruptions to the grid has led to national and state policies calling for storage to address these concerns and tight integration with the grid. FERC- and NERC-mandated policies require transmission companies to install storage to provide fast-balancing resources. State-level policies mandate that utilities procure storage in order to address operational problems that had developed as high levels of renewable generation displaced traditional centralized generation. Further, the standardization of inverter-connected resources has been identified as the best means by which to ensure grid stability and function.

As a result of these policies, interoperability and grid security are high. Innovation in storage markets is low due to barriers to entry that avoid complicating interconnection with the grid. Utilities maintain "command-and-control" authority over electricity dispatch, and tightly influence generation and storage procurement. That, coupled with the deployment of microgrids with storage as a key element of grid operations, enables utilities to provide a high level of reliability and resiliency to customers. Increased reliability is accompanied by higher electricity costs, as regulators allow utilities to rate-base their service contract procurements and investments, passing costs through to customers. Any net increase in electricity prices is generally accepted by consumers since they value the increased reliability and resiliency of the grid. Customers can also purchase various reliability "plans" from their local LSE that makes use of microgrids and storage-related products to achieve even greater energy assurance.

Scenario Assumptions

A set of assumptions was applied to all scenarios. Several are noted below; more detailed descriptions can be found in the Appendix.

- There is HPES.
- Energy storage technologies can include all forms of storage, electric and non-electric.
- While total storage penetration is high for all scenarios, market forces determine adoption of specific storage technologies.
- Wide varieties of energy storage technologies are safe, reliable, and commercially available.
- Electric vehicles by themselves could potentially become a significant storage resource.
- Demand for electricity is price elastic, as is customer demand for plug-and-play storage technology.
- Different scenarios enable utilities and consumers to monetize benefits from energy storage in various ways.
- The grid offers a minimum level of reliability, while greater operational reliability is achieved in various ways depending on policy or market drivers and system integration.

Scenario III: Consumer Segmentation (Loosely Integrated, Policy Driven)

In Scenario III, the grid is the provider of last resort. The defining factor is that policy decisions fuel grid defection, with the few remaining grid services focused on disenfranchised customers who are unable or unwilling to leave. When most states rejected or reversed net energy metering (NEM), these policies unleashed an energy independence movement where customers, in large numbers, bought storage to optimize their solar arrays, aided by significant reductions in energy storage and rooftop solar installed costs. Private technology companies now offer integrated "smart home" solutions that compete directly with utilities. As the provider of last resort, the grid owner provides basic reliability to remaining grid-dependent customers, but reliability differs among customers.

Storage is being used sub-optimally because it is not available for grid-support services. In spite of jurisdictional and regulatory battles with public utility commissions and utilities, demand for more reliable electricity fuels demand for microgrids *among* commercial customers and affluent communities. Independent microgrid developers flourish. Backlash due to high departing load charges, interconnection charges, and various forms of fixed costs only serves to drive wealthier and more energy-efficient customers off the grid at an accelerated pace. The remaining traditional grid-tied customers experience inflationary costs due to cost shifting as the ratepayer base has shrunk, effectively disenfranchising a segment of customers who are categorically less affluent. Disadvantaged communities that are linked to the grid must rely on political pressure to negotiate controlled or subsidized service costs.

Scenario IV: "Internet" of Energy (Loosely Integrated, Market Driven)

In Scenario IV, the grid is a flexible service provider that enables transactive energy markets by delivering a kilowatt-hour from any place to anyone at any time. A notable aspect is that the grid operates under high uncertainty with little control of events at either end, following fast-paced market development that has rapidly increased the penetration of energy storage on the grid. This scenario assumes the transactive market anticipates and provides the services that can support electricity delivery and reliability, although low levels of coordination with the utility in the implementation and operation of storage prevent optimal storage deployment. Utilities serving as Distribution System Operators (DSOs) continue to operate the distribution system as a regulated utility but with two-way, dynamic rates that recover the regulated costs of the distribution grid.

Transactive energy solutions have transformed many commercial and residential customers to become "prosumers."[1] Energy storage is now also part of a growing number of appliances, like televisions and refrigerators, and of course electric-powered automobiles. The "Internet of Things" (IoT) allows very small loads to respond to signals from the grid. Many offerings are available in the market that bundle transportation, building management, distributed generation, and security. As a result, transactive energy platforms are the norm, enabling consumer-automated systems to respond to purchase-and-sale offers from wholesale market participants as well as ISO/DSO markets. The combination of these responsive loads, storage, and quick start generation allows load balancing through transactive price response in the morning and evening peak hours while consuming midday over-generation of solar with high storage penetration. The communication of the tenders and the transactions among parties is managed by transactive energy platforms, which more evenly distributes load and decreases the need for new transmission and distribution infrastructure.

Impacts Highlighted by Each Scenario

Each of the four scenarios highlight unique impacts on various electricity market stakeholders and aspects of the industry. These were categorized into key focus areas and aggregated, as listed below, in order to demonstrate the wide range of impacts anticipated across all four planning scenarios. A detailed breakdown of the impacts by scenario can be found in the Appendix.

Customer interests: Customers face the lowest costs for storage and the widest selection of retail storage technologies when high market choice prevails, as described in Scenario IV, as well as to a lesser extent in Scenario I. In customer-centric scenarios, policy-driven structures can lead to segmentation, with some defection by wealthier frustrated customers who are enabled by a range of technologies and options (most notably observed in Scenario III). When the utility maintains tight control of grid integration, as represented in Scenario II, customers face the highest electricity costs and the lowest ability to operate storage assets as prosumers.

The utility business model: In Scenario II, "command and control" remains the traditional utility-owned grid business model, with the grid owner/operator either owning or procuring generation and coordinating with the

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[1] See full definition in Appendix footnote on page 13.

ISO. In outcomes projected in Scenarios I and IV, the utility remains a key component of the system, such as in the transactive energy future of Scenario IV where it seeks to meet customer demands by serving as a platform for an increasingly complex array of DER technologies. On the opposite end of the spectrum in Scenario III, a loosely integrated and policy-driven scenario, the utility is less pervasive, serving only as the provider of last resort for the customers unable or unwilling to defect.

Generation assets: Centralized generation prevails only as long as the utility business model governs its procurement and dispatch, as seen in Scenario II. In all scenarios, greater penetrations of distributed generation on the grid expanded the need for storage, either as a centrally controlled asset or deployed as a microgrid component, including at the customer level. Whether storage is the low-cost option (Scenario I), the reliability option (Scenario II), or a component of transactive energy markets (Scenario IV), greater storage penetration, in turn, supports distributed generation at higher volumes.

Grid reliability and resiliency: When the utility has strong control, as in Scenario II, higher costs and reduced product innovation are a tradeoff for greater reliability, security, and resilience. Ideally, greater deployment of energy storage as a flexible, dispatchable source of electricity could also improve reliability in multiple scenarios. However, as seen in Scenario IV, the rise of “smart” grid technology may simultaneously increase the entry points for cybersecurity threats. Scenario III, meanwhile, depicts a loss of customer faith in the utility to provide reliable service, speeding grid defection.

Ratepayer costs: Given the underlying assumption that power costs largely drive customer behavior, both customer load curves and demand for distributed storage assets are largely determined by the price and retail availability of energy storage in Scenarios I and IV. Customers face the lowest costs when high competition exists among storage technologies, such as in Scenario I. In Scenario IV, since grid infrastructure is flexible, automated and modernized to support bilateral energy flow and communication, electricity costs are similarly low. When the utility fails to meet expectations of reliability at low enough cost—like in Scenario III—customers who can afford to defect from the utility will do so, leaving those unwilling or unable to defect to bear the burden of stranded asset costs. In Scenario II, where the utility controls the entire system, customers bear all asset costs, paying substantially higher electricity prices, but have the highest levels of reliability in return.

Recommendations

Nearly all scenarios result in significant impacts to grid infrastructure, the utility role and business model, and the costs and flexibility facing customers. Several constants throughout all scenarios are:

- Substantial growth in the penetration of variable, distributed generation in driving the demand for storage;
- The high penetration of storage establishes a critical need to clearly define who holds responsibility for resource planning and reliability;
- A high penetration of storage will reduce the need for flexible generation and grid expansion; and
- The interconnection of distributed storage resources calls for an increased focus on infrastructure security and energy reliability.

Recommendations for DOE on critical research and analysis priorities are included in the table on the following page. Recommendations are broken out according to the stakeholders most directly impacted by each area of concern, as this may inform DOE’s prioritization of which recommendations to address.

Beyond the recommendations contained in the table, the EAC recommends that DOE conduct scenario studies that are similar to the one completed by the ES Subcommittee, yet that are more robust and comprehensive. The EAC recommends that DOE-led scenario studies address a wider range of subject questions and variable drivers, and include different sets of scenario planning participants from among electric grid stakeholders.

Stakeholders Impacted	Recommendations for DOE's Research and Analysis Efforts
	** Indicates a recommendation resulting from multiple scenarios.* *I ,II, III, and IV indicate which scenario resulted in the recommendation.*
Grid Owner/Operator	• Evaluate ways to expand electric system visibility, including visibility into available multi-use distributed energy storage capacity.* • Promote probabilistic forecasting and reliability modeling tools.* • Facilitate coordination and identify the operational needs between the reliability coordinator and the generation, transmission, and distribution operators that will enable transactive markets to function and support prosumer participation.* • Support research efforts into the cyber-hardening of grid tech.* • Evaluate how use of automation and AMI can support rapid response. (IV) • Support the development of planning and modeling tools that identify the "core grid characteristics," and optimize the types of storage to address system requirements, which can be applied to wide area interconnection or microgrids. (II) • Promote research into energy-efficient storage technologies. (III) • Support development of tools and strategies to address challenges associated with the reduction in system inertia due to stiff loads and asynchronous resource connections (e.g., new control strategies, power electronic controllers, and protection systems to address the high-speed, un-damped reaction from grid disturbances, such as from routine events like weather-induced faults)* • Develop coordination algorithms to enable optimal charging of battery resources, while at the same time supporting local demand and grid essential reliability services.*
Policymakers and Regulators	• Develop frameworks to quantify and value reliability and resiliency.* • Research minimum technical and economic requirements that would enable greater DER interconnection or grid defection.* • Research and publish rate design, regulatory, and policy best practices ("dos" and "don'ts" to help avoid grid defection). (III) • Convene working groups to resolve conflicts between policy and free market behavior. (I) • Research market design that will allow transactive and flexible markets to develop. (IV) • Examine potential conflict resolution between defector and disenfranchised consumers. (III) • Research business and regulatory models, roles, and platforms. (IV) • Evaluate two-way subscription and spot distribution tariff alternatives. (IV) • Continue to update and fund publicly available information on grid-connected storage deployment and policies.*
Market Designers and Facilitators	• Review jurisdictional responsibilities for ensuring grid reliability.* • Facilitate market designs that function according to the following:* ➢ In a highly regulated environment. (II) ➢ Where microgrids dominate the landscape. (III) ➢ In a transactive energy market. (IV) • Evaluate energy storage deployment in varied topologies and for a wide range of functions and uses. (I)

Stakeholders Impacted	**Recommendations for DOE's Research and Analysis Efforts**
Consumers	• Provide funding opportunities for pilot projects and testing to ensure storage products are safe, automated, and user-friendly.* • Develop standards to govern the operation and integration of energy storage assets that preserve cyber and physical security.* • Support development of storage technologies that can operate as part of a microgrid system.* • Research technologies that facilitate greater communication between participants in transactive energy markets. (IV)
All Electricity Market Players	• Develop detailed safety, performance, and consumer protection standards for storage technology.* ➢ Examine appliance standards that include storage for water heating and space heating. • Develop modeling tools and more elaborate scenario analysis methods (with a focus on storage) that yield greater system visibility and data transparency.* • Identify risk regions, utilities, and/ or sectors facing imminent grid defection.* • Develop integrated planning tools that model reliability.*

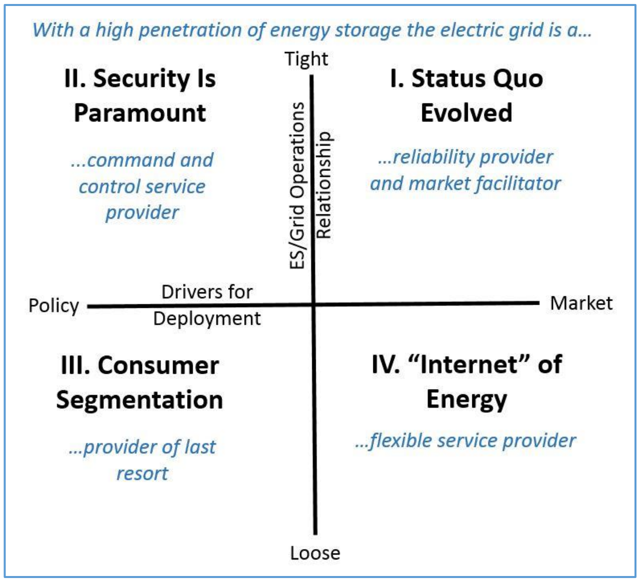
Appendix

Additional details on how each scenario was developed, the characteristics of each scenario, and the implications and recommendations resulting from each individual scenario (instead of in aggregate), can be found below.

Key Drivers

To help develop distinct scenarios of electric grid futures under HPES, the Subcommittee identified a number of highly unpredictable drivers that would have significant electric grid effects, and chose two to form impact axes.

The first axis, represented by the X-axis in the figure to the right, dictates the degree to which a future scenario is either policy driven or market driven. Policy-driven energy storage growth scenarios emphasize decisions likely resulting from government regulation and/or mandates that reflect societal goals, and the bulk of future storage investment returns will likely be cost-based (e.g., rate-based) in some manner. Market-driven growth scenarios will result from storage participation and success in competitive electricity markets and evolution of attractive and lucrative new market products for energy storage's flexible and fast ramping capabilities, and other unique asset properties. Investment returns will likely be largely based on price competition and reflect the goals of market participants—consumers and providers.



The second axis, represented by the Y-axis, dictates the degree to which the energy storage in the future scenario is either tightly integrated or loosely integrated with electric grid operation, design, and planning. Under the tightly integrated scenarios, the electric grid institution (e.g., utility or ISO) controls dispatch of energy storage that interfaces with the electric grid. In the loosely integrated scenarios, the electric grid operator does not control dispatch, deployment, and/or design. Under these two impact axes, the Subcommittee developed four distinct and different future scenarios of HPES and resulting grid impacts as indicated in the graphic.

Scenario I: Status Quo, Evolved (Tightly Integrated, Market Driven)

Scenario I assumes that the market will be the key driver with energy storage tightly integrated with the utility.

Continued growth of variable renewable resources triggers more demand for energy storage, which is largely met thanks to reduced costs of storage technologies and the evolution of new lucrative ramping and flexible capacity products in the competitive wholesale market. Storage is now the low-cost solution in the market for flexibility and is deployed throughout the electric power sector as a result of system planning and efficient price signals. Storage is well integrated with markets as a market participant and is directly controlled/operated by either the LSE or the ISO.

In addition, Federal and state policy efforts support an environment where the entire spectrum of values provided by storage across all functional areas (generation, transmission, and distribution, and behind the customer meter) is recognized by regional markets. This allows providers to monetize all value streams and provide services in all grid domains in a market-related manner. The growth in market-driven storage across all areas (centralized and distributed) significantly reduces the need for traditional rate-based utility investment but has increased investment in different technologies to monitor, control, and manage the distributed and dynamic, energy storage resources. Structuring of market products and providing revenue encourages innovation in the industry and results in new investments in several key areas by non-utility players.

The need for operating expensive peaking generation plants is lower and transmission & distribution (T&D) asset utilization factor is significantly improved. Organized market growth of storage results in efficiency increases for thermal generation that now operates close to day-ahead schedule at all times, with any deviations in real-time markets handled by storage and distributed energy resources. Many existing fossil units (and possibly large-scale renewables) have energy storage co-located at their site to take advantage of reduced interconnection cost and provide greater revenue certainty and reduced risk to plant operators. Generator performance insurance premiums are lowered for plants that incorporate storage.

With respect to long-term planning, the resource adequacy construct for reliability now considers available generation and storage in the system to meet peak demand (similar to the construct used in natural gas markets). Additional new, lucrative wholesale market products enable storage to participate in energy, capacity, and ancillary services markets, which help with renewable integration and accommodate the changing ramping and flexible capacity needs of the grid. Grid operators are now primarily using distributed storage resources more so than central station thermal resources for providing grid-balancing service, leaving remaining generation plants to focus on producing energy at higher efficiencies. New fossil-fueled power plant construction is now the exception, as storage plus low-cost intermittent renewable generation is the lowest-cost alternative for new builds. Congestion mitigation in the transmission system is increasingly handled using storage in real-time markets for grid operations, including the use of third party-owned, long-duration mobile storage to handle planned plant outages and N-1 contingency events, thereby increasing grid asset availability and utilization factors. The presence of high levels of storage and distributed resources including renewable energy also increases resiliency of the grid against natural and man-made disaster scenarios.

Utilities, who are responsible for local reliability, continue to invest, maintain, and rate-base assets, so traditionally rate-based energy storage is limited to some specific distribution and transmission applications to meet their local service and reliability responsibility. This responsibility is a driver for the need for energy storage deployment to be closely integrated with grid operations.

With lower cost options, customers have more choices for products and services including behind-the-meter storage. A more efficient market also supports lower costs for customers.

Scenario-Driven Grid Characteristics:
In this market-driven, highly integrated scenario, the grid has specific characteristics including:

- **Role**: The grid coordinates energy and power transactions with an increased system security. The grid operator is also responsible for long-term system planning in coordination with market operators and the market providers.
- **Infrastructure**: The grid infrastructure is modernized with increased sensors and controls to manage the more dynamic market infrastructure. The infrastructure scenario impact means increased heftier distribution investments including energy storage with decreasing transmission investments.
- **Operations:** The grid requires highly controlled operations through market signals augmented with reliability-driven command.
- **Business model**: Grid procurements are competitive and augmented with regulated investment.
- **Strategy**: The grid operator maintains control of grid operations and interfaces with market providers for high service reliability and resiliency.
- **Notable**: In this scenario, there is less use of traditional generation for ancillary services and congestion mitigation.

Scenario-Driven Grid Impacts:
In this market-driven, highly integrated scenario, the potential impacts to the grid include:

- Low-cost, diverse storage options enable a range of services for customers, utilities, and the market and is the low-cost solution.

- The role of the wire services company will be to provide access to the grid and platform for services on-grid. Its role will be as a coordinator and provider of capacity more so than provider of energy.
- The utility owns and operates the network and is responsible for reliability, which requires the ability to monitor, control, and coordinate with market providers and storage owners across the grid.
- There will be greater renewable generation, much of which is distributed generation.
- The utility and market operators and providers will coordinate on long-term, integrated planning, where relevant.

Scenario-Driven Recommendations to DOE:
Based on Scenario I outcomes, there are several areas for research consideration:

Stakeholders Impacted	DOE Research Recommendations
Grid Owner/Operator	• Enhance visibility, probabilistic forecasting, and communications and control at transmission, distribution, and prosumer levels of the grid, including visibility into available multi-use distributed energy storage capacity.
Policymakers and Regulators	• Address the potential conflicts between ➢ Free market behaviors and the needs for the tight integration of energy storage deployments. ➢ Market agent and asset agent deployments of energy storage. • Continue to update and fund publicly available information on grid-connected storage deployment and policies.
Market Designers and Facilitators	• Evaluate energy storage deployment across many different topologies and service functions in real-time to measure impacts.
Consumers	• Develop safe, automated energy storage products in a wide variety of technology forms, with simple market interaction mechanisms. • Examine appliance standards that include storage for water heating and space heating.
All Electricity Market Players	• Develop safety and performance standards, as well as other analytical tools, for integrating energy storage.

Scenario II: Security Is Paramount (Tightly Integrated, Policy Driven)

Scenario II assumes that policy will be the key driver of increased energy storage penetration and energy storage will be coordinated with and/or owned by the utility.

This scenario follows the enactment of a set of national and state policies focused on significant grid reliability and resiliency in response to concerns of terrorism or large-scale, weather-driven grid interruptions. In parallel, difficulties in accommodating high levels of renewable generation coupled with the retirement of traditional generation plants created operational problems. These problems were aggravated by the lack of inertial and governor response and grid impacts resulting from non-dispatchable renewables.

State-level policies now mandate utilities to procure storage to increase stability and dispatchability of variable renewable generation. The policies also require a standardization of inverter-connected resources provided directly or via third parties to support inertial and governor response. Further, FERC- and NERC-mandated policies require transmission companies to install storage to provide fast-balancing resources. The policies also include a buildup of utility-controllable microgrids that can be operated as an integral part of the grid. The microgrids have the ability to island/isolate loads and provide resources back to the grid at large, including black start capabilities. Policy efforts support the development of utility-driven electric vehicle (EV) charging infrastructure to encourage increased EV penetration.

Innovative regulatory policies enable electric utilities to recover their service contract procurements and investments in storage and microgrids at cost-based rates similar to other traditional capital expenditure. Standards for interoperability include dispatchability and resource controls. Due to the urgency to expand reliable microgrids, a higher rate of return is available to utilities for contracting services from third party-owned assets. Different business models govern the operation of the storage assets, such that value is driven from the ownership of the energy in storage as opposed to the ownership of the storage itself.[2] In most cases, the electric utilities choose to own the storage and microgrid assets, but some continue to negotiate long-term power purchase agreements (PPAs) with third-party providers. New microgrid operators enter the market, including large telecom and building infrastructure players.

The expansion of storage and microgrids supports improved load control, resulting in a flatter peak and increased system load factor. This increased grid optimization partly offsets the higher cost of the new grid infrastructure. The net increase in electricity prices is generally accepted by consumers since they recognize and appreciate the much more reliable and resilient grid. Microgrid consumers can purchase various reliability "plans" of varying levels of reliability from their local utility. The increase in the T&D tariffs to cover the costs of storage are offset to different degrees by reduced energy costs via accommodation of higher levels of low-cost electricity generation, whether from cheap natural gas or from renewable sources. Customer storage-related product and service are primarily offered through the utilities with service options focused on reliability.

Scenario-Driven Grid Characteristics:
In this policy-driven, highly integrated scenario, the grid has specific characteristics including:

- **Role:** The grid operator role is on system security, resiliency, and long-term system planning provider.
- **Infrastructure:** Grid investments are traditionally maintained, but with heftier distribution system infrastructure enhanced with microgrids.
- **Operations:** The grid operator maintains traditional command and control of dispatch with some augmentation based on competitive procurements.
- **Business model:** The traditional regulated, rate-based investments are continued with this scenario.
- **Strategy:** The utility is the central player in electricity policies and standards; it maintains control of grid operations and interfaces for very high service reliability and resiliency, with microgrids as a major strategic element.
- **Notable:** Reliability, security, and resiliency are the societal drivers with policy driving speed of implementation.

Scenario-Driven Grid Impacts:
In this policy-driven, highly integrated scenario, the potential impacts to the grid include:

- Increased rate basing of storage and microgrid assets for utilities resulting in increased ROI.
- Increased grid reliability and resiliency.
- Increased ratepayer costs with potentially increased risk of stranded asset costs related to speed of implementation.
- Increased interconnection and grid defection costs, which result in a barrier to grid defections.
- Fewer product and service offerings for customers, typical where market choice is limited.
- Increased electrification including EV charging infrastructure.
- Less innovation in new third-party business models, products, and services as the utility is the primary procurer and owner.

Scenario-Driven Recommendations to DOE:
Based on Scenario II outcomes, there are several areas for research consideration:

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[2] The storage model is similar to the gas storage model, especially in pipelines, with some also providing a merchant function.

Stakeholders Impacted	DOE Research Recommendations
Grid Owner/Operator	• Enhance visibility, probabilistic forecasting, and communications and control at distribution and prosumer levels for microgrid operations. • Develop performance standards and planning and modeling tools for integrating grid and ES, e.g., modeling for transmission-scale storage operations for fast-start. • Research visibility, analytics, and planning and forecasting models for microgrid/wide-area interconnection integration.
Policymakers and Regulators	• Design power markets that work well under highly regulated investment business models of grid operators. • Develop frameworks and quantify value of reliability and resiliency. • Continue to update and fund publicly available information on grid-connected storage deployment and policies.
Market Designers and Facilitators	• Facilitate power markets that work well under highly regulated investment business models of grid operators.
Consumers	• Develop safe, automated energy storage products in a wide variety of technology forms, which can participate in microgrid operations.
All Electricity Market Players	• Develop safety and performance standards, as well as other analytical tools, for integrating energy storage.

Scenario III: Customer Segmentation (Loosely Integrated, Policy Driven)

Scenario III assumes that policy will be the key driver of increased energy storage penetration with little coordination with the utility or system operator in the implementation and operation of storage.

Public policy continues to promote renewable energy. Similar incentives to those supporting wind and solar enable greater deployment of energy storage, resulting in a large expansion of storage resources, especially behind the meter.

Hundreds of thousands of customer-sited energy storage systems are operating throughout the United States, with Hawaii, California, and various states in the Northeast in the lead. Many wealthier commercial, industrial, and residential customers are completely off-grid, including new communities/loads that are significantly less dependent on grid interconnection. The remaining grid-tied customers experience inflationary costs due to cost shifting as a result of so much departing load. Grid operators and public utilities commissions across the country are largely unable to lure prior customers back to the grid. Energy storage and rooftop solar installed costs are low enough that they now match or fall below grid parity in the majority of U.S. states. Most states do not support net energy metering (NEM), unleashing an energy independence movement whereby millions of solar customers in an effort to capture value for their daytime solar generation now implement storage to capture and use solar energy to match production with consumption at a later time. Backlash due to high departing load charges, exorbitant interconnection charges, and various forms of fixed charges only continues to drive wealthier and more efficiency-minded customers off the grid at an accelerated pace. Initial customer-sited storage and EV charging incentives did not encourage customer-sited storage to be used for grid benefit, so innovation and investment in storage are driven solely by customer needs. Companies like Tesla, Mercedes, Nissan, and Apple now provide integrated smart home solutions and directly offer bundled electric and EV charging electric motor transport offerings directly to off-grid consumers, competing directly with utilities and accelerating grid defection. In this scenario, storage is being used sub-optimally because it is not available for grid support services.

Due to slow regulatory development, rules and markets that facilitate behind-the-meter storage and EV participation in wholesale markets and other utility programs are restrictive, and far less lucrative than simply leaving the grid. In spite of jurisdictional and regulatory battles with PUCs and utilities, microgrids are common among commercial customers and affluent communities. Independent microgrid developers flourish.[3] Thus, although this outcome was initiated by policy, market forces quickly took over and now drive the scenario.

As the provider of last resort, the grid owner provides basic reliability to remaining grid dependent customers, but reliability vastly differs between customer segments. For example, in many cases customers who are part of a microgrid experience higher reliability. Access to affordable energy is clearly delineated between the "haves" and the "have nots." Disadvantaged and low-income communities, many of whom remain linked to the grid, experience both high cost and lower grid reliability. As a result, they are agitated and create a lot of political pressure to help control costs, contributing to civil unrest.

Scenario-Driven Grid Characteristics:
In this policy-driven, low-integration scenario the grid has specific characteristics including:

- **Role**: The role of grid operators is significantly diminished with their primary role as a provider of last resort.
- **Infrastructure**: Increased cost pressure and low-integration mean that the utility infrastructure is retro-minimalist with the remaining customers receiving reliability service well below market provided services and wealthier off-grid solutions.
- **Operations**: The grid will ultimately be operated at low cost with a bare-bones, run-to-failure approach. Reliability and safety will be impacted and investments and operations will be highly prioritized to those necessary for worse-case outcomes.
- **Business model**: Regulated investment will be augmented with subsidies from society in line with land-line telecom service today for low-income customers. High prices for non-subsidized customers will drive grid defection in favor of lower-cost, higher-reliability unregulated off-grid services.
- **Strategy**: Grid operations will be focused on low-cost prioritized service to ensure "minimal requirements" service for remaining customers.
- **Notable**: In this scenario, customers will defect from the grid while remaining grid services will be minimal, and largely subsidized, focused on disenfranchised remaining customers.

Scenario-Driven Grid Impacts:
In this policy-driven, low-integration scenario the potential impacts to the grid include:

- Increasingly inefficient use of the system.
- Increased stranded costs affecting increasingly fewer customers.
- Increased cybersecurity issues due to larger entry points into the grid without a centralized integrated controlling mechanism to ensure standard security approach.
- Inherently more expensive, less reliable, and potentially less safe grid.
- Increased system reliability risk is driven by lack of clarity which entity owns reliability.
- Increased disenfranchised customers with "at-risk" utility as provider of last resort.

Scenario-Driven Recommendations to DOE
Based on Scenario III outcomes, there are several areas for research consideration:

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[3] An example of flourishing microgrid development is the Sonnen communities.

Stakeholders Impacted	DOE Research Recommendations
Grid Owner/Operator	• Research technologies to harden the grid against cyber-attacks, lower infrastructure and operational costs, and improve energy efficiencies of energy transport.
Policymakers and Regulators	• Research and publish rate design, regulatory, and policy best practices (“dos” and “don’ts" to help avoid grid defection). • Address the disparate and conflicting needs of the defectors and the disenfranchised. • Assure an adequate level of electric service, including reliability, to the disenfranchised at lowest cost. • Research on minimum economic and technical requirements for interconnection and to ensure interoperability to prevent total grid defection—standard set of protocols that establish roles and responsibilities of customers, utilities. • Continue to update and fund publicly available information on grid-connected storage deployment and policies.
Market Designers and Facilitators	• Facilitate energy markets that work well with a high volume of microgrid activity and ensure grid interoperability.
Consumers	• Develop safe, automated energy storage products in a wide variety of technology forms, which can participate in microgrid operations. • Study communications and automated decision-making for participation in transaction markets.
All Electricity Market Players	• Develop safety and performance standards. • Identify regions, utilities, and sectors where grid defection is imminent.

Scenario IV: “Internet” of Energy: (Loosely Integrated, Market Driven)

Scenario IV assumes that the market will be the key driver of increased energy storage penetration and there will be little coordination with the utility in the implementation and operation of storage.

Market development—especially on the Retail side—continues to drive grid transformation. Unlike RTOs/ISOs on the wholesale/transmission level, distribution operators (DO) now operate the distribution system as a regulated utility but with two-way rates that dynamically price distribution transport at prices (i.e., rates) that recover the regulated, mainly fixed costs of the distribution grid. Transactive energy solutions encourage many commercial and residential customers to become prosumers.[4]

As seen in the early 21st century when the convergence of consumer electronics innovations and greater internet connectivity created “leap-frog” energy solutions that are now commonplace throughout the world, the electric sector now resembles that of telecom in the 1990s; new functional models have democratized the industry. Energy storage is now a part of a growing number of appliances, such as televisions and refrigerators, and of course electric-powered automobiles. Appliance innovations formed in the developing world are now used in developed markets to reduce costs from the traditional grid, including to absorb energy from popular rooftop

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[4] According to the European Parliament Think Tank, active energy consumers—often called “prosumers,” because they both consume and produce electricity—could dramatically change the electricity system. Various types of prosumers exist: residential prosumers who produce electricity at home, mainly through solar photovoltaic panels on their rooftops; citizen-led energy cooperatives or housing associations; commercial prosumers whose main business activity is not electricity production; and public institutions like schools or hospitals. The rise in the number of prosumers has been facilitated by the fall in the cost of renewable energy technologies, especially solar panels, which in some member states produce electricity at a cost that is the same or lower than retail prices. Source: http://www.europarl.europa.eu/thinktank/en/document.html?reference=EPRS_BRI(2016)593518.

solar units on homes and businesses. Because of these innovations, nearly 25 percent of all electricity consumed passes through a storage device on its way to an end use.

In this same timeframe, due to high rooftop solar penetration and net-metering concerns, distribution operators maintain stable fixed costs for their customers by signing subscription contracts for distribution service with customers. This blunt signal encourages appliance makers and others to apply readily available storage technologies to help homeowners and businesses manage these costs. EV adoption is high, due to the low cost, high reliability, and attractiveness of electric driving. Many offerings are available in the market that bundle transportation, building management, distributed generation, and security. Due to aggressive customer load management solutions, electricity customers can now qualify for a lower rate class and reduce their grid connection and overall energy costs significantly. As a result, peak demand throughout the system is lower while overall consumption is up slightly due to round-trip efficiency losses of storage and increased demand via conversion of formally fossil fuel-driven load (such as electrification of transportation and increased electric space and water heating). Customers now routinely engage in informal master-metering to evade the higher fixed charges, as many already do with internet service.

Transactive energy platforms are the norm, enabling automated systems at the consumer level to receive and act on buy-and-sell tenders (offers) from retail storage and generation and from wholesale participants and ISO/RTO/DSO markets. This means system loads are more spread out during the day and the need for new transmission and distribution is very low. While the use of these storage systems is controlled within the premises, using sophisticated solutions such as Apple HomeKit, Nest, and others, the interface to the broader electricity ecosystem is simple and price-based, which maintains a simple customer experience at a low customer cost. Electricity providers continue to see a decline in peak demand, as well as steep peaks in net energy demand, due to the combined effects of solar and storage. Nevertheless, providers they still encounter load fluctuations that require them to keep significant amounts of flexibility resources online, including centrally controlled bulk and distributed storage. Granular, spot-priced tender signals from the grid to automated appliances and other devices provide substantial coordinated flexibility to offset substantially net load fluctuations. IoT-enabled devices allow very small loads to respond to the grid tender, including: smart air conditioners, electric space heaters, electric water heaters, pool pumps, dishwashers, clothes washers and dryers. These appliances and others participating on the transactive energy platforms—including many larger industrial and commercial loads—operate in the same way. The combination of these responsive loads, storage, and quick-start generation allows load balancing through transactive price response in the morning and evening peak hours while consuming mid-day over-generation of solar with high solar penetration. The communication of the tenders and the transactions among the parties is managed by transactive energy platforms.

Scenario-Driven Grid Characteristics:
In this market-driven, low-integration scenario the grid has specific characteristics including:

- **Role**: The grid is responsive to and indeed helps facilitate retail and wholesale market transactive power delivery.
- **Infrastructure**: The grid infrastructure is highly flexible, automated, and modernized to support two-way energy and communications flow.
- **Operations**: The modernized grid is highly responsive to uncertain generator, consumer, and prosumer needs.
- **Business model**: The grid operators have invested in flexibility, probabilistic forecasting, data mining, and robust visualization and provide these as services in the transactive market. The grid operator also charges a “transmission” fee for kilowatt-hours flowing in multiple directions.
- **Strategy**: The grid can deliver a kilowatt-hour from anyone to any place at any time.
- **Notable**: The grid operates under high uncertainty with little control of events at either end. It assumes the transactive market anticipates and provides the services that can support energy, reliability, etc.

Scenario-Driven Grid Impacts:

In this market-driven, low-integration scenario the potential impacts to the grid include:

- Role of utility is incredibly important, made increasingly difficult by lack of integration control. There needs to be a technologically feasible backbone to enable transactive energy. The PUC will likely continue to have oversight.
- Increasingly complex system with increased demand for facilitated multi-directional technologies and resources.
- Increased secured monitoring, measurement, tracking for transactions.
- Increased importance of cybersecurity.
- The "DSO" will be responsible for reliability, preventing market abuse, and facilitating market transactions with monitoring systems in place.
- Increased costs due to inefficient/redundant systems due to lack of coordinated planning.
- Increased disparity between customers regarding product offerings and cost.

Scenario-Driven Recommendations to DOE

Based on Scenario IV outcomes, there are several areas for research consideration:

Stakeholders Impacted	**DOE Research Recommendations**
Grid Owner/ Operator	• Enhance real-time visibility, probabilistic forecasting, and communications at transmission, distribution, and prosumer levels for transactive energy markets to work for electric product pricing along with electric grid operations. • Expand use of automated grid devices and systems, real-time system reconfiguration, hardened protection systems, etc., for extreme flexibility and rapid response. • Improve defensive cybersecurity.
Policymakers and Regulators	• Research the business and regulatory models, roles, responsibilities, and platforms, i.e., market accounting and security to support the transactive energy model. • Design transactive energy markets that work well under highly granulated, frequent transaction activities. Publish and disseminate regional best practices.
Market Designers and Facilitators	• Facilitate transactive energy markets that work well under highly granulated, frequent transaction activities, including accounting, payment, and settlement mechanisms. • Publish and disseminate regional best practices.
Consumers	• Develop safe, automated energy storage products in a wide variety of technology forms. • Study communications and automated decision-making for participation in transaction markets. • Research enhanced cybersecurity for IoT to prevent cyber and physical disruptive behaviors as threats to the electric grid and it customers.
All Electricity Market Players	• Develop safety and performance standards. • Address need for information, transparency, secure transactions, and consumer protections.