

The Role of Storage in Energy System Flexibility

Workshop Summary Report

22-23 October, 2014

IEA Experts' Group on R&D Priority Setting and Evaluation
Berlin, Germany

International Energy Agency

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its mandate is two-fold: to promote energy security among its member countries through collective responses to physical disruptions in oil supply and to advise member countries on sound energy policy.

The IEA carries out a comprehensive program of energy cooperation among 28 advanced economies,¹ each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency aims to:

- Secure member countries' access to reliable and ample supplies of all forms of energy—in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context, particularly in terms of reducing greenhouse gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organizations, and other stakeholders.

IEA Experts' Group on R&D Priority Setting and Evaluation

Research, development, and deployment of innovative technologies is crucial to meeting future energy challenges. The capacity of countries to apply sound tools in developing effective national research and development (R&D) strategies and programs is becoming increasingly important. The Experts' Group on R&D Priority Setting and Evaluation (EGRD) was established by the IEA Committee on Energy Research and Technology (CERT) to promote development and refinement of analytical approaches to energy technology analysis, R&D priority setting, and assessment of benefits from R&D activities.

Senior experts engaged in national and international R&D efforts collaborate on topical issues through international workshops, information exchange, networking, and outreach. Nineteen countries and the European Commission participate in the current program of work. Results provide a global perspective on national R&D efforts that aim to support the CERT and feed into the IEA Secretariat's analysis. For further information, see: <http://www.iea.org/aboutus/standinggroupsandcommittees/cert/egrdf/>. For information specific to this workshop, including agenda, scope, and presentations, see: <http://www.iea.org/workshop/egrdf-role-of-storage-in-energy-system-flexibility.html>.

This document reflects key points that emerged from the discussions held at this workshop. The views expressed in this report do not represent those of the IEA or IEA policy nor do they represent consensus among the discussants. This report has been prepared by the U.S. Department of Energy's Office of International Science & Technology Collaboration, in the Office of International Affairs. The report is available at:

<http://www.energetics.com/resourcecenter/products/studies/Documents/EGRDEnergyStorage.pdf>.

¹ Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Republic of Korea, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States; the European Commission also participates in the work of the IEA.

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Executive Summary

The IEA Experts' Group on R&D Priority-Setting and Evaluation (EGRD) convened a workshop on 22–23 October, 2014, in Berlin, Germany, hosted by the German Ministry of Economic Affairs and Energy, to illuminate the status and emerging trends of grid-scale energy storage and to advance solutions. A focus of the workshop was to identify research, development and demonstration (RD&D) needs related to energy storage, especially considering the increased integration of renewables into the grid. In addition, barriers to greater technology deployment and potential remedies were explored.

About 50 participants representing various EGRD national experts, government representatives, RD&D decision makers, strategic planners, and program managers from industry met to discuss the current challenges facing the industry and the research and development (R&D) strategies required for energy storage and electricity grids to make storage a commercial reality. Workshop participants discussed the current status of energy storage technologies; highlighted the technical, market and regulatory challenges faced by storage, including those presented by alternatives to storage and the lack of a viable business model for storage; identified current efforts to develop the more promising technologies in various countries; and importantly, discussed R&D and commercialization and deployment needs for storage technologies.

Overview

Governments around the world are increasingly using renewable energy sources for the generation of electric power. This creates both opportunities and challenges for energy systems, especially in terms of ensuring that the future power energy system is a reliable and affordable one. Increased use of renewable energy helps countries achieve their energy security and emissions reduction goals. However, integrating renewables into current grid systems creates many challenges. As opposed to traditional sources of energy, such as coal-fired or nuclear power plants, renewable energy's intermittent nature does not follow any social patterns of demand for electricity. This can lead to issues related to grid quality and reliability. Geothermal energy and bioenergy can be used to compensate for these fluctuations, but since they are available only in certain regions, these energy sources do not offer a general solution to fluctuations. Grid interconnection on a continental level could also make it easier to cope with diurnal load shifts, as different time zones have different peaks, but realization of such a grid also faces substantial technical and business-related challenges in some instances. As such, additional solutions should be examined for addressing quality and reliability issues associated with integrating large amounts of renewables into the grid.

Energy storage technologies offer promising solutions that can manage variability and potentially decouple short-term variations of supply from demand. Benefits of storage technologies include improving resource use efficiency in energy systems; integrating higher levels of variable renewable resources and end-use sector electrification; supporting greater production of energy where it is consumed; increasing energy access; and improving electricity grid stability, flexibility, reliability, and resilience.

Current and Future Landscape of Storage Technologies

The U.S. Department of Energy's (DOE's) publicly available database on global energy storage technologies (www.sandia.gov/ess/database) provides an overview of the storage technologies in use. The database identifies over 50 energy storage technologies currently in use around the world, representing 145 GW. Pumped hydro dominates, with 142 GW. The remaining 3 GW is distributed among thermal (1.6 GW), flywheel (0.9 GW), batteries (0.5 GW), and compressed air (0.4 GW). Leading regions in terms of capacity and projects are China, the European Union, Japan, and the United States.

Pumped hydro storage—a well-established technology—is widely used in mountainous regions or regions with significant elevation change, such as those found in Austria, Switzerland, and Norway. Limiting its broader applicability is the fact that the technology is dependent on a region's geography, although newer designs have reduced the site specificity. Various battery technologies are also widely used, including lead-acid, lithium-ion, NaS/NaNiCl, and vanadium redox flow batteries (VRFBs). Several recent projects are, collectively, implementing a wide range of innovative battery technologies that show promise, such as a commercially available grid-scale energy storage systems; a project investigating Fe-Cr flow batteries and possible uses in combination with photovoltaics (PV); research collaborations investigating novel materials research and mixed acid electrolyte; and efforts to develop solid polymer electrolyte, metal-air, lithium-sulfur, anodes with silicon, sodium-ion (Aquion), and liquid air. Apart from batteries, other storage technologies that can address grid-sale storage needs, directly or indirectly, include adiabatic compressed air energy storage (A-CAES) and a range of “smart” heat storage options.

Research is currently being conducted in different parts of the world to test the domain of applicability of these technologies. In the United States, the Department of Energy supports several large-scale demonstration and pilot projects testing different technologies. Megawatt-scale batteries and flywheel storage facilities are used to test frequency regulation in the distribution grid, and it has been found these can be commercially operated in Federal Energy Regulatory Commission (FERC)-compliant regions. Flow batteries are in operation or being tested in the States of California, Vermont, and Washington. Other advanced battery systems are installed and being tested in Australia and the United States (California, New Mexico, and Pennsylvania).

In Germany, several pilot projects are under way to examine which technology best meets the needs of the distribution grid and which battery systems can be operated economically. One of these publicly funded projects, the Modular Multi-Megawatt Multi-Technology Medium Voltage Battery (M5BAT) Project, is constructing and operating a pilot hybrid battery storage system with realistic operation and market participation in multiple applications. This includes evaluation of technical and economical results and development of recommendations for design and operation of hybrid battery systems.

Recent studies have estimated that energy storage commercial markets may reach or exceed \$500 million/year by 2015 and \$15 billion/year by 2025.² For the right product, with the right pricing regimes, the market potential for these technologies is high.

Barriers Inhibiting the Growth of Storage Technologies

In spite of the potential exhibited by storage technologies, challenges remain. While some storage technologies, such as pumped hydro are mature, most others command limited deployment or are still in the nascent stages of development.

Many energy storage technologies are costly and not well-adapted to local circumstances. Energy storage faces stiff competition from alternatives. Furthermore, a viable business model for storage technologies that can provide multiple grid services has yet to be determined. Complicating matters is the lack of a supportive regulatory and standards environment to reduce complexity and help monetize grid services provided by the use of these technologies.

Denmark provides an illuminating example of the competitive challenges faced by utility-scale storage as the country's grid transitions from a centralized to a decentralized energy supply system. In 2012, about 25% of Danish gross energy consumption (nearly 40% of electricity consumption) was from renewable energy, with wind comprising the majority share. Denmark has set for itself aggressive renewable energy goals, striving for 100% renewables by 2050. The rapid decentralization of its energy system calls for increased flexibility, especially needed to balance the intermittencies of wind and solar power. However, rather than investing in energy storage options, Denmark has found that it is more economic to utilize its robust network of grid interconnections with Norway, Sweden, Germany, the U.K., and beyond to balance supply with demand. Much of the externally supplied power is derived from hydro power and other low-carbon sources, and Norwegian hydro is relied upon as a source of flexibility. Storage may still be used, but only in situations that commend it.

Alternative Competing Technologies

Storage technologies also face competition from other well-established alternatives. Demand response, a system used to manage variability by adjusting the load on the demand side, is one such alternative. Various technologies can be used for demand response in the power grid, such as thermal storage devices, electric vehicles, or load shifting. Worldwide, a number of pilots and field tests are presently studying the practical implementation of different demand response technologies. Japan established an initiative in which large-scale energy management systems are tested in four demonstration regions. In the United States, a number of smart grid demonstration projects have been conducted under DOE funding as part of an economic stimulus program initiated in 2009.

Power-to-gas (with gas storage) technology is an alternative to electric energy storage on the grid as well, providing a means of balancing inter-seasonal fluctuations and enabling storage over longer

² Source: Robert C. Marlay, EGRD Workshop on The Role of Storage in Energy System Flexibility: Summary Briefing (PowerPoint presentation, International Energy Agency, Paris, France, 18-19 November 2014).

timeframes. Adopting flexible methods for operation, especially combined heat and power and biomass plant, is a strategy that serves a purpose similar to storage. Renewable energy curtailments, high-voltage direct current (DC) techniques, smart grids and information technology (IT) solutions, the coupling of electricity and district heating grids, developments in the domain of power electronics, and grid expansion are all options being explored by the industry as alternatives to storage.

Another avenue relates to fuels for the transport sector that seeks to be fully, or near fully, renewable in the long term. If present limitations of batteries preclude full electrification, then relevance increases for conversion of electricity to fuels, e.g., hydrogen, methane, and dimethyl ether. Conversion could become a significant aspect of the storage sphere, especially when the high financial value of transport fuels is considered. In some instances, electricity is so abundant that it has a negative cost. Inexpensive electricity can sometimes be exported, but at times, it may make more sense to use electricity to create combustible fuels that can then later be consumed.

Competitive Markets and Pricing Models

Against this backdrop, the future for energy storage is unclear. Whether a strong business model for commercial storage will fully develop is debatable. Current electric service revenue structures do not provide a sufficiently diverse suite of revenue streams to support economic viability of storage, even though the societal value of power at such times might be high. Rather, there is a need for a rational pricing model that accounts for a variety of services provided by storage, perhaps, in the form of “bundled values.” Values need to be assigned for various contributions in real time and for long-term system efficiency, cost avoidances, and a host of other services, such as reactive power, voltage control and frequency regulation. If the many and often unique contributions are given market values, storage may become a cost-effective solution at many sites.

California is an interesting case study. The increased use of renewables there, motivated by mandates and subsidies, has created challenges for balancing of supply and demand. Battery energy storage is seen as offering several advantages, such as quick response and flexible range per megawatt, but is also costly. In a move to address the issue and spur innovation, California regulators required its three primary investor-owned utilities, in total, to acquire 1,328 MW of energy storage by 2020. Initial results from the competitive solicitations suggest that, if rationally evaluated, battery energy storage can be purchased and operated economically in this specific market situation.

Electricity market models developed through European Union collaborative projects suggest that in the mid-term, grid extension and stronger market integration are more economically attractive solutions than electricity storage.

While simulation exercises may indicate that achieving a viable, economical business model for storage technologies is challenging today, there are emerging developments that suggest the success of these technologies may be improving in the coming years. For example, the need for security of supply may generate markets that may lead to an uptake of the technology. New technologies are arising, others are improving, and costs are falling with increased deployment and competition. It is expected that grid storage can increase its economic value considerably by bundling value streams, e.g., arbitrage, balancing services, substitution deferral, capacity, and outage mitigation. By offering these services to

utilities, market projections for battery energy storage increase substantially and encourage the realization of storage systems. Whereas in the short to mid-term, grid integration may offer the most economical solution, the demand for battery energy storage is expected to increase in the longer term, especially for decentralized storage (for more discussion of the California experience, see Discussion and Conclusion section).

Standards and Regulations

The lack of a supportive, enabling regulatory environment has been an impediment to the growth of energy storage technologies. Disincentives to storage implementation exist, e.g., regulatory curtailment of renewables can obviate the need for storage as a balancing service. Policies remain in a nascent phase. Development of standards and regulations has been uncoordinated and often conflicting. International standards for grid-connected storage systems are essentially non-existent. The very definition of “storage” remains in question (although efforts to define have been initiated, and the IEC now has draft standards for performance testing of grid energy storage).

A joint industry project, Gridstor, has recently been initiated to facilitate international guidelines for the optimal and safe implementation of energy storage. This initiative should lead to a standardization process that ultimately will enable producers of grid storage devices to develop products for standardized international markets. Additionally, there is a need to develop a guidebook that eases new entrants into the sector and establishes a framework standard for grid-connected energy storage.

RD&D Needs

Many promising advances in energy storage technologies are in early stages of discovery and development. RD&D needs are large in this space. These range from purely technical R&D needs, such as understanding the performance of battery stack design, to evaluating market drivers and commercial viability and reliability, especially under different regulatory regimes. Developing acceptance of these technologies within the industry is also critical to instill confidence in the private sector and for market adoption.

RD&D needs for storage technologies identified at the workshop are summarized below.

Technical Needs

- Achieve fundamental understanding of electrochemical phenomena, which is critical for the development of new efficient grid-scale batteries
- Actively pursue research in the development and optimization of new and alternative battery chemistries; the optimization of electrodes, electrolytes, membranes and critical components; and the development of novel cell/stack designs with engineered materials
- Conduct demonstration and pilot projects for the development and fabrication of new battery systems concerned with bench-top component and systems development testing, prototype development and test-bed evaluation or the refinement of manufacturing processes
- Develop technology cost models to guide R&D and assist innovators
- Refine manufacturing processes

Validated Reliability and Safety

- Conduct R&D on degradation, failure mechanisms, mitigation, and accelerated life testing
- Develop standard testing protocols and independent testing of prototypic storage devices
- Track, document, and make available performance data of installed storage systems
- Optimize power electronics and controls and battery management

Equitable Regulatory Environment

- Resolve grid benefits to guide technology development and facilitate market penetration
- Explore technology-neutral mechanisms for monetizing grid services provided by storage
- Develop industry and regulatory agency-accepted standards for siting, grid integration, procurement, and performance evaluation
- Encourage data cooperation
- Encourage supportive policy, e.g., purchase contracts, storage mandates, and competitive solicitations

Industry Acceptance

- Co-funded field trials enabling experience and evaluation of performance, especially for facilitating renewable integration and enhanced grid resilience
- Industry-accepted planning and operational tools to accommodate energy storage
- Storage system design tools for multiple grid services and energy management

Path Forward

Energy storage is today, and will continue to be, an increasingly important part of future energy systems. Grid-scale storage systems are being recognized, not just for their value as a storage option, but also for roles in improving system-wide efficiency, avoiding costly system expansion, and in ensuring that energy systems are reliable and stable. However, the path to full market potential is fraught with challenges.

Key actions needed to spur continued innovation and accelerate market adoption of energy storage over next decade include the following:

- Improve understanding of economics of storage technologies and facilities
- Establish a rational model for valuing storage across a full range of provided services
- Develop supportive markets, standards and regulatory environments
- Support targeted and strategic research, development and demonstration projects
- Establish a comprehensive set of international standards
- Develop tools to quantify the value of storage in specific regions and energy markets

The full report may be consulted at:

<http://www.energetics.com/resourcecenter/products/studies/Documents/EGRDEnergyStorage.pdf>.

Background

Storage Challenges and Opportunities

The utilization of electric power from renewable energy sources worldwide is growing steadily. This growth presents opportunities and challenges for institutions responsible for both realizing associated benefits and maintaining a reliable and affordable power supply system.

In contrast to traditional sources of electricity generation based on fossil fuels or nuclear power, renewable sources have compelling advantages: (1) they do not rely on scarce, imported, and/or potentially vulnerable (e.g., natural gas from geopolitically difficult regions) resources and, hence, afford a degree of national or regional energy independence; and (2) they are not encumbered by risk factors such as air quality issues, greenhouse gas emissions, or nuclear waste concerns.

However, incorporating a non-marginal amount of renewable energy from intermittent and/or variable sources into national energy production systems comes with challenges, many of which had not earlier been important management factors for grid system quality, stability, or reliability. For example, traditional electricity systems based on adjustable (fossil or nuclear) power plants were typically operated such that changes in energy supply followed system changes in power demand. With renewable energy sources, this is not always possible. Wind strengths and variations in available sunlight are, in many respects, unpredictable; they do not typically follow social patterns of demand for electricity. In some cases, bioenergy and geothermal sources of electricity can be used to compensate for fluctuations in more volatile energy sources, but many of these are available only locally or in limited supply.

Accordingly, any energy system envisioning the utilization of a large amount of non-hydroelectric renewable energy power must eventually develop solutions to address these issues. Large capacity energy storage, in conjunction with other system components, affords a means to manage variability and potentially decouple short-term variations of supply from demand. Of course, this includes traditional pumped-hydro storage power stations, which play important roles in mountainous regions such as those found in Austria, Switzerland, and Norway. However, not every country's geography allows for pumped storage. Possible alternative technologies include, among others, chemical and/or thermal energy storage, conversion of electricity to hydrogen via electrolysis, and coupling of electricity generation with district heating grids. Many of these are costly or not well adapted to local circumstances. There is growing awareness that novel paths need to be explored.

Additionally, the electricity grids themselves are facing infrastructure challenges, aggravated by the large-scale advent of energy production from renewable energy sources. Renewable electricity is not necessarily produced in close proximity to the centers of consumption, necessitating build-out of long-distance power transmission lines. Regional production varies significantly with regional weather conditions, suggesting balancing by out-of-region sources. Possible technologies include, among others, demand side management, high-voltage direct current (DC) techniques, smart grids and information technology (IT) solutions, power-to-gas (PtG), the coupling of electricity and district heating grids, and developments in the domain of power electronics.

As electricity grids are often interconnected, especially in Europe, these challenges cannot be examined from an exclusively national perspective. However, this interconnectivity can also be considered an advantage, since fluctuations in both renewable electricity production and power demand flatten out, statistically, in large interconnected grids spanning a more meteorologically diverse region.

How to overcome these difficulties and guarantee an environmentally friendly electricity supply that is both stable and cost-efficient will be among the more important considerations for the energy and power sectors in the near future. These issues invite creative thinking across a broad range of activities, from foundational research to the successful demonstration and commercialization of new technologies. Addressing the challenges will require a multitude of research, development and demonstration (RD&D) efforts, stimulated by public policy attention, governmental support, and private investment.

Current Activities

There are many ongoing activities focused on these concerns throughout the world—in China, Europe, India, Japan, Korea, the United States, and elsewhere. The IEA recently released an energy technology roadmap on energy storage³ that looks at the role of energy storage technologies within future energy systems. The document discusses how energy storage technologies can help to better integrate electricity and heat systems and the role of the technology in energy system decarbonization. The roadmap identifies the most important actions required in the short and long terms to successfully accelerate development and deployment of energy storage technologies. In Europe, the German approach, outlined below, epitomizes the level of interest and national priority now being given to such matters.

In Germany, the federal government is pursuing a strategy to increase the use of renewable sources to generate electricity to 80 percent by 2050. In conjunction with another goal to reduce national electric power consumption by 25 percent, this strategy is expected to reduce Germany's carbon dioxide emissions by 80 percent by 2050. Attaining these goals represents a reorganization of the German energy system. One of the plan's central pillars is the national RD&D program established to make existing technologies more effective and to trigger new innovations that will eventually provide acceptable solutions to the many-fold challenges associated with such a widespread transformation. Two initiatives have been launched:

- *Energy storage* (published in 2011). This RD&D initiative entails €185 M in funding. Nearly 80 different projects are being pursued, with a focus on battery applications in electrical grids, PtG, thermal energy storage, and adiabatically compressed air storage facilities.
- *Electricity grids and transmission* (published in 2012). This RD&D initiative is comparable in funding. It includes new developments in power semiconductor devices and operating equipment, decentralized automation concepts, IT solutions for smart grids, mathematical optimization procedures, simulation, and new sustainable infrastructures.

³ IEA. *Technology Roadmap: Energy Storage*. 2014. Available at <http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapEnergyStorage.pdf>

The Workshop

The IEA's Experts Group on R&D Priority Setting and Evaluation (EGRD) hosted a workshop on October 22 and 23, 2014, in Berlin, Germany, hosted by the German Ministry of Economic Affairs and Energy. The workshop focused on the evolving nature of the grid, with the goal of identifying novel approaches, RD&D needs, other areas not well covered but needing attention, and innovative case studies related to electricity storage in a flexible electricity grid of the future. The broad range of topics discussed concerned innovation and R&D strategies for energy storage and electricity grid enhancement with a focus on how best to welcome the inclusion of variable energy sources. Fifty workshop participants represented various actors, sectors, and regions and included EGRD national experts, government representatives, RD&D decision makers, strategic planners, and program managers from industry concerned with energy storage systems technologies related to electrical grids.

Questions addressed by the participating technology experts included the following:

- How are governments and power-managing institutions innovating to address the grid reliability concerns associated with the advent of significant renewable power supply?
- Which electricity storage technologies are currently used? Which are emerging as leading innovations for the near term? Which are most promising for the longer term?
- What is the current status of battery technology in a grid context?
- What are the ways in which such devices can be integrated into the energy market?
- What are high-priority grid storage RD&D needs, gaps, and opportunities?
- What other technical needs (e.g., safety) are not being well addressed today?
- What policy innovations are most effective in mobilizing energy storage innovation?
- Does the regulatory framework need adjustment for a better stimulation and integration of energy storage technologies?
- Can the grid be addressed separately, or do mutual interdependencies between electricity, gas, and heat markets lead to technical advantages and/or economic benefits?
- Which primary technological limitations and barriers need to be overcome to make energy storage more beneficial to power utilities?
- Does the IEA framework of Implementing Agreements need adjustments to tackle all aspects of necessary cooperation?

Report Structure

This report summarizes the workshop findings by identifying challenges concerning energy storage and energy grids, highlighting a broad sampling of activities under way in various countries and technology sectors, identifying priorities and gaps in current programs for RD&D planners, and suggesting a number of areas in the innovation arena needing public policy attention.

Following this background section, the report follows the same format as the workshop, with five session chapters:

- Session 1: Introduction
- Session 2: Energy Systems and Demand for Storage

- Session 3: Flexibility Options as Alternatives to Storage
- Session 4: Energy Storage Technologies
- Session 5: Energy Storage Markets and Business Models

Each chapter includes a summary of the presentations given during that session. Following the presentation summaries is a final chapter with discussion and conclusions. Appendices to the report provide a list of acronyms, workshop speakers, and the meeting agenda.

Session 1: Introduction

In this introductory session, speakers discussed the importance of energy storage in reducing greenhouse gas emissions and in the transformation of the world's future energy systems.

The IEA's Energy Technology Perspectives (ETP) 2014 lays out the roadmap for how to achieve a scenario that avoids catastrophic climate change and maintains only a two-degree rise in temperature. It is envisioned that the success of achieving such a scenario is primarily dependent on the ability of the power sector to decarbonize. In the 2°C Scenario, almost 90% of the electricity is expected to be generated from low-carbon sources. The ETP 2014 found that while energy storage plays a critical role in decarbonization, strategic planning is required. For the biggest markets, storage remains expensive, and the optimal role for storage varies widely across regions. Additional R&D is required since knowledge gaps still exist.

The global community needs to undertake key actions over the next 10 years for energy storage to become a commercial reality. These include developing an understanding of the economics of retrofitting existing storage facilities, developing markets and regulatory environments that enable accelerated deployment, supporting targeted demonstration projects and R&D, establishing a comprehensive set of international standards, establishing international and national data cooperation, and conducting analysis to quantify the value of storage in specific regions and energy markets.

The German policy landscape provides a useful illustration as the country commits to increasing its share of renewables in electricity consumption to at least 80% by 2050 as part of its "Energiewende" policy. The German energy policy has various focus areas including renewables, grid infrastructure, energy security, energy efficiency, and increasing the flexibility of the whole system. All these are supported by innovation.

A joint RD&D Initiative on Energy Storage Technologies announced by the German government aims to address energy storage for electricity and heat storage and there are various projects under this initiative.

In the German context, RD&D and innovation in energy storage and grids are crucial for successful implementation of the national Energiewende targets. A broad technological approach needs to be adopted for both the short and long terms. Increased, sustained efforts are required to better crosslink the comprehensive research landscape in Germany and internationally.

The IEA Energy Storage Roadmap

Luis Munuera, Energy Demand Technology Unit, International Energy Agency

➤ Link to presentation slides:

<http://www.iea.org/media/workshops/2014/egrdenergystorage/munuera.pdf>

The ETP 2014, recently published by the IEA, lays out a roadmap by establishing the current scenario (where are we today), the future scenario (where we go), and the path to get there. The ETP 2014 engages a cross-section of stakeholders and helps identify a baseline; establish a vision; identify

technical, regulatory, policy, financial, and public acceptance barriers; and develop implementation action items for stakeholders.

With an increase in anthropogenic carbon dioxide (CO₂) emissions in the atmosphere and the resulting impacts of climate change, the world has three possible futures:

- 6°C Scenario (current policies) – where the world is heading under current policy with potentially devastating results
- 4°C Scenario (new policies) – reflecting pledges by countries to cut emissions and boost energy efficiency
- 2°C Scenario – a vision of a **sustainable** energy system of reduced greenhouse gas (GHG) and CO₂ emissions

To achieve the 2°C Scenario, it is crucial for energy-related CO₂ emissions to be halved by 2050. The power sector will play a central role for deep decarbonization. For a 50/50 chance of a two-degree temperature rise by 2100, the power sector needs to bear 40% of the burden. In the 6°C Scenario, fossil technologies continue to dominate electricity generation with a share of 66% in 2050, whereas in the 2°C Scenario, more than 90% of electricity is generated from low-carbon sources (renewables, nuclear), and carbon capture and storage is implemented.

For the power sector to undergo decarbonization, energy storage must play a critical role. There are three pillars for low-carbon transformation of power supply—technology spread, geographic spread, and design of power plants—all constituting a system-friendly variable renewable energy (VRE). Currently, grid-connected electricity storage is dominated by pumped storage hydropower (PSH); however, more flexibility is required (Figure 1). By 2050, 22% of electricity generation will be from renewables; almost 60% of light-duty vehicle sales are projected to be electric vehicles (EVs) or plug-in hybrid electric vehicles (PHEVs) in 2050; and an increase in end-use electrification for heat and industrial end-uses is projected.

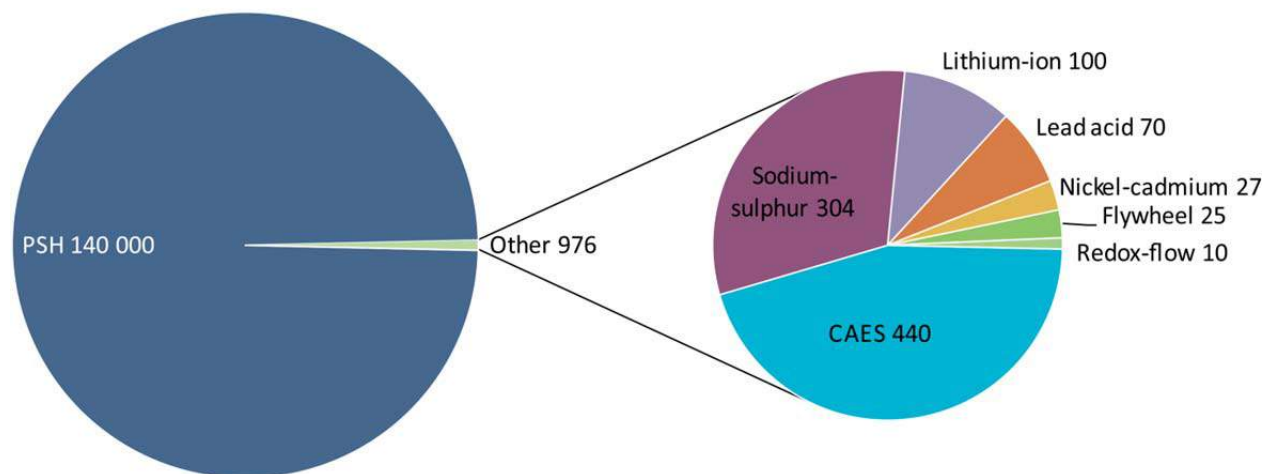


Figure 1. Installed electric storage capacity in megawatts.

Storage in the energy system will play the following roles: improving energy system resource use efficiency; helping to integrate higher levels of variable renewable resources and end-use sector electrification; supporting greater production of energy where it is consumed; increasing energy access; and improving electricity grid stability, flexibility, reliability, and resilience.

Currently, a heterogeneous mix of energy storage technologies exists in both electricity and thermal storage across various maturity levels: R&D, demonstration and deployment, and commercial deployment. Factors that determine the technology's stage of maturity are the technological risk and the capital requirement (Figure 2).

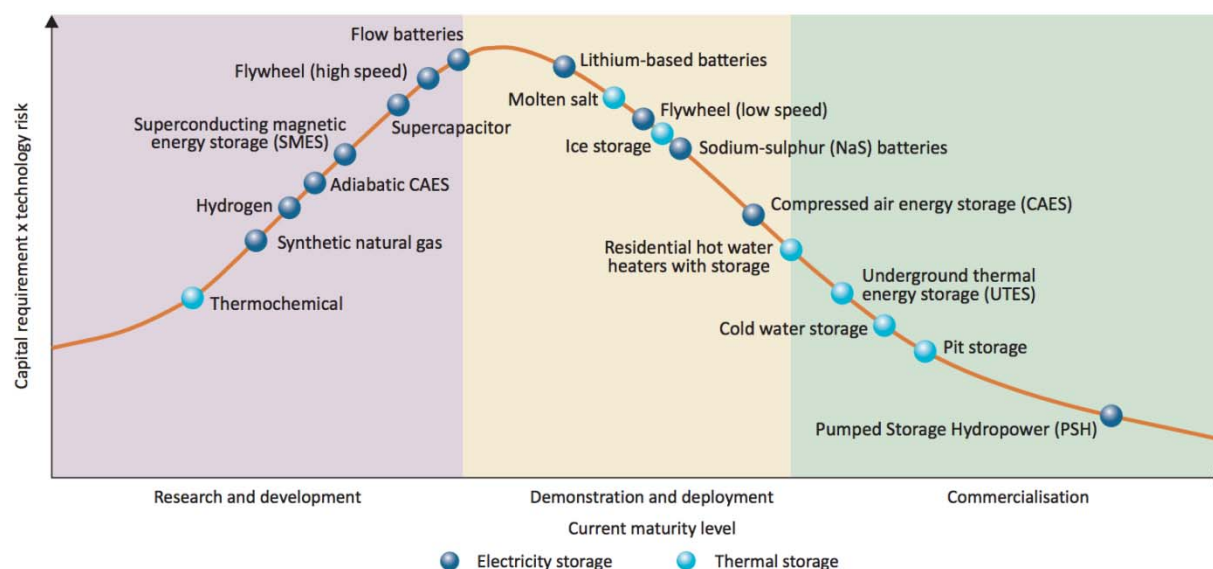


Figure 2. Range of energy storage technologies across various maturity levels.

For any specific type of storage technology there is a broad range in maturity. For instance, high speed flywheels and flow batteries, which are shown as R&D maturity in Figure 2, are available commercially in the United States. NaS batteries have been deployed, particularly in Japan, for more than a decade, and ice storage (for use in building cooling) have been in practice for at least two decades. More advanced versions of these technologies are being developed and have highly varying maturity level and technical performance. Pumped hydro, considered a mature technology, has a power output of 100–5,000 MW and an efficiency of 70%–85%; while supercapacitors, shown in the demonstration stage, have an efficiency of 85%–98%, but power output is less than 1 MW. The future role of storage, as well as its cost, will be defined according to its applications. The cost of electricity storage also varies widely. For example, the investment power cost for pumped hydro is \$500–\$4,600 USD/kWh, while for capacitors, the cost is \$130–\$515 USD/kWh.

The IEA conducted an analysis of storage potential in the 2°C Scenario in China, the European Union, India, and the United States. The study analyzed a one-hour time resolution for arbitrage, load following, integration of solar photovoltaic and wind, and a detailed dispatch model was developed. Three cases were analyzed: an estimation of storage requirements for the 2°C Scenario; a breakthrough scenario, which is the 2°C Scenario plus aggressive cost reductions for storage comparable to combined cycle gas

turbine for arbitrage (e.g., a levelized cost of electricity of \$90 USD/MWh, as compared in the European Union); and an “EV/DR” (electric vehicle/demand response) scenario: the 2°C Scenario plus DR and a 2°C Scenario projection of the number of electric vehicles (e.g., 45 million EVs in 2050 for the United States, resulting in a total storage capacity of 1 TWh).

The key takeaways from the study were that the potential for storage in key regions is highly context-specific, but increases greatly across all scenarios. Depending on the system, flexibility from demand response could provide greater returns.

It is critical to plan ahead for storage. It has been found that in the medium term, photovoltaic (PV) technologies *reduce* the value of pumped storage. In the long term, there is a mutual *increase* of market value; but long lead times exist for many storage projects—particularly large central station storage, such as pumped hydro and CAES—and this is a learning-by-doing process.

Storage is one of a suite of options for providing flexibility (Figure 3).

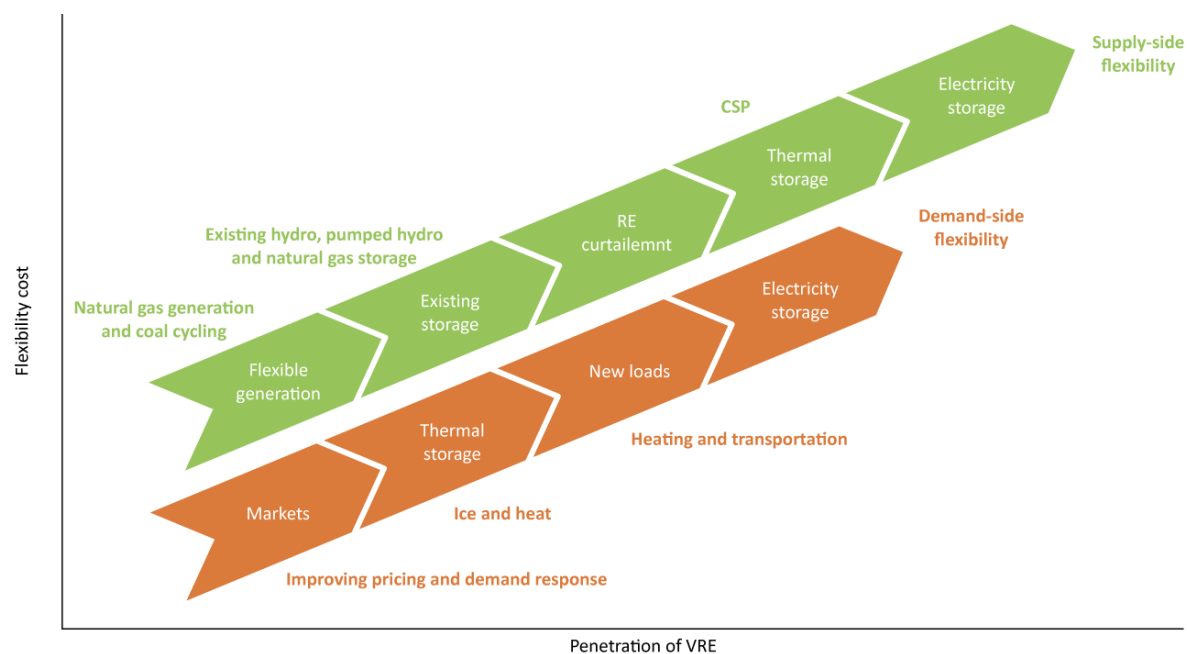


Figure 3. Various options for providing flexibility to a VRE, including storage.

The following are some key findings of the ETP 2014:

- Storage can support energy system decarbonization, but strategic planning is required.
- Some technologies are already competitive in some applications. For the biggest markets, storage still too expensive.
- Additional R&D is still needed to reduce costs, but it must be targeted. Some key knowledge gaps exist.
- The optimal role for storage varies widely across regions.
- Power markets are ill-equipped to compensate storage for the suite of services it can provide.
- Thermal energy storage systems could make better use of waste heat.

The global community needs to undertake key actions over the next 10 years for energy storage to be a commercial reality. These include developing an understanding of the economics of retrofitting existing of storage facilities; developing markets and regulatory environments that enable accelerated deployment, e.g., through benefits-stacking; supporting targeted demonstration projects and R&D; establishing a comprehensive set of international standards; establishing international and national data cooperation; and conducting analysis to quantify the value of storage in specific regions and energy markets.

IEA's next phase of work is focused on developing a multi-carrier energy system integration and on the release of its next two publications: *Smart Grid Roadmap 2015* and *Smart Cities ETP 2016*.

The German Energy Storage RD&D Initiative

Arne Höll, German Federal Ministry of Economic Affairs and Energy, Germany

➤ Link to presentation slides:

<http://www.iea.org/media/workshops/2014/egrdenergystorage/hoell.pdf>

In 2013, renewables accounted for about 24% of Germany's gross electricity production, lignite accounted for 25%, 20% was from coal, and 15% was from nuclear. Most of the renewable generation was from biomass and wind.

The Energiewende (clean energy transition) targets entail a fundamental shift in Germany's energy supply to focus more on renewables. The Energiewende targets in the power sector are:

- Reduce greenhouse gas emissions by 80%–95% below 1990 levels by 2050.
- Increase share of renewables in electricity consumption to at least an 80% by 2050.
- Reduce primary energy consumption by 50% by 2050 compared to 2008 levels.

These targets are complemented by sector-specific targets. The German energy policy has various focus areas including renewables, grid infrastructure, energy security, energy efficiency, and enhanced flexibility of the whole system. All these are supported by innovation.

The main objectives of the Energy Research Policy, released in 2011, are to contribute to achieving the targets of energy and climate policy; enhancing the leading position of companies in the field of modern energy technologies; and securing and enhancing technological options.

The German government announced a joint RD&D Initiative on Energy Storage Technologies (Figure 4), with a call for proposals in 2011 and a request for €925 million in funding. The government undertook a coordinated approach between the three ministries to provide one platform that would serve as a one-stop shop for all applicants. The objectives of this initiative are to develop medium-term and long-term solutions to cope with increasing electricity feed-in from volatile renewable energy sources; address both short fluctuations and long-term variations; address stationary energy storage for electricity and heat storage, including energy conversion into different material energy carriers; address basic and applied research, demonstration, fabrication processes, and aspects of further education; and address

integration and management of storage systems, smart technologies, system services, simulation and planning tools, and socio-economic aspects of storage implementation.

The initiative generates synergies by cross-linking projects and assigning developments to flagship projects (project cluster). Additional research topics include thermal storage, young researcher groups, smart grid-related storage aspects, and system studies. Currently, there are 273 projects with approved collective funding of €196 million.

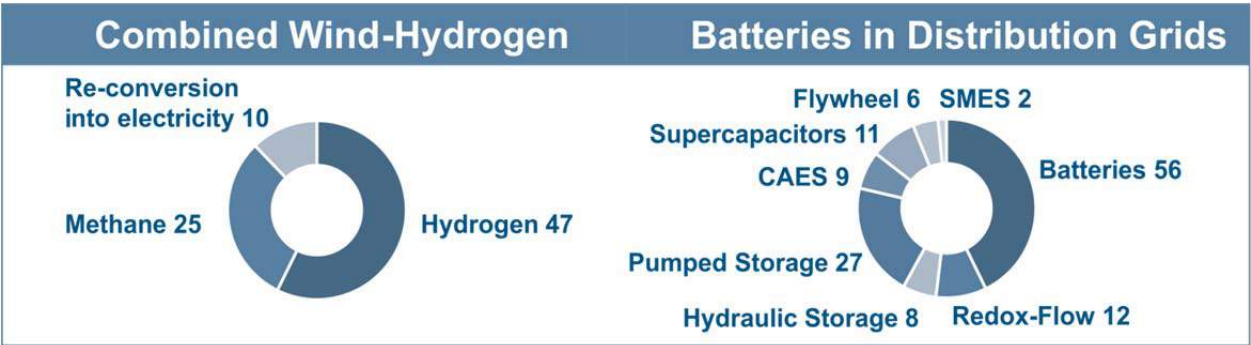


Figure 4. Types of technologies under the joint RD&D initiative.

An example of a project within this initiative is Energiepark Mainz, a combined wind–hydrogen project, where a PtG project is situated adjacent to an existing 8 MW wind park in Mainz. The project partners are Stadtwerke Mainz, Linde, Siemens, and Hochschule Rhein-Main. The main objectives are to implement peak-shaving in distribution grids; demonstrate ways to avoid grid expansion by producing, storing, and using hydrogen in different ways; bridge the gap between existing small-scale electrolyzers (100 kW) to large-scale devices (100 MW) (a 2 MW polymer electrolyte membrane electrolyzer was used); develop a large-scale ionic compressor; and conduct accompanying research activities. The total funding provided for this project was €8.9 million, and the total costs were €17.6 million.

Another example of a project funded by this initiative studied the use of batteries in distribution grids, specifically, a hybrid storage system based on renewable energy systems (RESs). Located in the Smart Region of Pellworm, which is a small island (37 square kilometers, 1,161 inhabitants), the project involves a hybrid power plant: 772 kW PV and a 300 kW wind power system. Research focuses on developing a hybrid storage system and an energy management system, developing business cases, and fostering customer interaction and technology acceptance. The coordinator of the project is E.ON Hanse AG. Figure 5 below shows a map of the project, and Table 1 shows a comparison of the lithium ion batteries and redox flow in such a system.



Figure 5. Map of the project.

Table 1. Comparison of Lithium Ion Batteries and Redox Flow in a Hybrid Storage System Based on RES

	Lithium-Ion	Redox-Flow
System Size Energy [MWh]	0.56	1.6
System Size Output [MW]	0.56	0.2
Efficiency AC/AC	95%	55-65%
Storage loss [1/d]	0.1%	0.0027% (<1% p.a.)
Cycle durability (80% discharge level)	9,200 by 0.5 I _{max}	>20,000
Service life of the system (1 cycle/day)	20	25
Typical discharge time [h]	1-2	5-10
Response time [ms]	10	4 (50 power electronics)
Typical period between storage and withdrawal [h]	0.5-5	2-24

WEMAG, an electricity provider in northeast Germany, is conducting a demonstration of large-scale battery storage. This region is unusual in that RESs can cover electricity demand completely if sufficient storage is in place. The project comprises a 5 MW / 5 MWh battery storage plant in Schwerin, lithium–manganese–oxide batteries provided by Samsung, and integration into a WEMAG transformer station (20 kV level). The project involves frequency-driven primary control. The project was expected to start officially in September 2014, with a total investment of €6.6 million.

Germany established a separate initiative for conducting R&D on future-proof power grids. A call for proposals was conducted in 2012, and €318 million was requested (currently €150 million is available). Topics addressed include transmission and distribution grids, including components, smart grids, IT

solutions, offshore grid connections, and new materials; grid planning, including simulating future power supply systems, modular and interconnected grids, as well as analyzing the demand for grid extensions; and grid operations, including system services, load management, analysis of critical grid conditions, decentralized automation, grid control, and security of the supply system.

To date, Germany has selected 116 projects, grouped into 54 collaborative projects, with a budget of €48 million. The projects involve 36 large enterprises, 24 small and medium enterprises (SMEs), 34 universities, and 21 research institutes.

In summary, RD&D and innovation are crucial for successful implementation of the Energiewende targets. A broad technological approach needs to be adopted for the short and long terms. To generate momentum and deliver results, joint funding initiatives, such as those described above, are needed in key areas such as energy storage and grids. However, increased efforts are needed to better crosslink the comprehensive research landscape in Germany and internationally.

Session 2: Energy Systems and Demand for Storage

This session analyzed the current and projected future energy systems of different IEA member countries and regions with respect to the need for energy storage solutions. The session introduced the overall challenges of how to integrate large-scale renewable energy sources in the energy system and discussed what role storage—among other measures—can offer to ensure energy security and grid stability. Examples on energy storage projects around the world, including different technologies, were described.

One of the perspectives offered at the meeting described that there was no demand for electricity storage. Instead, a demand for electric balancing exists with storage being one among many competing balancing technologies. Energy storage solutions can play a role in temporary energy balancing with demand side management, whereas permanent energy balancing is provided by generation curtailment, additional load, gas turbines for additional generation, and grid enhancements.

As mentioned before, the German energy system provides a good example of the changes underway in the European energy system and the need for storage capacity in such a system. Germany has undertaken ambitious political targets under its Energiewende policy including one for renewables (35% in 2020 and 80% in 2050), energy efficiency (primary energy consumption reduced by 20% in 2020 and 50% in 2050; power consumption reduced by 10% in 2020 and 25% in 2050), and GHG reductions (reduced by 40% in 2020 and 80%–95% in 2050)—all while implementing a plan to shut down all nuclear power plants by 2022. Studies estimate the need for storage capacity to be ~250 GWh in a scenario with 50% share of renewables, a strong increase of residual load gradient, and a +/- 60 GW_e range of residual load change. However, the electricity storage requirement depends on the share of renewables and the flexibility options available. In centralized structures, these include curtailment, flexible operation, new construction, and grid expansion, as well as hydraulic storage, compressed air storage, and PtG. In distributed structures, options include flexible operation, curtailment, grid expansion, and demand side management and response, as well as electric storage, thermal storage (power-to-heat), and chemical storage. Various models and studies have been conducted to analyze these scenarios.

A useful publicly-available resource being developed is the U.S. Department of Energy (DOE) global energy storage database, which contains information about 1,140 projects around the world representing 184 GW (145 GW operational) and over 50 energy storage technologies. As the database indicates, pumped hydro dominates at 142 GW, and the remaining 3 GW is distributed between thermal (1.6 GW), flywheel (0.9 GW), batteries (0.5 GW), and compressed air (0.4 GW). Leading countries in terms of capacity and number of projects are China, Japan, and the United States. Plans for developing the database include a section on codes, standards, and regulation and a section on international partnerships.

From the perspective of a European transmission system operator (TSO), more renewables, stronger grids, demand side response, and energy storage all indicate that energy will increasingly be based on electricity. The demand for flexibility in the system can be met by competing solutions, including increased pan-European interconnections, improved transmission/distribution grid capacity in different control zones, flexible combined heat and power (CHP) and biomass plant operation, improved flexibility

of fossil-fired power plants, power-to-heat, and energy storage. The rationale for storage is that it helps address issues associated with the immense restructuring of generation and demand, the need for balancing the power system in the short term, and the declining spinning reserves in traditional power plants. In addition, alternatives, such as establishing interconnectors, can be difficult to implement in some circumstances.

Energy systems differ from country to country and are characterized by differences in energy mix, different transmission and distribution infrastructure within and across borders, and different framework conditions—not least for electricity market operation. However, storage technologies and other flexibility options provide important solutions to the transformation of the energy system with a high share of fluctuating energy sources. Identifying which cost and system solutions to rely on will require advanced and detailed energy systems analysis, taking into account the complexity of the energy system from a longer-term perspective.

Worldwide Need for Energy Storage

Christian Doetsch, Fraunhofer UMSICHT, Germany

➤ Link to presentation slides:

<http://www.iea.org/media/workshops/2014/egrdenergystorage/doetsch.pdf>

IEA's Energy Conservation through Energy Storage Programme was established in 1978 and focuses on R&D of thermal and electrical energy storage technologies. The program mission is "to facilitate an integral research, development, implementation and integration of energy storage technologies to optimize energy efficiency in any kind of energy system and to enable the increasing use of renewable energy instead of fossil fuels." With 18 participating countries, the program is chaired by Halime Paksoy of Cukurova University in Turkey.

The IEA's Energy Conservation through Energy Storage (ECES) is implementing several projects in five ongoing annexes. Annex 26 (ECES26), Electric Energy Storage: Future Energy Storage Demand, analyzes future electric energy storage demand. The study is based on the premise that no electric energy storage demand exists; only an electric energy balancing demand exists, which opens a real market for different balancing technologies (storage, demand side management, curtailment, etc.) that compete with each other. Such a market is influenced by external factors such as technical feasibility, economics, and legal framework. Energy storage will be part of a future solution; its share will depend on its economics and climate gains.

To determine how energy balancing demand can be compensated, the study concludes that cheap solutions exist (curtailment, additive generation), but these are less efficient (CO₂ emissions) and only reasonable for short periods. Inexpensive solutions (e.g., demand side management and virtual power plant) are reasonable, but they are often not easy to realize and have a limited potential. "Leaving" the electric market (power-to-x) is reasonable for a permanent surplus but not for balancing short-term imbalances. Export and import remain limited because of the not-in-my-backyard (NIMBY) factor, transformer capacity, and unwillingness of neighbor countries to solve German balancing problems. Energy storage is the only solution with nearly unlimited potential and less NIMBY effect, but capital

expenditures are too high and thus cost degression is needed. Figure 6 and Figure 7 provide comparisons of balancing options.

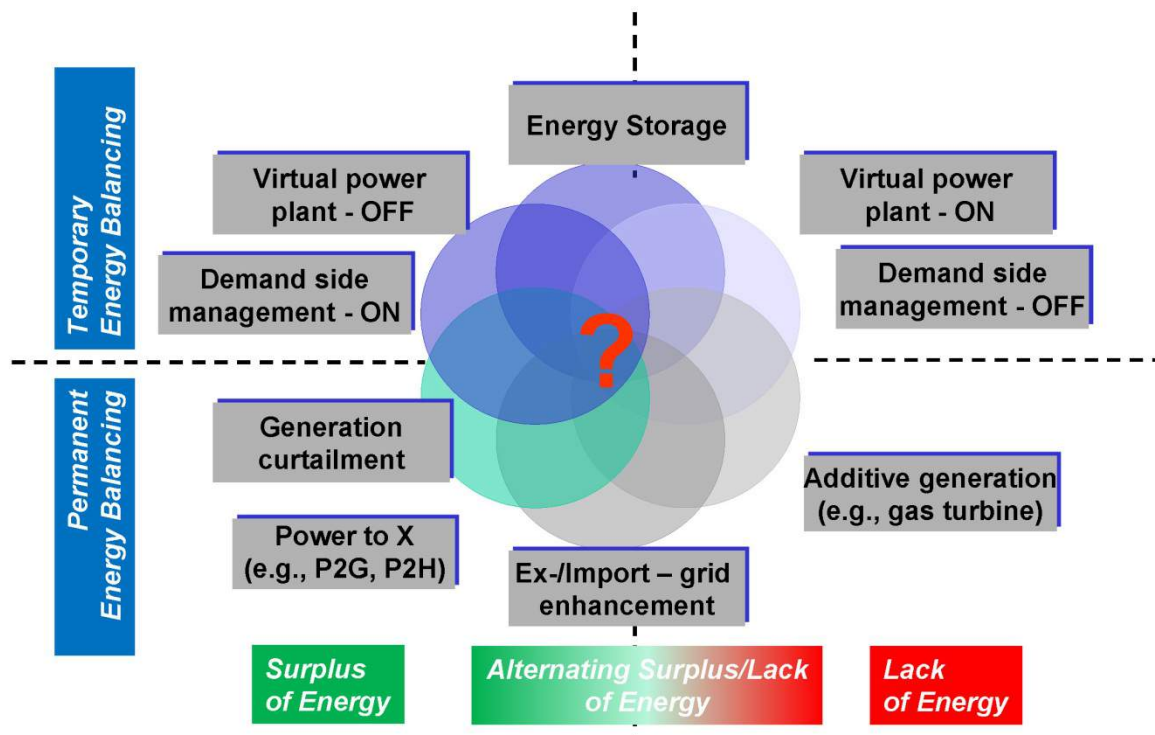


Figure 6. Comparison of energy balancing options and energy storage.

Highly flexible, multiple services, usage of unused energy	Energy Storage	Mostly high CAPEX
Inexpensive if existing power plant could be “virtualized”	Virtual power plant	Additional thermal storage needed, limited potential due to heat demand
Probably inexpensive	Demand side management	Additional thermal storage needed, limited potential due to heat demand
Easy and cheap to realize	Generation curtailment	Wasting energy, probably higher CO ₂ -emissions
Permanent balancing option, inexpensive (P2H), easy to manage	Power to X (e.g., P2G, P2H)	Expensive (P2G), need for high ramping rates, less operating hours
Highly flexible, multiple services/ applications	Additive generation (e.g., gas turbine)	Additive CO ₂ production; less operating hours -> business case?
Highly flexible	Ex-/Import – grid enhancement	NIMBY; probably only exporting balancing problems

Figure 7. Pros and cons of energy balancing options.

To get an overall efficient, environmental friendly, and economic solution for an energy balancing market, there must be fair access to the market for all technical solutions and stakeholders; a transparent market with publicly accessible price systems; market rules that enable business cases for the best-fitting solutions; and individual subsidies for new, promising technologies to reach maturity and to come to the market.

The main objectives of the ECES26 study are to develop a method or approach to calculate the regional energy balancing demand and to derive regional storage demand rasterizing the area, taking into account that there are competitive technical solutions. The study also provides an overview of the different technical, economic, and legal framework requirements in the different countries, as well as typical operation modes for energy storage derived from typical charge/discharge curves that will be needed for future standardizations.

The study uses an energy model to develop a grid balancing demand analysis for Germany (Figure 8 below). The analysis found that disparity exists between positive and negative balancing demands, with the positive balancing demand due to lack of electric energy (e.g., discharging storage or demand side management) and the negative balancing demand due to surplus of electric energy (e.g., charging storage or power-to-heat). In addition, if a total annual surplus or lack of electric energy occurs, then the potential market for energy storage devices could be derived.

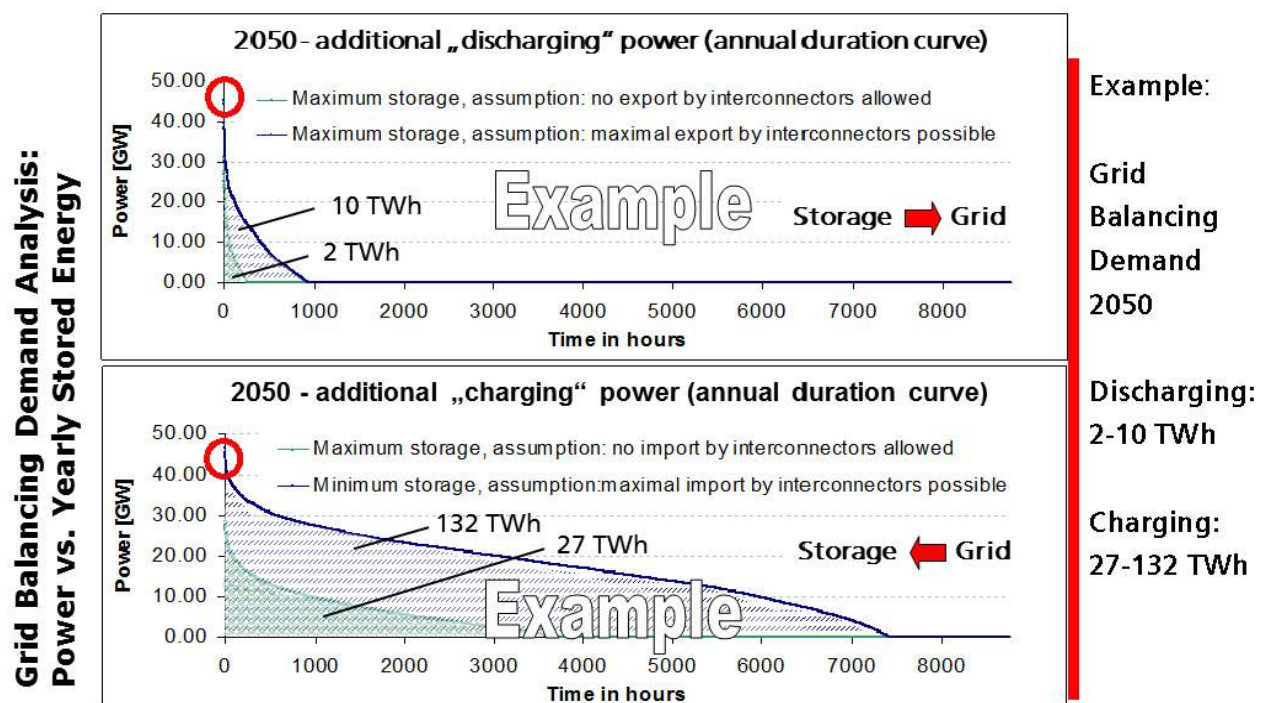


Figure 8. Grid balancing demand analysis for the year 2050 in Germany.

Another modeling study was conducted to determine the future overall electric balancing demand in Germany (Figure 9). The study found that in 2020, there will be almost no balancing demand; in 2030, a storage market will exist for 1.0 TWh per year; and in 2050, the storage market increases to 3.3 TWh per

year. Energy surplus will be 25 times higher than lack of energy, and energy utilization for high short generation peaks will be required.

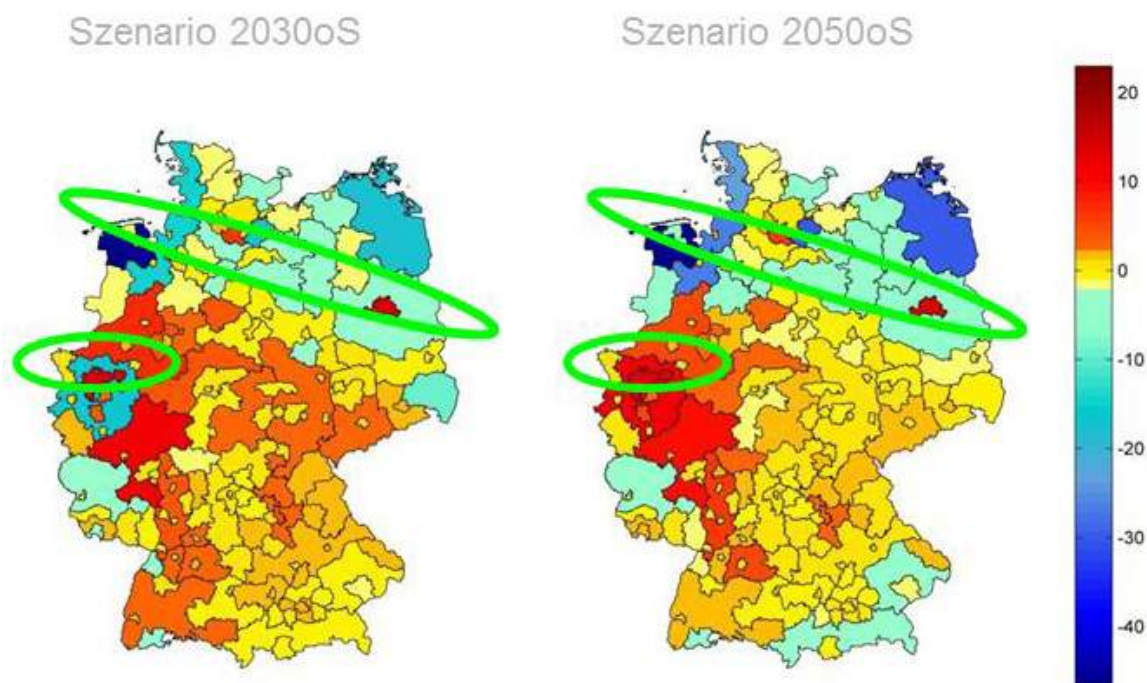


Figure 9. Future electric energy balancing/storage demand (Units: TWh/annum of demand).

Energy Storage in a Grid with Fluctuating Sources: The German Perspective

Kai Hufendiek, Institute of Energy Economics and Rationale Use of Energy, University of Stuttgart, Germany

- Link to presentation slides:
<http://www.iea.org/media/workshops/2014/egrdenergystorage/Hufendiek.pdf>

The current target by the German government is to achieve 35% share of renewable energy sources in gross electricity production by 2020. In 2012, 22.9% of gross electricity production was from renewable energy sources. The “Energiewende” power production targets from renewable sources are set at 50% by 2030 and 80% by 2050, with final energy from renewables at 60% by 2050. Additionally, targets have been set to boost energy efficiency: reduction in primary energy consumption by 50% by 2050 and reduction in electricity consumption by 25% in 2050. A complete nuclear power shutdown by 2022 is envisioned as part of Energiewende, and rapid EV deployment is expected, with about 6 million vehicles by 2030. These targets raise important questions about energy storage’s role in the achievement of these targets and the need to develop of various flexibility options to manage the high levels of fluctuating renewable energy sources (Figure 10).

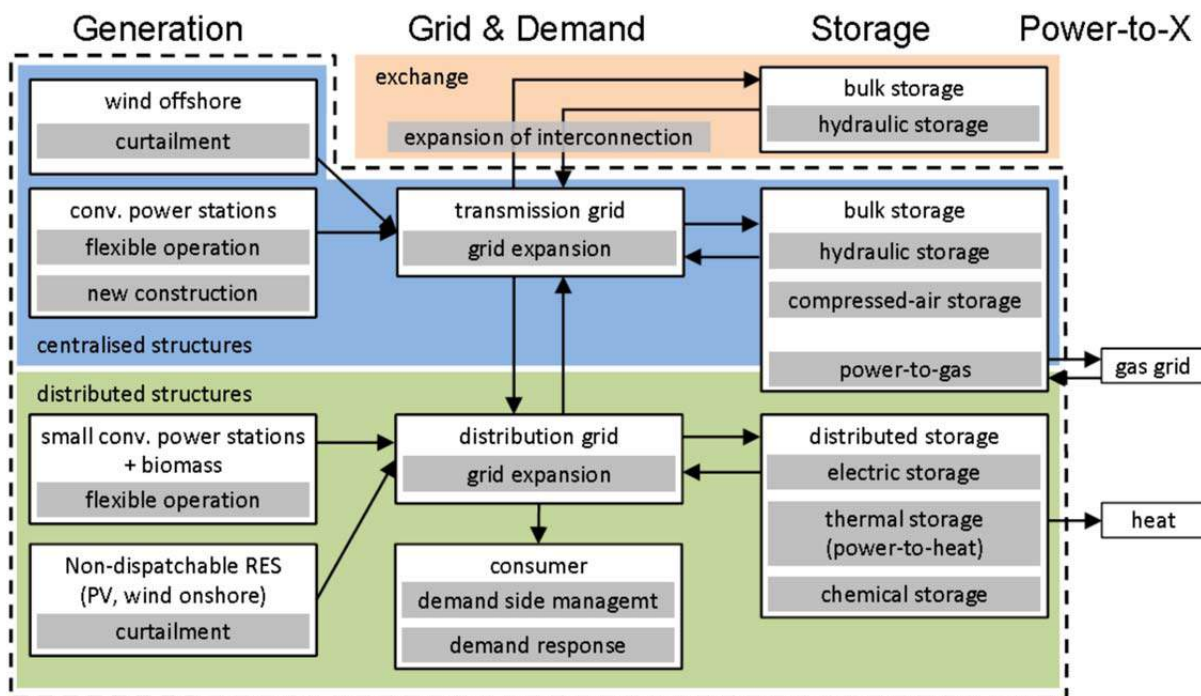


Figure 10. Flexibility options for the electricity system.

In a scenario in which renewables will have a 50% share of power production, excess renewable power of up to 27 GW is expected, as well as excess renewable production of about 2 TWh with a storage capacity requirement of 250 GWh. The range of residual load change is about $\pm 60 \text{ GW}_e$. In the scenario in which renewables will have an 80% share, the excess renewable power to be generated is expected to be about 78 GW, with renewable surplus production at about 43 TWh. This corresponds to 13% of wind and PV production. However, at a 50% share of renewables, only 1% of wind and PV production is surplus. The storage capacity requirement is 6.4 TWh. As a result, implementing these targets will require extensive grid expansion and reinforcements, including adding and upgrading AC and DC lines, upgrading transformers, and extending the grid to accommodate wind and PV. The estimated investment cost is about 22 billion euros for the transmission grid and 27 billion euros for the distribution grid.

As part of the Systems Analysis of Energy Storage research network, the Institute of Energy Economics and Rational Use of Energy (IER) is conducting a systems analytics evaluation of energy storage technologies, as well as an integrated analysis of the contribution of storage technologies for future requirements in Germany. To conduct such analysis, IER is developing two optimization models: the TIMES-PanEU and the European Electricity Market Model stochastic version (E2M2s) (Figure 11).

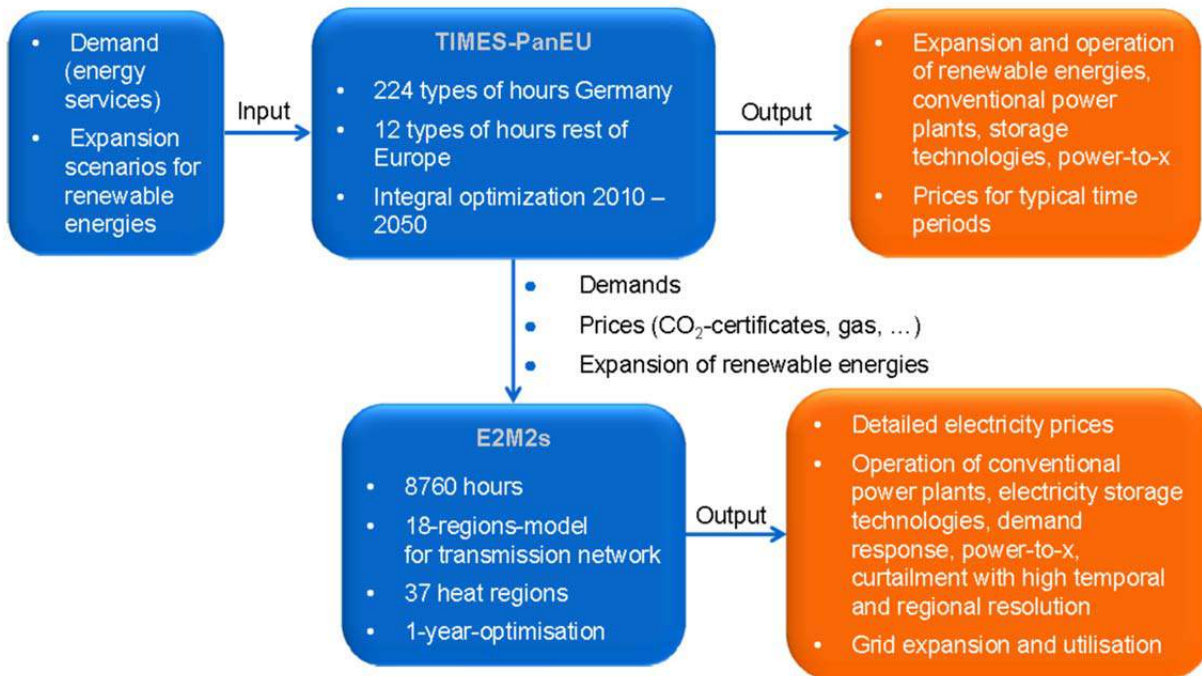


Figure 11. Model coupling TIMES-PanEU – E2M2s.

Model calculations of the different options were made by a coupling TIMES-PanEU and E2M2s and analyzing four scenarios (base scenario, demand response only, curtailment only, and demand response and curtailment). Preliminary results show that demand response is not sufficient. A 2% curtailment of renewables cuts the investments in storage capacity drastically but also increases the investment needs in flexible power plants because insufficient storage energy can be fed back into the system in times with high residual load. In the 50% renewables scenario, present German pump storage, planned new storage, and purchase rights from abroad offer sufficient storage capacity. With 80% renewables, cost-optimum storage is 4.2 TWh with a charging power of 54.8 GW, and fluctuating electricity generation will require curtailment. When including electric mobility and its impact on the residual load, the analysis shows a reduction of the negative residual load in approximately 2500 hours, a maximum avoided negative residual load of 14 GW, and an 11 GW increase of the peak load. The studies identified powerful alternatives to improve integration of fluctuating regenerative generation. These include an acceptance of renewable feed curtailment that achieves a strong reduction of additional controllable capacity requirement, and improved demand side flexibility that reduces the requirement for additional controllable capacity.

In summary, electrical storage plays an important role in the temporal balance between production and consumption. At the same time, it provides the option to include larger shares of renewables into the system. But there are competing options to storage as a means to balance the system. Therefore, an integrated assessment is needed, which can lead to new insights of the overall system in a European context.

The DOE Global Energy Storage Database

Georgianne Huff, Sandia National Laboratories, United States of America

➤ Link to presentation slides:

<http://www.iea.org/media/workshops/2014/egrdenergystorage/huff.pdf>

The DOE Global Energy Storage Database (www.sandia.gov/ess/database) is the only freely accessible database that showcases worldwide energy storage projects and facilities. It also has detailed information on related U.S. state and federal legislation/policies and serves as a tool for a wide range of stakeholders including policy makers; utilities and power providers; RD&D decision makers, strategic planners, and program managers; financial institutions; educators; and the Energy Information Agency. By providing data and assisting in corresponding analysis by a variety of users, the database encourages the growth of the energy storage industry. The database has had over 41,000 users from 161 countries, with more than 435,000 page views.

The database comprises over 60+ data fields, with information on 50+ energy storage technologies. It features third party verification process, and its data are exportable in both Excel and pdf formats. The database provides data visualization tools, allows for easy project sharing, and incorporates social media (Figure 12). The database is being continually improved to address the data needs of an emerging industry.

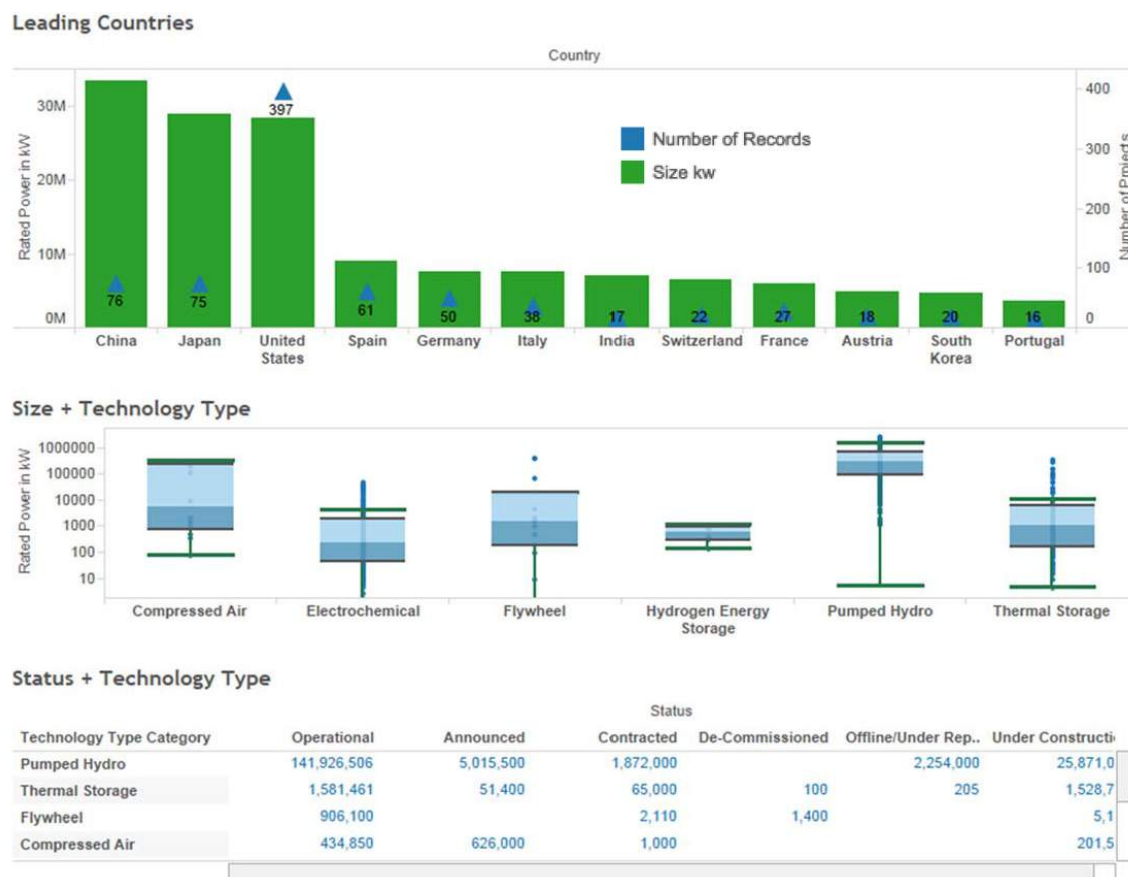


Figure 12. An example of an embedded data visualization tool in the DOE Global Energy Storage Database.

Thus far, the publicly available DOE Global Energy Storage Database contains information about 1,140 projects around the world, representing 184 GW (145 GW operational) and +50 energy storage technologies. Pumped hydro represents 142 GW, and the remaining 3 GW is distributed between thermal (1.6 GW), flywheel (0.9 GW), batteries (0.5 GW), and compressed air (0.4 GW). Only 1.8% of total electric capacity worldwide is currently stored. Leading countries in terms of capacity and projects are China, Japan, and the United States (Figure 13). When pumped hydro is excluded, the leading countries are Germany, Spain, and the United States, with thermal, compressed air, electrochemical, and flywheel storage technologies (Figure 14). The storage technologies are especially used to facilitate electric energy time shift (37%), electric supply capacity (29%), electric supply reserve capacity (spinning) (12%), frequency regulation (10%), and voltage support (6.1%), with miscellaneous other uses comprising the remaining 5%.

ES Technology by Country

Technology	Country								Rated Power in kW
	China	Japan	United States	Italy	Spain	India	Switzerland	Germany	France
Compressed Air			113,580				500	521,000	
Electrochemical	45,990	130,921	280,415	55,777	6,326	15,045	1,110	24,377	11,042
Flywheel	2,000		97,575		2,100		9,000	389,400	700
Hydrogen Energy Storage				1,200				3,520	150
Pumped Hydro	33,199,000	28,651,780	21,682,700	7,484,700	6,889,200	6,772,000	6,427,000	6,228,420	5,812,000
Thermal Storage	51,500		790,751	4,720	1,131,800	226,175		1,500	23,500

Figure 13. Energy storage technology by country.

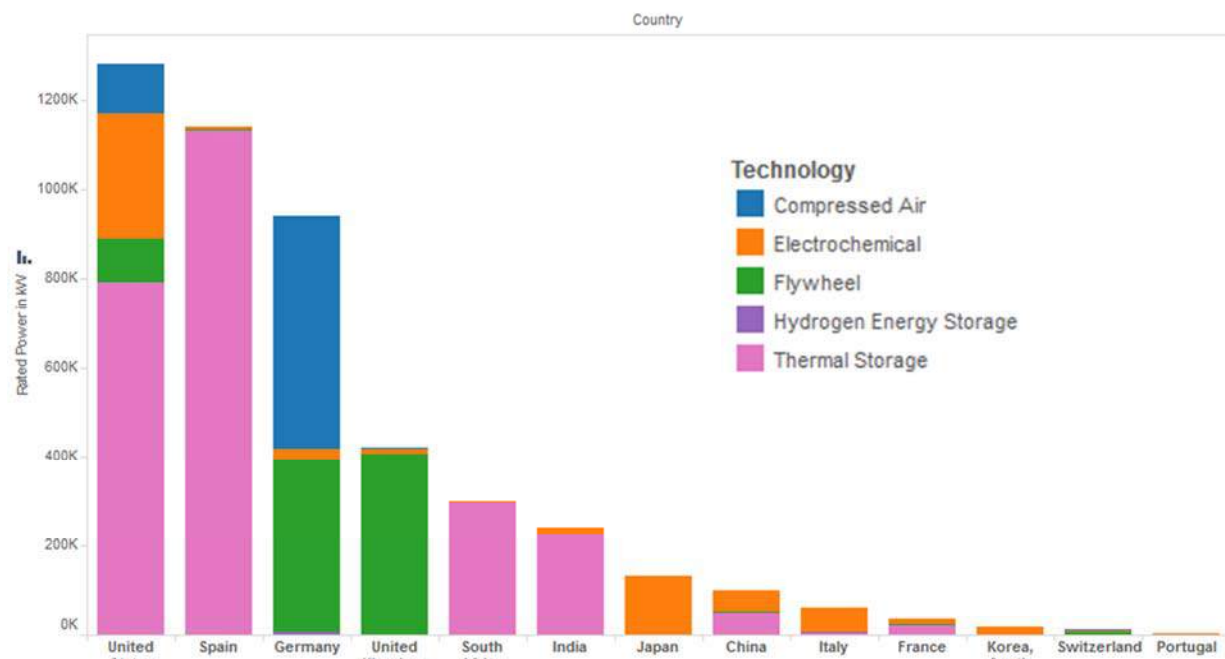


Figure 14. Energy storage by technology by country with pumped hydro excluded.

The plan for 2015 for developing the database include further developing a policy section and a section on codes, standards, and regulations; developing information on international partnerships; providing data visualization tools; increasing publicity and visibility; improving user friendliness; maintaining the database; and conducting project verification.

A TSO Perspective on Energy Storage

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➤ Link to presentation slides:

<http://www.iea.org/media/workshops/2014/egrdenergystorage/constantinescu.pdf>

The European Network of Transmission System Operators for Electricity (ENTSO-E) comprises 41 TSOs from 34 countries, serves 532 million people, generates 828 GW of electricity, and has over 305 thousand kilometers of transmission lines. From a TSO's perspective, for the European Union to meet its GHG emission reduction goals, more renewables will need to be added to the grid, resulting in the need for smarter grids, demand side response tools, and energy storage technologies. The European Energy Vision will require a paradigm shift. Figure 15 shows three installed generation capacity scenarios for the European Union: the current scenario, in which non-intermittent electricity generation dominates at 83%; followed by the ENTSO-E 2030 Ten-Year Network Development Plan (TNYDP) scenario, in which non-intermittent is less prominent ranging from 54% to 69%; and finally the 2050 e-Highway scenario, in which non intermittent generation is reduced to 23%–65% and intermittent (renewable) technologies take on a dominant role.

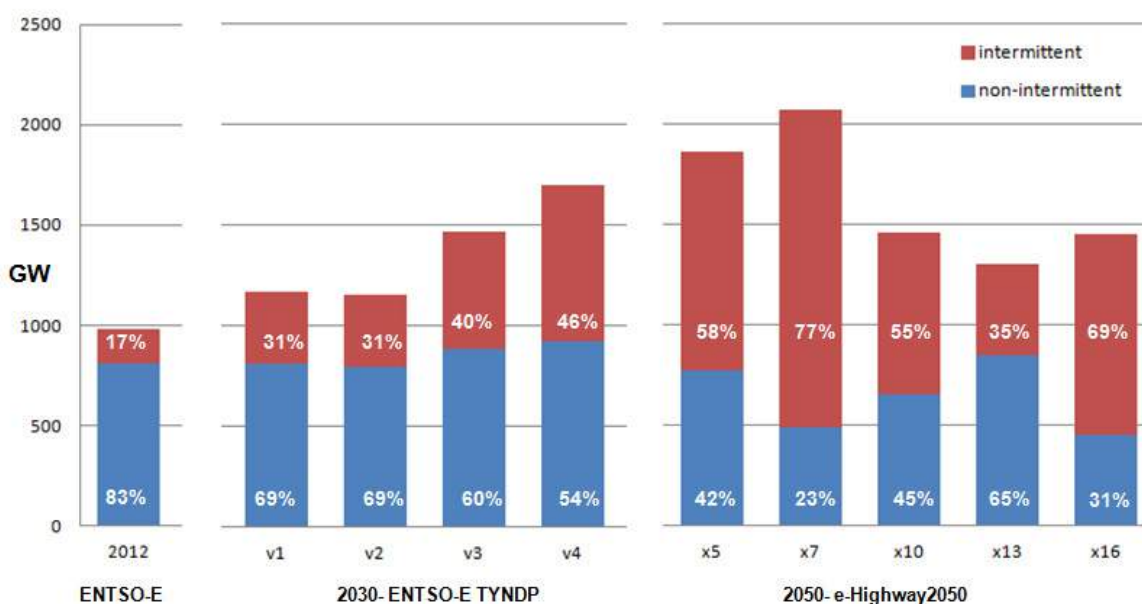


Figure 15. Installed capacity generation scenarios for the European Union in 2012, 2030, and 2050.

As renewables are added on the grid, huge variations are seen in the baseload that is a primary driver for the need for grid flexibility (Figure 16). The demand for flexibility in the system can be met by competing solutions, including increased pan-European interconnections, improved

transmission/distribution grid capacity in different control zones, flexible CHP and biomass plant operation, improved flexibility of fossil-fired power plants, power-to-heat, and energy storage.

Consumption hourly load curves on 16.01.2013 CET

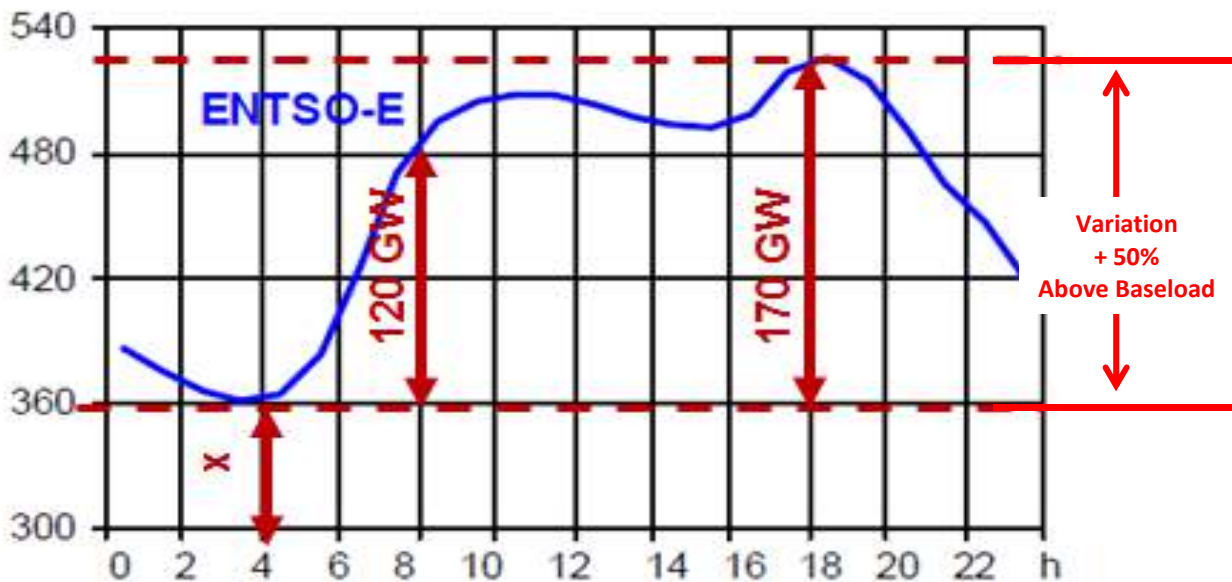


Figure 16. Daily load curve, an illustration.

The development of energy storage remains a challenge. To maintain or increase the security of supply, additional storage will be required. The rationale for storage is the immense restructuring of generation and demand, combined with the slow pace of establishing interconnectors, a need for balancing the power system in the short term, and the declining spinning reserves in traditional power plants. The TYNDP 2014 includes large-scale storage facilities connected at transmission level, with provisions for pumped hydro storage and compressed air energy storage technologies at transmission level, but other technologies need to be developed. Some of the challenges include identifying the appropriate owners and operators of the storage facilities and the business model for such facilities. The TYNDP is the basis of the 2015 Projects of Common Interest list, comprising 17 projects of common interests that include 8 transmission projects and 8 storage projects.

The European Framework is geared towards a more integrated energy system, with R&D within its integrated roadmap. Technologies that require R&D for an integrated energy system include heating and cooling, transportation, smart grid deployment, use of gas (including PtG technologies), and storage.

Session 3: Flexibility Options as Alternatives to Storage

This session discussed the various flexibility options that exist as alternatives to implementing energy storage. These include demand side management, renewable curtailment, and flexible power plants, among others. Various demonstration projects, such as smart community developments and energy management systems, can also provide the flexibility to an energy system. A key issue identified was the lack of an applicable standard for energy storage, which must be developed to help new entrants.

To enable a country to meet its renewable targets and provide it with the flexibility its energy system needs, various options exist. Along with energy storage, other options that countries are pursuing include demand side management, flexible power plants, grid extension, smart grids, renewable curtailment, and others.

Smart community demonstration projects provide another avenue for achieving flexibility within an energy system. Several of these demonstration projects are being implemented in Japan, including in Yokohama City, Toyota City, and others, which showcase the importance of energy storage technologies and their ability to enhance system flexibility. Energy management systems play a critical role in information exchange. However, there is a need for more demonstration projects to better understand the pragmatic effects of demand response.

A reduction in income and production from conventional sources, an increase in the share of renewables, the balancing of supply and demand without outage in transmission and distribution grids, and an increase in electricity demand are key factors that are driving exploration in flexibility options, including storage. Studies have shown that the market potential for energy storage is high, ranging in the hundreds of billions of dollars by the 2020s. For the right product at the right price, the market potential for these technologies is high.

However, the lack of standards for energy storage systems remains a key gap for the growth of these technologies that must be addressed in the future. There is a need to develop a guidebook that eases new entrants into the sector, and a framework standard for grid-connected energy storage is a must. Such an effort is being undertaken by an industry-led consortium called the Joint Industry Project, which will help in the facilitation and stimulation of energy storage guidelines and best practices.

One alternative to effectively reduce the need for electricity storage is demand response: instead of storing excess energy, the load on the demand side can to a certain extent be shifted to times with high production. Various technologies can be used for demand response in the power grid. These include thermal storage devices, electrical vehicles, and load-shifting in public services. Various pilots and field tests are being conducted to study the practical implementation of different demand response technologies, for example, the Smart Grids Model Region Salzburg in Austria and the gridSMART project in Columbus, Ohio, United States.

In Denmark, as the national energy system undergoes massive transformation to accommodate additional renewables in the system and no use of coal in power plants, natural gas and hydrogen are

expected to play an important role. However, the use of shale gas worldwide could affect pricing, affecting European markets. R&D in new technologies remains crucial, especially in fuel cell electrolysis, and thermal gasification, and the complex interactions between various sources such as power, heat, gas, and transport need to be explored further.

Convergence of Electricity and Gas Grids

Peter Markewitz, Forschungszentrum Jülich, Germany

➤ Link to presentation slides:

<http://www.iea.org/media/workshops/2014/egrdenergystorage/markewitz.pdf>

The energy sector is accountable for 42% of Germany's CO₂ emissions. To ensure that Germany meets its national renewable energy targets (35% by 2020, 50% by 2030, and 80% by 2050), the electricity system must transform to integrate fluctuating renewable energies. The system needs to move from a demand-oriented system to a more supply-oriented one, and make accommodations for increasing demand for flexibility and controlling energy supply. There is a need for flexible technologies, including energy storage, demand side management, flexible power plants, grid extension, smart grids, renewable curtailment, and others.

Renewable share in electricity production was 17% in 2010, and this number is projected to be 41% by 2020 and 85% by 2050. A simulation of renewable energy share of 41% in 2020 shows that only a limited number of days will have excess renewable energy, and that flexibility can be provided by conventional power plants, biomass, demand side management, and renewable electricity curtailment.

A simulation exercise of 85% of renewable energy by 2020 highlights that there will be numerous days with excess renewable energy, and there will be longer periods with low renewable production, which requires thermal power plants and storage to provide flexibility. Storage might also be an option for reducing renewable curtailment.

The main takeaways of studies on long-term storage demand highlight that an increasing share of renewables requires higher flexibility on the supply and demand side. In a scenario with 40% renewable energy, there is no long-term (i.e., long temporal periods) storage demand, there is limited renewable energy electricity excess, and flexibility can be provided by conventional power plants. When exceeding 40% renewable energy, long-term storage becomes more important, but demand response and curtailment can be economically favorable options. In a scenario with 80% renewable energy, flexibility can be provided by conventional power plants and storage technologies, long-term storage is an option for renewables integration and GHG reduction, and for the highest production peaks (sporadic events), renewable energy curtailment is an economic option. Only when exceeding 80% renewables are PtG technologies really needed.

In the case of 100% renewables, long-term storage technologies are required to provide carbon-free flexibility, large storage capacity is required, and additional flexibility is provided by renewable curtailment and renewable import. A maximal efficiency of 32% can be achieved by considering the whole chain of electrolysis, methanization, and power production in a combined cycle power plant.

Although the efficiency might improve in the future (e.g., by incorporating fuel cells in the chain), the value is still fairly low, explaining why PtG is economically ruled out in many situations from today's point of view. Even when omitting the last step (power generation in a combined cycle power plant) and considering the production of synthetic natural gas via electrolysis and methanization, long-term production costs of below €0.10 per kWh are expected, as compared to €0.022 per kWh for natural gas (Figure 17 and Figure 18).

The KonStGas Project, funded by the German Ministry of Economic Affairs and Energy (BMWi), was initiated in 2013 and is projected to end in 2016. With over 10 institutions as partners, the project aims to achieve a better understanding of PtG technology storage options. This includes understanding the magnitude of surplus electricity production, taking into account Must Run capacity, demand side management, controllable consumers, export, power-to-heat, etc.; the role of long-term storage options (with a focus on PtG); the impacts on gas and electricity grids if PtG is applied on a large scale; the best sites to integrate renewables (gas grid, electricity grid, installed renewable energy capacity); the circumstances that drive the need for synthetic natural gas production from PtG; and the macroeconomic impacts of different strategies.

Currently there are 18 PtG demonstration plants in Germany, of which 2 are methane injection plants, 5 are hydrogen injection plants, 8 are E-gas for mobility plants, and 5 are plants under preparation.

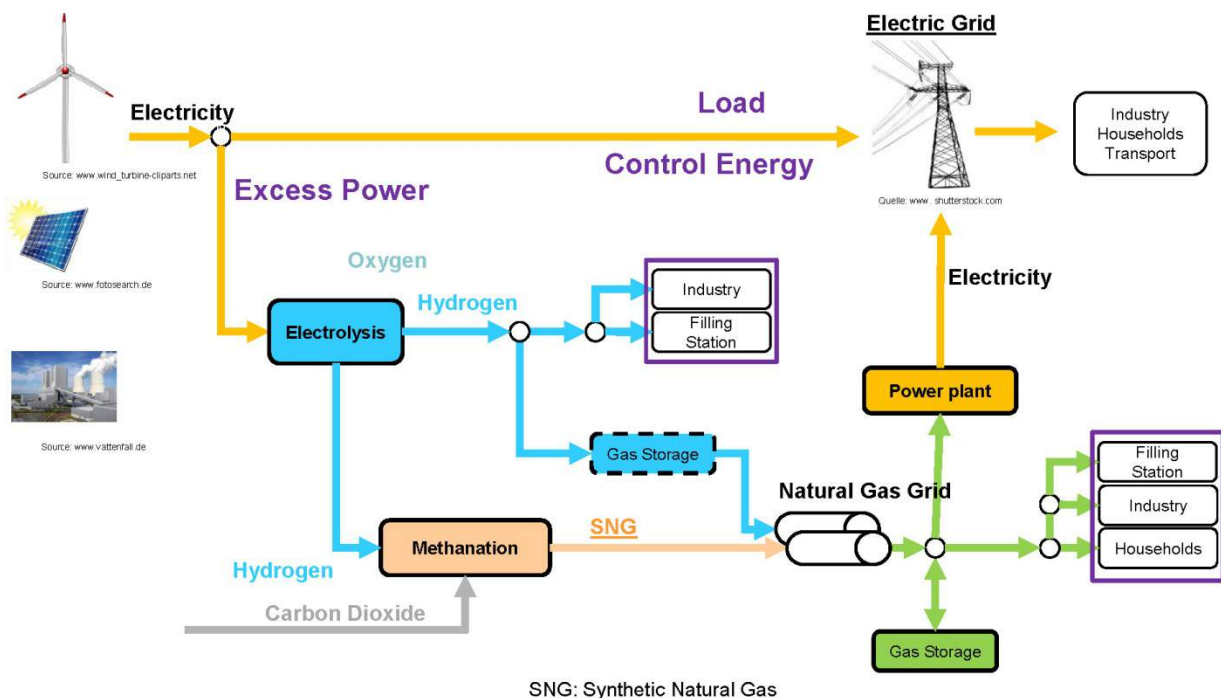
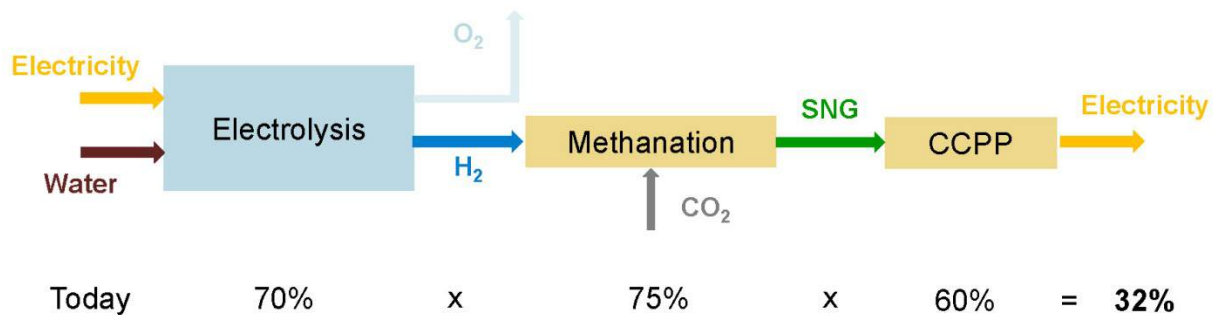
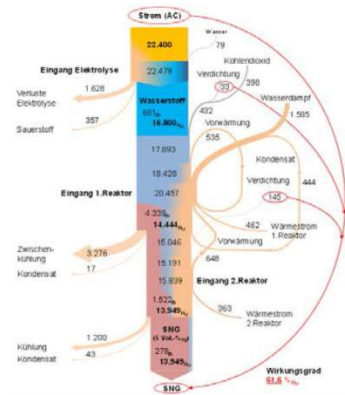


Figure 17. PtG: hydrogen or synthetic natural gas.



Literature: 28-35%
Maximum value: 45% (Stern, 2009)



Production costs of SNG

Today: ~18 €/kWh¹⁾ SNG

Mid term: ~13 €/kWh SNG

Long term: ~10 €/kWh SNG

Price for natural gas: 2.2 €/kWh

1) Electricity price: 3 €/kWh

Figure 18. Efficiency of the PtG conversion chain.

Japanese Perspectives on Storage Alternatives

Atsushi Kurosawa, Japan Institute of Applied Energy, Japan

➤ Link to presentation slides:

<http://www.iea.org/media/workshops/2014/egrdenergystorage/kurosawa.pdf>

Energy storage provides flexibility, allowing energy to be shifted in time and location, both on the supply side and the demand side. Japan has been implementing various energy management system demonstration projects. For example, in Yokohama City, there are three integrated energy management areas (commerce, residence, and industry) with large-scale demand response and energy management programs. The demonstration project includes integrated virtual batteries, fuel cell sharing (electricity- and heat-generated), smart building energy management systems, fast EV charging (using integrated charging machines with stationary batteries). The goal is to have 27 MW of energy generated from PV, 2,000 electric vehicles, and 4,000 households with energy management systems. In Toyota City, there is a focus on households and new-generation vehicles, which involves implementation of PVs, fuel cells, stationary batteries for households, and automatic control of some high-consuming residential functions. Incentives are given for demand conservation. Other demonstration projects are being implemented at in Kansai Science City and Kitakyushu City.

A smart community is a new community utilizing advanced information and communications technology with participation of citizens, and involves smart transportation, homes, and office buildings (Figure 19).

The Japan Smart Community Alliance was established in April 2010 and consists of 324 members from industry, academia, local governments, and non-profit organizations. The Alliance interacts with overseas organizations, such as the Global Smart Grid Federation.

The Japanese electric power market is undergoing significant transition, and it is anticipated that 100% of large customers will have smart meter installations by FY 2016, and 100% of small customers will have installations by FY 2020. A new electricity system is being planned that will have a TSO by 2015, retail market deregulations for small customers by 2016, and termination of price regulation and unbundling of the power supply structure by 2020.

The achievements of the social system demonstration project include community energy management system development and an information exchange interface standards operation. A demand response tariff-based experiment is in progress, and a megawatt trading experiment through an aggregator is planned.

In summary, the smart community demonstration projects showcase the importance of energy storage technologies and their ability to enhance system flexibility. Energy management systems not only play an important role through information exchange but also can be managed smartly through system learning (e.g., demand forecasting, virtual aggregation of storage devices, weather information-based renewable power output forecasting, and other operation experiences). However, more demonstrations are needed to better understand pragmatic demand response effects.

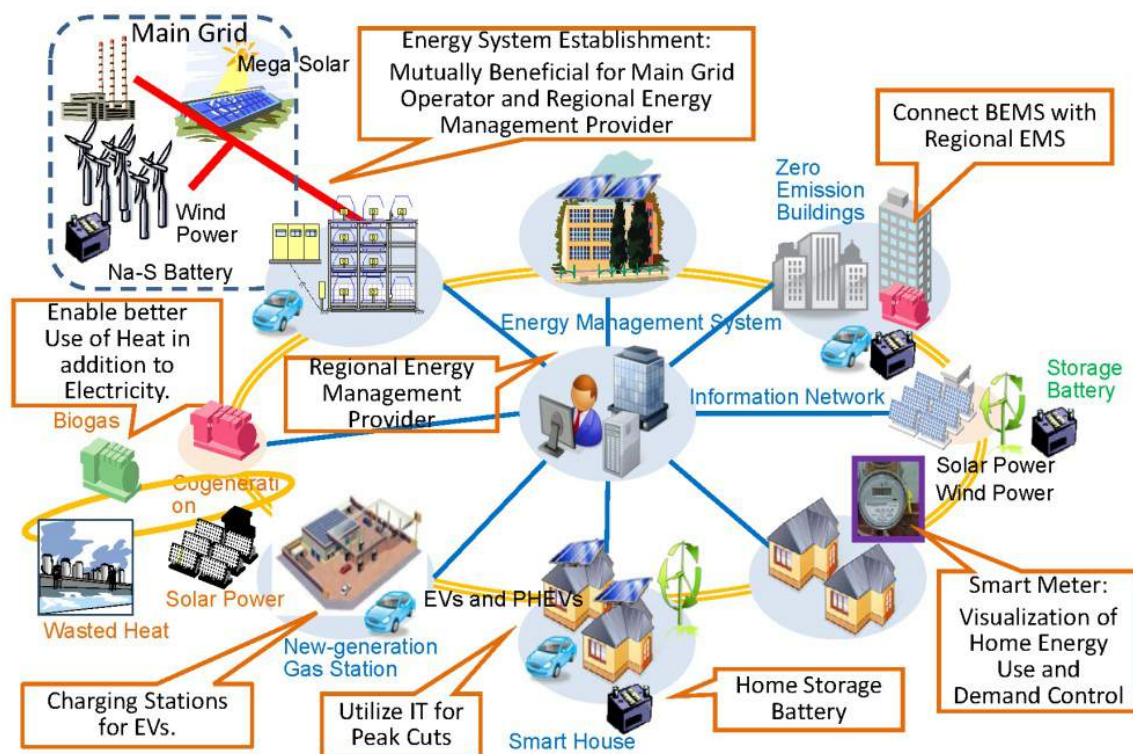


Figure 19. Smart community development in Japan.

Energy System Flexibility, Security, Standards

Rob van Dijk, DNV-GL, Netherlands

➤ Link to presentation slides:

http://www.iea.org/media/workshops/2014/egrdenergystorage/van_dijk.pdf

Currently, six major trends in energy markets are driving changes: increased electricity demand, environmental responsibility or stewardship, declining fossil fuel supplies, aging assets and workforce, advancing technology, and the need to maintain reliability. Increased supranationalization, such as cross-border energy exchange and interconnection capacity, and decentralization are resulting in changes in the scale and priority of the private sector in energy markets. Trends specifically driving the European power sector are decentralization, in which large amounts of distributed generation (DG) are being created; the venturing of SMEs and other new entrants into the energy market, resulting in the need for new ways of cooperation and increased participation from end-users; Europeanization, resulting in increased mergers and acquisitions and increased cross-border power flows; and the requirement to have an affordable, reliable, and sustainable grid.

From 2015 onwards, there will be a need to explore further flexibility options in earnest as there is a trend towards reduced income and production from conventional sources, increased intermittent production from renewables, balancing supply and demand without outage in transmission and distribution grids, and increased electricity demand. Various flexibility options include storage, increased plant regulation, strengthening the grid, and demand side response.

Various studies have been conducted that show that the market potential for energy storage ranges from \$114 billion in 2017 to \$600 billion by 2025. For the right product at the right price, the market potential for these technologies is high (Figure 20).

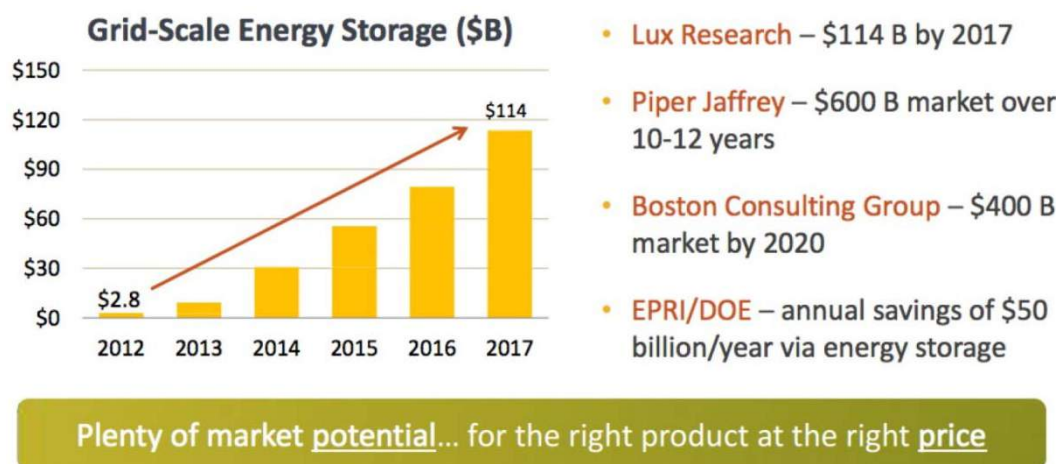


Figure 20. Energy storage market potential.

Both central and distributed resources will play a role in future grids because of lower startup costs, shorter construction time, higher reliability of electric service (backup power), redundancy (as unit outage is less critical to grid operations), higher flexibility (responsive to local needs),

higher resiliency (hard to totally shut down the grid, which is quick to recover), and higher synergy with transportation batteries. However, aggregated fleets of distributed energy are expected to dominate the market. (In certain countries where large central pumped hydro or compressed air energy storage is geologically feasible, this might not be the case.)

A survey of electric utilities, storage vendors, and other stakeholders in 2014 found that there was a “lack of clarity on applicable standards for grid-connected energy storage systems.” This can prove to be a risk for the sector as a whole. While various standards exist, there is no single standard that comprehensively covers and links all aspects relevant for grid-connected energy storage. Furthermore, it is impossible to combine ~100 standards into one comprehensive standard. All these have differing scopes, might not cover a particular aspect comprehensively, can be of low quality, and can be difficult to understand; and it is difficult to get an overview of all the existing standards. As such, a need has been identified to develop a new guidebook that allows new entrants to easily understand all the steps that must be taken to install storage systems, as well as a framework standard for grid-connected energy storage. Such resources should be comprehensive and complete, undertake a system-level approach but include components, address issues from an international perspective, and specifically address grid-connected energy storage. Such an effort should be undertaken by an industry-wide consortium that is independent and unbiased—one that will develop these resources and provide them to the market quickly and efficiently.

DNV GL is currently establishing an open source joint industry project to facilitate and stimulate optimal and safe implementation of energy storage. The project consortium comprises 10–15 participants, including end-users (TSOs, distribution system operators, utilities, etc.), energy storage system integrators, suppliers, and regulators. The consortium has been charged with developing recommended practices on grid-connected energy storage guidelines and methods, taking into account worldwide accepted regulations and best practices such as independent system operator, International Electrotechnical Commission, and Institute of Electrical and Electronics Engineers (IEEE) standards.

In summary, the energy markets of the future have a strong need for increased flexibility, and energy storage is one of the flexibility options that can improve system security on both international and decentralized levels. However, it is essential that standards are adequately developed to enable the safe and sustainable implementation of energy storage systems.

Demand Side Management

Matthias Stifter, Austrian Institute of Technology, Austria

- Link to presentation slides:
<http://www.iea.org/media/workshops/2014/egrdenergystorage/stifter.pdf>

Several factors are driving forces that emphasize the need for flexibility of demand and the motivation for having demand response as a flexibility option. These include an increase in local distributed generation, grid parity using PV, peak curtailment, higher dynamics in the power system, and higher unbalance due to forecasting errors. Demand response can be used as an alternative to energy storage;

instead of storing excess energy, the load on the demand side can, to a certain extent, be shifted to times with high production. In EVs, for example, controlled charging can be used as an alternative to electrical charging. Other technologies that can be used are thermal storage devices (warm water boilers, cooling/freezing, heating, etc.) and load shifting in public services (water pumps, waste water/sewage). In Germany, a potential of roughly 5 GW shiftable power is estimated for the present, and an increase up to 9 GW is expected for 2030. This amounts to total annual displaceable energy of roughly 42 TWh and therefore a share of 7%–15% of total electricity consumption. However, the amount of load that can be shifted decreases significantly with interruption time, which limits the major application of demand response technology to fluctuations on short timescales (a few minutes to one hour). Furthermore, there are differences between battery operation and demand requirements (storage of electric energy versus shifting energy), which restrict certain use cases. Differences between demand response and energy storage are highlighted in Table 2.

Table 2. Differences between Energy Storage and Demand Response

	Battery	Demand Response
Operation	charging / off / discharging	(forced) charging / off
Self discharging	losses	losses = customer demand
SOC range	depends on previous operation	unknown free rest capacity
Rated power	charging = discharging	withdraw > charging
Storage time	short to long term	(short term) “shifting”
Availability	dispatchable	external factors (demand, T, ...)
Purpose	dedicated system	part of demand side
Control	energy management system	simple control (e.g., thermostat)
Objective	storage of electric energy	shifting of energy
Scale	large / utility	settlement, building, households

One demonstration project, gridSMART® RTPda in Columbus, Ohio, United States, is the first real-time market at the distribution feeder level (Figure 21). The Ohio Public Utilities Commission approved a tariff for this project. The value streams include an energy purchase benefit, capacity benefits, and ancillary services benefits. The project uses a market bidding mechanism to perform distributed optimization with about 200 homes bidding on 4 feeders. A separate market runs on each feeder. There is also automated bidding for heating, ventilations, and air conditioning (HVAC) systems.

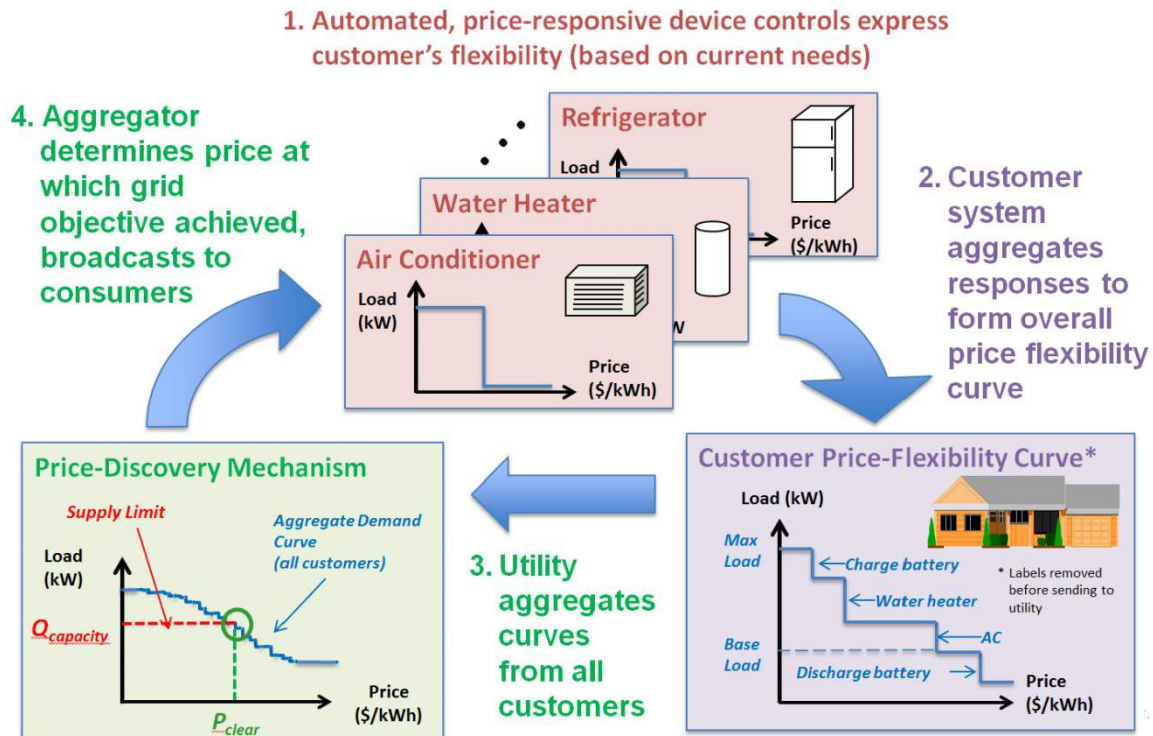


Figure 21. Project gridSMART® RTPda demonstration.

A dedicated Smartgrids model community is being developed in Köstendorf, Austria, that is supplied by a 250 kVA secondary substation. This demonstration area has a PV system on every other rooftop and an EV in every other garage. Field tests are being conducted of an integrated smart grid solution for low-voltage grids. This project is funded by Austrian Climate and Energy Fund and Province of Salzburg.

In the work being undertaken by the IEA Demand Side Management (DSM) Task 17 group, Phase 3 focuses on a systems view on enabling flexibility in the smart grid. Various perspectives are being taken into account, including those of customers, technology, policy, and market. The group is focused on enabling flexibility and its impact on stakeholders, including requirements, management, effects, and benefits. The IEA's activities in this sector are bundled in the DSM Implementing Agreement (<http://www.ieadsm.org/>); Task 17 is studying the integration of demand response into an energy system with distributed generation.

Worldwide, a number of pilots and field tests are studying the practical implementation of different demand response technologies. In the Smart Grids Model Region Salzburg in Austria, residential buildings are treated as an interactive participant in the Smart Grid through a 90 m³ thermal storage system, which is connected to the residential heating grid. The Ohio gridSMART project (mentioned above) is testing transactive grid control with residential real pricing; for the first time, a real-time market for private consumers is being implemented with a tariff approved by the local regulating body. The utilization of electric vehicles as a demand response source is being extensively tested in different regions in Austria.

In summary, while there are major differences between energy storage and demand response, several studies have identified demand response as a cost-effective way to integrate renewables. Thermal and electric storage have high potential, and while large customers are obvious targets, medium and small customers should also be targeted. Demand response can be used for balancing uncertainties related to forecasting or renewables. Research is required to develop a better understanding of load dynamics, and prediction tools need to be developed.

The Future Energy System – with Focus on Flexibility by System Interactions

Poul Erik Morthorst, Danmarks Tekniske Universitet, Denmark

- Link to presentation slides:
<http://www.iea.org/media/workshops/2014/egrdenergystorage/morthorst.pdf>

Denmark's climate change policy clearly states that Denmark can reduce its greenhouse gases and be independent of fossil fuels. To achieve these goals, a total conversion of the Danish energy system is needed.

Between 1990 and 2012, Danish energy consumption, CO₂ emissions, and energy intensity have fallen in spite of strong GDP growth. Denmark has a large domestic production of oil and natural gas with a high degree of self-sufficiency. The main future trends in the Danish energy market are that intermittent sources will play a significant role, the energy system will be dominated by electricity, biomass resources are limited, and a radical change will be needed in the transportation sector.

The Danish Parliament has set targets for 2020: 1000 MW of offshore wind power, 500 MW of near-shore turbines, 500 MW of land-based wind, and biomass in central power plants. The Parliament has also emphasized energy savings.

Additional targets set by the Parliament include the following: by 2020, wind power will supply 50% of Danish power consumption; by 2030, Danish power plants should use no coal, including oil furnaces; by 2035, renewables will supply all heat and power consumption; and by 2050, renewables will meet all Danish energy requirements.

To achieve these targets, various requirements will need to be fulfilled, some of which will require huge efforts in district heating and transport systems. These include a need for balancing wind power, back-up options for situations where wind power is low, and flexibility in energy demand, including smart energy. The need to balance fluctuations in wind power, which will be very great, could be addressed by increasing the interconnection to neighboring countries, especially the large number of pumped hydro storage facilities in Norway. Various options exist to ensure a continued and reliable supply of heat, such as heat pumps for district heating, geothermal energy, and waste heat from industry and incineration plants. For the decentralized power plants, solar heating and heat pumps are viable options.

In the transition phase, storage facilities may be required. Hydrogen and natural gas are both options, with the latter being a cheaper option for long-term storage. Building the hydrogen infrastructure

might take a long time, and it is unclear whether it is an economically viable option. Natural gas in CHP should be reconsidered after 2035, which could add to the energy system's robustness. Additionally, natural gas can be a good substitute for oil in industry and transport (Figure 22).

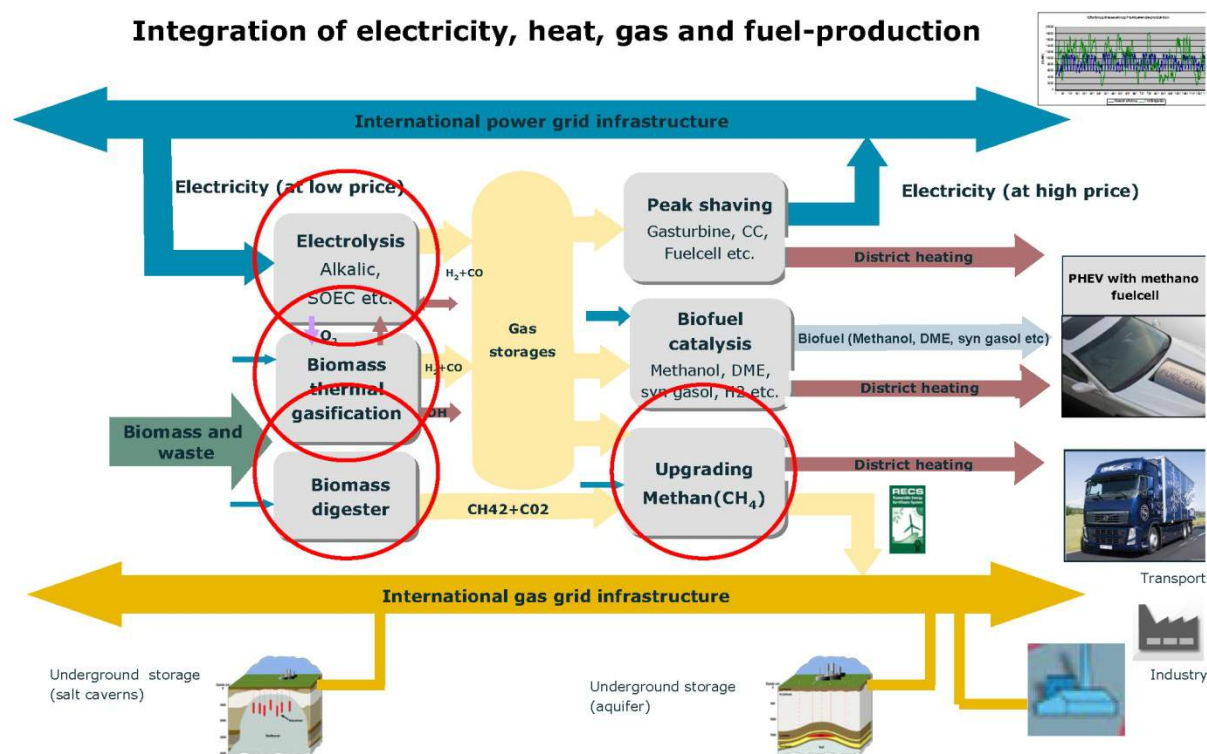


Figure 22. Integration of electricity, heat, gas, and fuel production.

There are two major threats to achieving these goals: increasing costs of energy supply, which would hurt Danish industrial competitiveness, and impacts of shale gas on energy pricing.

In summary, the Danish energy system will change significantly over the next few decades, with wind playing a more dominant role. Impacts of shale gas can affect energy markets in Europe. Natural gas and hydrogen are two energy sources that can also play a critical role in the future. There is a need for balancing, back-up options and storage for intermittent resources, and flexible fuels in industry and transportation. During the transition phase, ensuring increased use of gas might ensure system robustness. R&D is required in various new technologies such as fuel cell electrolysis, and thermal gasification and the complex interactions between various sources such as power, heat, gas, and transport will need to be explored further.

Session 4: Energy Storage Technologies

During this session, different energy storage technologies that are currently used and/or being researched were presented. Participants discussed the current status of storage technologies and the primary technological limitations and barriers.

Storage is seen as a critical component in implementing cost-effective low-carbon technologies, as evidenced by its prominence in the European Commission's Strategic Energy Technology Plan (SET-Plan) and in the DOE Energy Storage RD&D Program. The market for storage is growing, with several ongoing projects and increased interest led by the mobility market (e.g., electric vehicles) and, hence, battery technologies.

Battery technologies currently in use are lead-acid, lithium-ion, NaS/NaNiCl, and vanadium redox flow batteries (VRFBs). Although RD&D has historically focused on lithium-ion and fuel cells rather than redox flow batteries, VRFBs have experienced recent breakthroughs, in part thanks to UniEnergy Technologies' Uni.System™, a grid-scale energy storage system that became commercially available in summer of 2014. Several DOE-supported projects are also investigating flow batteries, including a project studying Fe-Cr flow batteries and possible uses in combination with PV, a collaboration conducting materials research into a mixed acid electrolyte, and a PNNL analysis program that selects the most cost-effective site and scale to optimize the value stream. New battery candidates include solid polymer electrolyte, metal-air, lithium-sulfur, anodes with silicon, sodium-ion (Aquion), and liquid air. Aquion Energy is finalizing an aqueous hybrid ion (AHI) battery, and SEEO has developed a solid polymer electrolyte battery. In principle, battery technologies can be scaled, but viability remains a challenge. Table 3 shows current battery system costs.

Table 3. Battery System Costs

System	Installed Cost (\$/kW)	Levelized Cost (\$/MWh)
Vanadium Redox Flow Battery	6,000	550
Zinc-Bromine Flow Battery	3,300–5,800	200–900
Iron Chromium Flow Battery	3,000–6,000	150–200
Lithium Flow Battery	N/A	N/A
Organic-Inorganic Aqueous Flow Battery	N/A	N/A
Organic Redox Flow Battery (USC)	N/A	N/A
Organic Electrolyte Flow Battery	N/A	N/A
Lead Acid Bulk Service	3,800–10,500	220–600
Lead Acid Transmission/Distribution	4,000–11,000	300–1,300
Lead Acid Commercial & Industrial	4,000–15,000	300–800
Li-ion Transmission/Distribution <2 h	2,000–4,500	700–1,150
Li-ion Transmission/Distribution >2 h	9,000–11,000	650–700
Li-ion Distributed Energy Storage <1.5 h	5,000–5,500	1,700–2,000
Li-ion Distributed Energy Storage >1.5 h	6,000–11,000	700–1,000
Li-ion Commercial & Industrial <2.5 h	6,000–13,000	900–2,000
Li-ion Commercial & Industrial >2.5 h	11,000–24,000	700–2,800

Other storage technologies in play include pumped hydro storage, adiabatic compressed air energy storage (A-CAES), and “smart” heat storage. Pumped hydro storage is one of the more established technologies, but there has been uncertainty as to whether there are enough potential sites for pumped hydro in Europe. A-CAES has potential as a large-scale alternative to pumped hydro for flat regions, but the technology has a small existing base, with only two existing plants worldwide. A successful demonstration is needed to establish confidence in the technology, and the market environment requires further evaluation. Smart heat storage capitalizes on the ten-fold increase in solar over the past decade. Heat storage ranges from individual solar/electric heating systems up to long-term large structures, such as Denmark’s water ponds.

RD&D is needed to address technical issues, such as battery stack performance and maturation of integration tools and energy management. However, there are a range of issues beyond the technical. Complications include regulatory and legal issues, costs, safety and standardization, and a lack of operational experience. More full-scale field deployments are needed to prove out reliability and value propositions and establish low financial risk. Assessing the value of storage presents its own complications; different studies yield different results. Storage is not a simple asset class; it has the potential to play multiple roles along the delivery chain, each of which must be considered. Furthermore, storage’s classification (e.g., as a distribution versus transmission asset) is a factor in regulations and in value assessment.

Market studies are also needed. More certainty about how storage technology will be driven—whether by a consumer pull or industry push—would support technology adoption. RD&D needs include better understanding of the innovation processes for historical and current storage technologies. RD&D is needed to understand the business model under different regulatory schemes and examine the implications of distributed storage on distribution grid sizing and operation.

DOE has a range of tools to support efforts to evaluate and implement new storage technologies, including the DOE Global Energy Storage Database, the world’s only freely accessible database, with information on 1,140 energy storage projects from 58 countries; the Energy Storage Technology Advancement Partnership (ESTAP), which provides webinars on storage policy and technology case studies; Sandia’s Energy Storage System Analysis Laboratory; and the Grid Energy Storage Safety Initiative.

Battery Storage for Grid Stabilization

Matthias Leuthold, RWTH Aachen University, Germany

- Link to presentation slides:
<http://www.iea.org/media/workshops/2014/egrdenergystorage/Leuthold.pdf>

RWTH Aachen University is a major technical university in Germany with five engineering institutes representing the largest research cluster on electrical energy technology in Germany. The university is studying multiple aspects of storage systems. Ongoing projects include the following:

- **WMEP** – Scientific Monitoring and Evaluation Program of the Market Incentive Program for PV–Storage Systems
- **GENESYS** – Genetic Optimization of the European Energy System. Moving toward 100 percent renewable energy sources across Europe, the project goal is to determine the cost-optimal energy system. The project entails simulating an all-renewable system using seven years of data; using a simplified model for fast analysis of multiple years of data; and estimating required capacities of generators, different storage types, and the grid. Results show limited short-term storage needs (1.55 GWh of battery storage) growing to 2.73 GWh of pumped hydro for the mid-term. Needs escalate to 802 GWh of PtG storage for the long term. Total system costs are dominated by generation, with storage representing roughly 25 percent.



Battery type	Power / Capacity
Lead-Acid (OCSM)	1,25 MW / 1,48 MWh
VRLA Lead-Acid (OPzV)	0,85 MW / 0,85 MWh
Lithium-Ion (NMC)	2,50 MW / 0,77 MWh
Lithium-Ion (LFP, LTO, or LMO)	1,25 MW / 0,6 MWh
NaNiCl	0,25 MW / 0,5 MWh

Figure 23. M5BAT technical data.

- **M5Bat** – Modular Multi-Megawatt Multi-Technology Medium Voltage Battery (Battery Storage for Grid Stabilization) (Figure 23). This multi-sector project involves construction of a pilot hybrid battery storage system with realistic operation and market participation in several applications (e.g., arbitrage and ramping support). The system will comprise five parallel strings and two parallel converters per string. The project team will evaluate technical and economical results and develop recommendations for hybrid battery system design and operation. The project will also develop supporting components: system control and monitoring, optimized design for stationary lead acid batteries, and optimized control for inverters.

The low price of PV sources creates a market opening for storage. Costs of generation, electricity, and storage help determine that market, as does regulation, while sizing and energy management determine system viability. In parallel, lithium-ion cell prices are declining. The electric mobility market, which is ten times the stationary market, is dominating development of storage technologies.

Battery technologies currently in use are lead-acid, lithium-ion, NaS/NaNiCl, and VRFBs. New candidates include metal-air, lithium-sulfur, anodes with silicon, sodium-ion (Aquion), and liquid air. In principle, battery technologies can be scaled, but viability remains a challenge; a range of complications exists

(e.g., regulatory and legal issues, costs, safety and standardization, and a lack of operational experience). In addition to research on new chemistries and technologies, research on system integration, market introduction, and operational experience is needed.

Flow Batteries

Z. Gary Yang, UniEnergy Technologies, United States of America

➤ Link to presentation slides:

<http://www.iea.org/media/workshops/2014/egrdenergystorage/Yang.pdf>

UniEnergy Technologies is working toward commercialization of break-through VFRBs. Uni.System™, the company's grid-scale energy storage system, became commercially available in summer of 2014. The modular system is factory-integrated, containerized, and plug-and-play. Uni.System stores hours of energy that can be released for a duration of hours or even days, with very limited self-discharge loss, while simultaneously supporting short duration power functions, and the system delivers multiple applications.

Pacific Northwest National Laboratory (PNNL) developed the chemistry behind the next-generation VFRB employed in this system (Figure 24). The battery is a reversible fuel cell that decouples power (determined by cell stacks) and energy (determined by electrolytes). Electrodes are inert, resulting in no structural change, stress buildup, or undesirable reactions with electrolytes. Storing large amounts of power for long durations in a VFRB with large tanks is significantly simpler than actively managing the states of charge (SOCs) for thousands of static batteries. The chemistry was paired with advanced power

electronics, including optimized software and control architectures, communications and control, and proprietary self-balancing and battery management. Stack development is a product of 14 years of R&D, including 9 years of field-driven development, resulting in a powerful stack that is ISO9000/14000- and GB/T28001-certified. Annual stack capacity is 100 MW and will be scaled up to 300 MW in 2016.

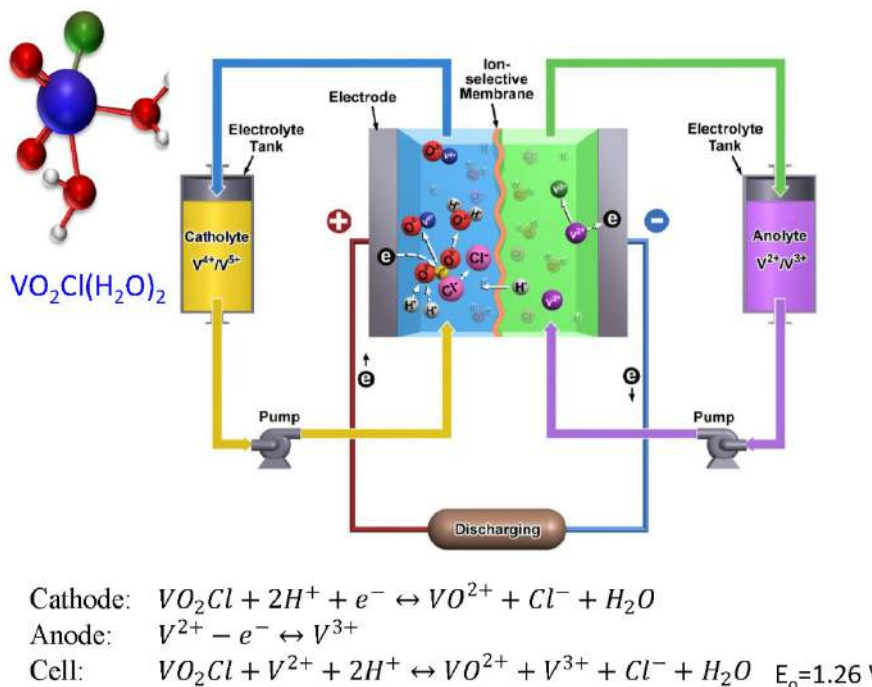


Figure 24. Next-generation VFRB chemistry.

While most emerging chemistries are still in

the experimental phase, Uni.System exemplifies some of the very high-performance and reliable technologies that are already available. There are products with the required seamless integration of chemical, mechanical, thermal, electrical, and controls engineering to deliver affordable, reliable, and safe systems.

However, there are still challenges to be addressed. More full-scale field deployments are needed to prove out reliability and value propositions and establish low financial risk. Government and industry should collaborate on demonstrations. Standardization is also needed. Furthermore, RD&D has historically focused on lithium-ion and fuel cells rather than redox flow batteries. Needed improvements include battery stack performance capability, durability, and reliability; extended electrolyte energy capacity and improved utilization; optimized battery management and power electronics and control; and maturation of integration tools and energy management.

U.S. Department of Energy's Energy Storage RD&D Program

Imre Gyuk, Energy Storage R&D Program, U.S. Department of Energy

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Federal government plays a role in grid storage system development, from research grants and cost-shared demonstration projects in the early stages to financial incentives in the marketing phase, as indicated in Figure 25. Figure 26 maps DOE's Office of Electricity Delivery and Energy Reliability (OE's) current activities in the field. Several recent DOE-supported projects have been influential in furthering and defining storage's role in the electric grid.

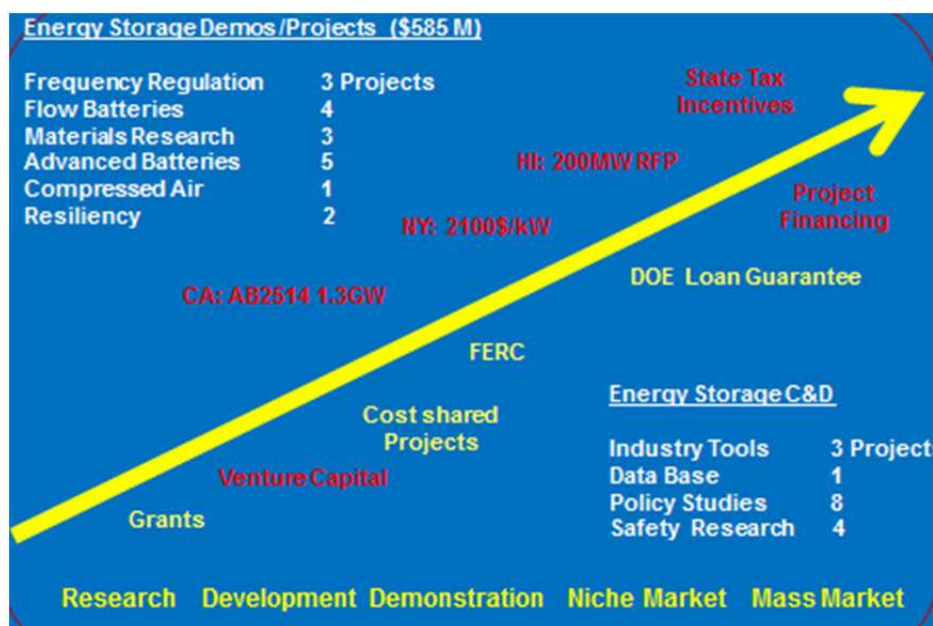


Figure 25. The federal role in energy storage development.

Vermont Public Service Department and one with the Washington State Clean Energy Fund, to develop storage systems that will provide emergency power.

DOE has a range of tools to support industry's efforts to evaluate and implement new storage technologies, including Sandia's Energy Storage System Analysis Laboratory; the DOE Global Energy Storage Database, the world's only freely accessible database, with information on 1,140 energy storage projects from 58 countries; the Energy Storage Technology Advancement Partnership (ESTAP), which provides webinars on storage policy and technology case studies; and the Grid Energy Storage Safety Initiative.

As a result of efforts such as those noted above, energy storage is coming of age, with new cost-effective technologies and new benefit streams. DOE, state governments, and industry are continuing their efforts with major solicitations and mandates to encourage storage development and implementation.

Technological Opportunities and Barriers for Utility-Scale Energy Storage

Estathios Peteves, European Commission–Joint Research Centre, European Union

- Link to presentation slides:

<http://www.iea.org/media/workshops/2014/egrdenergystorage/peteves.pdf>

The European Commission's Strategic Energy Technology Plan (SET-Plan) is developing a technology roadmap to prioritize the development of innovative holistic solutions to energy challenges, specifically the need for cost-effective low-carbon technologies. Inputs to the roadmap identify storage as a critical component.

Yet the role of storage technologies in electricity delivery is not yet established. Storage is not a simple asset class; it has the potential to play multiple roles along the delivery chain, each phase of which involves matters for consideration (Figure 27). The system requires increasing flexibility, but electricity storage technologies are competing with other options (e.g., thermal storage and demand response) to provide this flexibility.

The competing technologies have great potential but are largely undeveloped, and electricity storage has a cost advantage over many of its competitors. RD&D is needed to address several unanswered questions and to capitalize on the opportunities storage technologies present. The potential for all these technologies should be assessed, and the possible interactions of different sectors (power, heat, and transport) with energy system models should be studied.

Electricity value chain

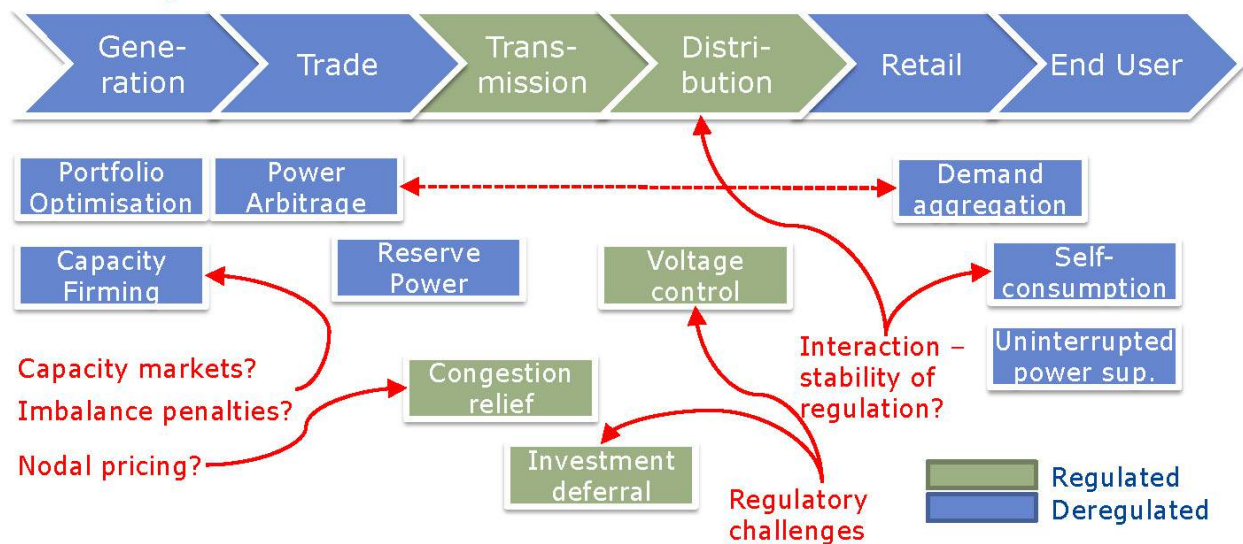


Figure 27. Storage considerations along the electricity value chain.

One technology in play is adiabatic compressed air energy storage (A-CAES). Advantages include its potential as a large-scale alternative to pumped hydro for flat regions, its lack of dependence on natural gas, and well-established turbo-machinery and heat storage as its technical foundation. However, A-CAES has a small existing base, with only two existing plants worldwide, and there is little financial incentive to deploy the technology. A successful demonstration is needed to establish confidence in the technology, and the market environment requires further evaluation.

Pumped hydro storage is one of the more established technologies, but there has been uncertainty as to whether there are enough potential sites for pumped hydro in Europe. However, the Joint Research Centre recently published a study that examined two topologies in Europe, and the results show that the theoretical potential in Europe is significant.

More certainty about how storage technology will be driven—whether by a consumer pull or industry push—is needed to support technology adoption. RD&D needs include better understanding of the innovation processes for historical and current storage technologies and mapping of ongoing R&D activities. Another aspect worth noting on the end user phase of the delivery chain is the possibility that photovoltaic self-consumption, paired with off-grid storage, will make electricity grids redundant. RD&D is needed to understand the business model under different regulatory schemes and examine the implications of distributed storage on distribution grid sizing and operation.

Assessing the value of storage does not always yield simple answers, and many assumptions might be inadequate. Different studies have come to different conclusions. The value of storage can be determined in two ways: maximizing profit from revenue streams (assessing the profitability of power storage from the investor's point of view) and minimizing costs of system operation (assessing the benefit of adding storage to the generation system).

Smart Heat Storage for Solar Heating Systems

Simon Furbo, Danmarks Tekniske Universitet, Denmark

➤ Link to presentation slides:

<http://www.iea.org/media/workshops/2014/egrdenergystorage/furbo.pdf>

Denmark aims to phase out all fossil fuel generation by 2035, providing all heat and electricity through renewable sources. The country is well on its way to achieving this target, e.g., wind energy supplied 41 percent of electricity consumption in the first six months of 2014, and the total solar collector area in Denmark is more than ten times what it was a decade ago. Heat alone accounts for roughly half of the final energy consumption in the European Union. Solar energy has tremendous untapped potential to meet this demand.

However, increases in renewable electricity production result in associated increases in mismatches of production and load and dynamic electricity prices. Solar heating systems must have good interplay with the electricity market.

The solution is combined technologies and smart heat storage interacting with the electricity grid. The various components of this solution all provide benefits, e.g., solar produces free heat, heat pumps produce inexpensive heat and reduce storage volume, and combined heat and power produces valuable electricity, enabling the user's own revenue stream. Smart heat storage provides the flexibility that makes the combinations of technologies possible.

For centralized systems, simple solar heating plants with solar fractions of 5%–25% are most common so far, but higher solar fractions/long-term heat storage may be more cost-effective. The technologies are simple (e.g., a water pond with borehole storage provides a heat capacity of 4.1 MJ/km^3 —see Figure 28), and large heat storages have small heat losses and low costs per volume. Denmark has several water ponds operational or under construction.

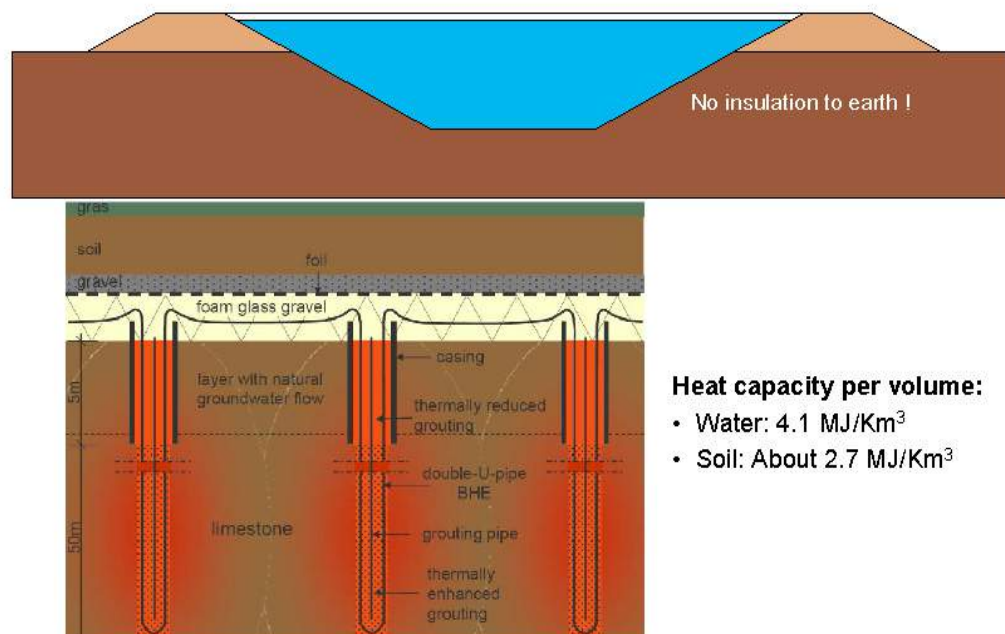


Figure 28. Cheap storage technology, water pond and borehole storage.

Regarding individual solar/electric heating systems, those with smart heat storage could be equipped with a smart control system based on prognoses for heat demand, solar heat production, and electricity price. The system can be heated by solar collectors and, when solar heat cannot cover demand and electricity prices are low, by electric heating elements or a heat pump. Systems with “smart solar tanks” (Figure 29) have increased thermal performance by up to 35 percent due to decreased tank heat loss and increased solar heat production. Further, electricity price screening gives smart tanks improved cost efficiency. Heating costs for the average homeowner with a smart solar tank are expected to decrease to 70–80 percent of pre-tank costs, and the difference would be even more significant with variable electricity pricing. Finally, individual smart solar heating systems with electric heating elements/heat pumps support wind power integration in the energy system and contribute to an increased share of renewable energy.

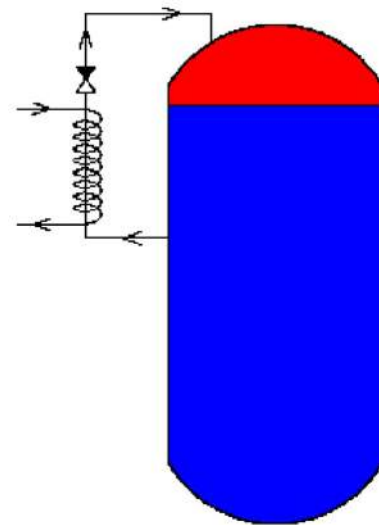


Figure 29. A smart solar tank.

To maximize the benefits of solar heat storage technologies, RD&D is needed on:

- Water ponds
- Borehole storages
- Individual smart solar/electric heating systems for low-energy buildings
- Individual smart solar/heat pump systems for normal houses

Session 5: Energy Storage Markets and Business Models

This session focused on how the regulatory framework can be adapted to accommodate for energy storage markets. Participants discussed whether the regulatory framework needs adjustment for better integration of energy storage technologies.

The electricity grid and the need for energy storage are being affected by major trends such as renewable generation, “smart grid” implementation, microgrids, high reliability zones, and electric vehicles. The mix of energy sources results in stochastic generation that affects grid operation. Variable generation resources result in a vast difference between forecasted load and expected electricity production during certain hours of the day.

Energy storage can address several of the challenges presented. As the grid evolves, markets are adapting to provide more flexibility, and grid-related services such as storage are quickly gaining market value. Several high-value storage applications are already economic, and as costs decline, the number of applications and markets grows. The diversity of storage applications and benefits makes bundling desirable; capturing multiple value streams makes storage implementation cost-effective. The technologies’ value should be evaluated in terms of benefits rather than megawatts. Potential benefits of storage technologies are summarized below:

- Greater system flexibility without changing customer behavior
- Faster response from grid assets
- Improved customer reliability
- Greater energy security
- Lower emissions
- Better renewable integration
- Opportunity to “leapfrog” the traditional grid in developing regions

Battery energy storage has potential to provide substantial benefits to both grid operators (peak shaving, load leveling, frequency regulation, voltage control, and renewables integration) and customers (consumption during non-generation hours, uninterruptible power supply, smoothing of renewables feed-in, and possibly opportunities to trade power with local utilities).

Storage needs can be determined from both a system-based and a market-based perspective. The former examines future needs and technologies using an energy system or electricity market model. The latter considers markets, prices, and incentives using a model that optimizes plant dispatch at exogenous prices.

One example of an appropriate electricity system model is ELTRAMOD, a bottom-up electricity market model that conducts fundamental system analysis. The model analyzes the interdependence between storage need, grid extension, and renewable curtailment and provides information on renewables integration in the European market, trade-offs between grid and storage extensions, and optimal dispatch of power plant capacity.

Evaluators must also consider how the industry will change. As use of renewable energy sources increases, the off-peak residual load curve will also increase while peak load increases. The surplus can be curtailed, exported, or stored. Another factor is centralized versus decentralized storage. Decentralized options currently have stronger drivers to market uptake. Centralized options could decrease differences between peak and off-peak rates. In the long term, renewable energy sources will change the price duration curve and, with it, the generation portfolio.

Despite all the potential advantages of storage technologies, their development is hampered by regulatory issues. The very definition of storage (i.e., as a regulated generating asset) is limited and inconsistent. Further, there are disincentives to storage implementation, such as regulatory curtailment of renewable energy. Other non-operational challenges to grid-scale energy storage include competing technologies, validation of reliability and safety, and industry acceptance. Other associated considerations include markets for transmission rights and transmission cost recovery and allocation.

Battery Systems for Grid Stability

Alfons Westgeest, EUROBAT Association, European Union

- Link to presentation slides:
<http://www.iea.org/media/workshops/2014/egrdenergystorage/westgeest.pdf>

The speaker represented EUROBAT, an association of European automotive and industrial battery manufacturers that works closely with relevant industry trade associations. EUROBAT provides expert information to stakeholders on the four battery technologies dominating the automotive and industrial battery market:

- Lead-based, a low-cost proven application
- Lithium-based, which has longevity and applications to consumer usage and electric vehicles
- Sodium-based, which has high energy density but also high weight and applications to consumer usage and electric vehicles
- Nickel-based, which is also heavy and energy-dense and provides large storage options

Overall, European manufacturers have committed to supporting global health, safety, and environment. This commitment involves developing new solutions, adapting to new applications, and emphasizing product sustainability. Battery systems help address long-term policies for low-carbon economies across different sectors, including building efficiency, transport, storage, and electrification.

An example of a new solution is the Seventh Framework Programme's (FP7's) large-scale ongoing battery project, "Materials for Green Cars." The project entails cooperation between nine organizations, including EUROBAT. In addition, joint industry cooperation has produced four recent studies:

- A Review of Batteries for Automotive Applications
- Life Cycle Assessment of Lead-Based Batteries in Passenger Vehicles
- Resource Availability of Materials Used in Automotive Batteries Technologies
- Study on the End-of-Life of Lead in Automotive Batteries in the European Union

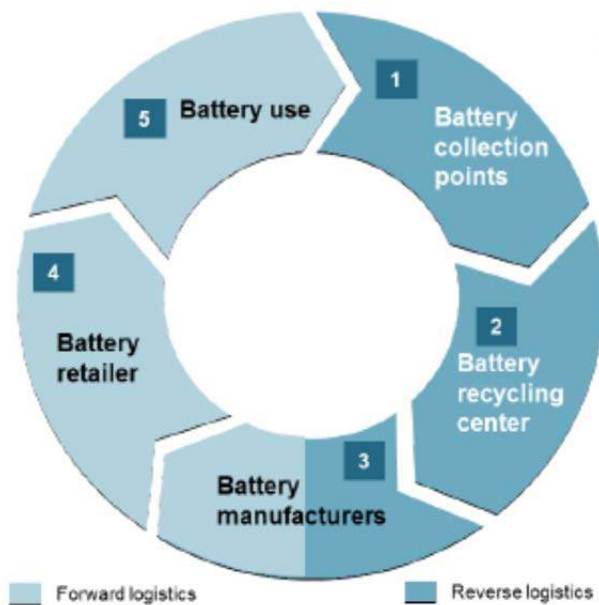


Figure 30. Lead-acid recycle closed loop.

These studies show that replacing established battery applications with alternative technologies would have a significant impact on the overall performance and cost of vehicles.

An example of the commitment to sustainability is compulsory recycling of lead-acid batteries (per EU Directive 91/157/EC and Directive 2006/66/EC). The collection rate of lead-acid SLI (*starting, lighting, ignition*) batteries is 99 percent, and a closed-loop system is in place (Figure 30).

Technologies in the automotive portfolio are playing a role in the current marketplace, including driving competition to achieve better technologies. Indeed, all

battery energy storage technologies are playing increasingly large roles in the global marketplace, as can be seen in Figure 31. The residential community market is currently small but, in some countries, is also growing rapidly. Battery energy storage has potential to provide substantial benefits to both grid operators (peak shaving, load leveling, frequency regulation, voltage control, and renewables

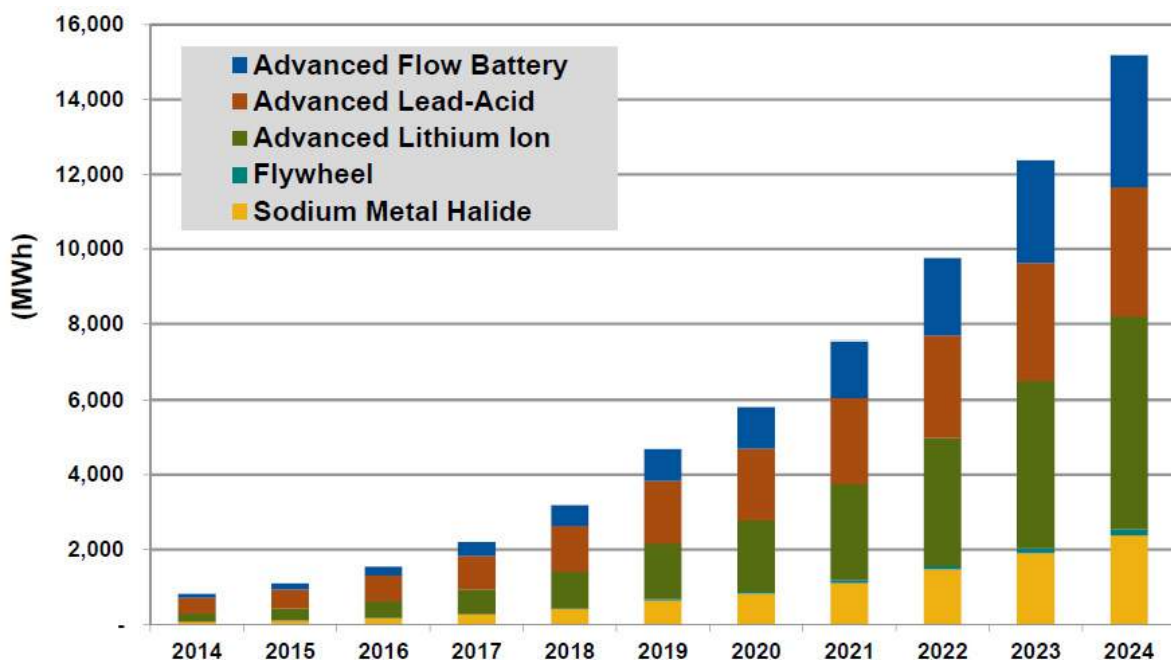


Figure 31. Installed energy storage energy capacity in microgrids by technology, world markets: 2014-2024.

Source: Navigant research

integration) and customers (consumption during non-generation hours, uninterruptible power supply, smoothing of renewables feed-in, and possibly opportunities to trade power with local utilities).

Despite all the potential advantages of storage technologies, their development is hampered by regulatory issues. The very definition of storage (i.e., as a regulated generating asset) is limited and inconsistent. Further, there are disincentives to storage implementation, such as regulatory curtailment of renewable energy. Recommended actions include opening the market for storage to all operators by broadening the definition of storage; implementing mandates not to curtail renewables implementation, including financial penalties; conducting product value and market value studies; rewarding grid functionality from batteries; and ensuring that regulatory incentives encourage rather than discourage investment in storage.

Governments, from local to multinational, are best positioned to discuss, identify, and implement regulatory solutions. Governments must work with multinational organizations, academics, and other stakeholders to obtain R&D input into policy studies. Storage functionality is broad, so multiple options can and should be unlocked.

California Utility Scale Update

Chris Edgette, California Energy Storage Alliance, United States of America

- [Link to presentation slides:](http://www.iea.org/media/workshops/2014/egrdenergystorage/edgette.pdf)
<http://www.iea.org/media/workshops/2014/egrdenergystorage/edgette.pdf>

In California, renewable resources are increasingly satisfying the state's electricity demand. However, variable generation resources result in a vast difference between forecasted load and expected electricity production during certain hours of the day, as seen in the so-called "duck chart" (Figure 34). Energy storage can address this net load discrepancy.

Energy storage can provide much greater benefits per megawatt as a flexible resource, and the technologies' value should be evaluated in terms of benefits rather than megawatts. Storage technologies can increase operational hours and utilization per megawatt three-fold. Response times are faster—a 100 MW gas peaker plant has a full-power ramp time of ten minutes as compared to less than one second for the equivalent storage system (Figure 32 and Figure 33)—and cycling conventional power plants has significant impacts on greenhouse gas emissions. Finally, the Electric Power Research Institute (EPRI) conducted a cost study of bulk storage implementation for a peaking power plant, and preliminary results showed a benefit-to-cost ratio over one for nearly every scenario. Similar savings can be achieved through implementing distribution storage at a substation. Potential benefits of storage technologies are summarized below:

- Greater system flexibility without changing customer behavior
- Faster response from grid assets
- Improved customer reliability
- Greater energy security
- Lower emissions
- Better renewable integration
- Opportunity to "leapfrog" the traditional grid in developing regions

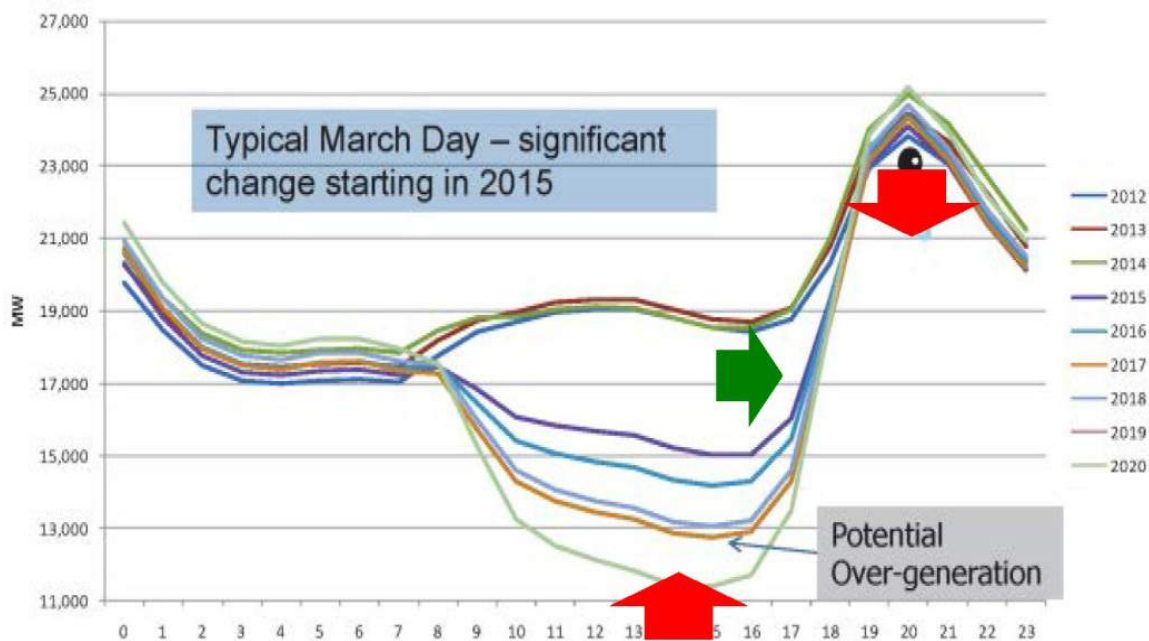


Figure 342. CAISO net load, 2012–2020 (duck chart).

Five California utilities—Southern California Edison (SCE), Pacific Gas & Electric (PG&E), San Diego Gas & Electric (SDG&E), Imperial Irrigation District, and the City of Redding—are in various stages of storage system procurement, and other states and regional entities are moving forward as well. SCE and SDG&E developed long-term technology plans with procurement authorization and energy storage requirements. PG&E evaluated the technology’s net market value, examining net energy value (discharging), ancillary services value, capacity value, and variable and fixed costs; then adjustments were made for localized benefits and portfolio effects (e.g., smoothing net load). One key issue is wholesale vs. retail rate treatment. The biggest dispute concerns what to include in round-trip efficiency (RTE).

Several high-value storage applications are already economic,

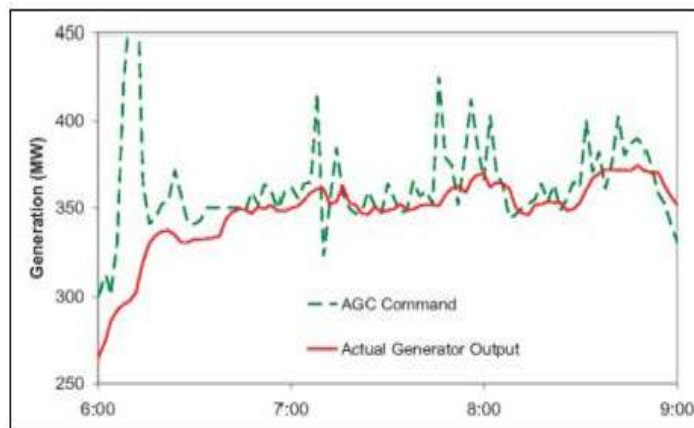


Figure 323. Ramp-time response for gas peaker plant.

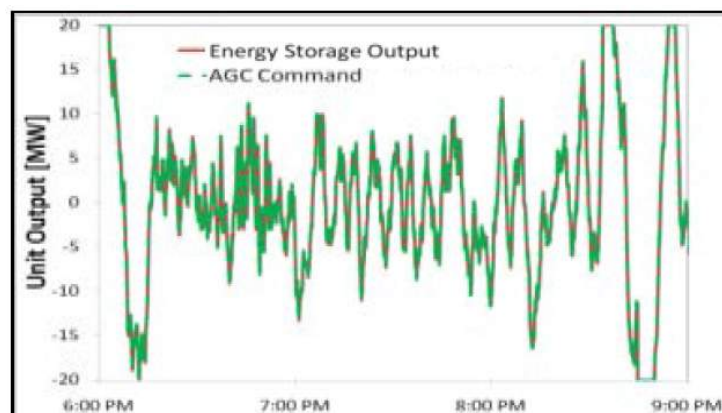


Figure 334. Ramp-time response for 100 MW energy storage system.

Graph Source: Kirby, B. “Ancillary Services: Technical and Commercial Insights.” Wartsilla, July, 2007. pg. 13

and as costs decline, the number of applicable applications and markets grows. Accelerating the learning curve will also accelerate this process.

Economics of Energy Storage

Dominik Möst, Technische Universität Dresden, Germany

➤ Link to presentation slides:

<http://www.iea.org/media/workshops/2014/egrdenergystorage/m%C3%B6st.pdf>

The need for storage capacities can be determined from both a system-based and/or a market-based perspective. The former examines future needs and technologies using an energy system or electricity market model. The latter considers markets, prices, and incentives using a model that optimizes plant dispatch at exogenous prices. Modelers must consider how to weigh various factors, as (for example) investing in a storage plant is more expensive than investing in a gas turbine; but operating a storage plant, which allows for arbitrage between off-peak and peak prices, is considerably less expensive than operating a gas turbine.

Decision makers should also consider how residual load will change. As use of renewable energy sources will further increase, negative residual loads will also increase, while peak load will remain nearly constant. Because of the need for additional flexibility, an increase in additional storage capacities can be expected (see also Figure 36). Nevertheless, storage is not the only option for solving challenges presented by the integration of renewables: the surplus electricity (in hours of negative residual load) can be stored, curtailed, or exported, or demand can be increased (demand side management). Fundamental market models can be used to evaluate the competition among the different flexibility options and to determine the amount of capacity needed.

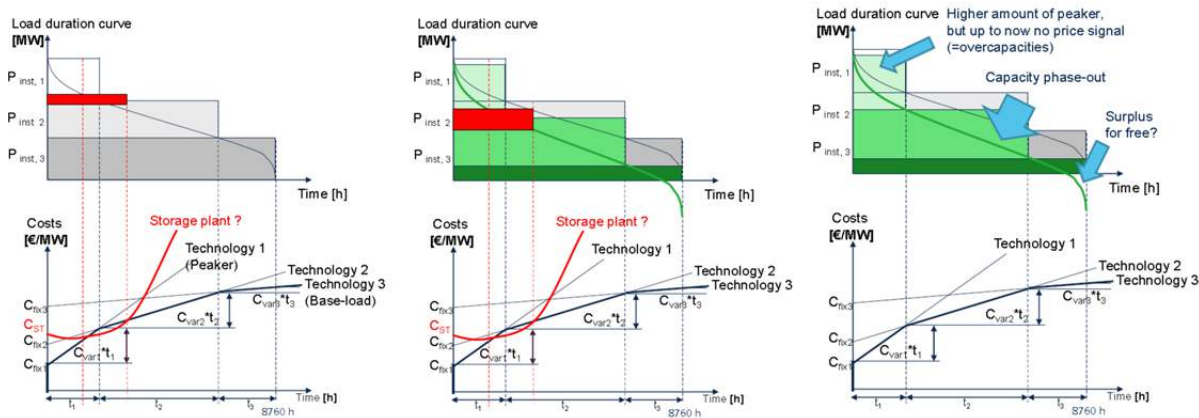


Figure 35. Load duration curves for a simple peak load model (left) and the system adapted for optimal capacity (middle and right). The green line indicates surplus.

Additionally, an extension of renewables requires a “correct” price signal. Currently, markets are not in equilibrium, as too much generation capacity is installed in Central Europe, and low prices do not generate sufficient revenue. This will (probably) lead to a phase-out of base and mid load. Currently,

discussions about policy interventions and introduction of capacity markets are addressing the challenge of adequate capacity, and some countries have already introduced such capacity mechanisms.

The electricity system model ELTRAMOD analyses the interdependence between storage need, grid extension, and renewable curtailment. ELTRAMOD is a bottom-up electricity market model that allows for fundamental system analysis. The model provides information on renewables integration in the European market, trade-offs between grid and storage extensions, and optimal dispatch of power plant capacity.

Shifting from a feed-in obligation to curtailment has limited effect on non-integrated renewable surplus supply. However, the small deviance of non-integrated renewable surplus has a significant impact on the additional need of storage and grid capacities. To integrate the last 3% of renewable feed-in, almost double the grid capacity and four times the storage capacity are needed. From an economic point of view, integrating every available unit of renewable energy sources is thus not optimal. For the mid-term perspective, the focus should be on grid extension and market integration. The need for grid extension is underestimated, whereas short- to mid-term storage demand is often overestimated; the need for additional storage capacities will be quite small in the mid-term (until 2025) but will increase significantly in the long term with a share of renewables larger than 50% to 60%.

Storage demand is sensitive to not only renewable penetration but also carbon costs. Low carbon prices result in a higher attractiveness of storage plants because of the cheap base load from conventional energy sources. High carbon costs make storage capacity less attractive (owing to higher base load price). Thus emissions reduction and renewable targets have a contradictory effect on storage demand.

Centralized storage capacities have to be distinguished from decentralized storage capacities, as incentive structure is quite different. Decentralized options currently have stronger incentives to market uptake, as one's own consumption can be subsidized—a more attractive option than buying expensive electricity at household tariffs. Centralized options currently suffer from the small difference between peak and off-peak prices as a result of (among others) the so-called merit order effect of renewables. Renewables are putting pressure on market prices as the market moves from a load orientation to a renewable energy sources orientation. In the long term, electricity prices will be more independent of the availability of renewable energy sources. Thus, the future price curve will lead to an adaptation towards a more flexible generation portfolio and demand side.

Perspectives on Grid Transformation and the Market for Storage

Landis Kannberg, Pacific Northwest National Laboratory, United States of America

➤ Link to presentation slides:

<http://www.iea.org/media/workshops/2014/egrdenergystorage/kannberg.pdf>

Major trends are affecting the electricity grid and the need for energy storage. Renewable generation is being rapidly deployed and is displacing conventional generation. As it is a variable energy source, the associated requisite flexibility creates a revenue stream for storage. At the same time, the implementation of a “smart grid” is enabling new sources of flexibility and multiple functions for distributed storage. Storage is also a vital component of modern systems that focus on resilience and

reliability, such as microgrids and high reliability zones, and batteries support increasing numbers of electric vehicles.

The mix of energy sources results in stochastic generation that affects grid operation. Associated issues include over-generation, congestion, frequency ride-through capability, impacts on dynamics and stability, impacts on reactive power generation, and dispatch of the remaining conventional units (e.g., more starts and cycling). PV penetration increasingly is displacing mid-day loads over time so that the ramp rate at the end of the day is expected to double that of current operations, complicating dispatch and creating reliability challenges. Furthermore, rapid distribution system voltage swings from fluctuations in output are disruptive to electronics and can damage equipment. Needed solutions include coordinating system protection schemes, system balancing, reserve requirements, and frequency control.

Non-operational challenges to grid-scale energy storage include competing technologies, validation of reliability and safety, industry acceptance, and regulatory issues. Other associated considerations include markets for transmission rights and transmission cost recovery and allocation.

The storage industry and governments are responding to these challenges with new technologies and new incentives. Another means of addressing these challenges is coordination. There are 37 balancing authorities in the Western Interconnection, and while increasing renewables integration is making individual operation more challenging, consolidation could save the collective entities over \$600 million each year (Figure 36).

		11% Case		33% Case	
		Up	Down	Up	Down
Regulation Capacity, GW	Individual BAs	1.76	-1.82	3.65	-3.78
	CBA	0.74	-0.75	1.05	-1.09
	Savings in %	58%	59%	71%	71%
Regulation Ramp Rate, MW/min	Individual BAs	566	-597	962	-993
	CBA	138	-143	222	-220
	Savings in %	75%	76%	76%	77%
Load Following Capacity, GW	Individual BAs	12	-11	18	-18
	CBA	4.1	-3.9	5.2	-5.0
	Savings in %	64%	66%	70%	72%
Load Following Ramp Rate, MW/min	Individual BAs	356	-357	708	-715
	CBA	186	-190	245	-254
	Savings in %	48%	47%	65%	65%

Figure 36. Balancing authorities (BAs) versus a consolidated balancing authority.

Storage technologies have a range of applications that require diverse attributes, which translates into multiple markets. As the grid evolves, these markets are adapting to provide more flexibility, and grid-related services such as storage are quickly gaining market value. The diversity makes bundling of applications desirable, which presents the question of what entails optimal bundling (e.g., arbitrage plus balancing). Capturing five value streams makes storage implementation cost-effective (Figure 37), which

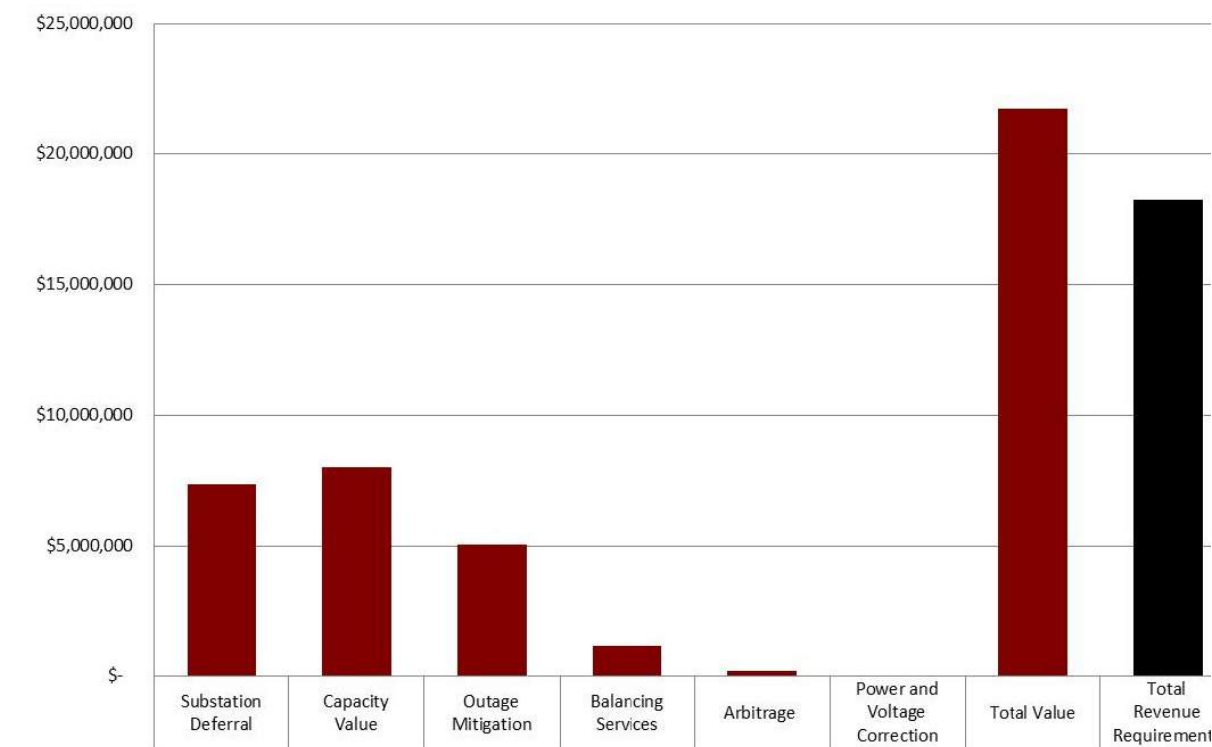


Figure 37. Energy storage value streams at a distribution system substation.

illustrates the multiple value streams that can be captured by an optimally sized and dispatched energy storage system at a distribution substation in the northwestern United States.

Discussion and Conclusion

As the use of renewables to generate electricity increases globally, it presents both opportunities and challenges for governments, private sector, scientists, and others in the industry. Recently, several countries, especially in Europe, have adopted aggressive renewable energy policies and their energy systems are undergoing massive transformation. Apart from being a cleaner source of energy, renewables offers energy security and does not have any air quality concerns usually associated with conventional sources of energy.

However, widespread generation of renewable power presents its own challenges that can affect grid system quality, stability, and reliability. Unlike conventional sources of power generation such as fossil fuel power plants or nuclear plants that are able to adjust to changes in power demand, renewable power generation remains unpredictable because of its intermittent nature and does not follow any social patterns of demand for electricity. As renewables become an integral part of current energy systems, investments in storage technologies that release energy on an as-needed basis, will play an increasingly critical role.

Energy storage helps in managing the diurnal and seasonal variability that comes hand in hand with renewables and can potentially assist in decoupling short-term variations of supply and demand. Currently, the only established storage technology is pumped hydropower, where water is pumped uphill to a reservoir and released to generate electricity when it is required. Austria, Norway, and Switzerland make widespread use of this technology. However, for the biggest markets, energy storage remains expensive, and the optimal role for storage varies widely across regions. Developing energy storage requires strategic planning, in both the short, and the long term.

Benefits of Storage

The development of energy storage technologies can address several of the challenges presented by the use of increased renewables. Apart from storing excess energy supply, these technologies have various co-benefits, and as such, the value of these technologies should be measured in “benefits” and not megawatts. From a systems perspective, these technologies provide reserves, capacity deferral, outage relief, and optimum utilization. Battery energy storage provides substantial benefits not only to grid operators but also to customers. For grid operators, these technologies can assist in peak shaving, load leveling, frequency regulation, voltage control, and renewables integration. For customers, storage technologies ensure availability of power during non-generation hours, uninterruptible power supply, and possibly opportunities to trade power with local utilities.

Additional benefits are:

- A “Swiss army knife” multi-functional toolkit, for various grid management tools
- Greater system flexibility without changing customer behavior
- Faster response from grid assets
- Increased operational efficiencies, including faster ramping, load leveling, frequency regulation, and voltage control

- Improved reliability
- Greater energy security
- Opportunity to “leapfrog” the traditional grid in developing regions

Current Technologies

A publicly available global energy storage database developed by DOE showcases the energy storage projects worldwide. Currently there are about 1,140 projects with over 50 energy storage technologies. Pumped hydro is the dominant technology followed by thermal, flywheel, batteries, and compressed air. China, Japan, and the United States are leading in this sector. Recent studies have shown that the market potential for energy storage is high and commercial markets may reach or exceed \$500 million/year by 2015 and \$15 billion/year by 2025. For the right product at the right price, the market potential for these technologies is high.

Pumped hydro storage is one of the more established technologies but its key limitation is that it is restricted by geographical locations, and it remains unclear whether there are enough potential sites for pumped hydro in Europe.

Various battery technologies are already in use: lead-acid, lithium-ion, NaS/NaNiCl, and VRFBs. UniEnergy Technologies’ Uni.System™, a grid-scale energy storage system that became commercially available in summer of 2014, has recently experienced R&D breakthroughs in VRFB technologies. Several other projects are studying battery technologies. These include a project examining Fe-Cr flow batteries and possible uses in combination with PV, a collaboration conducting materials research into a mixed acid electrolyte, and a program that selects the most cost-effective site and scale to optimize the value stream. Industry and scientists are conducting research into potential new battery candidates including solid polymer electrolyte, metal-air, lithium-sulfur, anodes with silicon, sodium-ion (Aquion), and liquid air.

Other storage technologies that show great promise include A-CAES, and “smart” heat storage. A-CAES can potentially be a large-scale alternative to pumped hydro for flat regions, but the technology has had limited adoption, with only two existing plants worldwide. A successful demonstration is needed to establish confidence in the technology, and the market environment requires further evaluation. Smart heat storage capitalizes on the ten-fold increase in solar over the past decade. Heat storage ranges from individual solar/electric heating systems up to long-term large structures, such as Denmark’s water ponds.

Challenges for Energy Storage Technologies

Alternatives to Storage

Several alternatives to energy storage technologies exist that are economically viable thus, making storage technology development challenging. Demand response or demand side management is one such solution. Instead of storing excess energy, the load on the demand side can, to a certain extent, be shifted to times with high production, thus managing variability. Various technologies can be used for

demand response in the power grid, such as thermal storage devices, EVs, or load shifting in public services.

PtG technology is another alternative to storage. Excess electricity is used to produce hydrogen or methane, which allows for balancing inter-seasonal fluctuations and longer electricity storage timeframes. Renewable energy curtailments, flexible operation methods, new constructions, flexible CHP and biomass plant operation, and grid expansion are some other options. Additionally, the demand for flexibility can be met by increased pan-European interconnections, as seen in Denmark and Norway; Norway's vast hydro resources supply Denmark's grid in terms of excess demand. Smart community projects and energy management systems, as demonstrated by some pilots in Japan, can enhance flexibility.

A recent study of the "Energiewende" targets of Germany found that for a share of 40% of renewables, flexibility can be provided by conventional power plants, and long-term storage requirements are negligible. Above 40% renewables, options such as demand response or curtailment tend to be economically most favorable. Only when exceeding 80% renewables does long-term storage play a role, and PtG technologies can fulfill that need.

Competitive Markets and Pricing Models

The future for energy storage remains unclear and is further complicated by the fact that the business model for commercial storage remains unsettled. Currently, there is no sufficient revenue stream that can be generated from intermittent sales alone. Additionally, there is a need for a rational pricing model for "bundled values." A value needs to be assigned for contributions in real time and for long-term system efficiency and cost avoidances. If unique contributions are valued correctly, then storage can be cost-effective.

California may provide a glimpse into the future of energy storage markets. California has seen rapid growth in the use of renewables in the past few years, especially with solar installations doubling recently, and the state is taking groundbreaking steps to sustain this momentum and make energy storage an economically viable technology. California's energy storage mandate requires the three major power companies to have electricity storage capacity of 1.3 GW in place by the end of 2020. This will help lay the groundwork for an effective policy environment.

To outline an economically sound business model, California is developing methodologies and tools for evaluating storage and others can learn from its experience. The California Public Utilities Commission is allowing utilities the latitude to propose their own methodology to evaluate costs and benefits of storage for its procurement decision making. Figure 38 outlines the approach taken by a major California utility, Pacific Gas and Electric (PG&E). The figure shows that the value of energy storage should account the local benefits and portfolio effects of storage technology, not only the net market value as traditionally defined. Since storage is too expensive to be justifiable for single service usage, it is almost impossible to recover costs based on sales of electricity to the grid alone. Taking additional adjustments into account can help assign a more accurate value on energy storage.

Energy storage also provides benefits to the distribution system. However, since tariffs are not in place monetization of these benefits is missing from the valuation of energy storage. By bundling different value streams, e.g., arbitrage, balancing services, substitution deferral, capacity, and outage mitigation, storage technologies can increase its economic value considerably. As a result, in a regulated market, where clear quantification of the benefits and costs of storage exist, these technologies can take off.

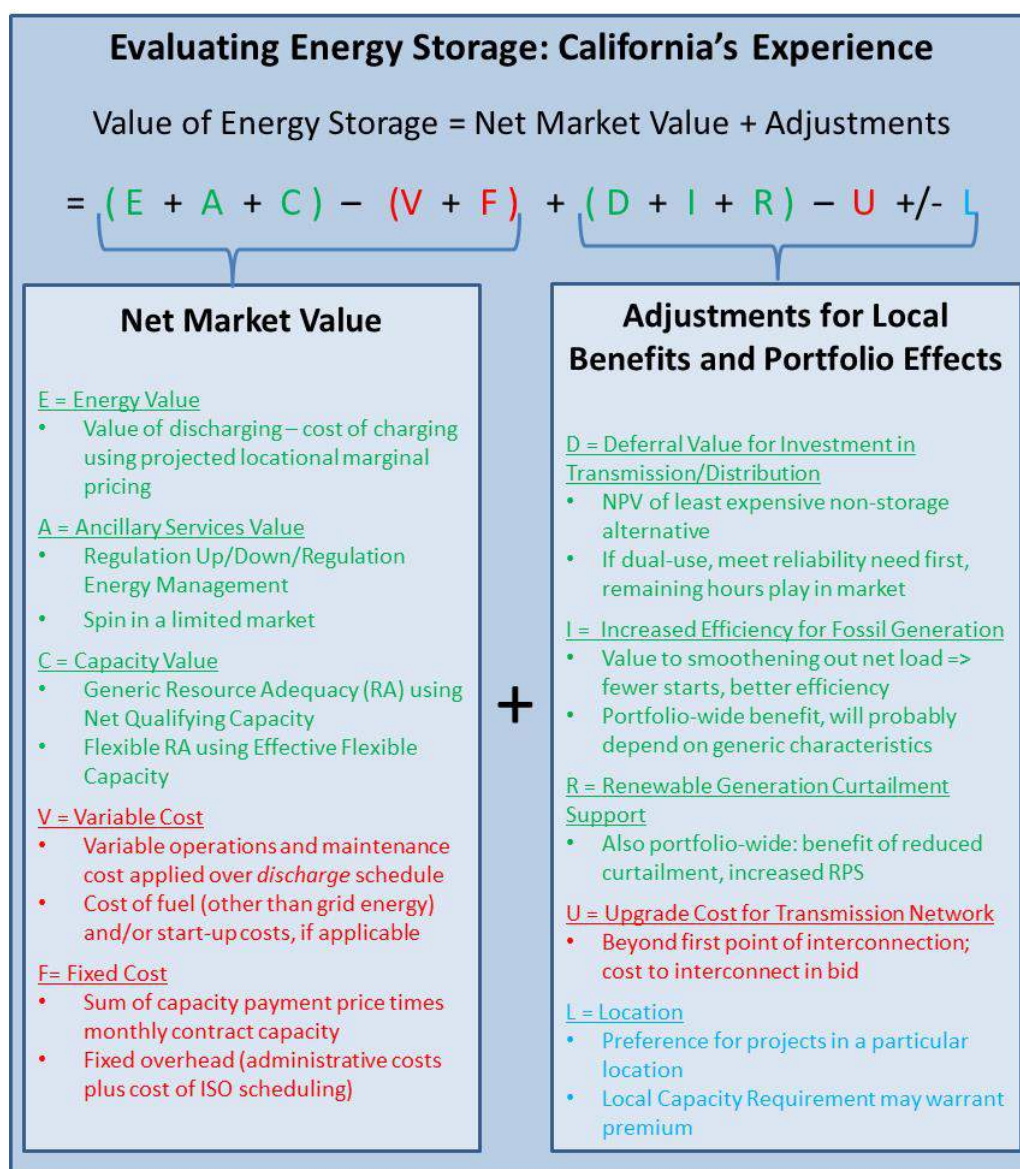


Figure 38. Evaluating Energy Storage, California's Experience.
Adapted from "California Utility Scale Update," Chris Edgette's presentation at the IEA workshop

Standards and Regulations

Despite the promise shown by storage technologies, lack of regulations and standards has been limiting storage's growth. Policies remain in a nascent phase, and development of standards and regulations has been uncoordinated and conflicting. The very definition of storage (i.e., as a regulated generating asset)

is limited and inconsistent. Further, there are disincentives to storage implementation, such as regulatory curtailment of renewable energy. The California mandate, which requires the state's three largest power companies to have 1.3 GW of storage capacity by 2020, is breaking new ground in policymaking. Additionally, there is a need to develop a guidebook that eases new entrants into the sector, and establishing a framework standard for grid-connected energy storage is critical for the growth of these technologies.

RD&D Needs

Energy storage technologies are still in the early stages of development, and there are several RD&D needs. These range from pure technical R&D, such as understanding the performance of battery stack design, to evaluating the market drivers and commercial viability and reliability, especially under different regulatory regimes. Developing acceptance of these technologies within the industry is also critical to instill confidence in the private sector and for market adoption.

Several limitations exist, including regulatory and legal issues, costs, safety and standardization, and a lack of operational experience. To establish the reliability and the value proposition of these technologies, more full-scale field deployments are needed. Most importantly, assessing the value of storage is essential. However, this is not a simple task since storage is not a simple asset class; it has the potential to play multiple roles along the delivery chain, each of which must be considered. Furthermore, storage's classification (e.g., as a distribution versus transmission asset) is a factor in regulations and in value assessment. Detailed market analyses will help determine the drivers of these technologies—whether by consumer pull or industry push—and strategies for technology adoption. A clear understanding of the innovation processes for historical and current storage technologies will help in charting a path for future energy storage technologies.

RD&D needs for storage technologies are summarized below.

Technical Needs

- Develop fundamental understanding of electrochemical phenomena
- Develop and optimize new and alternative battery chemistries
- Optimize electrodes, electrolytes, membranes, critical components
- Develop novel cell/stack designs with engineered materials
- Conduct development testing on bench-top component and systems
- Conduct prototype development and test-bed evaluation
- Conduct scale-up, field trials, and demonstrations
- Develop technology cost models to guide R&D and assist innovators
- Refine manufacturing processes

Commercialization and deployment needs are summarized below.

Validated Reliability and Safety

- Conduct R&D on degradation, failure mechanisms, mitigation, and accelerated life testing

- Develop standard testing protocols
- Conduct independent testing of prototypic storage devices
- Track, document, and make available performance data of installed storage systems
- Optimize power electronics and controls and battery management

Equitable Regulatory Environment

- Resolve grid benefits to guide technology development and facilitate market penetration
- Explore technology-neutral mechanisms for monetizing grid services provided by storage
- Develop industry- and regulatory agency-accepted standards for siting, grid integration, procurement, and performance evaluation
- Encourage supportive policy, e.g., purchase contracts, storage mandates, competitive solicitations

Industry Acceptance

- Conduct co-funded field trials enabling experience and evaluation of performance, especially for facilitating renewable integration and enhanced grid resilience
- Develop industry-accepted planning and operational tools to accommodate energy storage
- Develop storage system design tools for multiple grid services and energy management

Path Forward

As energy systems vary among countries, the use of storage technologies and other flexibility options will be determined by the type of energy mix, transmission and distribution infrastructure within and across borders, and market conditions. Storage technologies differ depending on the level at which they are to be used, i.e., determining their use at the national, regional, local, building, and household levels will determine the type of technology that should be used. Identifying which solutions to rely on will require advanced and detailed energy systems analysis, taking into account the complexity of the energy system in a longer-term perspective.

Key actions need to be undertaken in the next decade by the global community for energy storage to become a commercial reality, include the following:

- Improving understanding of economics of storage technologies and facilities
- Developing markets and regulatory environments that will foster accelerated deployment
- Supporting targeted and strategic demonstration projects and R&D
- Establishing a comprehensive set of international standards
- Conducting analysis to quantify the value of storage in specific regions and energy markets

These steps will help enable energy storage technologies to contribute to energy systems of the future that are more efficient, reliable, affordable, and low-carbon.

Appendix A: Acronyms

A-CAES	Adiabatic Compressed Air Energy Storage
AC	Alternating Current
AHI	Aqueous Hybrid Ion
BA	Balancing Authority
BMWi	Bundesministerium für Wirtschaft und Energie (German Ministry of Economic Affairs and Energy)
CERT	Committee on Energy Research and Technology
CHP	Combined Heat and Power
Cl	Chlorine
Cr	Chromium
CO ₂	Carbon Dioxide
DC	Direct Current
DG	Distributed Generation
DOE	U.S. Department of Energy
DOE-OE	U.S. Department of Energy Office of Electricity Delivery and Energy Reliability
DR	Demand Response
DSM	Demand Side Management
E2M2s	European Electricity Market Model, Stochastic Version
ECES	Energy Conservation through Energy Storage
EGRD	Experts' Group on Energy R&D Priority Setting and Evaluation
ENTSO-E	European Network of Transmission System Operators for Electricity
EPRI	Electric Power Research Institute
ES	Energy Storage
ESTAP	Energy Storage Technology Advancement Partnership
ETP	Energy Technology Perspectives
EU	European Union
EV	Electric Vehicle
Fe	Iron
FY	Fiscal Year
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GW	Gigawatt(s)
GW _{el}	Gigawatt(s) Electric
GWh	Gigawatt Hour(s)
h	Hour(s)
HVAC	Heating, Ventilation, and Air Conditioning
IEA	International Energy Agency

IEEE	Institute of Electrical and Electronics Engineers
IER	Institute of Energy Economics and Rational Use of Energy
IT	Information Technology
kVA	1,000 Volt Amps
kW	Kilowatt(s)
kWh	Kilowatt Hour(s)
LFP	Lithium Iron Phosphate
LTO	Lithium Titanate
LMO	Lithium Manganese Oxide, also Lithium Manganate or lithium-ion-manganese
MW	Megawatt(s)
MWh	Megawatt Hour(s)
N/A	Not Applicable
Na	Sodium
Ni	Nickel
NIMBY	Not in My Backyard
NMC	Lithium Nickel Manganese Cobalt Oxide, also lithium-manganese-cobalt-oxide
PG&E	Pacific Gas & Electric
PHEV	Plug-in Hybrid Electric Vehicle
PNNL	Pacific Northwest National Laboratory
PSH	Pumped Storage Hydropower
PtG	Power-to-Gas
PV	Photovoltaic(s)
R&D	Research and Development
RD&D	Research, Development and Demonstration
RTE	Round-Trip Efficiency
S	Sulfur
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
SET-Plan	Strategic Energy Technology Plan (European Commission)
TSO	Transmission System Operator
TWh	Terrawatt Hour(s)
TYNDP	Ten-Year Network Development Plan
U.S.	United States
USC	University of Southern California
USD	U.S. Dollars
VRE	Variable Renewable Energy
VRFB	Vanadium Redox Flow Battery

Appendix B: Speakers

Name	Position & Affiliation
Norela Constantinescu	R&D Advisor, ENTSO-E
Rob van Dijk	Head of Market & Policy Department, DNV-GL
Christian Doetsch	Division Director Energy, Fraunhofer UMSICHT
Chris Edgette	Senior Director, California Energy Storage Alliance
Simon Furbo	Associate Professor, Department of Civil Engineering, Danmarks Tekniske Universitet
Imre Gyuk	Energy Storage Systems Program Manager, U.S. Department of Energy
Arne Höll	Member of the Department for New Energy Technologies, Federal Ministry of Economic Affairs and Energy, Germany
Georgianne Huff	Principal Member of Technical Staff, Sandia National Laboratories
Kai Hufendiek	Director, Institute of Energy Economics and Rationale Use of Energy (IER), University of Stuttgart
Landis Kannberg	Manager, Energy Storage and Renewable Integration, Pacific Northwest National Laboratory
Rob Kool	Chair EGRD, Netherlands Enterprise Agency
Atsushi Kurosawa	Director, Global Environment Program, Japan Institute of Applied Energy
Matthias Leuthold	Scientist, RWTH Aachen University
Peter Markewitz	Scientist, Systems Analysis and Technology Evaluation, IEK-STE, Forschungszentrum Jülich
Poul Erik Morthorst	Professor, Systems Analysis Division, Danmarks Tekniske Universitet
Dominik Möst	Chair of Energy Economics and Public Sector Management Research, Technische Universität Dresden
Luis Munuera	Specialist, Energy Technology Policy Division, International Energy Agency
Estathios Peteves	Head of Energy Systems Evaluation Unit, Institute for Energy and Transport, European Commission–Joint Research Centre
Matthias Stifter	Scientist, Austrian Institute of Technology
Alfons Westgeest	Executive Director, EUROBAT Association
Z. Gary Yang	President and Chief Executive Officer, UniEnergy Technologies

Appendix C: Agenda

IEA Committee on Energy Research and Technology EXPERTS' GROUP ON R&D PRIORITY-SETTING AND EVALUATION

DAY 1 – Wednesday, 22 October 2014

Session 1: Introduction

The Session provides background and context for the Workshop. It reminds participants of the purposed, interactive nature of presentations, dialogue and social interactions, and the expected outcomes, and post-meeting activities and communications.

- *Previous work of the group*
- *Rationale of the workshop*
- *Expected outcome of the workshop*
- *Flexible energy systems and the increasing need for energy storage*
- *The IEA energy storage roadmap*
- *The German Energy storage RD&D initiative*

Introduction		
<i>Chair: Rob Kool</i>		
08:30	Registration	
9.00 - 10:30	Welcome	German Federal Ministry of Economic Affairs and Energy
	Introduction	Rob Kool, Chair EGRD, Netherlands Enterprise Agency
	1 The IEA Energy Storage Roadmap	Luis Munuera, Energy Demand Technology Unit, IEA
	2 The German Energy storage RD&D initiative	Arne Höll, German Federal Ministry of Economic Affairs and Energy
10:30	Coffee break	

Session 2: Energy Systems and Demand for Storage

This session analyses the current and projected future energy system of different IEA member countries / regions with respect to the need for energy storage solutions.

- *How can renewable energy sources be integrated into the market while ensuring sustainability and security of supply?*
- *Which measures can be taken to stabilise the grid against fluctuations coming from renewable energy sources?*
- *How is electricity storage handled in different countries?*
- *Which experiences do exist in different countries concerning the need for large scale electricity storage?*

Energy Systems and Demand for Storage

IEA Committee on Energy Research and Technology
EXPERTS' GROUP ON R&D PRIORITY-SETTING AND EVALUATION

<i>Chair: Birte Holst Jørgensen</i>			
11:00	3	Worldwide need for energy storage	Christian Doetsch, Fraunhofer UMSICHT
11:30	4	Energy storage in a grid with fluctuating sources: the German perspective	Ulrich Fahl, IER Stuttgart
12:00	5	The DOE Global Energy Storage Database	Georgianne Huff, Sandia National Laboratories, USA
12:30	Lunch		
13:30	6	A TSO's Perspective on Energy Storage	Norela Constantinescu, ENTSO-E
14:00	Discussion		

Session 3: Flexibility Options as Alternatives to Storage

This Session discusses whether the problem of energy storage can be effectively mitigated, or avoided entirely, through implementation of alternative technologies, such as demand side management in a grid context, power-to-heat and power-to-gas technologies, or intelligent trans-border coupling of national electricity grids.

- *Can the problem of energy storage be solved on a national basis or is an international perspective mandatory? Which benefits can be identified by adopting a transnational perspective?*
- *How can power, voltage and frequency be kept stable in an electricity grid where the supply side does not instantly follow the demand side?*
- *Can the electricity sector be treated separately or do mutual interdependencies between electricity-, gas- and heat markets lead to technical advantages and/or economic benefits?*
- *How can demand side management help to minimise the need for storage?*

Flexibility Options as Alternatives to Storage			
<i>Chair: Johannes Tamborino</i>			
14:30	7	Convergence of electricity and gas grids	Peter Markewitz, Forschungszentrum Jülich
15:00	8	Japanese perspectives on storage alternatives	Atsushi Kurosawa, Japan Institute of Applied Energy
15:30	Coffee break		
16:00	9	Energy system flexibility, security, standards	Jillis Raadschelders, DNV-GL
16:30	10	Demand Side Management	Matthias Stifter, Austrian Institute of Technology

IEA Committee on Energy Research and Technology
EXPERTS' GROUP ON R&D PRIORITY-SETTING AND EVALUATION

17:00	11	The Future Energy System - with focus on flexibility by system interactions	Poul Erik Morthorst, Danmarks Tekniske Universitet
17:30	Discussion		
18:00	Close Day 1		
19:30	Group Dinner		

DAY 2 - Thursday, 23 October 2014

Session 4: Energy Storage Technologies

During this session different energy storage technologies which are currently used and/or researched on are presented.

- *Which energy storage technologies are currently used?*
- *What is the current status of battery technology and can these batteries be used as large-scale electricity storage facilities in the foreseeable future?*
- *Which primary technological limitations and barriers need to be overcome to make Energy Storage more beneficial to power utilities?*

Energy Storage Technologies			
<i>Chair: Robert Marlay</i>			
09:00	12	Battery storage for grid stabilisation	Matthias Leuthold, RWTH Aachen
09:30	13	Flow Batteries	Gary Yang, UniEnergy Technologies
10:00	14	DOE Energy Storage RD&D Program	Imre Gyuk, Head, Energy Storage R&D Program, U.S. DOE
10:30	Coffee break		
11:00	15	Technological opportunities and barriers for utility scale energy storage	Estathios Peteves, EU-JRC
11:30	16	Smart Heat Storage for solar heating systems	Simon Furbo, Danmarks Tekniske Universitet
12:00	Discussion		
12:30	Lunch		

Session 5: Energy Storage Markets and Business Models

This session discusses possibilities as to how the regulatory framework can be adapted to accommodate for energy storage markets and presents selected business examples.

- *Does the regulatory framework need adjustment for a better integration of energy storage technologies?*
- *Is the energy-only market sufficient to ensure security of supply or do we need a complementary capacity market?*
- *Best Practice examples: a business in energy storage*

Energy Storage Markets and Business Models			
<i>Chair: Herbert Greisberger</i>			
13:30	17	Battery Systems for Grid Stability	Alfons Westgeest, EUROBAT Association
14:00	18	California Utility Storage Experience	Chris Edgette, California Energy Storage Alliance
14:30	19	Economics of Energy Storage	Dominik Möst, TU Dresden
15:00	Coffee Break		
15:30	20	Perspectives on Grid Transformation and the Market for Storage	Landis Kannberg, Pacific Northwest National Laboratories
16:00	Discussion		
16:30	Wrap Up of the Workshop, Panel Discussion, and Participants Round Table		
17:30	Close Day 2		

