Energy Storage White Paper 2016 (Summary Version)

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Preface

Promise in the Nascent Energy Storage Industry

Under the weight of the sluggish 2015 global economy, the energy storage market has emerged with promise and vigor. In the spring of 2016, Tesla announced its most affordable car to date, the Model 3, with an energy density of 300 Wh/kg and target cost of only US$200/kWh. Energy storage prices have turned a corner. In the last three years, the costs of lithium-ion battery systems have rapidly decreased by 50%, and will continue to do so over the next three years. Similarly, in 2015, lithium power was no longer the lone leader in energy storage technology since lead-carbon batteries and flow batteries among others became increasingly viable. As energy storage costs decrease, we can forecast the rapid growth of EVs and grid-connected energy storage projects, making the energy storage industry a fundamental driver of the energy and electricity transition.

2015 was an exciting year for the energy storage technology sector. Not only were there numerous performance breakthroughs in flow batteries, lithium-ion batteries, sodium-nickel batteries, compressed air energy storage, and phase change thermal storage, but also other exciting technologies entered the field, such as solid-state batteries, lithium-sulfur batteries, lithium-air batteries, and liquid metal batteries just to name a few. To those of us in the industry, the excitement is real, and the abundance of options almost feels like a "lavish display."

In 2015, three driving forces ushered in the start of the Chinese energy storage market. On the user-side it was distributed solar photovoltaic (PV) systems along with associated storage systems. On the grid-side, it was the use of energy storage frequency regulation and peaking plants while on the generation-side it was services supporting grid-scale energy storage. At the same time, several policy changes also helped promote energy storage business models. Reforms in the electricity market spurred ancillary services market policies and tariff and compensation policies will promote energy storage business models, and pave the way for large scale energy storage financing in the process. 2016 will be a year of hope for the energy storage industry, but many challenges remain.

In the first quarter of 2015, China's economy began to show favorable signs – electricity consumption growth picked up, especially in March, where consumption increased by 5.6%. However, investments in coal plants brought down overall energy efficiency, and challenges to new energy grid integration continued to intensify. In 2015, total wind curtailment rates reached 15%, even up to 39% in Gansu Province, with solar curtailment in many provinces approaching 30% (according to data released by the National Energy Administration).

Although the government issued a policy in 2015 titled *Guiding Opinions on Advancing New Energy Microgrid Demonstration Project Construction,* subsidy programs have been constantly changing, leaving many projects' finances uncertain and unfunded.

Electricity demand response compensation policies were piloted in four cities. Load aggregators participated enthusiastically, but project connection and degree of compensation are a far cry from the market's expectations, counter to the continued construction of inefficient grids and coal plants – all setbacks to the industry's development.

The curtain has been drawn open for electricity system reforms, and ancillary services have become a focal point. Since 2008, ancillary services were separated from the grid, and with the "Six Core Supporting Documents" of the *New Power Reform* issued at the end of November 2015, ancillary services were clarified as one of the reform's focal points. However, marketization following these reforms has been slow to take hold.

Despite these early policies falling short of many people's expectations, we have no doubts about the market potential of energy storage. As such, we should focus on developments in technology and application as starting points for 2016.

This 2016 white paper, in addition to detailing energy storage market trends and development outlooks, focuses on key energy storage technologies, economic analyses, and also shares the Alliance research department's findings on demand response markets. Adhering to our Alliance motto of "Openness, Equality, Cooperation, and Sharing" and the spirit of the internet, we will share the Alliance's analysis and research results, and enthusiastically welcome the opinions of peers and experts on the data and conclusions herein. We also hope that together, we can find solutions to overcome challenges in this nascent industry.

China Energy Storage Alliance Chairman

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Overview of the 2015 Global Energy Storage Market: Trends and Outlook

Chapter 1: The Global Energy Storage Market

Overview

According to the China Energy Storage Alliance (CNESA) Project Database, as of the end of 2015, there were 327 energy storage (ES) projects in operation (excluding pumped hydro and compressed air ES (CAES), and thermal storage), totaling 946.8 MW, with compound annual growth rates (CAGRs) of 18% for installed capacity and 40% for the number of projects from 2010 to 2015.

Geographic Distribution The US remains the leader, having surpassed Japan in 2014, with 426.4 MW of ES in operation as of the end of 2015 and making up 45% of the global market. Japan and China follow, making up 33% and 11% of global installed capacity.

Technology Distribution Lithium-ion (Li-ion) batteries are the clear leader in cumulative operational projects and projects under planning/construction, with 356.7 MW in operation (38% of all ES in operation) and 2.2 GW under planning and construction (83% of all ES in planning/construction). With six times as many projects under planning/construction, installed capacity of Li-ion batteries will see explosive growth in the next 2-3 years.

Application Distribution Renewables integration was the largest field with 43% of total installed ES capacity. Ancillary services had the largest share among projects in planning/construction, making up 48%, and with frequency regulation showing the fastest two-year growth of 31% CAGR (2013-2015). Distributed generation and microgrids made up the largest number of projects - 60% of the total.

Manufacturer Distribution In 2015 there were 44 ES technology manufacturers, 12 power control system (PCS) companies, and 34 integrators that installed ES projects (including commissioned, under construction, and projects in planning). These companies were based in 10 countries, covering 9 types of ES technology. The US had the largest number of companies, followed by Japan and China. In terms of technology, 7 of the top 10 manufacturers by installed capacity made Li-ion batteries; the other technologies were sodium-sulfur (NaS), all-vanadium flow batteries, and flywheels. Asian companies dominated the top 10 with 7 spots (largely with companies based Japan and Korea), with LG Chem in the lead, being twice as large as the second-largest ranked manufacturer, BYD. BYD is also the only Chinese manufacturer in the global top 10.

Investment and Government-Issued Financial Support

According to CNESA's worldwide industry tracking, as of end of 2015, of the top 17 ES companies tracked, the total amount in received investment, bonds sold, acquiring costs, etc., totaled US$1.02B in activity, up 155% from the previous year. The 5 companies with the most financial/investment activity were Main Street Power (US$250M), Energizing (US$250M), SolarCity (US$100M), Sakti3 (US$90M), and Stem (US$84M).

As of the end of 2015, US$2.04B had been allocated by government bodies to support ES-related projects of all types. The US provided the most support, with many institutions allocating funds and supporting the widest range of projects. In the US, two federal institutions and five state government institutions provided funds totaling US$1.28B.

2015 Global Market Highlights

In 2015, there were 143 newly added projects in operation, construction, or planning—a 4% increase from 2014, representing a total capacity of 1227.8 MW. This figure is up 78% from 2014's capacity, making the five year CAGR 100%. The global energy storage market development direction is becoming stable, with differentiating characteristics arising in different regions, applications, and manufacturing.

Australia's ES Market Emerges, Accelerating ES Globalized Development

Geographically, although US/Europe, China/Japan/Korea regions have long been leading markets (over 96% of the global installed capacity in 2015), the Australian market is growing fast with enormous potential. Australia is the fastest growing (356% growth from 2014), with great prospects.

In 2015, new projects were built in Southeast Asia, India, the Caribbean, Africa, and South America. These areas possess great wind and solar resources, but lack adequate economic resources and grid infrastructure. Some projects received planning and development support from foreign organizations, governments, and companies. Some projects were developed through government subsidies aimed at attracting the advanced technology investments of foreign companies. The Indian government forecasts that in India there will be over 15 GWh of ES by 2020, over 125,000 times the current market size.

The Distributed PV+ES Model is Expanding, Advancing ES Commercialization

Distributed PV+ES lead global ES deployment 2015 occupying 40% of the ES market while also being one of the fastest growth sectors over the last two years. The US, Japan, Germany, Australia, and China are the major distributed PV+ES users.

Data shows that distributed PV+ES is rapidly expanding in all countries, especially recently with the opening of Japan's retail electricity market, Germany's extension of its self-consumption subsidy, Australia's introduction of customer-sited ES subsidies, and China's retail electricity reforms. As costs continue to come down, prospects will expand rapidly, spawning more business and service models all while increasing the amount of ES products and customer-sited distributed PV+ES solutions providers.

EV "Vehicle Networks" + "Demand Response Charging" + "Second-Life" Applied Research Grows, Contributing to the Development of New ES Usage Models

In the last 2 years, in regions and countries with faster developing renewables and EV industries, particularly California, Germany, and Japan, the large scale grid connection of renewables and EVs is causing stress and threatens the structure and operational security of the traditional grid. However, this concern is mitigated if EVs participate in grid demand response plans. Furthermore, EVs acting as a flexible distributed energy storage unit can provide peak shaving, frequency regulation, and renewables leveling, effectively avoiding large-scale charging conflicts with the grid and adding an income stream at the same time.

In addition, when EV battery performance deteriorates and it is no longer suited for vehicular usage, it can still be repurposed for low-power requiring ES systems. Battery reuse can lower project costs and improve battery lifetime value, as well as avoid a waste of resources and reduce environmental impact. As such, more and more automakers, system integrators, utilities, and electric companies are all interested in EV "vehicle networks" and "demand response charging."

Monopolies Expand Overseas Distribution, Strengthen Strategic Cooperation, and Promote Enterprise Internationalization and Diversified Development

Since 2015, from the perspective of global ES project deployment, many monopolies are solidifying their existing market foundations, and continuing to leverage their technological advantages. They are seeking strategic overseas partnerships to advance market expansion abroad, spurring the development of the local ES industry and strengthening the company's internationalization and diversification capabilities. All such overseas market expansion routes have exhibited the following characteristics:

- Entering foreign markets with "core business + global partnership" bundling in mind
- Entering foreign markets with diversified service advantages
- Entering foreign markets with one core business
- Entering foreign markets with foreign financing

Future Market Outlook

CNESA has compiled market forecasts of several foreign research companies and institutions shown below in Table 1.

Table 1: Energy Storage Market Forecasts by Recognized Foreign Research Firms and Institutions

Location	Type	Research Organization	Forecast
Global	Distributed energy storage market	Navigant Research	By 2024: Installations will reach 12147.3 MW (12.1473 GW) and $165B annual revenue
	Grid-scale ancillary services market	Navigant Research	By 2024: Installed capacity will reach 20.8 GW with $68.5B in annual revenue
	Advanced energy storage market	Market and Markets	By 2020: Energy storage systems market will reach $15.96B (up from an estimated $12.89B in 2015)

Location	Type	Research Organization	Forecast
	Energy storage + renewables market	Navigant Research	By 2025: Newly added installed capacity will break 12.7 GW
	Distributed solar+ storage market	Navigant Research	By 2024: Industry will reach a scale of $23.1B
US	Microgrid market	GTM Research	By 2018: US microgrid capacity will reach 1.8 GW for a total value of $3B
	Customer-sited ES market	GTM Research	By 2019: market will represent 45% of all energy storage projects
	Energy storage market	GTM Research	By 2019: Newly installed capacity will reach 858 MW. By 2020: The market will reach $2B, of which customer-sited storage will account for 59%
Australia	Energy storage market	GTM Research	By 2020: Installation scale will reach 244 MW
		Bloomberg New Energy Finance (BNEF)	Within 20 years: Market capacity will reach 33 GWh
India	Distributed solar+ storage market	KPMG India	By 2023: Solar+ storage for residential power supply costs will become cheaper than the costs of grid coal power
Japan	Energy storage market	Yano Economic Research Institute	By 2017: Market will reach 1.196 GWh By 2020: Market will reach 3.307 GWh

Source: CNESA

From the table above, forecasts for the next 5-10 years for distributed ES, distributed PV+ES, microgrids, and other grid-facing and customer-facing sectors will be major development hotspots in both the short and long term globally.

2015 marks the first year CNESA has included Australia and India as ES markets in our global forecast. These two countries have abundant renewable energy resources, suitable market conditions, and have launched energy storage subsidies and procurement plans. By 2015, LG Chem, Telsa, Sunverge, Imergy Power, and other well-known ES companies have already entered these two markets. In the next 5-10 years, we predict that the Australian and Indian markets will show explosive growth.

Chapter 2: China's Energy Storage Market

Overview

As of the end of 2015, China had 118 ES projects in operation (excluding pumped hydro, CAES, and thermal energy storage) totaling 105.5 MW and making up 11% of the global market. Most remarkably, the Chinese ES market is drawing attention for its growth, with a CAGR of 110% (2010-2015), over six times the global rate.

Most of the current Chinese ES operations employ Li-ion, lead-acid, and flow batteries technologies, with Li-ion dominating two-thirds of the market.

More than 80% of China's installed ES systems (by both capacity and number of projects) are applied in distributed generation, microgrids, and renewables integration. Distributed generation and microgrids alone compose 56% of China's installed ES capacity and 77% of installed ES projects.

Domestic projects are largely run by Li-ion, lead-acid, and flow battery technology companies. As of the end of 2015, 6 out of China's top 10 ES companies ranked by project installation scale were Li-ion battery manufacturers. Lead-acid and flow battery companies each contributed 2 companies to the top 10 ranking. BYD is both China's largest Li-ion battery maker as well as the leader in most ES projects deployed domestically. Narada Power leads in lead-acid battery installation while Dalian Rongke has deployed the most flow batteries.

2015 Chinese Market Highlights

In 2015, China added 28 new ES projects (in operation, under construction, and in planning), totaling 37.5 MW. Although this growth figure has slightly decreased since 2014 in terms of project count and added capacity, it still shows steady progress. Additionally, since 2015 was the final year of the 12th Five Year Plan, preparations have already begun for the 13th Five Year Plan, setting a favorable policy environment for future growth. The 2015 ES market made advances in policy, opportunity, and new models—favorable policies are leading to new opportunities, new models, and advancing the industry's rapid development.

New Rounds of Electricity System Reforms

In March of 2015, China opened the doors for electricity system reform after many years of inaction, following up with a policy document titled *Six Supporting Documents*. These actions advanced China's electricity industry by introducing reforms in electricity generation, sales, and usage. This is positive news for the ES industry, since the most critical obstacles to ES expansion in China, outside of technological limitations, are in the economic mechanisms. The new round of electric industry reforms will open many electricity markets in China in fields like demand response, ancillary services, retail-side, and energy storage will have strong prospects in these sectors, able to provide even more value.

Support for Microgrid Advancement at the National Level

On July 22, 2015, the National Energy Administration released an official policy document *Guiding Opinions on Advancing the Building of New Energy Microgrid Demonstration Projects*, investigating the potential of establishing local electricity systems with integrated transmission, storage, and usage. The document mentions energy storage several times, a promising sign that the high levels of the national government recognize its importance.

In the last two years, the distributed generation + microgrid sector has been the leader in terms of both number of ES projects and installed capacity. This sector also has the most hope achieve grid-scale commercial application. In some areas with large differences in on-off peak prices and PV subsidies, a certain number of projects are already expected to be profitable and economically beneficial. Most areas, however, are limited largely by low subsidy levels and market inflexibility. This results in longer investment return periods for projects. This sector will quickly approach commercialization when the country provides policy support. The release of the *Guiding Opinions* is a good start, but further subsidy policies will greatly accelerate the realization of ES commercialization.

Electric Vehicle and Infrastructure Policies

In 2015, China's State Council, National Development and Reform Commission (NDRC), Ministry of Industry and Information Technology (MIIT), Ministry of Finance (MOF), and National Energy Association (NEA) launched a series of EV-related policies. Policies such as *Electric Vehicle Battery Industry Standardization Criteria* and *Li-ion Battery Industry Standardization Criteria*, advanced the thresholds for industry standards. Infrastructure to support the charging demands of five million expected EVs in China by 2020 is also a key issue being advocated by many organizations. In addition, EV battery recycling was put on the national agenda this year with the goal of instituting EV battery recycling systems. These policies all aim to promote the standardization and accelerated development of EV batteries, which will also lead to performance breakthroughs and cost reductions in ES technologies, advancing energy storage in all sectors and applications.

Implementing the "Energy Internet"

The "energy internet," fusing the technologies of the internet and smart energy, is one of the hottest topics of 2015. In early 2016 *Guiding Opinions on Advancing "Internet + Smart Energy" Development* was released, clarifying China's direction and targets for building its own energy internet.

Although China's energy internet research is in its preliminary stages, many parties have come to the consensus that the energy internet should become one of the cores of the electricity system, linking multiple types of power and transmission grids in large-scale interconnected systems. Combining nationally-approved reforms in energy consumption, electricity system, and energy management along with set targets and goals for distributed energy, migrids, and data-driven energy services, the energy internet appears to be a quickly approaching reality.

Within the framework of the energy internet, energy storage is no longer limited to electricity storing technology, rather hydrogen storage, thermal storage, and natural gas storage are also included. In the future, the ES field will likely see the emergency of even more application and business models all advancing energy internet development.

Progress in Chinese Demand Response Pilots

In 2014 and 2015, Shanghai, Beijing, Suzhou, Tangshan, and Foshan established and opened demand response pilots. These pilots differ from prior methods of regulating and reducing electric load where high-energy-consuming users were ordered when to shut down their load-causing operations. Demand response relies on prices and market signals to guide user behavior in reducing or shifting peak load electricity usage.

Each region's subsidy policies set and improve critical peak and seasonsal pricing/tariffs pricing and incentivizes electric service company participation in pilots. This will undoubtedly greatly strengthen the activity of demand response markets, giving rise to even more innovative products. Energy storage, as a flexible electric resource, will certainly have opportunities to come into its own in this field.

Future Market Outlook

Today in China, the primary ES applications are involved in large-scale centralized renewable energy, distributed generation and microgrids, frequency regulation ancillary services, and easing transmission and distribution capacity expansions. CNESA forecasts that by 2020, ES usage in these sectors, under ideal conditions, will total 24.2 GW in installed capacity and only 14.5 GW if there are no changes to current policies. These predictions are shown in Table 2.

Table 2: China's Energy Storage Installation Forecast for 2020

Application	2020 Installed Capacity (GW)	
	Base Case	Ideal Case
Large-scale centralized renewable energy	5.4	9.0
Distributed generation and microgrids	8.0	13.5
Frequency regulation ancillary services	1.0	1.2
Transmission and distribution expansions/deferalls/upgrades	0.1	0.5
Total	14.5	24.2

Source: CNESA. Forecast includes concentrated solar thermal power plant thermal energy storage projects.

The above forecast does not include pumped hydro. According to the government's Renewable Energy 13th Five Year Plan, by 2020, China's pumped hydro plants will reach an installed capacity of 40 GW.

Chapter 3: 2015 Trends in Energy Storage Battery Technology

In 2015 global ES technology developed rapidly. Not only did flow battery, Li-ion battery, and all solid-state battery performance advanced greatly, but aluminum-ion battery and Li-ion all-climate battery (ACB) cells emerged as technological breakthroughs. In addition, researchers also developed many solutions pertaining to Li-ion battery safety monitoring.

This section will summarize the major developments in 2015 battery research divided into the following topics: 1) improvements in traditional battery technology; 2) Li-ion battery safety research; 3) Li-ion battery electrode development; 4) solid-state battery R&D; and 5) emerging battery systems.

Improvements in Traditional Battery Technology

In 2015, battery researchers prepared and applied new electrode, electrolyte materials and catalyst systems. Flow batteries, metal-air batteries, sodium-nickel batteries, and supercapacitors all achieved breakthrough R&D achievements, with flow batteries remaining a hot topic of research.

Flow batteries: Breakthroughs include improvements in and selection of different solid and liquid electrolytes, production methods with decreased toxicity, lower costs, and higher energy density flow batteries. Many research efforts were directed towards different redox non-aqueous flow battery systems such as low cost all-iron flow batteries and organic polymer electrolyte irrigated flow batteries.

Molten salt batteries: Research efforts worked towards reducing battery operating temperatures and raising energy density in molten salt batteries such as sodium-sulfur and sodium-nickel batteries.

Metal-air batteries: Research in zinc-air, lithium-air, and other metal-air batteries focused on development of low-cost non-platinum catalysts.

Lithium-Ion Battery Safety Research

Li-ion batteries are already widely applied in EV and other ES sectors. Aside from battery performance and lifetime, operational safety has become a major issue for practical applications. In 2015 researchers made major progress in this field, generally forgoing external monitoring and heating directions and moving instead towards using internal components (electrolytes, membranes, electrode materials, etc.) to regulate battery functioning and safety. Some representative research achievements are shown in Table 3.

Table 3: 2015 Li-Ion Battery Safety Research Achievements

Organization	Technology	Application Value
Stanford University	Li-ion battery thermal control technology	This group develops polymer conversion materials with fast, reversible thermal response properties. Under abnormal temperature conditions, normal battery conductance quickly decreases, causing the battery circuit to be interrupted, and sensitivities to temperature changes increase 10^3-10^4 times. New materials ensure Li-ion batteries in short circuit or over-heating conditions automatically stop charging or discharging prevents further dangers. When dangerous conditions pass, the material will return to its original state and without any effect on the battery's performance.
Pennsylvania State University	Li-ion battery reaction temperature monitoring control technology	A temperature sensor on the inside of a battery can faster and more accurately detect internal battery temperature changes. It can also more quickly interrupt the circuit during a short circuit, usually three times faster than standard surface sensors. This can prevent battery temperatures from exceeding 50℃ and resulting internal structural damage. This technology is highly portable, and can be applied in lithium-sulfur batteries, lithium-air batteries, and other battery systems.
Stanford University	Li-ion battery membrane sensor	This group uses a dual function diaphragm material to monitor lithium dendrite formation via the voltage change signal. This sensor technology is highly sensitive and can make precise readings before an short circuit occurs. This increases Li-ion battery safety, and can be extended to other battery systems.
Pennsylvania State University	"All-Climate Battery" (ACB)	The "All-Climate Battery" uses its own energy to quickly heat itself, raising its temperature by 20℃ in under 20 seconds, only using about 3.8% of the battery's energy. It also has high power charging and discharging

		performance. This technology helps Li-ion batteries operate normally in low temperatures and can be employed in plug-in hybrid vehicles, robots, space exploration to name a few.

Source: CNESA

Lithium-Ion Battery Electrode Development

Although Li-ion batteries have already reached large scale commercial usage, high material costs encourage improvements in in battery energy density, cycle life, rated performance, and capacity retention. In particular, developing better anode and cathode materials is an important area of research as electrodes are a critical factor in determining battery performance. Additionally other research efforts focus on lowering costs and increasing efficiency in the industrial fabrication processes.

Solid-State Battery R&D

Solid-state Li-ion batteries are Li-ion batteries that use solid materials for the electrolyte. Solid-state batteries generally have a good safety performance, high energy density, and a wide operating temperature range. Given all of these benefits, many researchers hope to apply this technology to the next generation of Li-ion batteries. This has spurred on researches to develop solid and quasi-solid electrolytes.

Some research teams are working on improving the compatibility of solid-state electrolytes, conventional cathode materials, and metallic lithium anodes, all while inhibiting lithium dendrite formation in these setups. Others are focusing on the construction of high-rated power and stable cycle solid-state Li-ion battery systems. Gel-type electrolyte materials have also become a major subject of materials science research.

At present, since solid-state batteries have shown promising results, new research efforts are now transitioning away from electrolyte development and increasing towards total battery structural design and industrial production processes, with battery samples and prototypes constantly rolling off the assembly lines.

Emerging Battery Systems

Limited reserves of the raw materials required for Li-ion batteries and economic factors are driving efforts to find Li-ion alternatives. In 2015, major developments were made in metal-ion, solar-charging, metal-air, and metal-carbon dioxide batteries.

Developments in metal-ion battery technology built on the design principles behind Li-ion batteries in addition to continued research into sodium-ion batteries and sodium-ion supercapacitors. Researches made advances in developing battery systems employing other high valence metals such as aluminum-ion and calcium-ion batteries.

In metal-carbon dioxide and metal-air batteries, the metal acts as an anode and uses ambient air as the cathode. Because the cathode doesn't need to be stored within the battery, these batteries have high energy density and are environmentally friendly. At present, research into lithium-air batteries is focusing on selecting high efficiency catalysts and protecting the cathode metal lithium. It will be some time yet before wide-spread application is available employing this technology.

Chapter 4: Analysis of China's 2015 Energy Storage Policies

In 2015, China began its new round of electric system reforms, the 13th Five Year Plan was begun, and renewable energy, smart grid, new energy vehicle, and other industries developed strongly. From strategic master plans (*guihuas*) to demonstration projects, energy storage application value and potential in markets also took shape in policy sectors including energy, electricity, science and technology, transportation, and environmental protection. These relevant industries and application sectors had a series of policy support, mechanism changes, and development master plans (*guihuas*) that will also greatly spur the development of the energy storage industry, further increasing confidence and expectations.

In 2015, ES-incentivizing policies were primarily in energy development master plan (*guihua*) policies, electricity reform tariff policies, renewable energy development policies, energy storage technology industry standards and regulations policies, and new energy vehicle policies. These policy developments are summarized below in Table 1.

Table 1: 2015 China Energy Storage Related Policies

- Energy Storage Related Policies Launched in 2015
  - Energy Development Master Plan Policies
    - <13th Five Year Plan Outline>
    - Energy Development Strategic Action Plan (2014-2020)
    - China Manufacturing 2025
    - <Guidelines on "Internet+" Smart Energy Development
    - Central Committee Guidelines on Deepening Electricity Reforms
    - Guidelines on Smart Grid Development
    - Distribution Grid Construction Reform Action Plan (2015-2020)
    - Guidelines on accelerating distribution grid construction reform
  - Electric Reforms and Tariff Policies
    - Guidelines on multi-front improvements in electric operation adjustment to clean power
    - Notice on implementing Policy No. 9 – accelerated T&D pricing reforms
    - Implementation views on advancing T&D pricing reform
    - Implementation views on advancing electricity market construction
    - Implementation views on electricity trading mechanisms and normal operation
    - Implementation views on beginning of electric usage planning
    - Implementation views on retail side reforms
    - Notice on expanding T&D pricing reform pilot scopes related matters
  - Renewable Energy Development Policies
    - Mgmt measures for the fully protected purchase of renewables generation (Draft for comments)
    - Guidelines for establishing renewables development via guiding targets
    - Guidelines on promoting new energy microgrid demonstration project construction
    - Notice on solar thermal generation demonstration project construction
    - Interim opinions on renewables local consumption pilots
    - Notice on electricity storage participation in 'Sanbei' region frequency regulation ancillary service (Draft for comments)
  - Energy Storage Technology Industry Regulations and Standards Policies
    - Li-ion battery industry standardization conditions / Notice on interim management methods for Li-ion battery industry standards
    - Lead-acid battery industry standardization conditions (v. 2015)/ Notice on interim management methods for lead-acid battery industry standards (v. 2015)
    - Waste battery pollution prevention technology policy (Straw proposal)
  - New Energy Vehicle Policies
    - 2016-2020 New Energy Vehilce Popularized Usage Financial Support Policy
    - State Council Guiding Opinions on Accelerating EV Charging Infrastructure Construction
    - EV Charging Infrastructure Standardized Project List (2015 Version)
    - Notice On "13th FivE Year Plan" New Energy Vehicle Charging Infrastructure Incentive Policy and Strengthening New Energy Vehicle Popularized Usage
    - EV Battery Recycling Technology Policy (2015 Version)
    - New Energy Vehicle Worn Out Battery Comprehensive Usage Industry Regulations and Conditions
    - New Energy Vehicle Worn Out Battery Comprehensive Usage Industry Regulations Interim Management Announcement

Source: CNESA

Volume 1 - Analysis of Major Energy Storage Technologies

Chapter 1: Lithium-Ion Battery Applications and Second-Life Industry

Applications for Lithium-Ion Batteries

Li-ion batteries are the most commonly type of installed battery globally and in China. At present, they are used in a wide array of applications including ancillary services, large scale renewables, distributed generation and microgrids, transmission and distribution, and EVs.

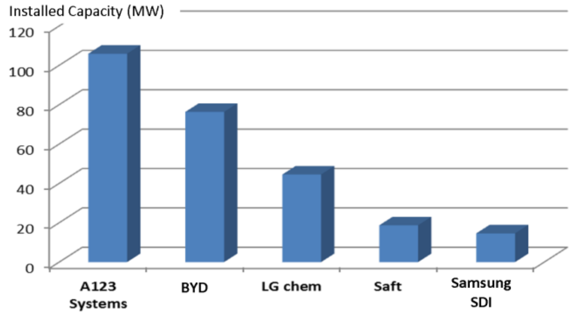
According to CNESA's Global Energy Storage Project Database, as of the end of 2015, 356.7 MW of Li-ion batteries were in operation globally, making up 38% of the global ES market. Li-ion batteries in China, on the other hand, dominated the market occupying a market fraction nearly twice this with 69.3 MW in operation, representing 66% of the country's total ES market.

The US, China, Europe, Japan and South Korea are the major users of Li-ion technologies. Here we break down the principal applications of Li-ion battery systems in each country.

- US: Li-ion batteries are principally used in frequency regulation, ancillary services, and large scale renewables. In addition, new advances in distributed energy systems will probably increase Li-ion technology application in this sector as well in the near future.
- China: Li-ion technology is largely used in distributed generation and microgrids. Most often this occurs in commercial and industrial settings, in buildings, and on islands.
- EU: Most Li-ion batteries are employed in transmission and distribution large-scale smart grid projects. Germany, UK, Italy, and other countries have many MW-scale Li-ion battery projects in operation.
- Japan and South Korea: Smart grids, large scale wind farms, and frequency regulation ancillary services, use the majority of installed Li-ion battery capacity in these two nations. Toshiba, Panasonic, LG Chem, Samsung SDI, and other large-scale Li-ion battery makers have greatly encouarged ES usage.

Manufacturers: As of end 2015, globally, Li-ion ES project technology providers were mainly traditional large scale EV Li-ion battery manufacturers. The five manufacturers with the most Li-ion batteries installed in operation in ES projects are, as shown in Figure 2: A123, BYD, LG Chem, Saft, and Samsung SDI. Outside of these five other companies with a significant number of Li-ion batteries in operate include: Toshiba, Sanyo, NEC, Wanxiang, China Aviation Lithium Battery, ATL, Kokam, EnerDel, and Electrovaya.

Figure 2: Top 5 Global Li-Ion Battery Manufacturers by Installed ES Project Capacity in Operation



Source: CNESA's Global Energy Storage Project Database

Large scale Li-ion battery makers usually have technology and cost advantages, strong market influence, and branding, allowing them to lead the market as compared to smaller scale EV Li-ion manufacturers. As the ES market gradually matures, these large Li-ion battery makers will leverage their previous experience and business relationships to accelerate installation scale and expand. Also, with the rapid growth of distributed PV, customer-sited ES is growing each day, and more and more of these large-scale manufacturers will enter this ES sector.

Second-Life Lithium-Ion Batteries in Electric Vehicles

Second-Life EV Li-Ion Battery Industry Overview

Second-life is the term used for when a retired EV battery is converted for use in an ES project. The second-life battery usage industry is the undertaking of the EV battery industry, covering EV battery production, EV onboard usage, retired EV battery recovery and performance evaluation, battery system reorganization, second use ES sector, and battery disposal and recycling. Of these, retired EV battery recovery and performance evaluation, battery system reorganization, and second-life application in ES are the core segments of the second-life process.

Second-life battery applications are still in project validation and demonstration stages, therefore there are no companies yet to specialize in the field. Current projects are mainly run by research institutions, EV battery manufacturers, EV makers, ES component developers, ESS aggregators, customers, and battery recyclers. In the near-to-middle term, EV and EV battery system producers will be the major drivers of the second-life usage market.

Status Overview of the International Second-Life EV Li-Ion Battery Industry

Since 2010, American, European, and Japanese EV producers and research institutions have begun second-life battery projects with the support of national and local energy departments, transportation departments, environment departments, and science and technology R&D groups.

At present, backed by economic research and technological validation, real-life applications of second-life EV batteries are still in early stages. Participants in the industry are currently exploring ways to providing second-life products and services, finding the best methods and products to bring to market.

Some large automakers advancing second-life usage include Nissan, General Motors, Daimler, BMW, and Renault. Among existing second-life demonstration and commercial projects, distributed microgrids (PV+ES), customer-sited ES, backup reserve power, fast charging stations, and large scale ES stations are the current major application fields. Most projects are below 100 kWh. Representative projects include:

- Vattenfall's virtual power plant second-life project (Germany)
- GM's Milford Data Center second-life project (US)
- Sumitomo's solar PV power plant second-life battery large scale ES project (Japan)
- Daimler's Remondis battery recycling plant second-life project (Germany)

Status Update on China's Second-Life EV Li-Ion Battery Industry

China is setting and issuing new energy vehicle (NEV) promotion policies, all of which involve EV battery disposal and recycling efforts. These will gradually expand to EV battery recycled usage regulations and management measures.

Since 2011, Chinese policy efforts aimed at popularizing NEV have included EV battery recycling measures. From the end of 2015 to early 2016, the NDRC and MIIT have issued documents on EV battery recycling guidance and regulations, promoting the development and regulation of the NEV waste battery industry.

At present, China's second-life battery research is focused on evaluating retired EV battery performance. Under the leadership of the China Electric Power Research Institute (EPRI), local electric companies, EV vehicle and battery manufacturers, a few research projects have been begun, focusing on collecting preliminary data to optimize performance.

Necessary Technology for Second-Life EV Li-Ion Batteries

In order for second-life EV batteries to be effective in the ES sector, the battery must match the ES system's technological requirements despite the battery's deterioration. This makes technology for evaluating, selecting, and sorting usable batters critical for second-life recycling systems. For example a battery with a broken exchanger membrane would not be economically feasible to recycle and would need to be sorted out.

Recycling schemes also must bear in mind the lifetime and performance limits of recycled batteries. For example, the usable lifetime of current EV battery technology is around 10 years, after this, mechanical and electrochemical factors will quickly cause the casing and components to corrode and ultimately break. A battery able to realize its "second-life" requires high standards on the battery's performance, lifetime, balancing, design, and heat management.

Risks and Challenges for Second-Life Batteries

Everyone can agree in theory the idea of reusing retired EV batteries in ES applications is a great way to improve the original battery's lifespan, reduce resource consumption and waste, and create opportunities for a new market. However, the actual economic feasibility of recycling schemes depends on the following factors:

1. Whether or not the mechanical and electrochemical components of the retired EV battery

system still have value for a second-life system, and whether it can incorporated economically and safely.

2. Whether or not the second-life application's technical capability and market tactics are viable, from EV battery disassembly/uninstallation, to inspection, push to market, and finally system maintenance.

3. Whether or not the second-life battery can economically compete with new batteries of comparable capacity in the ES project.

Given these factors, the second-life industry is facing many technological and market risks. Thus, governments, EV manufacturers, and battery manufacturers, must jointly promote the technology.

The Lithium-Ion Battery Recycling Industry

Overview of Waste Li-ion Battery Recycling

EV batteries have a useful life of about 5-8 years in an EV. When the battery's capacity falls below 80% of its original capacity (considered to be a significant reduction,) the battery is no longer suited for use in an EV. Most of the EV batteries in use today will gradually enter this stage in the upcoming few years, and the conflicts between the EV industry's development and the strain it places on the environment will become more and more pronounced. If there is no way to recycle large amounts of EV batteries, this will have severe ecological and public health repercussions.

Recycling is the last segment of an EV battery's life cycle, and the loop can be closed by regenerating the active materials or repairing the critical components for use in another battery.

At present, the worn-out EV Li-ion battery recycling industrial chain is led by traditional battery recyclers. Existing recycling services are being improved through research of industrial processes and technology capable of disassembling and recycling Li-ion battery components. Gradually these services are advancing from small scale demonstrations towards large scale commercialization. Plus, to ensure a source of worn out EV Li-ion batteries and improve recycling rates, battery recyclers will jointly participate with NEV makers, battery producers, battery material producers, old car recyclers, deteriorated resource recyclers, and pollutant processors.

International Developments in the EV Li-ion Battery Recycling Industry

The EV and EV Li-ion battery recycling industries are closely linked as advances in the EV industry are generally followed by advances in battery recycling.

The US, Europe, and Japan lead the world in Li-ion battery production, application, efforts to popularize, and are thus the major markets for the recycling industry. The US, Europe, and Japan have already established regulations for recycling and enforce "polluter pays/producer is responsible" measures. Since many EV batteries have not yet reached retirement, many research efforts aim at the following:

(1) Government-lead R&D projects promoting EV battery recycling technology development

and industrialization.

(2) Large scale NEV company battery recycling efforts, investigating the establishment of recycling systems and business models.

(3) Metal and resource recycling companies are expanding existing services into EV battery recycling.

(4) How to incorporate EV Li-ion batteries into existing battery recycling rules and regulations management systems.

(5) Robust battery registration tracking mechanisms and improved worn out battery recycling network ensuring smooth establishment of the field.

Although EV battery recycling efforts of the US, Europe, and Japan have just begun, these countries have a strong existing foundation to build from: sound laws and regulations, complete and convenient battery recycling networks, advanced vehicle battery recycling equipment, generally accepted public education, and wide participation rates. NEV companies and battery makers are taking responsibility for worn out EV battery recycling, and the batteries entering a unified system will be advantageous and significant to all.

The Status of China's EV Li-Ion Battery Recycling Industry

As China EVs are still largely in the demonstration stage, private ownership numbers are limited, and so far there has not been large scale EV battery disposal. Thus, a commercialized Li-ion EV battery recycling system has not taken shape in China. The costs of such battery disposal are high, and the recycling industrial chain is incomplete. However, the move towards large scale adoption of EVs in China is inevitable as more and more EVs enter the market. The Li-ion EV battery recycling industry will, in turn, gradually take shape.

As an emerging interdisciplinary field, China's EV battery recycling efforts are mainly categorized as battery pollutant prevention, an unavoidable environmental issue.

A comprehensive set of policies pertaining to EV battery recycling has already been launched. China has preemptively issued a series of technology policies, industrial rules and regulations, and industry management methods before the retirement of vast amounts of EV batteries. Documents have been issued that clarify the government's positions on recovery responsibility, establishing second-life uses, project construction conditions, environmental protection requirements, chemical element recycling/reuse levels, and industry action management. Building recovery systems, establishing business models, and providing recovery subsidies, have all been proposed.

In recycling handling technology, China's EV Li-ion battery recovery pathway mainly follows that of the consumer electronics recycling pathways for nickel-hydride, nickel-cadmium, and Li-ion batteries. This uses wet industrial processes for extracting nickel, cobalt, manganese, and other rare earth metals. At present, China already has the basic facilities to recycle metals. To improve recovery efficiency and reduce environmental impact, Central South University, Tsinghua University, Beijing Technical University, and Beijing Industrial University, are spearheading R&D

efforts in recycling processes. In the industry sector, GEM, BRUNP, Umicore, and TES-AMM, are the major enterprises developing Li-ion battery recycling efforts in China.

Core Technology in EV Li-Ion Battery Recycling

In order to efficiently and effectively recycle used EV Li-ion batteries, Chinese research institutes have focused on two major areas of core technologies:

(1) Disassembly and preprocessing of the used Li-ion EV battery system. This involves battery system dismantling, battery discharge processing, mechanical crushing and separation, and electrode material and fluid separation.

(2) Mineral recovery and material recycling. In particular, this process aims to recover metals in the anodes such as nickel, cobalt, manganese, and lithium. The recycling processes for used Li-ion EV batteries are divided into three types: pyro-metallurgical methods, hydro-metallurgical methods, and direct recycling. Pyro- and hydro- metallurgical methods are the most common recovery methods.

Systems and Mechanisms for EV Li-Ion Battery Recycling

The NEV industry supply chain is long, with many parties involved. Thus building a sound and highly effective EV Li-ion battery recycling system must follow certain principles, coordinating the participation of automakers, battery companies, consumers, and recycling companies.

A good system will meet the following requirements:

1. Building sound recovery systems for used EV batteries so they can be reused.

2. Safe and economic transportation, storage, resource recovery, and material recycling processes.

3. Environmentally advantageous recycling processes.

4. Post-recovery products meeting certain performance and quality requirements for reuse value.

Whether used Li-ion EV batteries can be effectively recycled is not only a technical problem, but also a mechanistic and business model problem. Thus, building an efficient recycling system that coordinates policy and economic incentives ensuring all participants to work together is necessary.

The recycling system is made up of two parts: recovery and recycling. The battery recovery network is made up of scrap vehicle recovery and dismantling companies, the “4S” stations (automotive sales, spare parts, service, and survey), car repair stations, and battery dealers. The recycling network is made up of EV battery recycling companies (including battery system dismantling plants), EV battery second-life companies, scrap resource recovery companies, and companies with pollution controls.

EVs are just becoming popular, and even though there is not a huge present demand for EV batter recycling, it is still necessary to make preparations. System construction, legal systems, R&D support, and economic subsidies all must be well conceived to avoid future difficulties in large scale health problems and environmental damage.

Chapter 2: Thermal Energy Storage with Phase Change Materials

Thermal ES technology includes two major elements: one is thermal transformation– transitioning between heat energy and other forms of energy (including transferring heat between different carrier materials.) The second element is thermal storage– where heat is stored in a carrier material with proper thermodynamic properties. In addition, thermal storage technologies are not just storing and using ambient heat, but also include storing sub-ambient temperature thermal energy, a process called cold storage.

At present, there are three types of thermal storage: heat storage, potential heat storage (also called phase change thermal storage or phase change material (PCM)), and thermodynamic reaction thermal storage. This chapter will focus on phase change thermal storage technology.

Overview

Phase change ES systems are made up of three basic components: a phase change material (PCM) suited to the required temperature range, the container for the PCM, and the heat exchanger. Of these, the PCM is the foundation of phase change energy storage technology. Thermal energy, including electric, solar, or other types of energy transformed to thermal energy, are absorbed through thermal storage material. The required energy is released as the PCM undergoes a phase change. Also, depending on different heat sources, phase change energy storage systems also can have electrothermal or heat transfer management, heat extinguishers, and other ancillary equipment.

At present, phase change thermal storage is in the research and demonstration stage, and the technologies involving energy storage systems are still quite immature, facing a series of issues from thermal storage materials to systems. Overall, these problems can be summarized as below:

(1) Thermal storage materials: major problems include low heat conductance and incompatible container/sealant materials. Resolving these issues is a major research focus.

Based on the type of phase change, phase change thermal storage materials can be categorized as solid-solid PCMs, solid-liquid PCMs, solid-gas PCMs, and liquid-gas PCMs. Of these, research into solid-liquid PCM systems has been around for a longer time, thus this technology is more mature, more widely used, and consequently currently showing the greatest potential. Traditional solid-liquid PCMs include organic and inorganic PCMs and compound/complex PCMs.

(2) Thermal storage systems: in these systems, heat exchangers are a critical component. Despite the high level of industrialization and mature market in heat exchangers, relatively few are built for use in the phase change heat storage sector. Technological problems include high heat resistance, short usable lifetimes, and uncontrollable heat storage/release rates. Strengthening the heat exchanger and optimizing the design are major focuses of large

laboratory research.

Applications

Phase change thermal storage has many types of applications. This section will focus on the current status of existing applications and the focuses of applied research. There are six primary categories we will detail below: 1) buildings, 2) regional power supply, 3) concentrated solar thermal generation, 4) large scale renewables (wind) consumption, 5) industrial diffuse heat recovery (cogeneration), and 6) other applications.

Buildings

There are two types of phase change thermal storage applications in buildings: 1) PCM and building envelope (i.e. phase change wall panels, ceiling and roofing panels, floor boards, curtains), and 2) using PCMs to directly store energy for use in heating, cooling, and water heating, helping the building conserve energy.

Regional Power Supply

Phase change thermal storage systems can be used in the regional power supply where the main energy source is heat, cold, and or hot water. Phase change thermal technology can be used in coordination with heat pumps, combined heat and power, water chillers, and solar thermal technology to name a few.

In the local power supply sector, phase change thermal storage technology can also be paired with electric boilers/furnaces, overcoming issues such as the low energy storage density associated with using water as the medium. Use of water as a storage medium usually requires large floor space, has potential for severe heat damage, has low thermal efficiency, and can facilitate bacterial growth and dirt accumulation.

Concentrated Solar Thermal Generation

Solar thermal stations paired with large capacity thermal ES systems can increase the station's output hours, allowing it to provide power all day long and improve the station's profits. At present, the thermal storage functionality of molten salt is used as the thermal storage medium in concentrated solar thermal plants.

Large Scale Renewables Consumption (Wind)

At present there are two major phase change thermal storage application types. One type is at the energy source in wind turbine-coupled combustion thermal turbines (coal, natural gas, etc.).This uses electric heating equipment and large capacity thermal storage technology to realize the thermo-electric control decoupling of the wind and combustion thermal units. The heat supply is thus allowed to activate in response to wind power output fluctuations. The other type is in load-side facilities in wind curtailment heating systems. By adding large capacity thermal storage equipment at the load-side, wind power is fed into the grid during the day, and stored as thermal energy at night.

Industrial Diffuse Heat Recovery

Energy consumption is extremely high in industrial processes that require high temperature furnaces such as metallurgy and the production of glass, cement, and ceramics. Thermal efficiency, however, is usually below 30%. Capturing waste smoke and heat is the major focus of energy conservation in these sectors (heat loss can reach over 50%). Traditional methods use the high heat capacities of flame-resistant materials to act as thermal storage. However, this method requires large volume without clear results. If phase change thermal storage systems are used instead, the storage device volume could be reduced 30-50%, adding 15-45% energy savings, as well as also improving operational stability.

Other Application Sectors

The application space for thermal energy storage systems is vast. In to the five sectors above, thermal storage also has uses in military fields, agricultural greenhouses, medical temperature regulators, textiles, and livestock operations to name a few.

Supporting International Policies

(1) Overview of International Research Developments

European and American researchers began investigating phase change energy storage materials in the 1960's. Using solar and wind power and capturing waste heat have been continuously developed, gradually expanding to the chemical, aerospace, and electronics industries.

In recent years, research and applications of PCMs have been focused on building materials and building envelopes, central air conditioning, heating, and solar power. In addition, although current concentrated solar thermal plants use molten salt for thermal storage, we expect future R&D efforts in both China and abroad will focus on how to apply PCM in solar thermal generation.

Building Envelopes and Enclosures

For over 20 years, many scholars in China and abroad have been advancing applications research on using PCMs in building enclosures/envelopes. The US and Germany are leaders in this field while France, Italy, UK, Australia, Sweden, and Japan also conducted their own research.

In the last 10 years, many demonstration projects were put in place with PCMs used in building materials with favorable results. Examples include Comfortboard by Knauf Group in Germany, BASF's paraffin microcapsule technology, and DuPont's Energain panels.

It is important to note that despite the many years of research already invested in PCMs in building enclosures, with existing commercial products and applications, there are many technology problems that must be resolved before more widespread application of this technology.

Energy Conservation in Buildings

At present, most phase change thermal storage technology in building energy conservation focuses on low temperature energy storage, or cold storage. In the cold storage sector, air conditioning systems are a more mature building energy consumption reduction technology, and have been applied for the longest amount of time in the widest range in both China and abroad. Phase change cold storage technology is more mature than high temperature heat storage technology with many products already commercialized such as Cristopia (France), Mitsubishi Chemical (Japan), TEPA (Australia), and other companies making PCM thermal storage products (salt solutions, hydrated salt, paraffin types, and fatty acid types). However, when compared to chilled water storage and ice storage, these PCMs are used relatively less in the cold storage field.

Concentrated Solar Thermal Generation

Since 2006, every energy storage system paired with a solar thermal system, without exception, used molten salt thermal storage, with durations between 5-10 hours depending on variations in solar resource. Compared to the battery ES paired solar PV systems and pumped hydro, solar thermal systems with thermal ESS's are low cost and more highly effective (with round-trip efficiencies over 95%).

Most current applications of double-tank molten salt sensible heat storage are in concentrated solar thermal systems and commercialized solutions. But these are not the only cases. Developers are also studying PCMs in a storage tube as a single tank temperature step system, but this is still under active research without any commercial use.

(2) International Phase Change Thermal Storage Related Polices

In the international market, the US and Germany are the world leaders in promoting the thermal storage industry, and this is tightly tied to their related incentive policies and market mechanisms. The US has its energy efficiency tax credit program, demand response policies, and reasonable peak electricity pricing. Germany gives discounted electric prices to thermal storage users. These are critical methods for promoting user-side thermal storage.

Developments in Chinese Thermal Energy Storage Technology and Supporting Policies

(1) Current Status of China's Phase Change Thermal Storage Development

China began researching PCMs and phase change thermal storage technology in the late 1970s, but most research efforts were fragmented. Since the mid-1990s, China's research focus shifted towards organic PCMs and composite materials. Despite making large strides, compared to developed countries, China's PCM theoretical and applied research ventures are still rather weak.

Major phase change thermal storage technology applied fields like the building energy conservation sector, distributed power supply sector, industrial waste heat capture sector, and the renewable energy sector, have not realized large scale usage, if any.

Energy Conservation in Buildings

To overcome severe gaps between electric peaks and off-peaks, China implemented a peak/off-peak electricity tariff policy to encourage both industry and civilians to use off-peak electricity for things like heating, air conditioning, water heating, and hot air drying. This created opportunities for phase change thermal storage applications.

Of these, China's passive solar heating technology is quite mature, but local solar building heating technology is still in its early stages. There is some small scale research underway on local building concentrated heating core technology and interseasonal energy storage, but no experience in large system design, construction, and operation.

Concentrated Solar Thermal Generation

China began research on solar thermal generation thermal storage technology rather late. Research into large scale solar thermal technology has achieved many advances, with many critical technological components already industrialized. However, China does not have commercially operating solar thermal power plants. China's domestic enterprises in this field do not have system process experience, lacking system planning capability and integration technology. High temperature concentrated solar/heat absorption, and thermal storage technologies are not mature. Even though there are a few solar thermal power plants planned or in demonstration operation in Qinghai and Gansu provinces, they are still in experimental and exploratory stages.

Industrial Energy Conservation

In mid-temperature solar power technology and industrial energy conservation applications, China has made very little progress. There are only a few current projects, since the Chinese generally lack experience in large system design, construction, and operation. There are already several cases of transferring thermal storage equipment into industrial waste heats recovery systems. The domestic company, Zhongyi, has already commercialized mobile heat storage products, but due to profit model limitations, they are facing challenges expanding the use of this type of equipment.

Overall, China's thermal storage market has just begun to develop, and phase change thermal storage technology is not often used. However, as energy conservation and emissions reduction continues to be promoted, solar thermal generation thermal storage technology research improves, and as coal-fired furnaces are renovated, opportunities for and usage of phase change thermal storage technology will grow.

(2) Chinese Policies in Phase Change Thermal Storage

Though thermal storage technology is used in a wide array of fields, Chinese policies regarding this technology, outside of a few macro-level plans, are mostly application-specific policies, including on-peak electricity tariffs, demand-side response, and building energy conservation. These policies have both direct and indirect effects of the developing thermal storage industry.

It is important to note that China's government aims to curb nation-wide energy consumption and is implementing pilot demand response programs to ease load conflicts. In particular, the government intends to gradually increase the on-peak off-peak electricity tariff spread by over 3x in many regions. Applying such tariffs to more areas and increasing the peak to off-peak price ratio will necessitate the expansion and application of thermal storage technology.

Overall, however, peak electricity tariffs only apply to a relatively small portion of China. As it stands, most demand response subsidies are also insufficient, so phase change thermal storage technologies and products are too expensive to be environmentally and economically deployed. As such, the expanding the market will be a difficult undertaking without widespread changes in policy.

Chapter 3: Graphene Technology in Energy Storage

Graphene is an atom-thick carbon crystalline material whose properties and functions are a major topic of applied research. This chapter will introduce graphene technology and the status of its industrialization, delving into applications in Li-ion batteries, supercapacitors, and other energy storage technologies.

Overview

Graphene is made of six membered carbon rings in a 2D honeycombed lattice structure. It is an elemental building block of other carbon materials. It can be twisted into spherical fullerenes, rolled into carbon nanotubes, or stacked into graphite.

Its unique mechanical, thermodynamic, electrical, optical, and quantum mechanical properties are leading to more and more applications of graphene in semiconductos, sensors, green energy, and electrochemistry for example.

With the expanding prospects of graphene, countries like the US, Europe, Korea, and Japan, are putting great emphasis on its development. China's graphene industry's development has strong policy leadership.

Graphene Applications in Lithium-Ion Batteries

Graphene has a large surface area, outstanding conductive properties – both electronic and thermal, giving it strong potential in energy storage, perhaps most so in Li-ion batteries where it can act as an electrode.

1. Graphene in Li-Ion Battery Cathode Materials:

Graphene in Li-ion battery cathode materials includes using graphene directly as the Li-ion battery's cathode material in combination with tin-based, silicon-based, and transition metal-based cathode materials. Graphene doping is the major direction for graphene in silicon, tin, and non-carbon cathode materials. Graphene can effectively decrease the size of the active material, prevent the aggregation of nano-particles, increase the material's electron and ion transfer capabilities, and provide mechanical stability. This gives the electrode material greater capacity, faster charging, and longer lifetimes.

2. Graphene in Li-Ion Battery Anode Materials

Graphene is mainly used in improving the anode material's overall ion/electron conductance. It is hoped that graphene's larger surface area and outstanding electron transfer abilities will increase the material's high current discharge and lifetime. At present, research on such applications is focused on LiFePO4 as the representative polyanion anode material system.

3. Graphene as a Conductivity Booster

Using flexible, single layer graphene conductors to replace rigid, multi-layer graphite and carbon conductors to make a conductor grid can greatly reduce the mass/amount of carbon additives, and thus conductor additives can also become a critical direction for graphene in Li-ion batteries. Currently, graphene still faces the same challenges as traditional battery additives, such as scattering problems and ion transmission resistance. Research efforts are also limited by the challenge of improving cycle life and capacity under low rate capacity conditions.

4. Graphene in Lithium Sulfur Batteries

Research has found that graphene can better improve lithium sulfur battery problems with low conductivity, volumetric expansion, and polysulfide decomposition, and thus improve lifecycle efficiency and high current discharge performance.

Graphene is most commonly applied in lithium sulfur batteries by fabricating sulfur-graphene composites for use as an anode material. Although graphene application in lithium sulfur batteries has seen a certain amount of progress, it still faces many challenges. Sulfur and graphene are both relatively low density, and are not advantageous in terms of energy density. At present, the lithium sulfur battery's reaction mechanism remains unclear, and the roles of graphene in all uses still must be further investigated.

Graphene Applications in Supercapacitors

Supercapacitors have high power densities, long lifetimes, and high operational safety, and are excellent in power-type energy storage systems. Electrode materials are a critical factor in determining the supercapacitor's electrochemical performance. The electrolytes largely determine the supercapacitor's working voltage range and its energy density.

Graphene has a large surface area, high conductance, good chemical stability, as well as being a high efficiency, high energy, flexible material with great potential in micro-supercapacitors. In addition, as a fundamental building material for sp2-hybridized carbon materials, graphene can functionally be directed towards designing different structures and functions of new carbon composite materials, and these materials can also bring new opportunities in high efficiency supercapacitor energy storage.

Graphene supercapacitor's capacity ratio to the graphene material's effective surface area and pore diameter distribution are linked. It is often difficult to realize the full exceptional performance of a single graphene-made electrode material. In practical application, graphene usually has its electrochemical performance reduced due to the ease of piling concentration building between the layers.

Three-dimensional graphene macro materials are being built by advancing graphene composites with polymers, metals, metal oxides, and carbon fiber/carbon nanotubes. These 3D conductor grids are becoming a major direction of graphene application. These 3D graphene macro materials can serve not only as electrode materials, but also as a base body, forming composites with pseudo-capacitive materials (transition metal oxides and conductive polymers, etc.), and making supercapacitor electrode materials of high electrochemical performance.

Realizing graphene's high effective specific surface area and outstanding conductivity is prerequisite to realizing other applications in supercapacitors. Currently, the usage of graphene composites in supercapacitors is being rapidly researched, but it is still in the laboratory research stage, and does not have ideal large scale methods for making high quality graphene and composite materials. Also, less consideration is given to the volumetric performance ratio of graphene in supercapacitors, and component performance research and reporting has not yet produced a generalized standard.

Volume 2 - Energy Storage Technologies: Economic Assessment and Development Roadmap

This volume focuses on the current statuses of several mainstream energy storage technologies. We have used tiered analysis to perform an economic evaluation of six existing energy storage application fields already in the demonstration stage in China. We also provide a roadmap forecasting future developments in China's energy storage technology.

Chapter 1: Applications and Overview of Key Energy Storage Technologies

CAES (Compressed Air Energy Storage) has large capacity, long duration, good economics, long useful life, and other advantages. It is suited for grid peak shifting, reserve power, and renewable energy grid integration. However, traditional CAES has poor energy conversion efficiency, relies heavily on fossil fuels, and requires caverns to store the gas/air. This largely limits its popularization and application. At present, there are only two such commercialized traditional CAES plants in operation, one in Germany and another in the US, totaling about 400 MW.

Flywheel energy storage has high power density, long usage life, is convenient for system management, is insensitive to the surrounding temperature, and has relatively low operational safety requirements. It is very well suited to frequency regulation, railway stop-start energy recovery, and enterprise scale uninterrupted power supply. The US already has commercialized flywheel energy storage frequency regulation stations, with currently operating stations totaling about 48 MW. However, the self-discharge rate of flywheel systems is quite serious – over 2.5% per hour. It is too expensive for energy (long duration) applications, and is ill-suited for such.

Lead-acid batteries – Traditional lead-acid batteries have a long history, and are the earliest to reach scaled usage. They are low cost and have a mature industrial chain. They have mature applications in vehicles, communications, defense, and aviation. However, they also have slow charging speeds, low energy densities, short life cycles, and can easily become an environmental hazard. As such, lead-acid batteries have a limited application scope in the electricity system.

Li-ion batteries are one of the most popular energy storage technologies at present, and in recent years has been the fastest growing technology type. Their use is widespread, including renewable energy grid integration, frequency regulation, transmission and distribution, distributed microgrids, and EVs. Different electrode materials are used, giving rise to the following major types of Li-ion batteries: lithium manganate batteries, potassium titanate Li-ion batteries, titanate Li-ion batteries, and ternary Li-ion batteries (lithium-nickel-cobalt-manganate).

Flow batteries mainly include 4 types of technologies: all-vanadium batteries, zinc-bromine batteries, iron-chromium batteries, and sodium-polysulfide/bromine batteries. Of these, all-vanadium and zinc-bromine batteries have been used most frequently. All-vanadium batteries have high energy capacities and long cycle life durations, but have low energy densities, large volumes, and high costs. They are already deployed in several grid-scale demonstration projects, and are mainly used for power plant peak shifting, large scale renewable energy grid integration, intermittent power sources, and emergency power sources. Advantages for zinc-bromine batteries include high energy densities, low costs, as well as their ability to be flexibly deployed. However, these batteries have high self-discharge rates due electrode reactions. This type of flow battery is mainly used by commercial and industrial users in remote areas and military bases.

Sodium-sulfur batteries have high energy densities, good power performance, and long cycle lifetimes. They have already reached MW scale deployment and are the most mature chemical ES technology, the most installed technology, and are already in commercial operation. However, their operational safety requirements are rather high (as their operating temperature is around 300℃), and they have long start and stop times. These batteries are mainly used in grid peak shaving, large scale renewables grid integration, and independent power systems.

Supercapacitors have high power densities, fast charging rates, long cycle lifetimes, good performance in low temperatures, and are safe, reliable, and environmentally friendly. They are already mature in applications in the storage components of electronics and reserve/backup electricity uses. Superconductors have been more widely used in the transportation sector in regenerative braking, where scaled production and profit models are fundamentally clearer. However, supercapacitors in energy storage usage are rather expensive, and at present there are only a few grid scale power application demonstration projects.

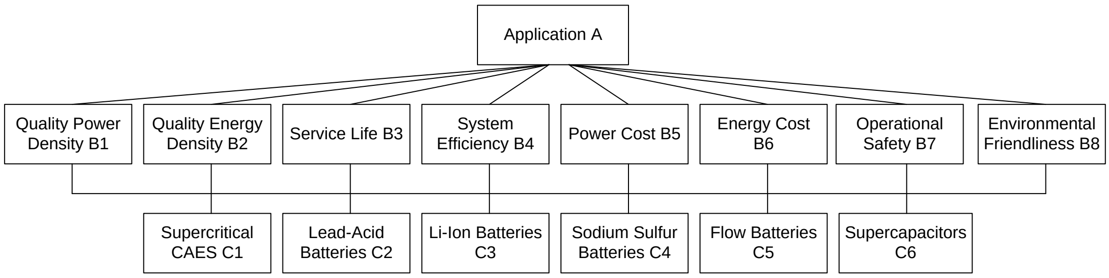
Although these energy storage technologies will continue to maintain a diverse development structure, most technologies are still in improvement and validation phases, but improving safety, lifetimes, energy efficiency, and lowering costs continue to be development directions. In different energy storage application sectors, each technology faces different challenges, and must continue to be optimized and verified through demonstration applications. In the future, each type of energy storage technology will develop their advantages in different sectors, and gradually advance towards maturity.

Chapter 2: Economic Assessment

Methodology

This white paper's discussion of energy storage economic evaluation methods is based on the opinions of the State Grid Energy Storage Technology Economic Research Special Experts Group. It uses a tiered analysis method, selecting the following applications for study: peak shaving, frequency regulation ancillary services, power supply reliability, grid stability, electricity quality, and island/remote area power supply. Eight critical metrics/targets and six energy storage technologies already deployed in demonstration projects in China are included. The tiered analysis structure is shown in Figure 3.

Figure 3: Energy Storage Economic Evaluation System Blueprint



Source: CNESA

Assessment Results

This study, through the structured ES technology evaluation system, calculates the weighted values for six energy storage technologies in six application fields, and based on these, combined with real operational status of ES in demonstration projects, arrives at a comprehensive evaluation of each ES technology. Using these results, we arrived at the optimal technology for each application.

Application: Peak shaving

Optimal technology: Flow batteries, especially all-vanadium flow batteries

Discussion: Looking at the demonstration projects China has deployed, centralized wind/solar power plant energy storage projects mostly use all-vanadium flow batteries. But, due to the fact that the deployed capacity is relatively small, their current ability to resolve peak shaving wind curtailment issues is limited. Sodium sulfur batteries, supercritical CAES, lead-acid batteries, and Li-ion batteries have also been used in such demonstration projects. As the technology performance continues to improve, there are many future possibilities.

Application: Frequency Regulation Ancillary Service

Optimal technology: Li-ion batteries

Discussion: There is currently only one company deploying frequency regulation ancillary service energy storage projects in China – Ray Power. They have used Li-ion batteries exclusively. The projects have had favorable operational results greatly improving the coal plants' frequency regulation performance, and reducing risk of penalties (due to subpar performance). In addition, flywheels are another technology well suited to frequency regulation, and there are several commercialized projects abroad. However, Flywheel ES is still in the research and experimentation stage in China, and still about 10 years away from potential applications in demonstration projects in the domestic market.

Application: Power Supply Reliability

Optimal technology: Li-ion batteries followed by lead-acid batteries and performance optimized lead-carbon batteries

Discussion: Both Li-ion and lead based batteries have their own advantages. Lead-acid batteries are lower cost, but can easily cause environmental pollution. Li-ion batteries have better energy density and system efficiency, but are not as safe or as low cost as lead-acid batteries. Users can choose based on their own requirements.

Application: Grid Stabilization

Optimal technology: Li-ion batteries followed by supercapacitors

Discussion: Supercapacitors have excellent power performance when compared to Li-ion batteries. Not only is their power density high, they also have high system efficiency and long service life. However, in China currently, they are mostly used in small-scale distributed generation and microgrid projects, with not very large power levels, where they are mainly used for leveling abrupt power changes. In comparison, Li-ion batteries are more mature, used in more grid-side demonstration projects, and are approaching commercialized operation.

Application: Power Quality

Optimal technology: Supercapacitors and Li-ion batteries

Discussion: Supercapacitors, in addition to high power density, also hold advantages in system efficiency, service life, and low lifetime power costs. At present, in domestic demonstration projects, a high-power technology is paired with a high-energy technology in a hybrid energy storage system. This uses the advantages of each technology, and helps improve power quality.

Application: Island/Remote Area Electricity

Optimal technology: Li-ion batteries and lead-acid batteries

Discussion: In current domestic demonstration projects, hybrid energy storage technologies were highly favored by users. They can use high-power energy storage technology power functionalities, such as instantaneous leveling of the discontinuities from renewable electricity, and can use the energy functionalities of high-energy energy storage technologies, such as storing renewable or off-peak energy for use during peak times or as reserve power.

Chapter 3: Development Roadmap

Prior to setting China's ES technology roadmap, CNESA organized four expert conferences to make preliminary preparations, separating discussions on the roadmap's basic framework, existing technology and applications, and future development trends. In addition, topic experts addressed questions via email and in-person interviews if they were unable to attend meetings in person. Experts came from China EPRI (Electric Power Research Institute), CAS-IET (Chinese Academy of Sciences – Institute of Engineering Thermophysics), CAS-IoP (Chinese Academy of Sciences – Institute of Physics), CAS-DICP (Chinese Academy of Sciences - Dalian Institute of Chemical Physics), CITIC Guoan MGL (Mengguli), Narada Battery, Dalian Rongke, and SPSCAP (Supreme Power Solutions). Finally, the expert opinions and data from the meetings and interviews was arranged and analyzed, giving rise to the China Energy Storage Technology Roadmap

Forecast of Technology Development

Supercritical CAES

By the end of 2020, we forecast that with improvements in turbines, cold storage, heat exchangers, and other critical technologies, costs will be reduced to CNY 1000-1500/kWh (150-US$225/kWh), system efficiencies will raise to 60-70%, and system operations will become more and more stable. By 2030, all critical technologies will have reached a mature level.

Flywheel Energy Storage

By 2020, we expect flywheel bearings, rotors, flywheel arrays, and materials will see breakthrough advances, with power ratios reaching 8000W/kg, power costs reduced to CNY 1600/kW (US$240/kW) ultimately achieving fundamental stability. By 2030, the core technologies will be advanced, closing the gap between domestic and foreign flywheel technology levels.

Lead-Acid Batteries

By 2020, plating materials, membrane materials, electrodes, substitute materials, and other critical technologies will improve, with cycle life increasing to 1500 cycles, and energy costs decreasing to CNY 500-600/kWh (US$75-90/kWh). By 2030, continued development of new technologies will improve battery performance/functionality.

Li-Ion Batteries

By 2020, with improved Li-ion battery components and equipment technology, domestic Li-ion batteries will become competitive with foreign batteries, with battery lifetimes increasing to 6000-8000 cycles, and costs decreasing to CNY 1000-1500/kWh (US$150-225/kWh). By 2030, we foresee the scaled wholesale production of high performance long lifetime Li-ion batteries.

Flow Batteries

By 2020, with improvements in battery materials, electrolytes, and other critical technologies, domestic flow batteries will maintain competitive advantages at the international level, with all-vanadium flow battery energy costs reduced to CNY 2800-3000/kWh (US$420-450/kWh), and zinc-bromine energy costs to CNY 2100/kWh (US$315/kWh). By 2030, continued improvements in flow battery industrial processing technology will reach maturity.

Sodium Sulfur Batteries

By 2020, with improvements in sodium sulfur battery materials and electrolytes and other critical technologies, we forecast energy costs will be reduced to CNY 1400/kWh (US$210/kWh). By 2030, continued improvements in sodium sulfur battery industrial process technology will reduce battery costs even further.

Supercapacitors

By 2020, we expect breakthroughs in high energy electrode materials and core technologies continuing to 2030 and beyond.

Roadmap of Technology Application

The Chinese ES application development roadmap is as follows.

Before 2015: most ES projects are application demonstrations, covering renewable energy grid integration, frequency regulation ancillary service, transmission and distribution, distributed generation and microgrids, EV solar + storage charging stations.

2015-2020: ES projects will begin preliminary commercialization but are still not scaled to the point where projects can be replicated. Projects will progress gradually into replicable business models as well as commercializing in a way suitable to domestic conditions.

After 2020: Energy storage will reach maturity in frequency regulation ancillary service, distributed generation and microgrids, EV solar + storage charging stations, and demand-side management. Archetypal business models will take shape, and other applications will gradually realize commercial development.

Volume 3 - Demand Response Market and Energy Storage

Demand response is a pricing scheme where price signals and incentive mechanisms are employed towards modifying customer electricity usage behavior. The primary purpose of demand response is to reduce and shift peak electricity usage and demand.

Given the pressures of grid demands, peak loads increasing by the day, peak shifting resources becoming scarcer by the day, and renewable energy consumption difficulties, demand response is receiving more and more consideration in China. In 2015, building on Shanghai's demand response pilot, Beijing, Suzhou, Tangshan, and Foshan also opened demand response pilot projects.

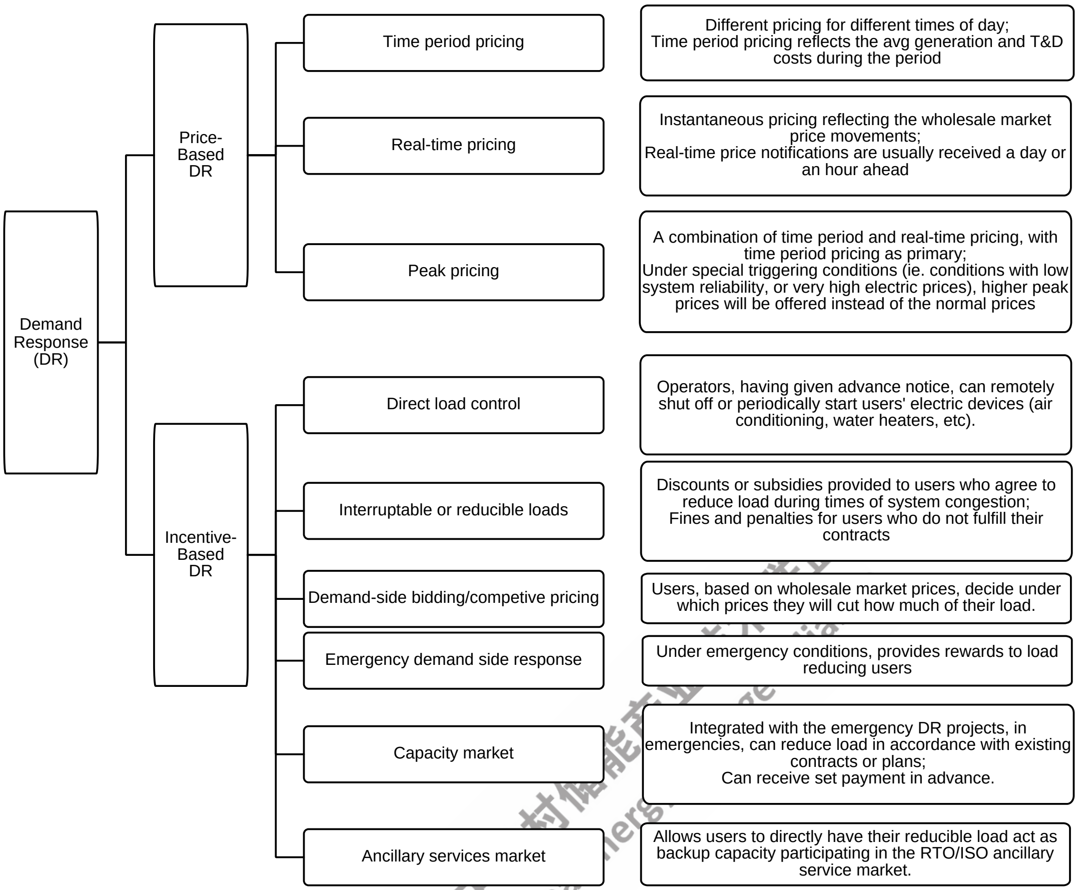
Demand response is taking on an important role. It is gradually entering China's energy markets, and as the 13^{th} Five Year Plan states, it will grow greatly. Considering foreign experiences, as installed capacity grows, energy storage has already begun entering the demand response markets. The development of China's demand response markets, and whether or not it will give energy storage similar market opportunities, has already attracted much attention worldwide.

Chapter 1: Demand Response Systems Outside China

Types of Demand Response

As central air-conditioning usage has gradually increased since the 70's, summer peak demand is posing operational challenges for electric companies. Demand response has been gradually developing and taking shape in Europe, the US, and other developed countries. In over 40 years of development, many types of demand response models have emerged globally. Overall, these models fall into two categories, price-based and incentive-based, as shown in Figure 4.

Figure 4: Demand Response Types

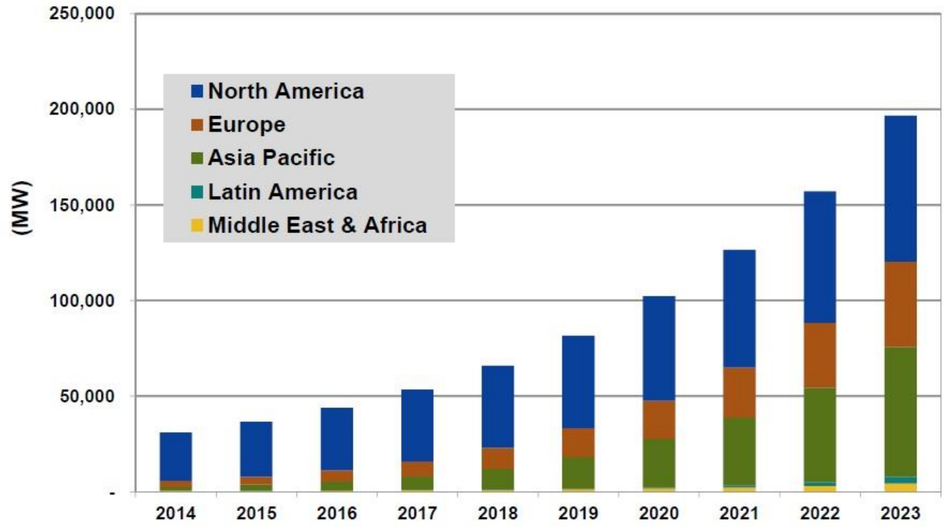


Source: US DOE, 2006

Applications

The market potential of demand response is huge. Navigant Research forecasts that the global demand response market would grow from 30.8 GW in 2014 to 196.7 GW in 2023. The US has the most demand response projects, and Europe and Asia will see rapid development, as shown in Figure 5.

Figure 5: Global Demand Response Market Forecast by Region



Source: Navigant Research

US

In the last 10 years, the US implemented policies that greatly helped the demand response market develop. The relevant policies are shown in Table 4.

Table 4: US Demand Response Policies

Policy	Year Issued	Summary
Energy Policy Act	2005	Clarifies support of DR project implementation.
Energy Independence and Security Act	2007	Requires FERC (Federal Electricity Regulation Commission) to evaluate potential DR resources in the US.
ARRA (American Recovery and Reinvestment Act)	2009	Invested $4.5B in supporting grid modernization and integrated demand response installations and smart grid technology research.
FERC Order No. 719	2009	Allows DR resources to directly participate in wholesale market bidding.
National Action Plan for Demand Response	2010	DR advanced to the national level.
FERC Order No. 745	2011	Requires grid operators in wholesale electricity markets to pay DR providers the same prices as generators.
Demand Response Auction Mechanism pilot project	2015	DR market opened to distributed energy resources.

Source: CNESA

The data shows that in 2000, demand response projects lowered US peak load by 22.9 MW, and in 2015 this peak louds decreased by 32.8 MW (an increase of 43% since 2000.) The demand response market is continuing to grow. In 2009, FERC (US Federal Electricity Regulation Commission) released its *National Assessment of Demand Response Potential* report. This showed that with smart meters and time-of-use (TOU) tariffs, demand response could reduce peak load by 188 GW by 2019 compared to the no demand response scenario, a 20% reduction in that year's forecast peak load.

Current US demand response projects are mainly serving commercial and industrial users, wholesale electricity markets, and residential sectors. These are primarily demand response projects with sufficient generator capacity, price-based projects, and ancillary service projects, with the generator projects being the most numerous (which are primarily load reduction and direct load control projects).

Europe

In 2010, the European Commission released its 2020 Climate and Energy Package. The Package recognizes demand response as an important means of meeting energy targets, and directly promotes the development of demand response projects in Europe.

Similar to the US, Europe's demand response projects are primarily in three sectors: generation sufficiency, price-based and ancillary service projects. However, due to the differences in each European country's electricity market regulations, the relative proportions of these project types are different in each market.

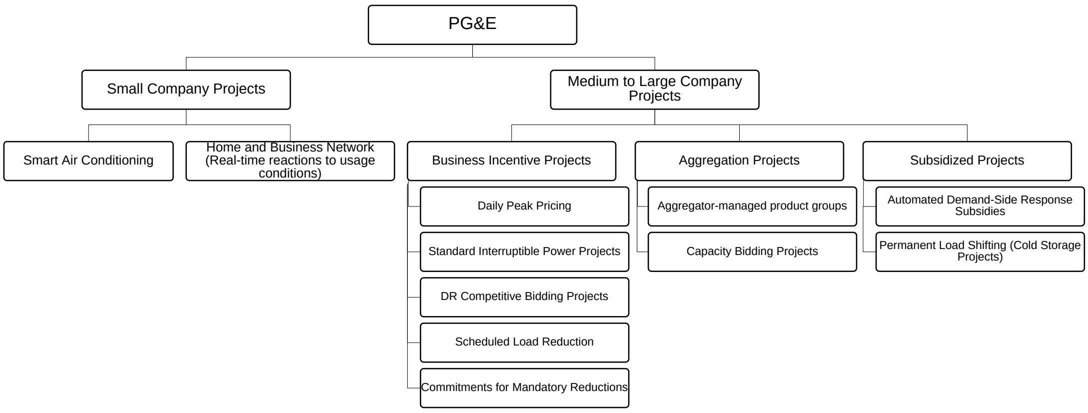
For example, generation sufficiency projects are primarily in France, Italy, Norway, the Netherlands, and Spain. Price-based projects are mainly used in the UK, Italy, Spain, France, and the Netherlands. Ancillary service projects are mainly deployed in Norway.

Case Studies

California's demand response projects are mainly implemented by the state's three largest investor-owned utilities: Pacific Gas and Electric (PG&E), Southern California Edison (SCE), and San Diego Gas and Electric (SDG&E). These companies, in accordance with customer requirements, set up several demand response projects, attracting user participation. In addition, these three grid operators also attract participation from aggregators and demand response providers.

Figure 6 uses PG&E as an example, showing its types of demand response projects.

Figure 6: PG&E's DR Projects



Source: CNESA

Chapter 2: Status of China's Demand Response Pilots

In 2014, China NDRC selected Shanghai for the country's first demand response pilot. At the same time, demand-side management master plans (*guihuas*) and demand response pilots were set into motion in Beijing, Suzhou, Tangshan, and Foshan. In 2015, pilots in these markets continued to progress. Each of projects has its own characteristics due to differences in participants, organization methods, and incentive methods.

Shanghai Demand Response Pilot

In 2014, as China NDRC's first pilot city, Shanghai began its first demand response efforts. On August 9, 2014, at the Shanghai Customer Service Center, the first pilot began with six industrial users and 28 office buildings participating to reduce load by 55 MW within 30 minutes.

In 2014, The National Resource Defense Council (NRDC, not to be confused with China NDRC, a governmental agency) and Oxford University joined together to release a report titled *Assessment of Demand Response Market Potential and Benefits in Shanghai*. In the ideal scenario, by 2030 Shanghai's demand response benefits would reach CNY 811.2M (US$125M), reducing peak load by 2.5 GW, or 4% of that year's peak load.

Shanghai Electric Company's demand response pilot had relatively high participation. In April 2015, Shanghai's demand response center, through its initial design review, was China's first to begin master plan (*guihua*) construction. Shanghai Electric Co. planned in 2015 to have 28,500 high voltage users on their demand response management platform, realizing collection, big data analysis, and guiding optimal customer electricity usage behavior.

Beijing Demand Response Pilot

Beijing, on August 12, 2015, began its first demand response action with 17 load aggregators and 74 customers participating, lowering the peak load by 71 MW. By the end of 2015, Beijing had implemented demand response actions on 18 days, for a total of 40 hours, and lowered the grid load by an average of 40 MW.

In addition to directly reducing peak load, Beijing's demand response and air quality control are inseparably linked – a precious characteristic of Beijing's demand response efforts. For example, from August 20 to September 2, to better ensure improved air quality for the 70th Anniversary of the Global War of Resistance Against Fascism (WWII) Memorial and the World Track and Field Championships, Beijing implemented the demand response pilot over 10 continuous days, being in effect for 2-5 hours each day.

Since August 12, CNESA has acted as a load aggregator in Beijing's first demand response actions, managing 7 electricity users and implementing 9 demand response actions totaling 19 hours, for an average peak load reduction of 2.3 MW/h and a maximum of 4 MW.

CNESA's involvement in the Beijing pilot project allowed us to ensure that battery ES powered microgrids participated in the project, thus taking the initial steps in investigating ways to apply energy storage in demand response and possible profit models.

Foshan Demand Response Pilot

In March 2015, the Foshan City Electric Demand-Side Management City Comprehensive Pilot Leadership Office released *Foshan Electric Automated Demand Response Pilot Project Implementation Plan (2014-2015)* advancing the development of demand response efforts.

At 10 AM, July 30, 2015, Foshan implemented demand response for the first time, with 33 users and 3 electricity service companies participating, reducing the load by 42 MW.

The Foshan project received relatively strong support from the local electric companies. The Foshan Economy and Information Technology Bureau ('Information Technology' referring to 'Informatization' – the information age analog of industrialization) and the Foshan Power Supply Bureau cooperated effectively to implement the project, gather electricity data, analyze results, and select users. From June 19 to July 16, these two bureaus jointly trained and mobilized 258 users and the project continues to expand.

In early 2016, the Foshan Electric Demand-Side Management Platform passed its evaluation, allowing it to provide electric services. At present, the Foshan project has enrolled nearly 20,000 homes, 111 companies, and 153 subsidiary off-shoot projects, totaling 210 MW in demand response load reduction capacity.

Suzhou Demand Response Pilot

In April 2015, the Suzhou Electric Demand-Side Management Urban Comprehensive Pilot Leadership Office set its own demand response pilot in motion by issuing the *Notice on Advancing the Suzhou Power Usage Optimization and Demand Side Management Efforts*. In June 2015, the Jiangsu Province Economic and Information Technology Commission issued *Jiangsu Electric Demand Response (Trial) Implementation Rules and Regulations*, clarifying demand response metrics, evaluation, penalties, and payment methods, advancing the implementation of the demand response pilot.

Suzhou's demand response had two types: annual standby and temporary. Annual standby demand response describes how commercial and industrial users in a concentrated area realize optimized electricity usage, and by managing their schedules, lower the peak load by over 10% each day. Temporary demand response describes the situation when during grid power shortages, industrial users in commercial and industrial areas, in accordance with demand response agreements, reduce their loads either one day ahead or temporary organize load staggering.

Suzhou's demand response plan reduced peak load by 200,000 kW (200 MW). Participant compensation for the daily participants (annual standby) was CNY 110/kW (US$16.41/kW), and for temporary load reduction CNY 100/kW or CNY 0.5/kWh (US$15/kW or US$0.075/kWh). Participants also recieved priority power supply guarantees and priority participation in the direct electricity purchasing pilot.

From July to the end of 2015, Suzhou had a total demand response load capacity of 387 MW, more than the planned minimum. A total of CNY 7.849M (US$1.17M) in incentive funds were paid in accordance with the provincial CNY 20.3/kW subsidy standard (US$3.03/kW).

Chapter 3: Energy Storage Use in Demand Response Markets

Energy storage and demand response can be thought of as both competitive and mutually inclusive technologies. On the one hand, demand response and energy storage can act in direct competition as both work to lower the peak load. Demand response accomplishes this by modifying the user's electricity consumption while energy storage lowers peak load by drawing from stored energy to provide peak adjustments and load balancing. On the other hand, the two can work in conjunction when users draw from energy stores to reduce their own consumption during a peak period in a demand response scheme.

In the past, both cold storage and heat storage ES technologies have participated in demand response programs. Now as demand-side distributed energy is expanding, energy storage batteries will be used more and more in demand response.

Customer-sited energy storage in demand response applications includes the following three types:

Air Conditioning-Paired Demand Response

Cold and heat storage systems play an important role in this category. For commercial and government buildings participating in demand response, controlling the air conditioning load is the most common method. This is usually paired with a cold storage/thermal storage unit to increase the flexibility of the air conditioner's response. For example, in 2015, in Beijing's demand response pilot, over 60% of the demand response capacity provided by commercial and public buildings came from cold storage-paired central air conditioning equipment.

Distributed Energy Storage and Demand Response

Distributed energy includes both distributed generation sources like distributed PV and paired energy storage units in addition to customer-sited distributed ES resources.

In areas with time-of-use (TOU) tariffs and demand charge mechanisms in place, distributed energy storage units are used to reduce the customer's electricity bill. They respond to the price signal, reducing or shifting peak usage, to provide demand response results. For example, STEM (US) has popularized customer-sited energy storage system on this basis, and is growing as a company.

In addition, as distributed energy, including distributed energy storage, continues to expand, grids are also considering expanding demand response markets to include distributed energy. For example, in June 2015, California released its DRAM (Demand Response Auction Mechanism), opening the California direct response market to distributed energy, including customer-sited battery energy storage systems, allowing them to bid into the wholesale market and provide demand response services. Stem, Green Charge Networks (GCN) and Tesla + SolarCity and other companies have expressed interest in participating in bidding as well.

In Beijing's demand response pilot in 2015, CNESA's demand response project also involved distributed generation + storage microgrids. This is also the initial step of investigating and validating energy storage's participation in demand response strategies.

Electric Vehicles as Energy Storage Units Participating in Demand Response

With the continued expansion of EVs and their batteries, they will become a significant grid-connected energy storage resource. Reasonable and orderly management of charging behavior will likely become a demand response service provided by the grid. For example, PG&E (California, Pacific Gas and Electric) and BMW are cooperating in an 18 month demand response experimental project with 100 BMW i3 EVs. The project is investigating ways to manage charging behavior based on the grid's needs, i.e. suspending charging during peak times and engaging in charging during off-peak times.

Special Thanks

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