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# Revisiting Energy Storage

*There Is a Business Case*



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# Revisiting Energy Storage

*There Is a Business Case*

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## AT A GLANCE

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Batteries and other forms of energy storage will be crucial to the large-scale deployment of fluctuating renewable energy worldwide. As the use of renewable energy grows and technologies mature, the market for storage will gradually increase, reaching approximately €10 billion annually by 2020 and offering strong first-mover advantages to a range of potential stakeholders.

### **STORAGE APPLICATIONS**

Analysis of the business case for eight storage applications combined with different storage technologies—assuming 2015–2020 costs and no subsidies or other additional sources of revenue—shows that good financial returns are possible, especially for facilities that provide balancing energy, conventional-generation stabilization, and island and off-grid electricity storage.

### **POTENTIAL BUSINESS OPPORTUNITIES**

There are business opportunities in energy storage for utilities and other power-system stakeholders, for suppliers of raw materials (such as lithium), batteries, and energy and RE technology, for end-product companies such as automotive OEMs, and for financial players such as venture capital and private-equity firms—and the time to start evaluating such investments is now, before the best lots are claimed.

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**S**TRONG GROWTH IN FLUCTUATING renewable-energy (RE) generation, such as wind and photovoltaic (PV), is producing an increasing need for compensation mechanisms. (See *Electricity Storage: Making Large-Scale Adoption of Wind and Solar Energies a Reality*, BCG White Paper, March 2010.) While some markets saw a dip in RE growth rates during the financial crisis in 2009, overall growth continued. Some countries, such as the U.K. and China, have even defined more ambitious growth targets.

We believe that once the share of wind and PV has increased to around 20 percent or more of actual electricity generation, compensation power in the range of 30 to 40 percent of the average vertical grid load will be required to balance RE fluctuations. Compensation capacity can be provided, as shown in our previous paper, through grid extension to achieve interregional balancing and through flexible conventional backup, demand-side management, and electricity storage. We consider electricity storage to be a key enabler of the large-scale deployment of fluctuating RE generation capacity around the world.

Our analysis of the business case for various storage applications suggests that a mix of technologies will be required. Pumped hydro will continue to be the leading storage technology in terms of installed capacity, but various types of stationary batteries will become increasingly important because of their flexibility, especially in smaller, decentralized applications. (See *Toward a Distributed-Power World: How Renewables and Smart Grids Will Reshape the Energy Sector*, BCG White Paper, June 2010.) The success of stationary batteries will largely depend on technology cost reductions, which are expected to take place across the board. Our analyses show that there could also be noteworthy business potential for compressed-air energy storage (CAES) as an interim solution in the coming years in a number of centralized applications. CAES has relatively moderate investment costs, and it seems to provide a feasible technological solution. Nonetheless, we continue to have some reservations regarding this technology because of its continued reliance on fossil fuels, its low efficiency, and its limited operational flexibility. We also believe that after 2020, hydrogen storage technology could partially replace CAES (and to a degree even pumped hydro), since it offers greater operational flexibility and can store larger amounts of energy at efficiency levels not distinctly lower than that of CAES. As a result, the market potential of CAES will likely decline by about 2020.

In this paper, we will assess electricity storage from a business point of view, arguing the case from a bottom-up perspective. We believe that growth will be

driven by individual projects once potential investors find the technology sufficiently attractive financially. And since a positive business case can be demonstrated for a fair share of storage applications, we believe that there is a bright future ahead for electricity storage in the next decades—driven mainly, but not solely, by the growth of fluctuating renewable energy.

## Storage Applications

Electricity storage is neither a new technology nor a novel application within power grids. More than 100 gigawatts of pumped-hydro storage exist today globally. More than 1 GW of stored power relies on technologies such as CAES or batteries, and an additional 4 GW of electricity storage projects have been announced. Storage infrastructure can be built and operated in a very large variety of applications, both centralized and decentralized.

Centralized applications are usually connected to the high-voltage transmission grid (typically more than 110 kilovolts) and are designed to buffer fluctuations originating from a large number of sources on both the generation and the demand side. The advantage of centrally located storage facilities is that they can leverage the “self balancing” of independent fluctuation patterns. For example, if a sudden increase in wind generation coincides with a sudden rise in demand, essentially no storage may be needed. However, this scenario would require a strong grid infrastructure across the “catchment area” and large storage facilities in terms of power and energy, which only pumped hydro, CAES, and hydrogen storage can provide. Decentralized storage applications are tightly integrated into the distribution grid and are often dedicated to balancing fluctuations induced by a smaller number of sources and/or sinks (such as solar- or wind-power-plant installations). Decentralized deployment reduces grid capacity requirements because fluctuations are dealt with near their origin, but the overall utilization of individual storage facilities may be lower than that of centralized facilities.

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Since a positive business case can be demonstrated for a fair share of storage applications, we believe there is a bright future ahead for electricity storage in the next decades, driven mainly by the growth of fluctuating renewable energy.

We have classified storage applications into eight groups. For each one, we defined an illustrative business case in order to test whether an investment in a storage facility would yield an acceptable return on investment and thus offer an attractive business opportunity for the operator. In these calculations, we maintained a true cost/revenue perspective; that is, we did not consider any subsidies or additional sources of revenue that would provide a financial upside and strengthen the business case. Also, we assumed individual projects without any dependence on other types of assets, such as grids or generation assets. We based our calculations on technology cost assumptions for the period 2015 to 2020. We did not consider further cost reductions, especially in battery technologies, that could present an additional upside. On the other hand, for each of the applications, we calculated the internal rate of return (IRR) for a representative setup in which fluctuations in generation and demand occur as assumed for 2015 on, without the impact of future storage assets being factored in. We assume that these two assumptions more or less cancel each other out.

The following sections describe these eight applications and our findings regarding their financial attractiveness. (See Exhibit 1.)

## EXHIBIT 1 | Financial Attractiveness of Electricity Storage Applications and Related Technologies

Application	Pumped hydro	CAES	A-CAES <sup>1</sup>	Hydrogen	Sodium-sulfur batteries	Redox-flow batteries (VRBs)	Lithium-ion batteries
Price arbitrage	○	○	○	○	○	○	○
Balancing energy	○	○	○	○	○	Pooling of many dispersed installations needed to achieve minimum power	
Provision of black-start services	○	○	○	○	○	○	NA
Stabilizing conventional generation	○	○	○	○	●	NA	NA
Island and off-grid storage	NA	NA	NA	○	●	●	●
T&D deferral	NA	NA	NA	NA	●	○	●
Industrial peak shaving	NA	NA	NA	NA	NA	NA	●
Residential storage	NA	NA	NA	NA	NA	NA	○

○ Attractive today<sup>2</sup>    
 ● Attractive in 2015 (given expected 2015 costs)    
 ○ Needs further cost degradation and/or subsidies to be viable

Source: BCG analysis.

<sup>1</sup>A-CAES is the second generation of CAES technology. It includes a thermal storage unit to avoid thermal energy losses during compression and decompression, thereby potentially increasing round-trip efficiency to approximately 70 percent. The technology is not yet mature and faces several challenges.

<sup>2</sup>Expected IRR of 7 percent or more.

**Price Arbitrage.** This application refers to the leveraging of the price spread of electricity between peak and off-peak periods by storing when prices are low and discharging when prices are high. Our analysis showed that price differences are generally not large enough for a sustained period to generate a sufficient return on investment. We tested this finding by simulating much higher price variations than those that exist today; the resulting business case was still not attractive. Adding to the challenge is the fact that it is virtually impossible to make perfect decisions about price developments before the fact; moreover, this application has a tendency to self-destruct, since price differences tend to disappear as the number of players aiming to leverage them increases. Hence, price arbitrage does not appear to be a viable standalone business case for storage. It can, however, be combined with other applications. Notwithstanding certain size requirements for participation in power markets, price arbitrage can be utilized with any storage technology that is connected to the transmission or distribution grid.

**Balancing Energy.** Provision of balancing energy is one of the most attractive business cases for storage at present. Given the power and energy required to participate in the balancing-energy market (for example, the minimum required power for minute reserves in Germany is currently 15 MW), financially attractive

electricity-storage applications based on balancing energy could be implemented within the next few years. A precondition is obviously the presence of a market mechanism for balancing energy. Such mechanisms are in place in several developed power markets in Europe and the U.S. (such as in PJM's grid and other U.S. locations to follow). The underlying drivers of this business case are the price paid up front for the provision of balancing energy, the price paid for the actual energy provided, and, to a lesser extent, the amount of time that balancing energy is called for by the grid operator.

The principle is straightforward. Because generation and demand in power grids need to be matched perfectly at all times, transmission grid operators must be able to balance continuous and unforeseeable fluctuations both in generation (caused, for example, by the sudden technical failure of a power plant) and in load (caused by a sudden increase in demand). To provide the required flexibility, operators maintain sufficient reserves, which they obtain from generators and other providers—both negative balancing energy (for example, to mitigate a sudden electricity surplus) and positive balancing energy (to react to a sudden electricity deficit). With the rise of fluctuating RE generation, the need for balancing energy tends to increase.

These reserves can be called on at short notice (within milliseconds to several minutes) and, because of the technical and reliability requirements that must be met, they usually command prices independent of—and higher than—those of the main power market. In Germany, for instance, balancing energy is auctioned in various tranches according to the required reaction time: primary balancing reserves for immediate response (within milliseconds), secondary balancing reserves (for response within 30 seconds), and minute reserves (for response within approximately 15 minutes). Auctioned prices for minute reserves in the markets that we analyzed (Germany and the U.S.) are in the range of €10 to €30 per MW per hour throughout the year, with average monthly prices as high as €58 per MW per hour (in January 2010) and peak prices of more than €100 per MW per hour; minute reserves are usually auctioned for the next day. Primary and secondary balancing reserves receive even higher prices and are usually auctioned for an entire month.

In general, the advantage of balancing-energy pricing is that the bulk of the revenue is generated by the commitment to provide energy if and when it is needed. It is not necessarily linked or limited to the actual provision of energy. The business case for this application is therefore quite attractive. (See Exhibit 2.) At current price levels, large storage facilities using pumped hydro and CAES achieve an IRR of around 10 percent, especially when their focus is on providing negative balancing energy.

The beauty of providing negative balancing energy is that the storage facility can use surplus energy taken from the grid at nighttime, for example (for which the facility is paid as agreed to in the balancing-energy tariff), to generate additional revenues by selling it on the power market at peak prices 12 hours later. This option of being double-paid is not available to other providers of balancing energy. Developing the optimum operating model for the provision of balancing energy through electricity storage is a complex problem, since numerous combi-

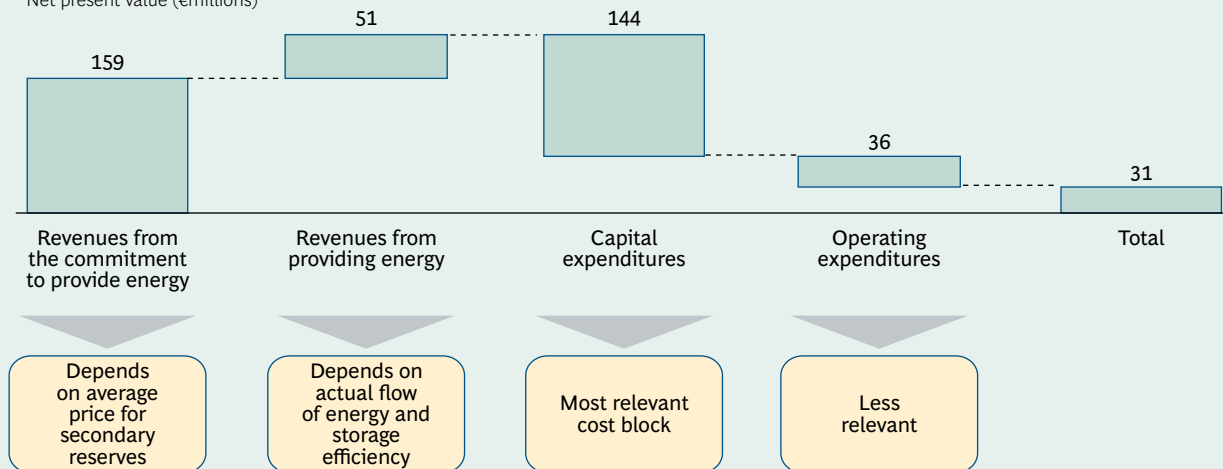
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The beauty of providing negative balancing energy is that the storage facility can use surplus energy taken from the grid at nighttime, for example (for which the facility is paid), to generate additional revenues by selling it on the power market at peak prices 12 hours later.

## EXHIBIT 2 | The Business Case for Balancing Energy Is Quite Attractive

### Example: Negative secondary reserves for an off-peak period in Germany

Net present value (€millions)



#### Assumptions:

- Small CAES storage (100 MW)
- Average price for negative secondary reserves (off-peak): €10/kW/month
- Provision of balancing energy during off-peak periods only
- Average price difference between charging and discharging: €0.05/kWh
- Time share with actual flow of energy: 25%
- Discount rate: 7%

Source: BCG analysis.

nations of time slots are possible and the auction mechanism needs to be well understood for best results.

This application is, in our view, a great opportunity for any storage operator and is available in some markets already. In the future, the need for balancing energy—and hence its price—is likely to rise as RE generation causes fluctuations on the supply side to increase, and more and more power markets will introduce sophisticated market mechanisms for the procurement of balancing energy. Both factors result in a very positive outlook, although it may be slightly dampened by stronger competition going forward.

**Provision of Black-Start Services.** Black start refers to the initial power supply required to rebuild a power grid after a full blackout. Dedicated, 100-percent-reliable power sources are needed to provide this emergency energy, since standard plants themselves require some electricity for startup and operation. Usually power plants rely on diesel generators, but given the rare occurrence of blackouts, these are used more for insurance than for actual energy generation. All highly developed power grids require black-start services, and contracts are often negotiated bilaterally between grid operators and providers. In the U.S., a number of independent system operators have implemented transparent mechanisms for the procurement of black-start services.<sup>1</sup>

Our research on black-start services as an application for electricity storage indicates that revenues of €5 per kW per month are realistic for the next few years, the price of the service being the key driver of profitability.<sup>2</sup> Another important driver is the amount of energy needed, which corresponds to the number of hours that the black-start power supply is required in case of emergency—the fewer the better for the storage-based business case.

While provision of black-start services is certainly not a prime storage application—diesel generators yield better returns—it deserves consideration as a source of additional revenues. It is characterized by low-frequency utilization but is technically easy to implement. All that is required is the setting aside of a certain share of the charged energy for blackout emergencies. This is a particularly interesting option for storage technologies in which power is not fully discharged on a daily basis. Batteries, for example, achieve a higher number of cycles when the depth of discharge is less than 100 percent, and in pumped hydro, the impact on the shoreline of the upper reservoir is less when the water level is not reduced by the maximum amount. Obviously, this application makes sense only for storage technologies in which there is no or nearly no self-discharge. In addition, regulations in some countries require certain power plants to provide their own black-start capacity, reducing the opportunities for external providers.

**Stabilizing Conventional Generation.** Existing storage facilities are frequently used for an application that is a core element of many energy markets today—and will be even more so in the future: stabilizing power generation in order to make the best use of conventional and renewable generation assets. This can be accomplished by minimizing ramping (in the case of conventional power plants) and minimizing throttling (in the case of renewables).

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Existing storage facilities are frequently used for an application that is a core element of many energy markets today—and will be even more so in the future: stabilizing power generation to make the best use of conventional and RE generation assets.

The underlying rationale is straightforward. Any energy-generation system must be able to react flexibly to changes in load and generation. Some of this flexibility is provided by balancing energy, as described above with respect to sudden, momentary fluctuations. Longer fluctuations—lasting hours or days—can be accommodated by ramping conventional power generation up and down or by throttling peaks in renewable generation. But with RE-induced fluctuations growing, this procedure is becoming increasingly uneconomical because of ramping losses, reduced utilization of the plant, and lost RE generation. Whereas peak-load power plants are designed to ramp up and down quickly several times a day, older, conventional power plants are restricted in their ability to do so—and, even if they can operate more flexibly, they are restricted in their ability to achieve better results under continuous operation. For example, with demand dropping significantly, many U.S. utilities are operating their coal-powered plants like midcycle plants, which is uneconomical. Operating them more steadily would have a strong economic upside and reduce reliance on gas peakers, whose variable cost of generation is substantially higher.

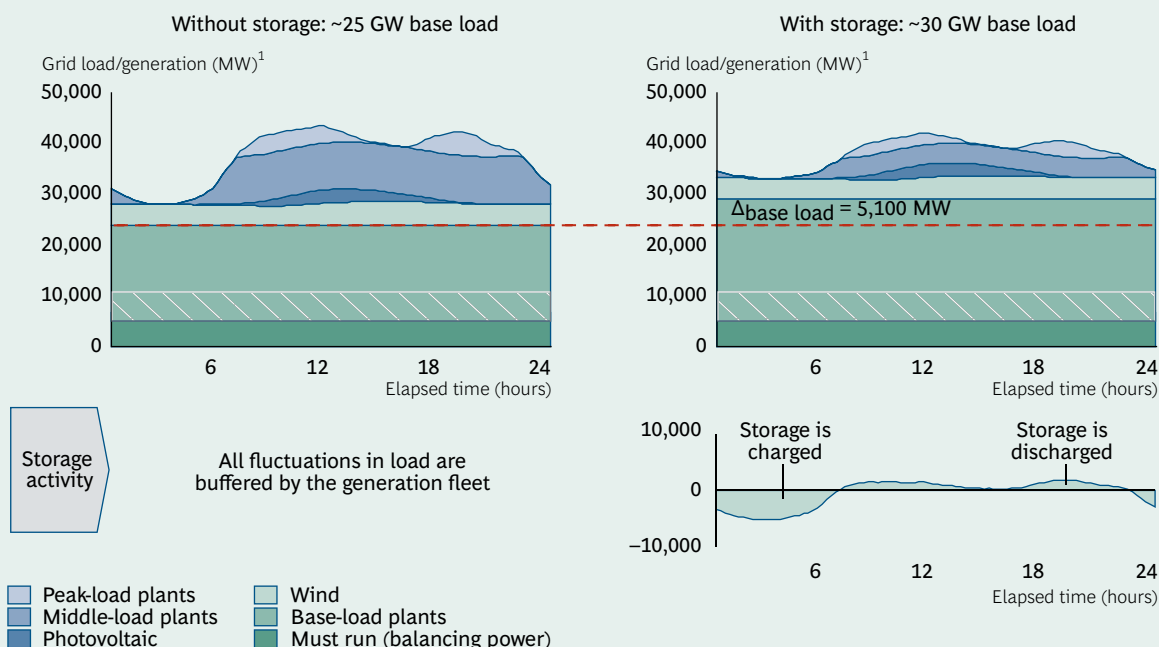
There are substantial economic benefits to stabilizing conventional generation or, to put it differently, to maximizing the share of base-load generation. Flexible assets such as pumped-hydro storage can be used to “soak up” fluctuations, resulting in a less steep load-duration curve. This is nothing new—many pumped-hydro stations

are doing exactly that today—but with flexibility requirements increasing due to RE generation, a larger share of flexible assets is needed. In fact, such assets are currently being built, especially gas peakers. But our calculations show that storage facilities are equally up to the task of providing flexibility and buffering the base-load fleet. Indeed, they have a clear advantage because they can store excess RE electricity generated during periods of low demand (such as at night) and feed it back into the grid when demand rises (at noon)—as opposed to the uneconomical throttling of excess RE generation, which is otherwise hard to avoid. This would allow fewer conventional power plants to be ramped down at night, lowering overall generation costs—and also overall CO<sub>2</sub> emissions. (See Exhibit 3.)

Given the large amounts of power and energy required to buffer conventional generation assets, the use of storage facilities in this application is mainly relevant to large-scale CAES and pumped-hydro storage. According to our calculations, CAES can—despite its technological limitations—provide an IRR of more than 15 percent in certain scenarios, with approximately 80 percent of revenues originating from saved generation costs and approximately 20 percent from saved CO<sub>2</sub> emissions costs.<sup>3</sup> It is important to note, however, that this calculation, rather than viewing each asset as an isolated profit center optimizing itself against the market, which is common practice at many utilities today, assumes several integrated generation assets taken together.

### EXHIBIT 3 | Storage Can Increase the Share of Base-Load Power Generation

#### Potential generation portfolios with and without storage



Sources: Amprion; 50Hertz; EnBW; Transpower; BCG analysis.

Note: In this illustrative example, we assumed constant fluctuating RE generation; we modeled several alternative cases with similar results. The load profile is based on average data for January and June 2009 in Germany.

<sup>1</sup>Energy flowing through public grids only, without direct industrial consumption.

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Using electricity storage in combination with RE sources, especially wind and PV, in island and off-grid settings is a straightforward application that not only offers an attractive financial upside but also entails an impressive reduction in CO<sub>2</sub> emissions.

The main lever in this application is increasing—or, despite growth in fluctuating RE, maintaining—the share of base-load power generation in order to leverage its low marginal costs (and reduce ramping costs), thus increasing utilization and reducing the levelized cost of electricity of the total fleet. The degree and characteristics of the fluctuations in any given power grid are the main drivers: the more frequent and steep the fluctuations in residual load, the greater the benefit of buffering them. We analyzed this application for five days in Germany under varying weather conditions, first with 2009 RE installed power (10 GW PV and 25 GW wind) and then with RE installed power forecasted for 2015 (36 GW PV and 44 GW wind). The application worked on all but one of the sample days, and the benefits of using storage facilities increased over time in terms of generation cost savings. Dena (the German Energy Agency) had similar results in its assessment of a planned pumped-hydro facility in southwestern Germany.<sup>4</sup>

**Island and Off-Grid Storage.** Today, diesel generators ensure electricity generation in many island and off-grid settings, despite their high generation costs of around €0.25 per kWh or more, simply because there is no simple, feasible alternative. This is a sizable market, representing an installed fleet of 600 GW of diesel generation capacity.<sup>5</sup> Using electricity storage in combination with RE sources, especially wind and PV, in island and off-grid settings is a straightforward application that not only offers an attractive financial upside but also entails an impressive reduction in CO<sub>2</sub> emissions. Even when the cost of an emergency backup diesel generator is included, a positive return on the overall investment (RE generation plus storage plus backup diesel) can be realized, since storage involves negligible variable costs. Batteries are well positioned for this storage application given its usual size, and we considered four different types: lead-acid, sodium-sulfur, redox-flow (VRB), and lithium-ion. They all returned positive business cases; the ideal technology is likely to vary according to the specific on-site conditions.

As a base case, we assumed power supplied exclusively by diesel generator. The first alternative was a combination of RE generation and diesel generator, with the diesel generator operating whenever RE generation was insufficient to meet power demand. Excess RE generation was throttled. The second alternative was a combination of RE generation and battery storage plus backup diesel, with almost the entire power demand being satisfied by (partly stored) RE generation. We found that with diesel prices higher than €0.20 per liter, both alternatives were clearly more financially attractive than the base case.

We then analyzed the two alternatives under different weather conditions, given a sample load pattern, and found that in almost all cases, the storage solution yielded better returns than the solution without storage, especially in cases with high fluctuations in residual load. In every case, there was a positive return on the storage investment, particularly in settings with a high share of wind generation (which is generally less aligned than PV generation with power demand). The IRR for various RE and storage combinations in island and off-grid settings ranged from 3 percent to as high as 50 percent and more under conditions of high wind.

As noted above, an additional highly attractive aspect of this application is its direct positive impact on emissions, especially CO<sub>2</sub>, since the use of diesel generators is

almost completely replaced by RE generation. Assuming a 600 GW installed fleet of diesel generators running an average of only 5 percent of the time (that is, approximately 400 hours per year), reduction of CO<sub>2</sub> emissions would equal approximately 200 million tons per year—the equivalent of half the emissions of France.<sup>6</sup>

**T&D Deferral.** Transmission and distribution (T&D) deferral uses electricity storage as a means of either avoiding or deferring an investment in grid infrastructure—an investment that becomes necessary when the maximum load is exceeded during peak hours owing to an increase in power demand. The principle is simple: instead of increasing the capacity of an existing power line to meet peak demand, a suitably sized battery is installed near the load, discharging at peak times and charging at off-peak times. This storage application is already being used in the U.S.—since 2007 in Charleston, West Virginia, for example. (Such installations often serve additional purposes, such as frequency stabilization, which are not considered here.) The T&D deferral application is particularly useful and attractive under the following circumstances:

- Transmission bottlenecks can be clearly identified.
- Grid infrastructure is not particularly dense or close to overloading at the bottlenecks of concern.
- Demand for electricity is growing, either continuously or on a one-time basis (for example, because of new housing or industrial infrastructure), ideally at the end of the transmission line.

Given these conditions, two main parameters determine the attractiveness of setting up a storage facility instead of upgrading the power line: the additional capacity required and the length of the power line requiring upgrade.

Where power ratings are relatively low, batteries are the technology of choice for this application. Our initial calculations show that storage can also be beneficial under certain circumstances in higher-power settings, such as optimizing the linkage of a wind park to the transmission grid. Depending on the size of the wind park, CAES (for offshore wind, located near the landing point) or sodium-sulfur batteries (for onshore wind) are the best-suited technologies.<sup>7</sup> Besides the pure economics, government subsidies incentivizing the feed-in of less-fluctuating wind power are a key driver of such installations, as is the case in Japan, where feed-in tariffs for wind energy depend on the current demand/supply profile and vary between ¥9 and ¥27 per kWh.

**Industrial Peak Shaving.** Peak shaving aims to flatten industrial power demand and is particularly relevant for companies whose demand varies greatly throughout the day. The power tariff in most markets comprises a fixed component, determined by the maximum, or peak, power required at any point in time, and a variable component, which is the actual energy consumed. Exceeding the agreed-upon maximum power can result in severe penalties, depending on the contract, and shaving the peaks can significantly reduce the fixed component. When more load is needed than can be taken from the grid according to the

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Assuming a 600 GW installed fleet of diesel generators running about 400 hours per year, battery storage in island or off-grid applications could reduce CO<sub>2</sub> emissions by approximately 200 million tons per year—the equivalent of half the emissions of France.

delivery contract, a battery serves as the temporary source of extra power in this application.

While peak shaving can be financially viable, depending on individual load and tariff patterns, demand-side management provides an attractive and easily implemented alternative with a similar result. Shutting down some of the equipment, such as the ventilation system, for a few minutes when the hydraulic press is operating can prevent the power ceiling from being exceeded just as effectively and with hardly any investment required.

When demand-side management is not an option, however, and when load fluctuations are infrequent and steep, peak shaving can be advantageous. Our calculations show that for various types of lithium-ion batteries, an IRR of 10 percent or more can be achieved if suitable load characteristics are present. In addition, once the battery is installed, there is great potential for combination with other applications, such as price arbitrage.

**Residential Storage for Self-Consumption.** Residential storage is frequently discussed in connection with the impressively dynamic development of residential PV installations, especially in Germany but increasingly in other countries as well, such as Italy. A small lithium-ion battery in the basement stores excess electricity generated at around noon and retains it for the afternoon and evening, increasing self-consumption and reducing strain on the distribution grid. In Germany, self-consumption of PV generation receives a bonus of approximately €0.08 per kWh. However, the required 7 kWh battery and two-way meter together cost €3,500 or more—far more than can be offset by the self-consumption incentive.

We believe it unlikely that subsidies for self-consumption will increase relative to conventional feed-in. Currently, the grid infrastructure is paid for by all users; that is, every kWh carries a grid usage fee. As almost all electricity is carried across the transmission and distribution grid, the (fixed) grid costs are spread across a relatively large number of total users, making the cost per kWh bearable (currently approximately one-third of the retail price). Were more and more customers to become self-sufficient in their power supply, fewer kWh would be delivered via the power grid, although self-suppliers would likely retain their grid connection for backup. Hence, the (unchanged) grid costs would be borne by fewer people, providing a further incentive to self-supply. Eventually, it would no longer be possible to allocate the grid costs.

## Assessment Methodology and Conclusions

In our analyses of the preceding storage applications, we used sensitivity analysis, where possible, to assess the impact of changes in some of the relevant parameters. And while our analyses give a good indication of the business opportunities for these applications, only a thorough assessment of specific projects, their context, and the details of key operational parameters will provide a reliable basis for investment decisions. Exhibit 4 provides an overview of the feasibility and financial attractiveness of each storage application. The size of the bubbles indicates the

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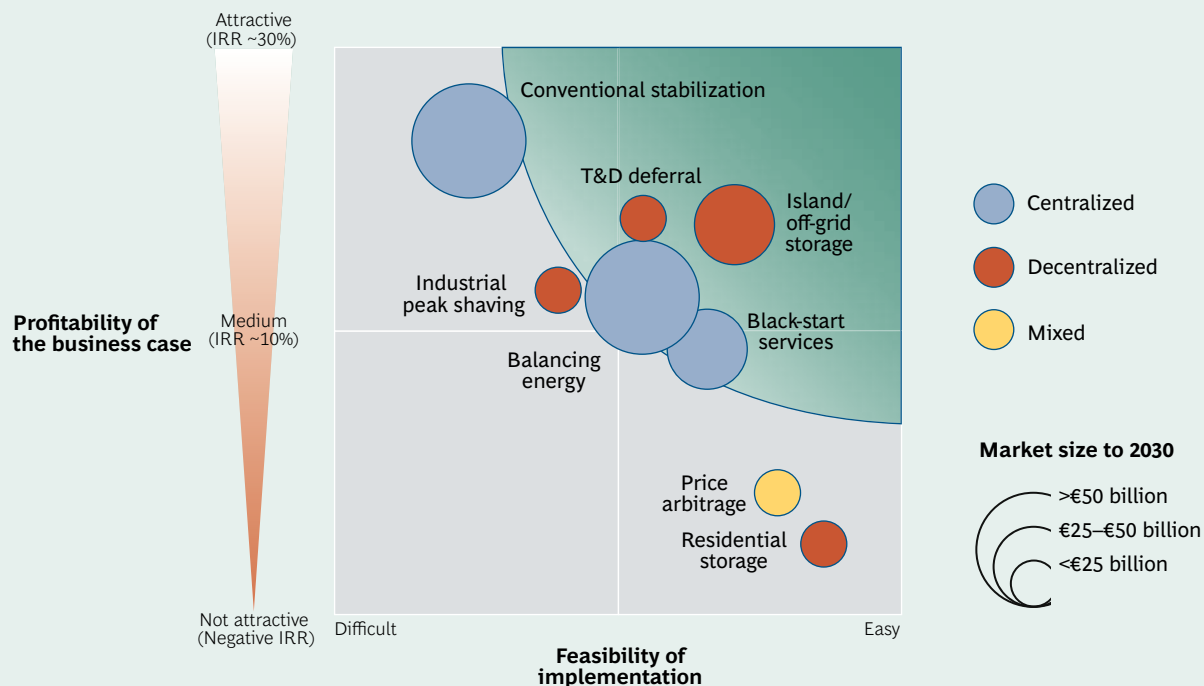
Residential storage is frequently discussed in connection with the impressively dynamic development of residential PV installations, especially in Germany but increasingly in other countries as well, but we believe it unlikely that subsidies for self-consumption will increase relative to conventional feed-in.

cumulative market potential for each one to 2030. We assessed feasibility qualitatively according to four criteria: the availability of technical alternatives, the technical complexity of the implementation, its match with long-established business models (for example, those of utilities), and general opposing or supporting trends. Feasibility as well as profitability may of course vary by regional or project-specific context.

We analyzed the business cases individually, assuming that a given storage facility will be used for a single storage application. However, storage facilities can be used to generate revenues from different sources, either by assigning parts of the capacity to different applications (horizontal combinations) or by using different applications at different times of day (vertical combinations). The benefit is essentially a higher utilization of the storage infrastructure and (as described in the discussion of balancing energy) the ability to leverage excess electricity to generate double revenues. Price arbitrage, T&D deferral, and industrial peak shaving (in addition to balancing energy) are especially suited to vertical combinations.

Several key insights can be drawn from our assessments. First, storage applications can, under favorable conditions, be profitable today. Cost depressions, especially in the case of stationary batteries, will significantly improve profitability in a number of additional applications, as discussed above. However, in most applications, the underlying drivers of the business case have to be analyzed very carefully on a

#### EXHIBIT 4 | Four or Five Storage Business Cases Will Be Attractive in the Near Future



Calculations based on estimated storage prices for 2015–2020; price decreases would improve profitability in all cases

Source: BCG analysis.

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Making the most of an investment in any storage facility requires sophisticated operational optimization and experience, suggesting strong first-mover advantages for the operators of new facilities.

project-by-project basis. Thus, in the case of T&D deferral, for example, financial attractiveness varies with distance, required power, and load pattern.

Second, although any storage technology can theoretically be used for almost any application (by pooling several smaller units, for example), performance characteristics and costs point to a number of obvious combinations of technologies and applications, such as off-grid settings combined with batteries, or stabilization of conventional generation combined with pumped hydro or CAES. Our calculations also indicate that, under favorable conditions, large-scale storage technologies such as pumped hydro and CAES—despite the latter’s technological shortcomings—are already financially attractive today, while decentralized applications using batteries will become so within the next five years or so.

Third, given the many parameters influencing storage revenues and the countless horizontal and vertical combinations that are possible, successful operation of a storage facility is a complex task. Hence, making the most of an investment in any storage facility requires sophisticated operational optimization and experience, suggesting strong first-mover advantages for the operators of new facilities.

## The Market for Storage

To forecast the overall business potential of relevant storage technologies, we took the overall demand for a specific application as a starting point. For example, the overall demand for balancing energy can be quantified as a share of the total vertical grid load in a particular energy system (for example, 5 percent in Germany, given actual amounts for 2010). For an off-grid application, our starting point was the installed capacity of diesel generators worldwide (approximately 600 GW), of which 50 percent was assumed to be used for continuous off-grid power generation. These calculations allowed us to estimate the overall storage capacity needed if electricity storage were to satisfy 100 percent of demand (which will never be the case).

We then calculated the actual market potential of electricity storage for each application by assessing the financial attractiveness of the storage business case, the complexity of implementation, and the availability of alternatives to storage for the specific application. Finally, we calculated the share of each storage technology to 2030, again on the basis of financial attractiveness as well as technical requirements, using forecasts of the underlying parameters for 2020 and 2030. As noted earlier, however, our initial business-case calculations were made using technology cost parameters for 2015 to 2020; further cost reductions beyond 2020, which are likely, could provide additional upside potential. On the other hand, the initial deployment of storage facilities may have an effect on the business case of those that follow, exerting a dampening effect on overall market potential. We assume that these two effects more or less cancel each other out.

On the basis of these considerations, we calculated the overall market potential of the eight applications and storage technologies to 2030. On top of the approximately 100 GW of storage that exists today, we forecast an additional market potential for approximately 330 GW of storage distributed among the different technologies.

This translates into an additional *cumulated* investment need of approximately €280 billion to 2030, including replacement. Balancing power will drive approximately one-third of the market potential; in terms of regional distribution, Western Europe, the U.S., and China will take the largest shares. Batteries will account for almost 50 percent of this market in terms of financial investment, although they will represent a very small part of the storage energy capacity needed by 2030. (See Exhibit 5.)

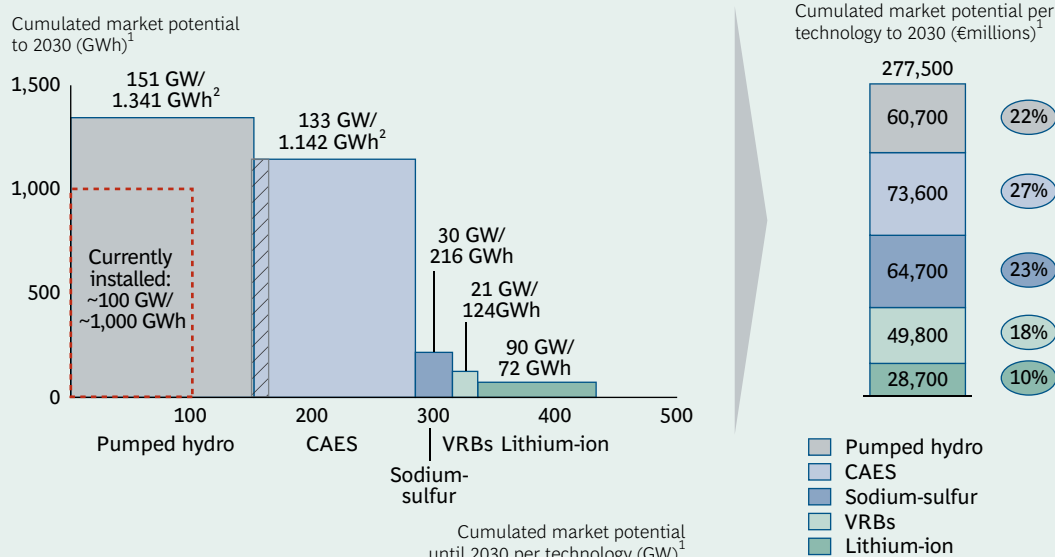
We believe that a gradual increase in the storage business will take place over the next few years, driven by increasing penetration of RE generation and the need to manage fluctuations and by the growing technological maturity of the key storage technologies, especially batteries. Today, the storage market is worth around €1 billion per year. We expect annual global market volumes of €2 billion to €3 billion per year in the next few years, increasing to €4 billion to €6 billion per year after 2015 and to more than €10 billion per year after 2020.

As already noted, our calculations were made purely from a cost perspective, omitting the potential beneficial effects of storage-related regulation. Such regulation is currently being discussed in several countries with high or quickly growing shares of RE generation, such as Germany, the U.S., Japan, and China, and its implementation has the potential to boost the storage business well beyond the forecasted volumes. We are therefore convinced that a sizable and sustainably growing market is unfolding in the stationary-storage arena. While business in

### EXHIBIT 5 | Market Potential of the Storage Technologies

Batteries will account for half the market in terms of power but significantly less in terms of capacity

Batteries will represent ~50 percent of cumulated market potential



Source: BCG analysis.

<sup>1</sup>Without price arbitrage, driver trees based on 2030 values, 2015 technology costs.

<sup>2</sup>The future split between pumped hydro and CAES will be driven largely by site restrictions; the gradual replacement of both technologies by hydrogen storage is expected after 2020.

absolute terms will be small in the next few years, we forecast strong and continued growth after 2015 that can best be tapped by taking the right steps now.

## Potential Business Opportunities

Electricity storage offers a wide range of business opportunities to a wide range of stakeholders. Obvious market participants are utilities, in their capacity as operators of storage facilities, and technology providers. However, other players—in the chemical industry and in the automotive sector, for example—and even financial investors may discover that storage is an attractive means of entering a new segment of the energy business in which stakes are yet to be claimed. Indeed, one-third of venture capital companies polled in January of 2010 listed electricity storage as their number-one investment focus.<sup>8</sup> While this indicates that some of the relevant technologies are still in their infancy, it also shows that now is the time to start considering storage-related business opportunities, before the best lots are taken.

There are four main groups of potential stakeholders that might want to consider entering this market: power generation players, suppliers, end-product companies, and financial players.

**Power Generation Players.** In addition to power generation companies such as utilities, power system stakeholders such as municipalities and grid operators may benefit from running electricity storage facilities—to mitigate grid bottlenecks through T&D deferral, for example, or to better leverage their existing generation assets through stabilization of conventional generation.

**Suppliers.** Business opportunities exist for raw-material sellers, for battery producers, and for technology companies that serve the energy industry, including the following:

- Producers of lithium, in particular, but also of vanadium (for redox-flow batteries) and copper (for cabling), and, to a lesser extent, mining companies and raw-material producers interested in greening their remote operations through the use of RE generation paired with batteries for reliability
- Battery producers that are building up large production capacities in anticipation of the takeoff of the e-car market and are looking to broaden their footprint by supplying batteries for stationary applications in what is likely to become an even more profitable sector
- Producers of energy technology and components such as pumps, compressors, turbines, inverters, switchgear, and other devices (such as ABB, whose Dynapeaq product line—available today—integrates high-voltage switchgear with battery storage solutions)
- Manufacturers of RE technology such as wind turbines and PV modules, as well as project developers and operators (such as IPPs) seeking to integrate their fluctuating-generation assets, either voluntarily or owing to potential changes in legislation

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One-third of venture capital companies polled in January 2010 listed electricity as their number-one investment focus, indicating that some of the relevant technologies are still in their infancy but also that now is the time to start considering storage-related business opportunities, before the best lots are taken.

**End-Product Companies.** Energy storage capacity could enable these companies to provide more innovative products to their clients and to enhance their own operations. In particular, many automotive OEMs are looking into leveraging their e-car capabilities in the grid storage arena. Using e-cars for vehicle-to-grid energy storage may become an option as soon as a sufficient fleet of e-cars is on the road. While there are a number of challenges to be overcome (such as the control system, consumer interest and privacy issues, and the capacity of the charging infrastructure), innovative business models are being developed around the use of decentralized e-car batteries as virtual storage facilities.

**Financial Players.** In addition to venture capital companies, private equity will come into play once the market has matured. The renewable-energy sector has been attractive to private-equity players, helped by generous feed-in tariffs for RE generation.

## Identifying Potential Business Opportunities

While all of these players will identify and evaluate potential storage-related business opportunities from a different perspective and with a different focus, we propose a general four-step approach.

**Step one: Thoroughly understand the storage technologies and their potential applications and operational models.** Given the many independent parameters involved in determining the operational profitability of individual applications, this is a precondition for identifying business opportunities. For example, there are currently five competing lithium-ion battery technologies under consideration in the market. Since each one has different implications for raw-material and component requirements, stakeholder companies need to understand each technology in order to make sound investment decisions.

**Step two: Analyze and quantify the relevant end market.** This involves the analysis of key trends, market drivers, and growth factors. On the basis of the analysis, realistically quantify market demand, starting from the relevant applications and taking into account regional focus and specific regulations. This step is, of course, particularly important for power-generating companies. But it is equally important for private-equity players, whose investment success depends on, among other things, selecting the right setting and timing their market entry—not too early, when the market is not yet mature owing to high technology costs and low RE generation, and not too late, when the presence of many players means that the best claims are already staked.

**Step three: Identify the technology that best meets market demand.** Given the technical requirements of the particular application, select the most suitable storage technology. Alternatively, a company may choose to leverage a particular technology because of existing in-house capabilities or in response to external factors such as government or financial incentives. In that case, the potential applications of the chosen technology must be identified. Both approaches are legitimate and depend on the individual company's starting position. Whereas future operators will in most cases start by singling out relevant applications,

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A company can select the most suitable technology on the basis of the particular application's technical requirements, or it may choose to leverage a particular technology because of existing in-house capabilities or in response to government or financial incentives.

potential technology providers will most likely start with a specific storage technology.

**Step four: Determine the implications for the relevant market of each stakeholder.** Technology providers will analyze storage technology road maps in order to determine and assess the related investment case. A mining company, for example, can look at the attractiveness of the identified commodities relevant to the chosen technology and determine the profitability of any corresponding capital-expenditure projects. An automotive OEM will develop a view on the timeline of available storage technologies and apply that to its view on the development of the e-car market. It then can tailor its e-car strategies accordingly.

**E**LECTRICITY STORAGE OFFERS an exciting option for a much wider range of market players than is generally assumed. Corporate electricity-storage strategies based on a thorough assessment will have the best chance of succeeding in this field of business. Because the financial return on a storage investment is strongly contingent on finding a location with a suitable set of parameters, we believe there is a clear first-mover advantage for the operators of energy storage facilities. It is therefore essential to evaluate opportunities in this sphere quickly.

#### NOTES

1. See Alan Isemonger, "The Viability of the Competitive Procurement of Black Start: Lessons from the RTOs," *Electricity Journal*, vol. 20, issue 8, October 2007.
2. In the U.S., the New England independent system operator, ISO-NE, is paying at a rate of \$4.58 per kW per year until 2011 (see, for instance, [http://www.iso-ne.com/regulatory/tariff/sect\\_2/oatt/index.html](http://www.iso-ne.com/regulatory/tariff/sect_2/oatt/index.html)). Others, such as PJM, CAISO, and NYISO, quantify the direct costs and allocate them to the general power tariff; ERCOT uses an auction system. In Europe, bilateral agreements between generators and grid operators are in place.
3. We assumed emission costs of €15 per ton. When phase III of the European Union's Emissions Trading Scheme goes into effect in 2013, EU power generators will have to pay for their emission certificates (with certain exceptions for Eastern European power plants). See [http://www.decc.gov.uk/en/content/cms/what\\_we\\_do/change\\_energy/tackling\\_clima/emissions/eu\\_ets/phase\\_iii/phase\\_iii.aspx](http://www.decc.gov.uk/en/content/cms/what_we_do/change_energy/tackling_clima/emissions/eu_ets/phase_iii/phase_iii.aspx).
4. See <http://www.dena.de/de/themen/thema-esd/projekte/projekt/psw-integration-ee/>.
5. This is the cumulated market for 1980 to 2010, representing an installed capacity of diesel generators with a nominal power of 500 kW or greater and assuming a 30-year generator lifetime. See Power Systems Research at <http://www.powersys.com/>.
6. Emissions calculations assume specific emissions of 0.27048 kilogram CO<sub>2</sub> per kWh diesel and 35 percent generator efficiency. See U.N. Millennium Development Goals Indicators, <http://mdgs.un.org/unsd/mdg/Data.aspx>.
7. A reference site is already operational at Rokkasho, Japan, where 34 MW of sodium-sulfur batteries were installed by NGK in May 2008 alongside a 51 MW wind park in the north of the main island of Honshu. See <http://www.ngk.co.jp/english/products/power/nas/installation/index.html>.
8. For details, see [http://graphics.thomsonreuters.com/0110/US\\_CLNTCH0110.gif](http://graphics.thomsonreuters.com/0110/US_CLNTCH0110.gif).

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