Second Life-Batterien als flexible Speicher für Erneuerbare Energien

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KURZSTUDIE IM AUFTRAG DES BUNDESVERBANDES
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KURZFASSUNG

Die Energiewende hat massive Auswirkungen auf den deutschen Energiemarkt. Erneuerbare Energien ersetzen fossile Brennstoffe und machen schon heute 35% der landesweiten Stromerzeugung aus, wobei das Endziel darin besteht, bis zum Jahr 2050 80% des deutschen Strombedarfs mit diesen Energieträgern abzudecken. Um diese Vision in die Praxis umzusetzen und seine Wirtschaft zu dekarbonisieren, muss sich Deutschland der Herausforderung stellen, diese nicht kontinuierlich verfügbaren Energiequellen so kosteneffektiv wie möglich zu integrieren. Unter den etablierten Energieunternehmen herrscht die Meinung vor, dass die Speicherung der Energie nicht erforderlich und zu kostenintensiv sei.

Die Energieunternehmen sind der Ansicht, dass Speicher für die Energiewende nicht notwendig sei, doch sie wird sich am Ende durchsetzen, ob sie es nun wollen oder nicht.

Dies ändert sich jedoch, da die Batterie- und Automobilhersteller auf der ganzen Welt die Batterieproduktion für Elektrofahrzeuge weiter ausbauen. Die Kosten der fortschrittlichsten Batterietechnologie, Lithium-Ionen-Batterien, sinken rasch. Heute sind Lithium-Ionen-Akkus für rund 300€ pro kWh erhältlich, während sie vor einem Jahr noch 500€ pro kWh kosteten. Bis zum Jahr 2020 wird der Preis höchst wahrscheinlich auf € 100 pro kWh sinken.

Wenn diese Entwicklung tatsächlich eintritt, dann werden die Gesamtbetriebskosten – die Summe aus Kaufpreis und Betriebskosten – von Elektrofahrzeugen so stark sinken, dass sie unter denen von Verbrennungsmotoren liegen werden. Dies wird den Verkauf von Elektrofahrzeugen ankurbeln, was sich wiederum stark auf das Stromnetz auswirken wird. Wenn es Deutschland gelingt, den Meilenstein von einer Million neuen Elektroautos bis 2020 zu erreichen, dann könnte das Land über eine ans Stromnetz angeschlossene Speicherkapazität von knapp unter 25 GWh verfügen. Dies würde ausreichen, um ganz Deutschland eine halbe Stunde lang mit Strom zu versorgen.

Bis zum Jahr 2025 könnten bis zu 25 GWh an Second-Life-Batterien auf den deutschen Markt kommen

Die Fahrzeugelektrifizierung ist eine einmalige Chance und könnte zu einem entscheidenden und kostengünstigen Eckpfeiler der Energiewende werden. Durch neue Ladestrategien und die Schwarmaggregation der Elektrofahrzeuge (EVs) werden die EVs die operative Verwaltung und die Struktur des Stromnetzes auf noch nie da gewesene Art und Weise verändern. Dadurch wird es nicht nur zu einem Anstieg der Stromnachfrage und einer Zunahme der Belastungen für das Stromnetz kommen, sondern die BMWs und Teslas werden wahrscheinlich durch Energieverträge mit den Autobesitzern die Stromflüsse in und aus den Batterien kontrollieren.

Eine weitere interessante Auswirkung wird darin bestehen, dass in unseren Haushalten und Unternehmen wahrscheinlich kostengünstige, rekonditionierte Batterien, sogenannte Second-Life-Batterien, zum Einsatz kommen werden. Wenn die Batterien der ersten Elektroautos das Ende ihrer Nutzungsdauer erreicht haben, werden die Automobilunternehmen vor der

Entscheidung stehen, diese zu recyceln oder ihnen eine andere Verwendung zu geben. Eine Alternative zum Recyceln der Batterien ist, sie zu rekonditionieren und für solche Anwendungen wiederzuverwenden, in denen sie weniger Belastungen ausgesetzt sind. Das wären z.B. stationäre Anwendungen, wo die Batterien in der Regel in kleinen Raten ge- und entladen und in einer kontrollierten und sicheren Umgebung eingesetzt werden. Auf diese Weise kann der Recyclingprozess verzögert und die Lebensdauer um bis zu 10 Jahre verlängert werden wodurch zugleich neue Umsätze generiert werden.

Batterien könnten den Umstieg der Wirtschaft auf erneuerbare Energien schneller als von der Regierung geplant

Dies bedeutet, dass Second-Life-Batterien die gleichen Leistungen erbringen können, aber zu einem Bruchteil der Kosten. Außerdem werden Second-Life-Batterien durch den Anstieg des Lebensdauerwerts der Batterie die Kosten sowohl für die Primär- als auch für die Sekundärnutzer senken.

Und dies könnte dazu führen, dass die Batterien einen Übergang zu einer Wirtschaft basierend auf erneuerbaren Energien in einem kürzeren Zeitraum ermöglichen werden, als dies derzeit im Plan der deutschen Bundesregierung vorgesehen ist.

Die wichtigsten Ergebnisse:

- Lithium-Ionen-Akkus sind die bevorzugte Art der Energiespeichertechnik für Elektrofahrzeuge, wobei in den nächsten Jahren mit starken Kapazitätserweiterungen von 50 GWh an weltweiter Produktionskapazität im Jahr 2015 auf mindestens 200 GWh im Jahr 2020 gerechnet werden kann.

- Lithium-Ionen-Akkus sind für rund 300€ pro kWh erhältlich und ihr Preis wird bis zum Jahr 2020 höchst wahrscheinlich auf 100€ pro kWh sinken. Zugleich werden technologische Fortschritte zu einer Verbesserung der Speicherkapazität, der Stabilität sowie des relativen Gewichts und Volumens führen.

- Die Elektrifizierung des Verkehrs wird die Stromwelt radikal verändern. Jede Million an neuen EVs wird das System um circa 25 GWh Speicherkapazität erweitern.

- Die Automobilindustrie dringt in den Energiemarkt vor und stellt Batterien für Haushalte und gewerbliche Nutzer sowie Dienstleistungen für Energieversorger und das Stromnetz zur Verfügung. Dadurch wird das Angebot an verfügbaren Produkten und Dienstleistungen für Endkunden verbessert.

- Rekonditionierte Elektrofahrzeug-Batterien, sogenannte Second-Life-Batterien, werden zunehmend in Anwendungen wie in Off-Grid-Systemen, in der Notstromversorgung und im PV-Eigenverbrauch in Privathaushalten verwendet.

- Die Preise für Second-Life-Batterien sind bereits sehr überzeugend und liegen bei 150€ pro kWh. Mit der zunehmenden Anzahl von Elektrofahrzeugen werden mehr und mehr dieser Batterien auf den Markt kommen. Bis zum Jahr 2025 könnten allein in Deutschland bis zu 25 GWh an Second-Life-Batterien pro Jahr auf den Markt kommen.

- Durch kostengünstige Energiespeicher wird der Umstieg auf erneuerbare Energien schneller erfolgen, als von der deutschen Bundesregierung derzeit vorgesehen.

Abbildung A1

Anwendungsfälle für Batterien

Off-Grid-Systeme

- Mikronetz
- Eigenverbrauch
- Notstromversorgung
- Netz-Verschiebung

Privathaushalte

- Eigenverbrauch
- Flexibilität
- Notstromversorgung
- Energiearbitrage

Gewerbe & Industrie

- Eigenverbrauch
- Flexibilität
- Nebenleistungen
- Notstromversorgung
- Peak Shaving
- Energiearbitrage

Elektrofahrzeuge

- V2G & V2H
- Laststeuerung
- Energiearbitrage
- Peak Shaving

Übertragungs- und Verteilungsnetz

- Ausgleichsmarkt
- Schwarzstart
- Spannungsregulierung
- Redispatch
- Netz-Verschiebung
- Flexibilität

Erneuerbare Kraftwerke

- Energiearbitrage
- Asset-Optimierung
- Nebenleistungen
- Schwarzstart

Thermische Erzeugung

- Nebenleistungen
- Asset-Optimierung
- Schwarzstart
- Energiearbitrage

- **Off-Grid-Systeme:** Einer der schnell wachsenden Märkte sind Pay-as-you-go-Geschäftsmodelle, die den Kunden eine elektrische Lösung in Form einer Solar- und Batterielösung (PVS) anbieten. Darüber hinaus weiten diese Unternehmen ihre Angebote auf Mikronetze basierend auf Batterien und anderen Formen der Energiegewinnung an jenen Orten aus, die noch nicht an das Stromnetz angeschlossen sind. Dabei umgehen sie die gesamte Energieinfrastruktur des 20. Jahrhunderts. Fernmeldetürme, Bergbaubetriebe in entlegenen Gebieten und andere dezentralisierte Infrastrukturen, die rund um die Uhr mit Diesel betrieben werden, werden auf PVS umsteigen, wodurch es zu einer massiven Annahme dieser Technologie kommen wird.

- **Privathaushalte:** Die Optimierung des Eigenverbrauchs ist am deutschen Markt einer der Hauptantriebsfaktoren für die Energiespeicherung. Photovoltaikanlagen in Verbindung mit Batteriesystemen können den überschüssigen Solarstrom am Tag speichern, damit er später in der Nacht verwendet werden kann. Dadurch wird die Eigenverbrauchsquote um bis zu 60 - 70% erhöht, und die Amortisationszeit liegt heute in Süddeutschland bei 10 Jahren.

- **Industrie und Gewerbe:** Jeder sechste Inustrie in Deutschland verfügt bereits über eine Anlage zur dezentralen Stromerzeugung. Der Einsatz von Batterien wird den deutschen Unternehmen durch Peak-Shaving, Preisarbitrage sowie die Bereitstellung der Notstromversorgung bei der Senkung ihrer Energiekosten helfen.

- **Elektrofahrzeuge:** Die Elektrifizierung der Mobilität hat das Potenzial, die Umsetzung von Smart-Grid-Technologien zu beschleunigen und den Energiesektor zu revolutionieren. Anstatt durch das gleichzeitige Aufladen einer großen Anzahl von Fahrzeugen zusätzliche Spitzenlasten zu erzeugen, werden Elektroautos die überschüssige Windenergie in der Nacht nutzen, als mobile Energiespeicher dienen und neue Einnahmequellen für Autobesitzer generieren, was zur Senkung der Gesamtbetriebskosten führt.

- **Übertragungs- und Verteilungsnetz:** Die erste große kommerzielle Anwendung für Batterien liegt in der Bereitstellung von Nebenleistungen und insbesondere im primären Reservemarkt für die Frequenzregulierung. In Zukunft werden Batterien die herkömmliche Energieerzeugung auf diesem Markt verdrängen und es wird zur Entwicklung anderer Anwendungen kommen, insbesondere im Verteilungsnetz, wo ein großer Teil der durch erneuerbare Energien verursachten Belastungen auftritt. Durch Batterien wird auch ein Aufschub des teuren Ausbaus und der Verstärkung des Stromnetzes ermöglicht, zugleich dienen sie zur Lastverlagerung, wodurch das Stromnetz zu den Spitzenlastzeiten entlastet wird.

- **Erneuerbare Kraftwerke:** Die größte Schwäche der erneuerbaren Energien wie Wind und Sonne ist, dass sie nicht kontinuierlich verfügbar sind. Die Kombination aus Batterien und erneuerbaren Energien ändert jedoch alles. Sobald erneuerbare Energien in Verbindung mit Batterien eingesetzt werden, steht der erzeugte Strom dann zur Verfügung, wenn ein Bedarf besteht. Batterien ermöglichen die Speicherung der überschüssigen Energie aus erneuerbaren Energien, sodass sie später bei Bedarf ins Netz eingespeist werden kann.

- **Thermische Erzeugung:** Batterien ermöglichen es konventionellen Kraftwerken, bei gleichzeitiger Steigerung der Flexibilität höhere Umsätze auf dem Ausgleichsmarkt zu erzielen. Darüber hinaus geben sie den konventionellen Kraftwerken die Möglichkeit, das Netz im Falle eines gefürchteten Totalausfalls neu zu starten. Eine Kombination aus traditionellen Kraftwerken und Batterien erhöht die Gesamteffizienz des Systems, indem die Kraftwerke dadurch effizienter betrieben und mehr Nebenleistungen bereitgestellt werden können.

Die fünf wichtigsten Empfehlungen:

- Die Anerkennung der Speicherung als Schlüsselkomponente der Energiewende.

- Die Beschleunigung der Entwicklung flexibler Märkte, einschließlich der Rolle der Speicherung.

- Die Unterstützung bei der Einführung von EVs im ganzen Land, bevor die deutsche Automobilindustrie ihren Wettbewerbsvorteil an Startups wie Tesla und Länder wie China verliert.

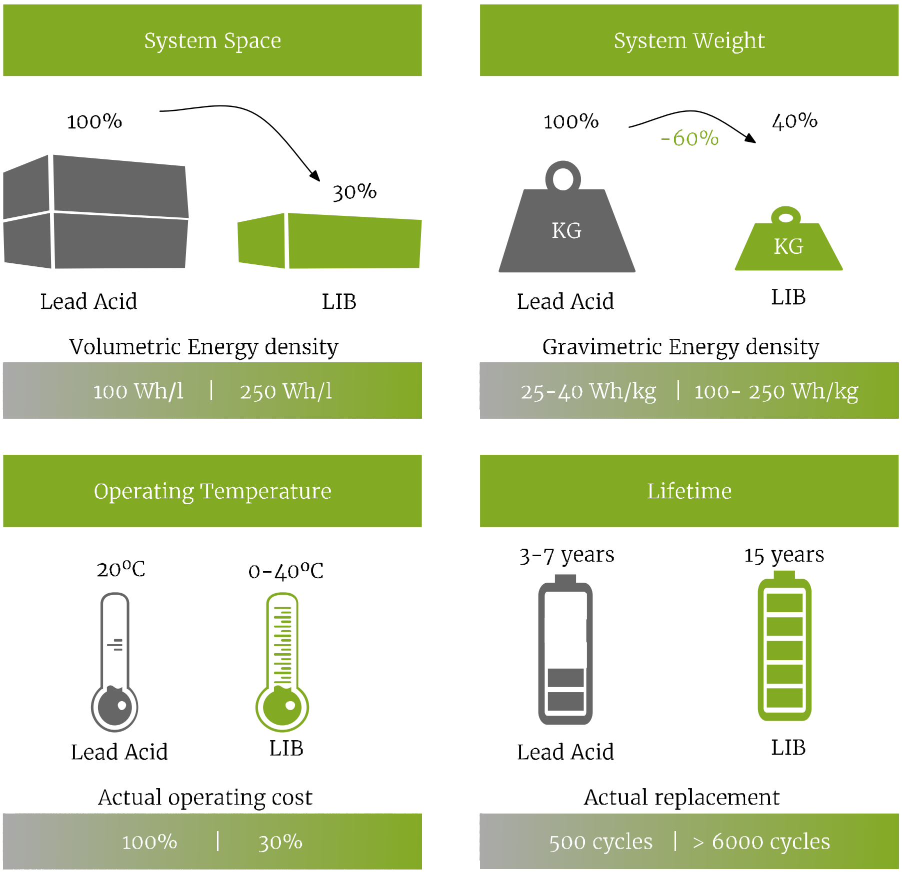
- Die Gewährleistung der politischen Unterstützung und Festlegung eines entsprechenden Rechtsrahmens, um den weiteren kommerziellen Einsatz von Technologien für Second-Life-Batterien zu fördern.
- Die Zusammenarbeit mit Übertragungs- und Verteilungsnetzbetreibern sowie Aufsichtsbehörden, um zur Quantifizierung und Realisierung des wahren Potenzials der Speicherung für das Stromnetz beizutragen.

SECTION 1: BATTERIES

How we generate energy is one of the major challenge of our era. Climate change induced by the burning of fossil fuels to power our energy system and move our cars is threatening our planet and our lifestyle. Despite living in a time of constant innovation and technological breakthrough, the technology that could change the energy world in the 21st century, the battery, was invented three centuries ago. Advanced batteries have the potential to power our transport system thereby shaping global demand for fossil fuels while at the same time enabling the increasing usage of renewables in the electric grid, not to mention bring reliable electric power to businesses in developing economies and extend electricity to millions of the world's poorest.

Batteries allow energy to be stored chemically which can be converted when needed to electricity and used as a source of power. There are thousands of applications where batteries are required, from mobile phones to laptops and from car starters to medical devices. Each application has its own requirements with different performance profiles for the batteries, which results in a range of different battery chemistries to fulfilling those needs. There are two key types of batteries — primary and secondary. Chemical reactions in primary batteries are irreversible, which makes them non-rechargeable. Primary batteries account for roughly 90% of total global battery unit volume, mainly small consumer disposable batteries. With regards secondary batteries, the chemical reaction can be reversed, which allows for recharging the battery, with the number of recharging cycles dependent on the battery's material.

Exhibit 2
Characteristics comparison Lithium-ion vs lead acid batteries



The battery space is in the midst of a radical transformation as advances in battery technology together with the emergence of new applications such as vehicle electrification and renewable energy storage drive tremendous growth. Although the most common battery technology is lead acid, lithium-ion batteries are fast becoming the technology of choice given their significant advantages in terms of energy density, lifetime, working temperature and weight. This is particularly the case with electrical vehicles (EVs).

Lithium Batteries

Most current plug-in electric vehicles use lithium-ion batteries and they are already the standard technology for the vast range of consumer electronic products, such as mobile phones and laptops, which are such a big part of our modern lives.

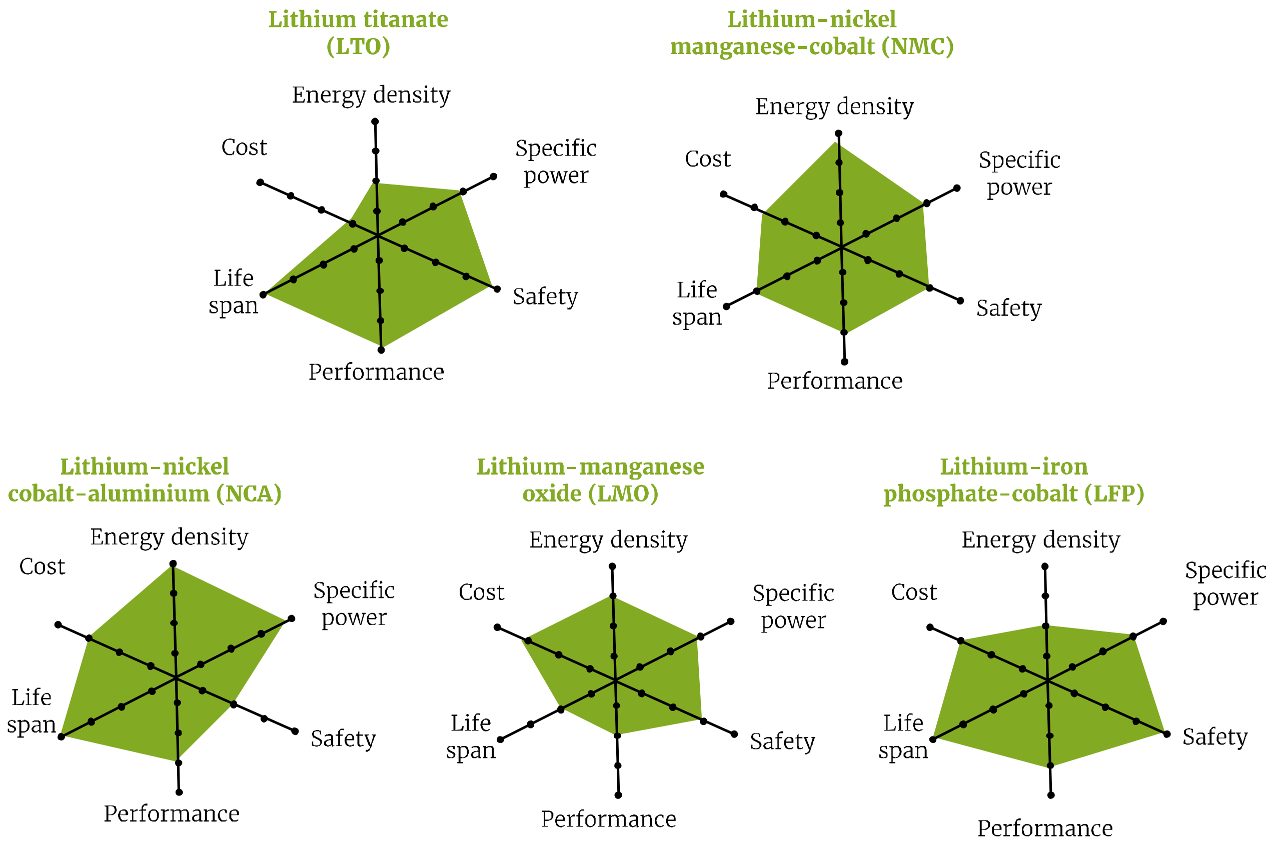
The structure of a lithium-ion battery is made up of two electrodes, a cathode (positive) and an anode (negative), and a medium, called the electrolyte, through which the electric charge flows. Lithium ions move back and forth between the cathode and the anode when a lithium-ion battery charges and discharges. Lithium-ion batteries comprise a family of battery chemistries that employ various combinations of anode and cathode materials. The cathode part of the battery is the place where traditionally the lithium-ion battery industry can tweak the energy and power density—or how much energy and power can be stored per volume. Different material combinations can make the battery able to store more energy or produce more power, and likewise make the battery more or less stable. Currently, there are five major lithium-ion battery chemistries available: lithium-titanate (LTO), lithium-nickel-manganese-cobalt (NCM), lithium-nickel-cobalt-aluminium (NCA), lithium-manganese-oxide (LMO) and lithium-iron-phosphate-cobalt (LFP) each of which have different characteristics and thus different advantages and disadvantages.

In Exhibit 3, we compare these chemistries along six dimensions. What is clear is that no single technology wins along all six dimensions. Choosing a technology that optimizes performance along one dimension inevitably means compromising on other dimensions. This is the reason why multiple chemistries are likely to coexist for some time as technologies evolve.

Safety: The most important criterion for electric-car batteries. The main concern is avoiding thermal runaway, a process in the cell chemistry producing heat and potentially resulting in a fire. Thermal runaway can be caused by an overcharged battery, too-high discharge rates or a short circuit. Chemistries that are prone to thermal runaway must be used in conjunction with safety measures that either enclose the cells or monitor their behaviour.

Exhibit 3

Tradeoffs among principal lithium-ion batteries chemistries



Life Span: Battery life span is measured using cycle stability and useful life. Cycle stability is the number of times a battery can be fully charged and discharged before being degraded to 80% of its original capacity. The useful life which is measured in years remains a hurdle, in part because aging accelerates under higher ambient temperatures.

Performance: Batteries can be optimised for different temperatures but it is difficult to engineer them to function effectively over a wide temperature range.

Energy density: The specific energy density of a battery is the capacity of storing energy per kilogram of weight. Battery cells today can reach nominal energy densities of 250 watt-hours per kilogram (Wh/kg) while the specific energy of the resulting battery pack is typically 40% lower.

Specific Power: The specific power is the amount of power that batteries can deliver per kilogram of mass. Currently, batteries' performance in terms of specific power exceeds that of internal combustion engines.

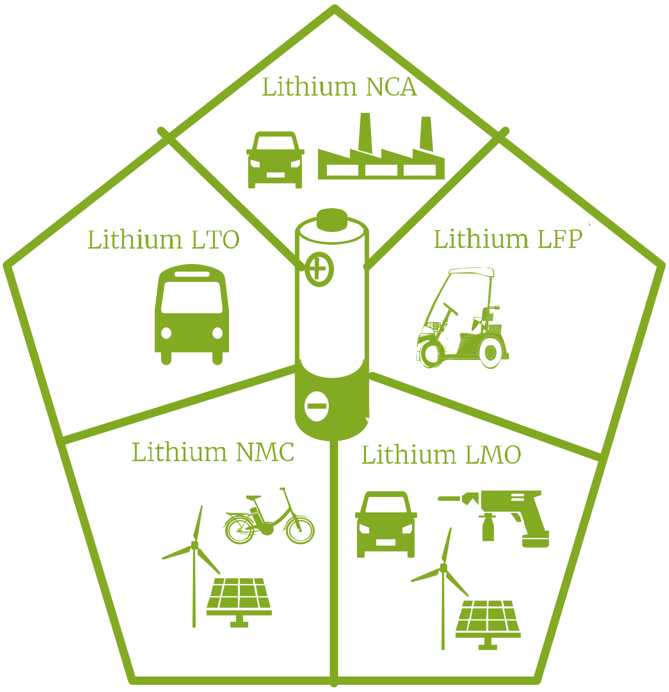
Charging Time: Lithium-ion cells are very sensitive to overcharge and thus cells need a long time to be safely charged. Charging times are a major challenge for commercial acceptance by the end customer.

Different Chemistries Different Applications

The optimal battery chemistry for any given application is determined by the specific discharge and charge power requirements as well as ambient conditions. This means, for instance, that an electric car and an electric bus will not use the same type of battery given their different driving patterns. Electric buses need to have batteries that have long life and which allow fast charge which is why the LTO technology is being used here. In contrast, Tesla in order to give its customers lots of torque and thus acceleration, chooses a more powerful and energy dense battery the lithium NCA.

A battery coupled with a photovoltaic installation can have a lower energy density, but it needs a longer cycle life, it needs to be able to be charged and discharged many more times than a Tesla battery. Here most manufactures choose the lithium LMO chemistry. In contrast, lithium-ion batteries that are used in our phones need to have high specific energy density and tend to use lithium cobalt oxide (LCO). What this all means is that there is no “right” lithium-ion battery chemistry.

Exhibit 4
Principal lithium-ion chemistries and main applications



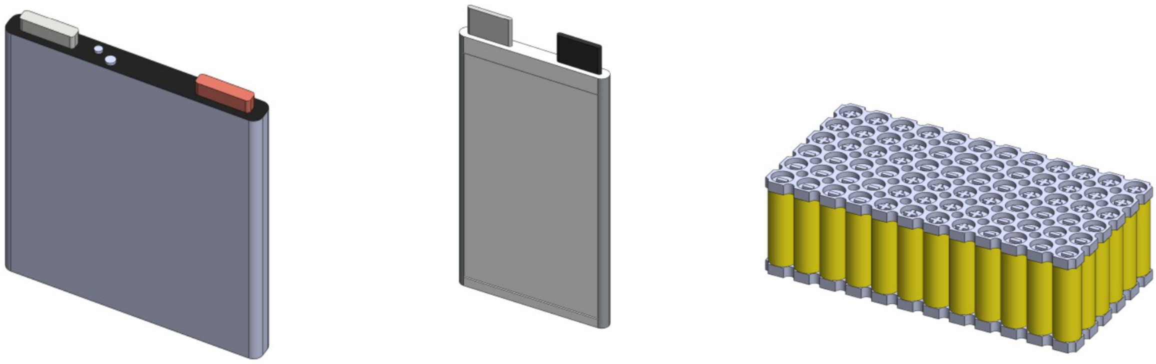
Physical types of batteries

The physical design and size of the battery is important when considering what will happen to the battery after the first life of the battery. Will the battery be recycled or reconditioned and reused as a second life battery depends a lot of the design of the battery. The large format cells are clearly of prime interest for consideration for second use applications. Small cells by contrast increase the remanufacturing, quality testing and assembling cost and makes a second use application economical unviable.

Cylindrical: The cylindrical batteries that we have in our remote controllers and flashlights were introduced in 1907 and continue to be one of the most widely used packaging styles. The advantages are an optimized and well-known manufacturing process and good mechanical stability. Tesla is the main supporter of cylindrical cells for both their mobility and stationary battery applications. Unfortunately cylindrical batteries present an unaffordable challenge for second life applications, due to their small size.

Prismatic: Prismatic cell were first introduced in the early 1990s and make optimal use of space by using the layered approach. These cells are predominantly found in mobile phones and tablets. Each manufacturer design its own cell size, as there is any universal standard defined. Panasonic and Samsung SDI are strong supporters of prismatic cells for their applications and allow economical second use applications.

Exhibit 5
Physical shape batteries



Prismatic Pouch Cylindrical

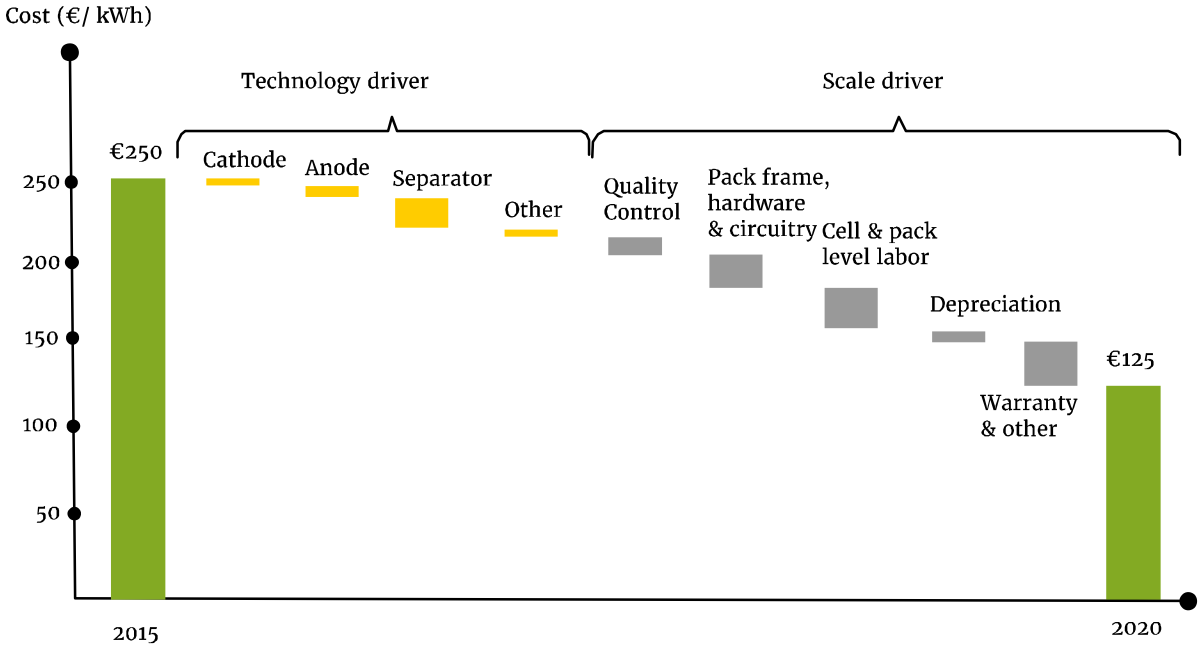
Pouch: The pouch cell is based on a relative light new envelope resembling a tetra brick, first introduced in 1995. The envelope offers a simple and lightweight solution that permits different battery designs, but it needs support and free space to expand. LG Chem and Nissan are strong supporters of prismatic cells for their applications.

Future Battery Cost Evolution

Lithium-ion battery pack costs have come significantly in recent years falling from US$1,000 per kWh in 2008 to around US$350 per kWh today, with the cost leaders such as Tesla/Panasonic even lower at US$250 per kWh. Going forward costs are expected to half to $125kWh by 2020 with main cost reduction drivers coming from technology improvements in the anode and cathode chemistries and scale effects in the battery and pack assembling processes (see Exhibit 6).

Exhibit 6

Leading battery supplier cost breakdown 2015-2020



And as these costs come down, increasing numbers of applications for lithium-ion batteries and in particular the EV market will open up. This in turn will have significant implications for the assumptions used when modelling future energy and transport systems and permits an optimistic outlook for EVs contributing to a low-carbon transport.

Future Lithium Battery Manufacturing Capacity

In 2013, the total global production capacity for lithium ion batteries was just over 35GWh with the vast majority going into all our mobile phones and laptops. But the numbers required for electric vehicles and thus the economies of scale potential is huge. One Tesla, for instance, takes the equivalent of over 1,000 laptop battery packs. Tesla alone, together with their battery cell partner Panasonic, is building one production plant, the Gigafactory which will be capable of producing 35GWh of cells and 50GWh of battery packs per year which should be enough capacity for a half a million automobiles. And there are not the only ones. Other Asian battery manufacturers, especially Korean and Chinese are increasing they capacity production well above estimates. Our view is that that battery manufacturing capacity could be as high as 250GWh by 2020. This capacity increase will have huge repercussions for not only the motor vehicle industry but also the oil and power industries.

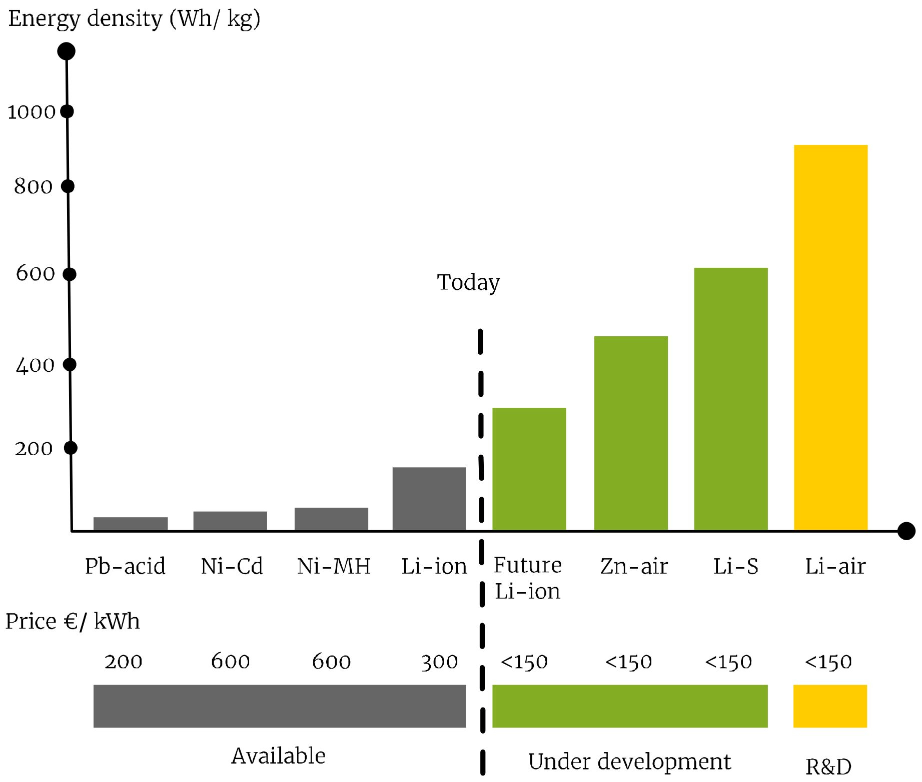
Future Battery Chemistry

The industry is aware that lithium-ion performance will plateau around 250-350 Wh/kg. Therefore new chemistries will be needed to have a disruptive improvement in performance and cost in batteries. We have seen a similar evolution with silicon photovoltaic modules, which were averaging 15% efficiency 10 years ago and nowadays market leaders are at 23%. Different chemistries offer the theoretical potential to disrupt in 10 years time the actual technology in terms of energy density by more than 100%. The most promising technology to appear in the next 10 years according and become market leader is lithium-sulphur (LiS). Currently the best

Li–S batteries offer specific energies on the order of 500 Wh/ kg, significantly better than most lithium-ion batteries, which are in the 150 to 200 Wh/ kg range. Other best class performance characteristics are its reduced costs and is relatively light (about the density of water).

Exhibit 7

Present and future batteries technologies



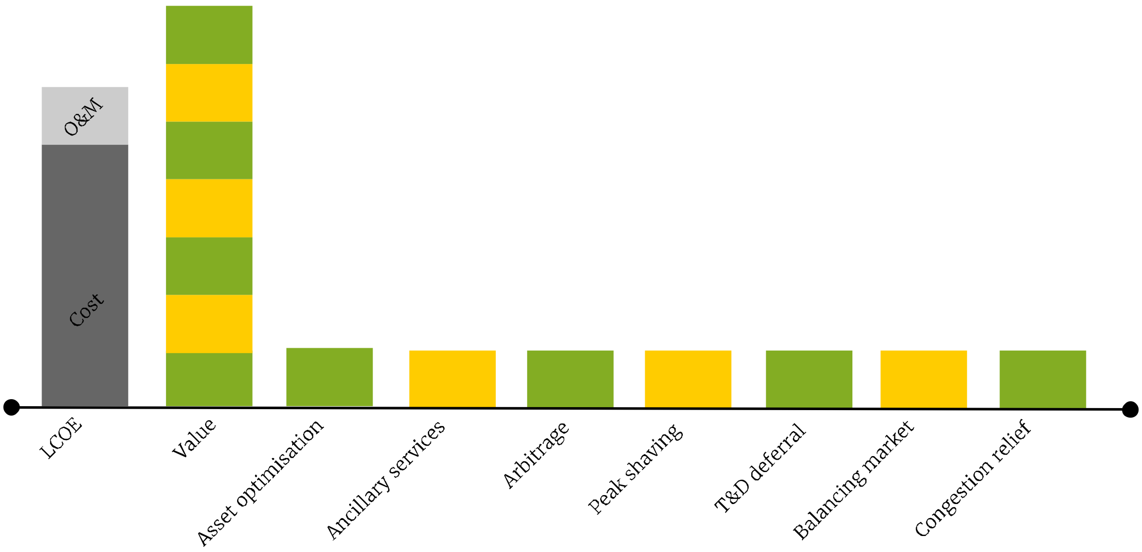
Section 2: Battery Uses Cases

Following rapid cost reductions and significant improvements in capacity, efficiency and performance, the global energy and mobility sector is captivated by the promise of deploying batteries. Batteries are promoted as the game changer or as the Holy Grail, which could contribute to solving the intermittent challenge of renewables and climate change. But there is much more to it than that.

Until now the common metric when comparing the cost profile of different generation technologies is the levelised cost of energy (LCOE). The LCOE calculation involves combining capital costs, operations and maintenance (O&M), performance, and fuel costs and then dividing by the amount of electricity produced over the lifetime of that technology to arrive at a cents per kilowatt-hour (kWh) cost.

Using this metric for batteries maybe misleading as the LCOE only considers batteries as a production plant and neglects all the different applications and revenue streams that are possible. The key question with a battery is thus not the cost but what value that can be generated with that battery, and what stacks of revenues besides selling power can be generated with that battery.

Exhibit 8
Batteries cost vs value



From a system perspective, the value of storage is the ability to provide power quality and reliability, and security of supply. This can be in the form of uninterrupted power supply to end-users, providing some reserve margin or initial power to restart the grid after a blackout. In this context, high reliability is more important than high costs. Many of the different services that battery can provide are not economically attractive as a standalone application. However, since a single energy battery storage can deliver a stack of different services, lithium-ion batteries focusing in one application can also deliver a host of other services during non-committed hours in the main application. Below we look at some of the most common revenue streams available across the European Union.

Asset Optimisation: Power plants are categorized according to their speed and the duration that they deliver power. Some of them run almost all the time at full capacity such as nuclear plants and others only at peak times as is case with gas plants. Apart from providing power, all thermal generation plants also provide grid stabilization services but by running these stabilization services they often don't run in the most efficient and cost effective way.

Coupling lithium-ion batteries with traditional thermal generation units enables the conventional generation plant to react quicker and more effectively to grid operator needs as well as changes in power prices.

Energy arbitrage: Arbitrage refers to the situation when power is purchased and stored when power prices are low and sold or used when it is higher. This arbitrage opportunity will only increase as penetration rates of intermittent renewables increase. When operating storage in this manner, energy will be time-shifted. The economic reward is the differential in the prices between buying and selling electrical energy, minus the losses during the full charging and discharging cycle.

Using batteries as an arbitrage application helps to mitigate high electricity prices and to reduce potential low load conditions in cases where there is insufficient demand commonly at night or at the weekends, coincident with large electricity production attributable to growing wind and solar generation capacity.

Balancing market: Balancing refers to the situation after power markets have closed in which a grid operator acts to ensure that demand is equal to supply, in and near real time. This situation occurs at the sub fifteen-minute timescale. Because of this, energy storage is particularly well suited for load following due to the technology's fast ramping capability. Traditional thermal power plants providing this service often have sufficient capacity for load following, but they cannot ramp up or down nearly as fast as a battery-based energy storage system providing the same service.

Furthermore, energy storage is a very capable mid-merit generation facility since its output can be adjusted throughout the day to respond to load and demand fluctuations with no penalty to efficiency.

Peak shaving: Commercial and residential customers can reduce power draw from the grid during specific time periods in order to reduce the demand charge component of the electricity bills. Depending on the utility and country, demand charges are set based on the highest 15-minute demand period of the month. In others, utilities monthly peak demand is overestimated to avoid expensive penalties charges in case of demand breach. In some countries demand charges can account for over half of customer's monthly electricity costs.

Lithium-ion batteries are a reliably solution, called upon at key times throughout the day, it is a very dependable approach to managing peak building loads and reducing demand charges. Batteries can provide this service and as little as 30 minutes of storage can provide sufficient power to reduce demand charges. Electric vehicles if configured in a V2H structure can provide this service while ensuring that sufficient charge remaining to be driven away at the end of the day.

Transmission congestion relief: Transmission congestion occurs when there is insufficient transmission capacity among the transmission grid during peak demand. When this occurs power generators must be redispatched to alleviate congestion during certain times of the day incurring in extra cost.

Energy storage can help the grid operator avoid the redispatching process when batteries are deployed downstream of the congested area. Lithium-ion batteries can store power downstream of the congestion point during non-congested periods and dispatching that electricity during periods of congestion. While this process occurs only 1% of the time, batteries can provided other services.

Power generation deferral: Batteries can be configured to provide peak demand and entirely avoid utility investments in peak power generation or retired actually diesel and gas peak generations units. For peaking purposes generators are run at 70-80% of capacity and ramped up or down depending on the grid needs. Putting in storage would enable such plants to be run closer to full capacity which is a significant cost saving which is critical in countries which have strong growth in electricity demand. Electricity storage is a compelling alternative to ramping up and down existing plants or using expensive and rarely used peakers plants.

T&D deferral: Batteries can delay or entirely avoid utility investments in transmission and distribution system upgrades that are necessary to meet load and supply growth on specific regions of the grid. When peak demand at a transmission or distribution node is at or near its rated load-carrying capacity and load growth forecasts indicate that the system may soon be overloaded, utilities invest in system upgrades to meet the forecasted load growth. These upgrades are normally driven by a small number of peak hours throughout the year that cause load to exceed the system capacity of certain equipment.

Instead of investing a large, lump sum to upgrade a transmission- or distribution-level substation, utilities can defer or completely avoid this investment by installing batteries. Lithium-ion batteries are especially well suited for this service. Batteries can be readily called upon (either through direct utility control, a smartly designed rate, or a market signal) for the few hours each year when the existing substation may be overloaded. Since the battery will only be called upon for some 20–60 hours each year to actually alleviate load on the substation, that means that the battery is able to deliver other services to the grid upwards of 99% of the time.

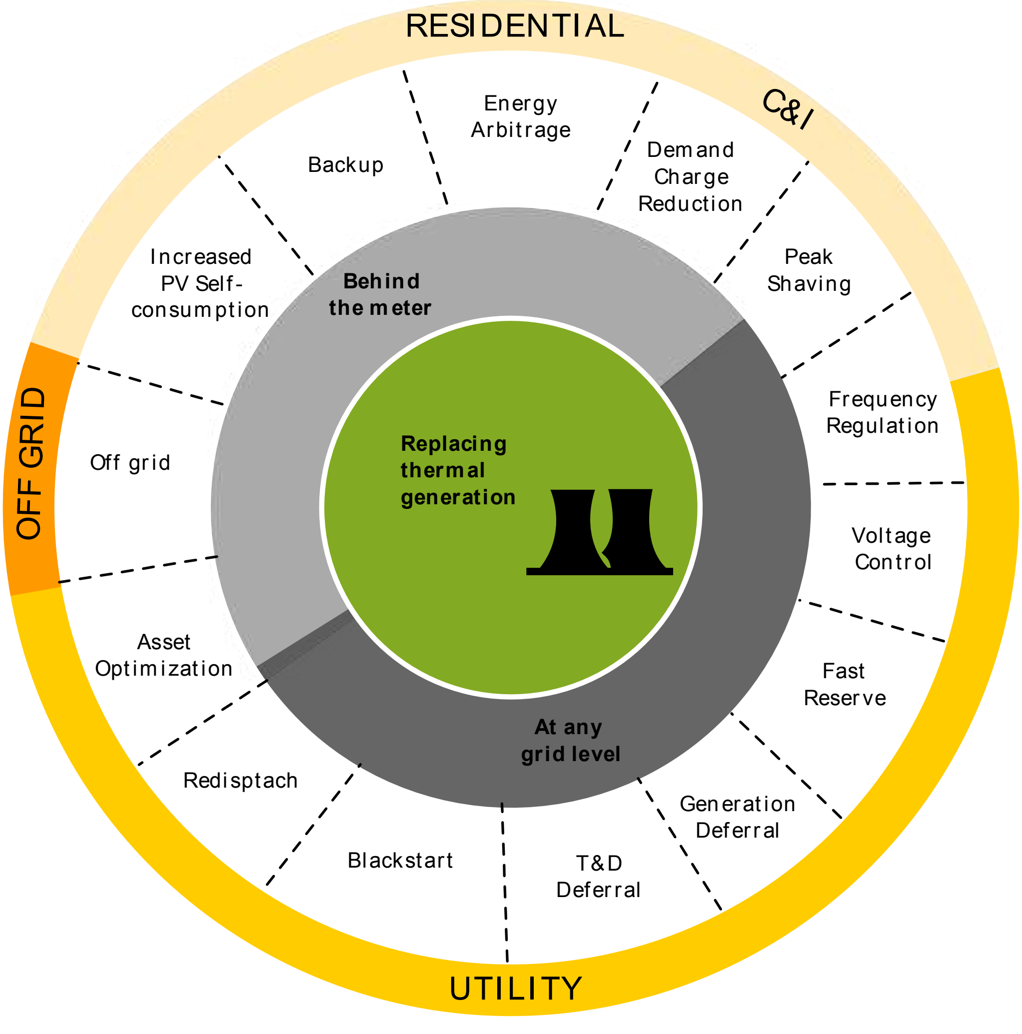
The value of deferral varies dramatically depending on the condition and age of the transmission or distribution system, the prevailing load profile, and load forecasts. However, deferring upgrades is one of the more valuable services that an energy storage system can provide.

Backup: For large industrial customers and datacenters, even the smallest variation in power quality resulting from grid instability can cost millions of euros in lost productivity. Energy storage can provide backup power at multiple scales ranging from sub-second-level power quality for industrial operations to household backup when paired with onsite PV generation. This service has long been valued and provided to different customers by many technologies, most prominently by on-site diesel gensets and lead-acid batteries.

Lithium-ion based technologies have evolved to a point where they can now deliver reliable backup power at a price point well below that of diesel gensets when paired with a renewable generator. Furthermore, lithium-ion batteries are flexible enough to easily deliver specific power demands. Since the battery will only be called upon for less than 1% of the time that means that the battery is able to deliver other services to the grid upwards.

Exhibit 9

Batteries can provide up to 14 services to four stakeholders group



Frequency response: Regulation ensures that the frequency of the grid is held within an acceptable tolerance band in order to avoid grid instability. In Germany and Europe this tolerance band lies between 49,8Hz and 50,2Hz. Lithium-ion battery based energy storage can rapidly ramp its power output up or down, the technology is particularly well suited to ensuring that grid frequency remains within an acceptable range. While delivering frequency regulation it is not able to directly provide other services. However, it can easily split its capacity between regulation and other services.

The batteries ability to rapidly ramp up can be as fast as 50 ms. This advantage also creates a potential problem for regulation markets everywhere. Because of how capacity payments are currently calculated, frequency regulation prices may collapse when lithium-ion batteries saturates the market. Currently, the market clearing process automatically assigns a working or opportunity cost to all participating assets, which allows the unit with the highest working cost to set the market-clearing price. But energy storage has no working COST associated and when storage is deployed at scale and able to meet all market calls for regulation, the price could collapse under the current market-clearing mechanism.

Voltage regulation: In order to ensure reliable and continuous electricity flow, voltage on the transmission and distribution system must be maintained within an acceptable range to ensure that both real and reactive power production and demand are matched. Voltage Regulation and Volt Ampere Reactive Regulation (Volt/VAR) is also required to support reactive power needs of the bulk power system in the event of system emergencies.

Energy storage is well suited to provide distributed Volt/VAR support close to the point on the system where it is needed. Reactive power cannot be transmitted long distances efficiently, and power electronics providers are enabling distributed storage to supply reactive power more efficiently than traditional approaches to Volt/VAR in both regulated and deregulated markets. Lithium-ion batteries can provide voltage support together with other ancillary services, while not causing any operational conflicts.

Black start: In the event of a grid outage many thermal power plants are unable to operate because the grid cannot provide power for the unit to come online in the first place. Accordingly, black start units (typically diesel gensets located on-site at thermal power plants) are run in emergency situations and used to start up larger units in order to help the grid come back online as a whole. Black start capability is compensated with a standard black start rate or a cost-of-service rate.

Lithium-ion battery systems can be collocated with power plants and provide black start support, just as diesel gensets do now. Systems located at these stations would be called upon very rarely, leaving black start-focused, collocated energy storage systems at the transmission level available to provide any number of other grid services.

Secondary reserve: Secondary reserve is power generating capacity available to the grid operator within a short interval of time to meet demand in case a disruption of supply or an unexpected grid situation. Reserves require a storage device to maintain a minimum discharge duration to meet hourly commitments in case of a contingency event. Since these events are infrequent, energy storage devices can provide reserve capacity while simultaneously providing several other services, so long as they maintain a certain charge level. This makes energy storage a ripe technology for provision of this particular service.

Time of use management: The gradually introduction of smart meters with the coupled introduction of time of use (TOU) tariffs open a new opportunity for batteries. TOU rates are generally structured as peak, partial-peak and off-peak time periods, where the time blocks differ in winter and summer based on the system load profile during these periods. This rate structure allows the utility to send a price signal to the customer that flattens the system's load profile and lowers overall production costs.

Energy storage can be configured to pre-charging during off -peak hours and discharging to meet customer load during peak periods. Furthermore, an energy storage system used for TOU bill management will be idle for a large portion of the day and therefore available to collect revenue from other grid services. The combination of solar + storage increases the system performance and maximize savings.

Increase PV-self consumption: Batteries are the primary method being used by households (and increasingly commercial customers) today to maximize solar self-consumption and become grid independent. Self-consumption has become a major trend in Germany and Australia, places where feed-in-tariff levels for residential PV customers have plummeted well below the retail rate, incentivizing customers to maximize the amount of PV they consume on-site. Using energy storage to shift as much of a building's load under a solar production curve as possible dramatically increases the value generated by a customer under either of these proposed rate structures.

Four main market opportunities for batteries

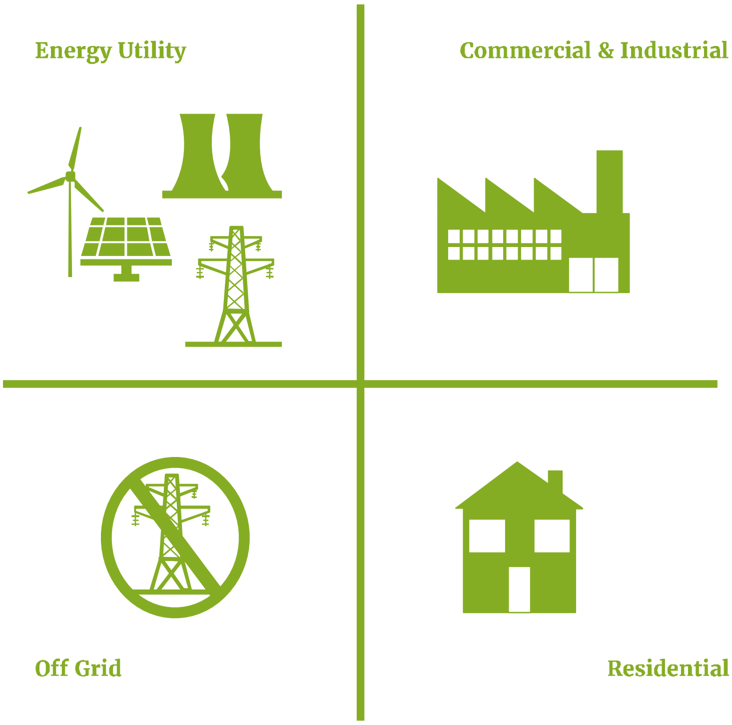
Energy storage can be sited off grid, behind the meter, at the distribution level, or at the transmission level. At all levels on the electricity system batteries can add value to the grid. However, customer-sited, behind-the-meter energy storage can technically provide the largest number of services to the electricity grid at large (see exhibit 9).

Off grid: There are about 1.3 billion people living without electricity, but there are at least a billion more people with a grid connection that's often expensive and unreliable. People in these regions want access to affordable, reliable energy in sufficient quantities for them to light their homes, cook, do homework, charge their phones, and listen to the radio. These unserved and under-served customers are willing to invest in solutions like solar and batteries. Yet more megawatts of renewables will not resolve the equity challenge that has to be addressed if the world is to achieve universal energy access. 60% of this population will have to be reached off-grid, through household-level systems or mini-grids serving communities. The governments responsible for these communities are either too poor to afford the construction of the energy grid or to corrupt to manage such investment infrastructure.

The 1.3 billion people who have no access to electricity spend an estimated $30 billion annually on kerosene. Many companies such as Berlin based Mobisol are beginning to offer solutions for this untapped market segment. The system typically consists of a 50-watt solar panel and a lithium-ion based battery capable of powering lights and small appliances for a few hours in a 12-volt DC system. They tend to upgrade asking for more gadgets and appliances after a few months once they get comfortable with the company’s services and know they’re reliable. The system is normally based in a mobile-payment platform to allow customers to purchase energy in small amounts. It’s basically a decentralized prepaid utility, with almost no running cost and no grid to maintain.

Exhibit 10

The four battery use cases

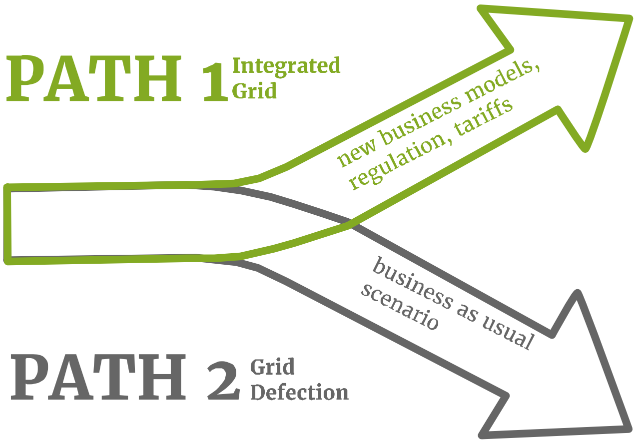


Batteries are allowing millions to leapfrog from no electricity at all straight to renewables and batteries. The combination of batteries and solar is cheaper and quicker to build than to build out the grid circumvallating the 20th century. In many parts of the western world the energy systems are changing faster than nearly anyone has expected. From a centralised model built around large fossil fuel generators and an expansive network, to a decentralised model where suburbs and communities use micro grids to serve their own energy needs and in most cases completely defecting from the grid. Australia and Hawaii are the first cases and good examples of this evolution that will affect other locations and regions as the economics of batteries and renewables improves.

In Australia regional towns, where the average network costs alone amount to around 20c/kWh, are already defecting from the grid today. In some cases the local utility SA Power Networks (SAPN) is installing batteries and solar in order to avoid building the grid and local communities are building private micro-grids to cover their energy needs. SAPN says batteries and solar will be a cheaper option for the network than upgrading its extended grid, and also in making repairs to lines damaged by storms and fires. And it will increase safety. In the main cities on the Australian east coast the investment bank UBS stated it could be economically attractive for the average household in Sydney and Melbourne to disconnect from the grid by 2018. In Hawaii, where electricity rates are similar to the Germans ones is seeing how residential users after the net metering program has been cancelled are beginning to defect form the grid.

The dilemma that western energy systems are presented is to allow maximize the benefits of storage and change the energy system as we know it or continue with the industry as it was 100 years ago. One path leads to grid optimized smart transactive solar-plus battery systems, and ultimately an integrated optimized grid in which customer-sited distributed energy generation such as solar batteries contribute value and services alongside traditional grid assets. Another path favours non-exporting solar PV, behind the meter solar plus-battery systems and ultimately actual grid defection resulting in an overbuilt system with excess sunk capital and stranded assets on both sides if the meter. Solar PV and batteries are an important role in the future electricity grid, but decisions made today will encourage vastly different outcomes

Exhibit 11
Grid defection



Residential: The value proposition for residential energy storage today is where solar PV was six or seven years ago, and the factors that led PV to mass affordability will likely have a similar effect on storage. Battery costs have declined by 80 percent in the past decade, and dozens of startup and big corporations are now competing to develop safer, more efficient and cheaper battery chemistries.

The economies of scale introduced by automotive manufacturers and Tesla’s Gigafactory battery manufacturing plant will place additional downward pressure on residential energy storage prices. Incentives like the German federal government of 30% capex on home battery systems (at least through 2018) will further sweeten the deal for potential purchasers of home-based energy storage.

But the key drivers that will make the economic case for residential energy storage are higher energy prices and changes to residential rate structures. The initial findings of battery coupled with solar is still an expensive investment, an actual payback of around 12 years in Germany with actual market conditions and regulation. At the end of the day, early adopters are not looking for a financial return, there are buying empowerment and transparency. They want to manage their bill. Mass appeal will come later once economics improve and business models are established. At the moment high energy prices and lack of transparency incentivize the purchase of both solar PV and energy storage systems. A home battery solution enables a PV system owner to shift energy from when it is generated to a later time for consumption. Homeowners save money when they use either direct PV power or stored excess PV power instead of expensive utility-generated power. Some early adopters see batteries and solar as an insurance policy to hedge against hikes in retail electricity prices. As a result, demand for residential energy storage products will continue to accelerate as PV energy reaches grid-parity in a number of countries.

The deployment of residential storage and solar system is seeing the awakening of new business models provided by aggregators, changing the nature from on-site to centrally controlled. Aggregators are changing the use of storage from self-consumption to revenue maximisation thank to the new revenue sources provided by peer to peer, energy arbitrage and balancing power. The beginning of this trend bring us to Sonnen and Lichtblick. As they launched services to maximize the operational of decentralize units. The most interesting service is the community program, which connects people who produce, use and share renewable energy. Energy arbitrage optimized the usage of storage by increasing the system performance especially in winter. Through buying power in the spot market at nights when the price are lowest or even negative.

In the near future 3rd party Home energy management is likely to be "Pay TV" service of the future for homes.

Commercial and industrial: The main driver to install batteries in the commercial and industrial segment in Europe is not energy but insurance, quality and cost. This is why, in Germany for example, every sixth commercial has its own power generation unit, providing electricity, heat or steam. We only see this trend intensifying as costs of self-generation particularly using a combination of PV+S continue to fall.

Batteries can target multiple uses in Commercial projects at the same time such as grid charge reduction and back-up power supply, as well as creating new revenues sources by participating in the ancillary services market.

Commercial customers, unlike residential customers, typically pay for peak demand (kW) charges in addition to energy (kWh) charges. The peak demand charge is normally calculated as the highest peak demand during the monthly billings cycle based on a 15 minute sample interval. For many commercial customers the peak demand part of their utility bill can be 30–40 percent of their total electric bill. The batteries system utilizes predictive analytics to anticipate and control energy demand, releasing stored energy at times throughout the day that are best suited to shave consumption peaks. Normally the system if financed through an ESCO model and is backed by a 10-year asset management service agreement. In times where the battery system is not required for peak shavings applications, the system can participate in the ancillary market. For example providing operating reserve to balance supply and demand on the grid in Germany can generate up to €150,000 per megawatt.

In addition to peak shaving batteries can be used to improve power quality inside the manufacturing premises by avoiding frequency hopes and voltages spikes, increasing therefore the production efficiency and avoiding unexpected production outages. Actual production equipment are really sensitive to power quality and effects of poor power quality result loss data, program failure, equipment lock-up or complete shut down.

Utility: The fascinating thing about batteries is that it’s such a multifunctional technology beyond just generating power, it's the Swiss knife for power, distribution & transmission engineers. Batteries can play a major role in all the duties from the energy system, simultaneously it can secure balance capacity and supply, and protects the grid from stress events as well as defer T&D grid investment and peaker generation.

As the price of energy storage continues to decline, it’s going to provide more and more utilities with an ability to defer capital expenses, especially those associated with the cost of having to build out new cables and transformers for the increasing integration of renewables. The build out of most utility grids is driven by peaks, where during an average of 15 to 20 hours a year, a conductor will overheat because it has to accommodate an increased amount of current to satisfy a particular load. When that happens, utilities typically over-duty existing resources creating significant costs for them and their customers. If a utility were to deploy an energy storage strategy instead and provide the extra transmission capacity needed at the end a problematic feeder, it wouldn’t have to transmit extra power down the line because it’s already down there. You eliminate the peak on the line and more importantly you eliminate the expenses needed to upgrade it. It’s through such a strategy that energy storage becomes a real capital-deferment tool for utilities.

In technical terms, large-scale battery-storage systems are ideally suited for provision of ancillary services. In addition to the dynamic advantages of the power electronics connection, other advantages of using batteries for grid stabilisation include fast implementation, simple scalability and the fact that they can be used in almost any location. Batteries are already today the de facto technology to provide new frequency control mechanisms and to reduce imbalance costs, which occur when forecasts of its sales portfolio does not match customer demand.

Large scale battery storage is going to be coupled in every large renewable generation plant in the next years. The reason why is to reduce the volatility at the origin point. Renewable energy generators will be connected to the utility grid only if a significant portion of daily energy production is postponed until the evening hours and this postponement can be achieved only with a storage system. In this case, the storage system stabilises the utility grids statically by balancing consumption and generation over the course of the day. In addition it can increase system performance, for example in the case of large scale photovoltaic a sudden decreases in generation in the event of cloud drift can only be countered with a storage system.

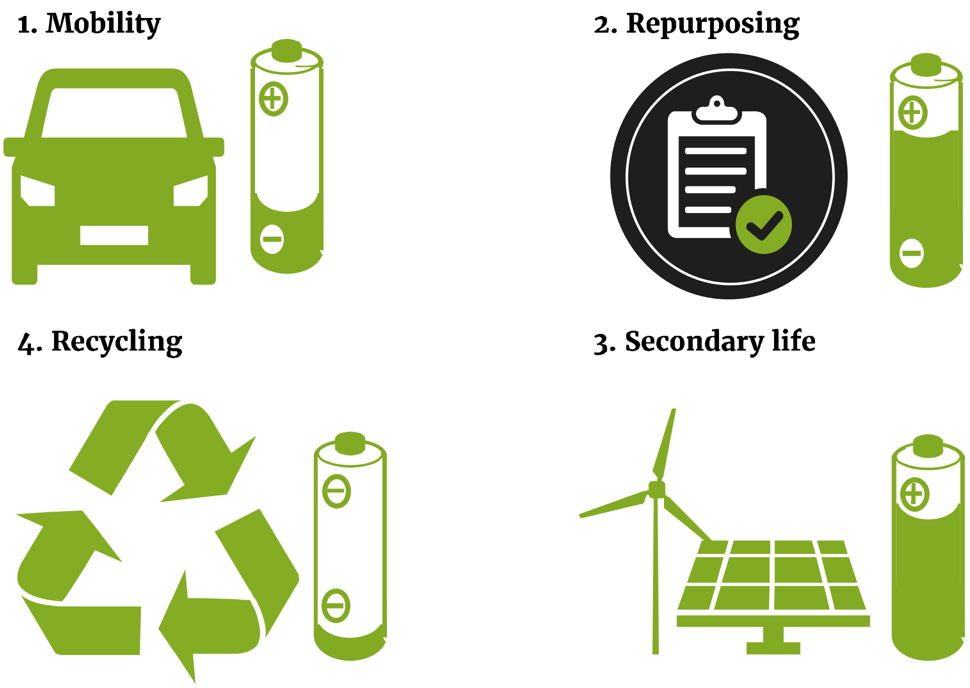
SECTION 3: SECOND LIFE BATTERY

Batteries like all of our gadgets are susceptible to time and age, with their life span depending on chemistry and use. In EVs batteries are usually charged and discharged at very fast rates. Frequently, those batteries have to endure adverse circumstances of high and cold temperatures. Typically batteries capacity will decrease to about 80% of the original capacity after five to seven, depending on a number of factors like their design, working temperature, charge protocol and state of charge. While an electric car battery with 80% capacity will significantly limit driving range, it will still retain enough capacity for use in other less stressful applications such as in the backup power market.

The other possibility is to recycle those batteries after they are taken out of the motor vehicle. However, recycling lithium ion batteries entails costs and potential waste. Instead of recycling the EV batteries after 5-7 years, the thousands of batteries that will be coming out of electric vehicles in the coming years could be repurposed, leading to a flood of inexpensive batteries that can provide energy storage services for households, utilities, and grid operators. These second-life batteries will provide multiple value streams to customers and grid operators and benefit the environment by integrating variable renewable energy and reducing the upfront cost of electric vehicles.

Mobility: The purpose of lithium ion batteries in the car industry is to power electric cars efficiently, cost effectively and in a low carbon way. When the battery capacity have been reduced and are not suitable for the first use they were originally designed for, users can swap their old batteries for new ones.

Exhibit 12
Second life battery process



Many of these old batteries will be repurposed for a secondary life. Understanding this first life of a battery is critical to predicting when automotive batteries will become available for second use in stationary purposes, as well as how healthy they will be and how long they will last. The following three processes are of critical importance: Apply big data to predict battery degradation as a function of duty cycle, temperature and time. These parameters are being collected by most EV battery management systems. Understanding how drivers will make automotive battery replacement decisions to estimate when the batteries will be available for second uses. Estimate the battery degradation, dependent of factors like breadth of duty cycles and climate environments.

Remanufacturing: The remanufacturing process includes the removement of the battery from the EV and the quality analysis of the different components. The quality analysis are based on components test and on analysis of the data stored in the battery management software. As more data is available the more precise can be determined the state of health of the battery. From an economic standpoint disassemble the battery into cells and analysing them separately is uneconomical, as they increase the workload. The reason for this is the differing designs of the battery and in particular the cylindrical and small size of the Tesla and Panasonic cells which makes the cost of reconditioning prohibitive. On the other hands the rectangular shaped batteries from LG Chem are much more suited to being reconditioned and used for second life purposes. Other components like the battery management system, sensors, cooling and housing can be reuse and therefore remanufacturing costs can be reduced further. Actual remanufacturing costs according to pilots projects conduct by NREL lies between 25-50€/kWh and is highly dependent on the type and state of the battery, the scale effects and the remanufacturing process.

Second Use Applications: After the batteries are remanufactured they can be use for a second life applications in the stationary sector. Accordingly the battery management system needs to be adjusted to the specific application to extend lifetime and economic benefit. As we saw see in section 2 and summarize in Exhibit 9.

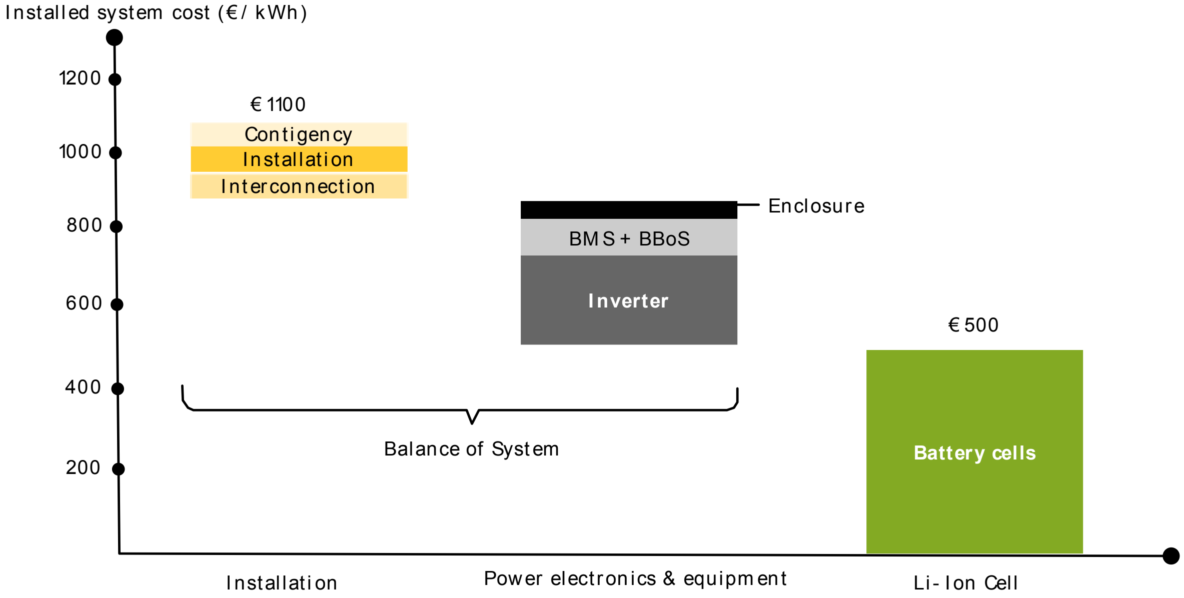
Recycling: After 10-15 years of second use, batteries can be collected and recycled. Current rules place the obligation for collection on distributors and for recycling on the producer of the battery. While lithium is 100%, recycled lithium is as much as five times the cost of lithium produced from the least costly brine based process. The value for the recycling business currently comes from the valuable metals such as cobalt and nickel that are more highly priced than lithium. Due the actually lithium low prices, almost none of the lithium used in consumer batteries is completely recycled. The slag containing lithium is used for non-automotive purposes, such as construction. However, with the increasing number of EVs entering the market in the future and with a significant supply crunch, recycling is expected to be an important factor for consideration in effective material supply for battery production.

PV + Storage residential model

In many European markets solar retail grid parity has been achieved, which means that the levelised cost of energy of producing electricity using rooftop solar is below what retail customers pay for electricity. And this is not going to change as PV systems prices continue to drop and electricity rates to increase. But there are other drivers, which are location dependant. These include the irradiation quality, the exempt from paying taxes, levies and surcharges for self-consumption, as well as the low compensation for surplus electricity fed into the grid and the government support for decentralised power generation systems. These factors have improved both near-term economics and the investment payback on the system. The economics of a residential PV system can be increased if the share of self-consumption is increased. This can be achieved by coupling the PV system with a lithium-ion battery. Batteries shift the solar energy production from when it is produced to when it is needed in the house thereby reducing consumer energy bills. This combination of PV+S already makes sense in countries like Germany and going forward we will see these offering being rolled out across most of Europe.

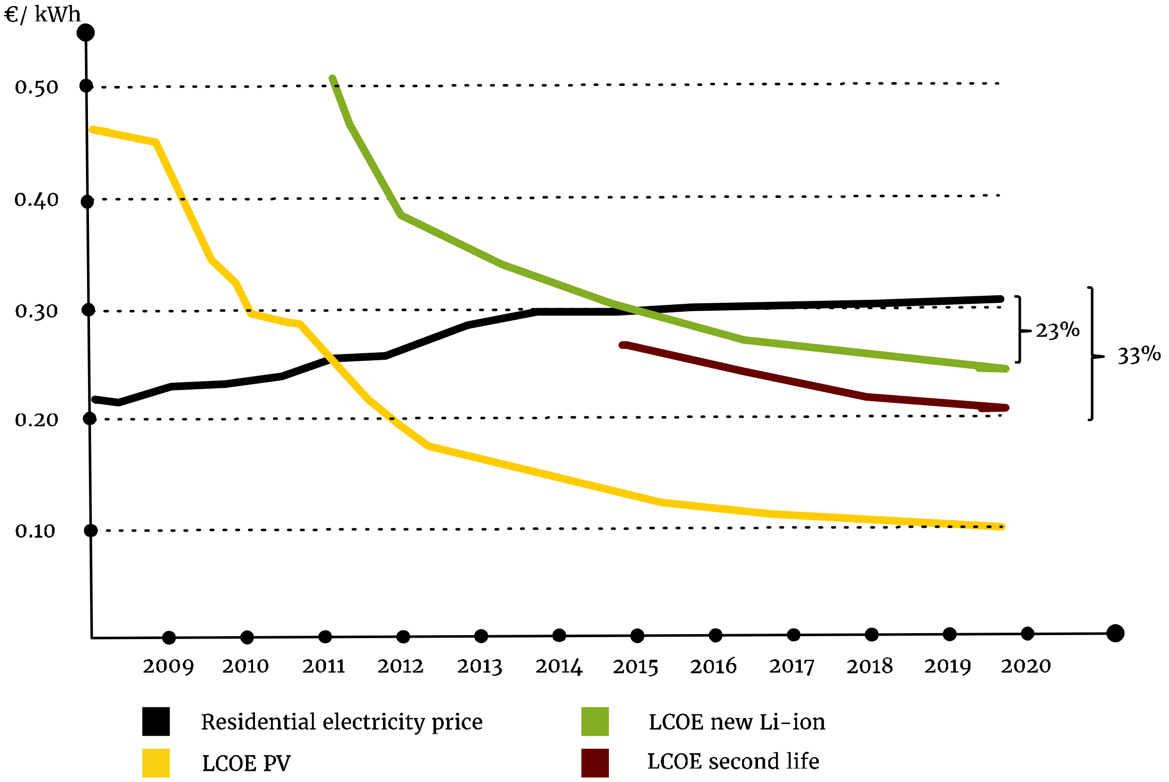
Exhibit 13

Residential energy storage cost breakdown



The economics improvement of a PV-storage system is based on increasing self-consumption, thus reducing the amount of power taken from the energy utility. By adding batteries this ratio can be increased theoretically up to 100%. But the economics of totally grid defection are at the moment prohibitive in Europe (but not in much of Africa), because the incremental increase in storage size to cover the whole energy demand. A single PV system has a self-consumption ratio of 35% in average. Due the high cost of residential storage systems up to €1100 kWh, a balance between investment in storage and self-consumption ratio is the key to improve the systems economics. As we can see in exhibit X with the battery system cost breakdown, the battery amount almost 50% of the system cost reaching €500. We add storage to the PV system in a 1.25 proportion and the self-consumption ratio increases to 65-70%.

Exhibit 14
Residential cost PV+S in Germany



Source: Own model

Nowadays the LCOE of a PV system in Germany is around €0.11/ kWh in the sunniest locations in Southern Germany. We are expecting the LCOE pf PV to come down to €0.10 /kWh in central Germany by 2020. While the LCOE of a PV+S system already reached grid parity in 2015. Going forward we expect the cost of PV+S to decrease significantly driven by technology improvement in solar as well as storage as well as cost reductions around balance of system costs. In addition we expect more competition as aggregators begin to mainstream added value services like energy arbitrage, which can even reduced farther the LCOE. By 2020 we are expecting LCOE of new PV+S to be 23% cheaper than electricity grid rates. Second life batteries are already under grid parity today and we are expecting by 2020 to be 33% cheaper than retail electricity rates.

The potential market size of second use batteries

As electric vehicle sales increase, the number of batteries that will become available for a second life usage will increase. The number of EVs in Germany has increased by over 50% annually in the last five years with similar growth expected in the coming years thanks to the introduction of second generation EV models and expected government support.

It is difficult to predict the exact size of the second life battery market which will be strongly influenced by four factors: sales of EVs; average and type of battery; customer's behaviour on battery upgrade; and percentage of second life batteries coming to the market. For these factors we are assuming realistic values based on the information available today:

- **Number of electric vehicles:** We are assuming as feasible the German government's target of one million electric vehicles by 2020 and of six millions by 2030. The reason why is the recent presentation success of Tesla model 3, achieving an astonishing 250,000 pre-order in 36 hours after its presentation. Tesla has shown again that there is real consumer interest and a market for EV. We also note that all the German car manufacturers will bring out new electric offerings over the next 18 months and we also believe that the German government will put in place a support mechanism for EV purchases next year.

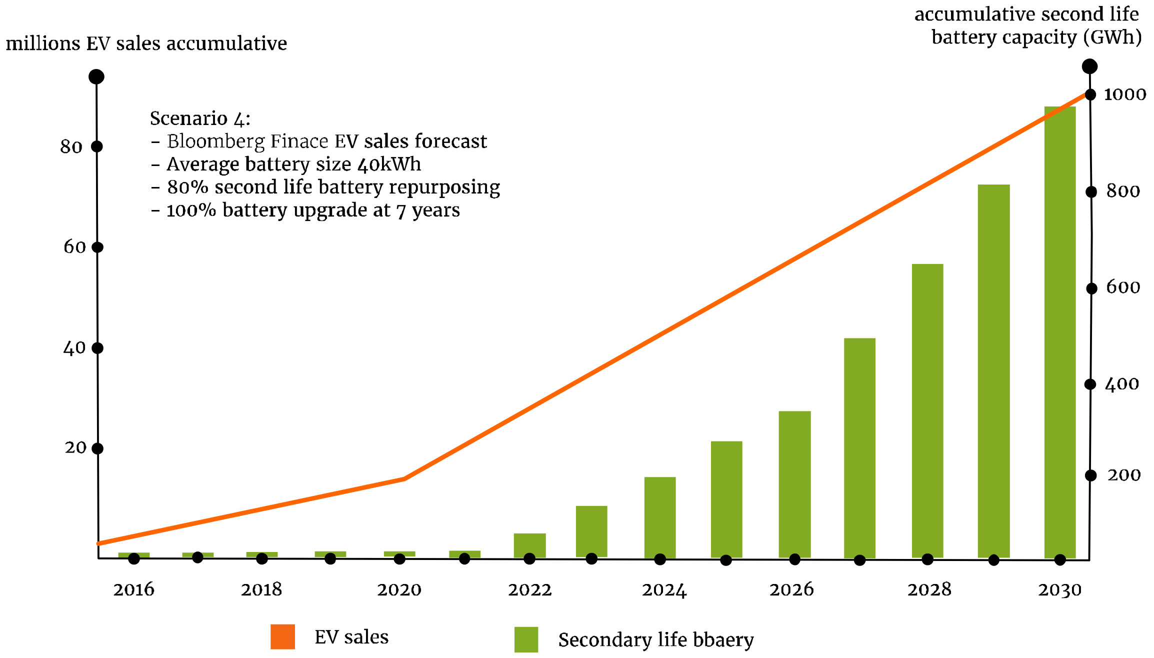
- **Size and type of the battery in the next 10 years:** EV batteries are evolving, the latest generation of batteries have 20-30% greater capacity than those of 5 years ago, and upgrades are being offered by EV manufacturers. The Tesla Roadster released in 2008 is offering today a battery upgrade which involves swapping its original 53kWh battery for a new one of 70kWh. Nissan Leaf (released from 2010) is also offering an upgrade to the old batteries keeping its 24kWh capacity. We are assuming the low end battery and establishing an average battery of 40kWh. Noting that the new Tesla Model 3 has a battery capacity of 64kWh and this will affect considerably the market in the next years.

- **Percentage of secondary life battery:** We are assuming a repurposed rate of secondary life batteries of 80%. The reason why is because all battery upgrade programs require the old batteries to be exchanged for the new ones. In some cases there is an economic return for the original owners and in others case of Tesla there is none. Noting that Nissan is reducing €1,000 the 24kWh battery upgrade. We are course of do not know whether this will happen or not as it will depend on customer's willingness to upgrade their existing batteries.

- **Battery upgrade rate:** We are assuming that the batteries from the first generation of EV are going to be replaced in a timeframe of 5 to 7 years in 100% of the cases. The reason why is because battery replacement is actually an upgrade, improving the quality and performance of the battery as well as the driving range and increases the value of the car.

Exhibit 15

Global accumulative sales of EV and second life batteries

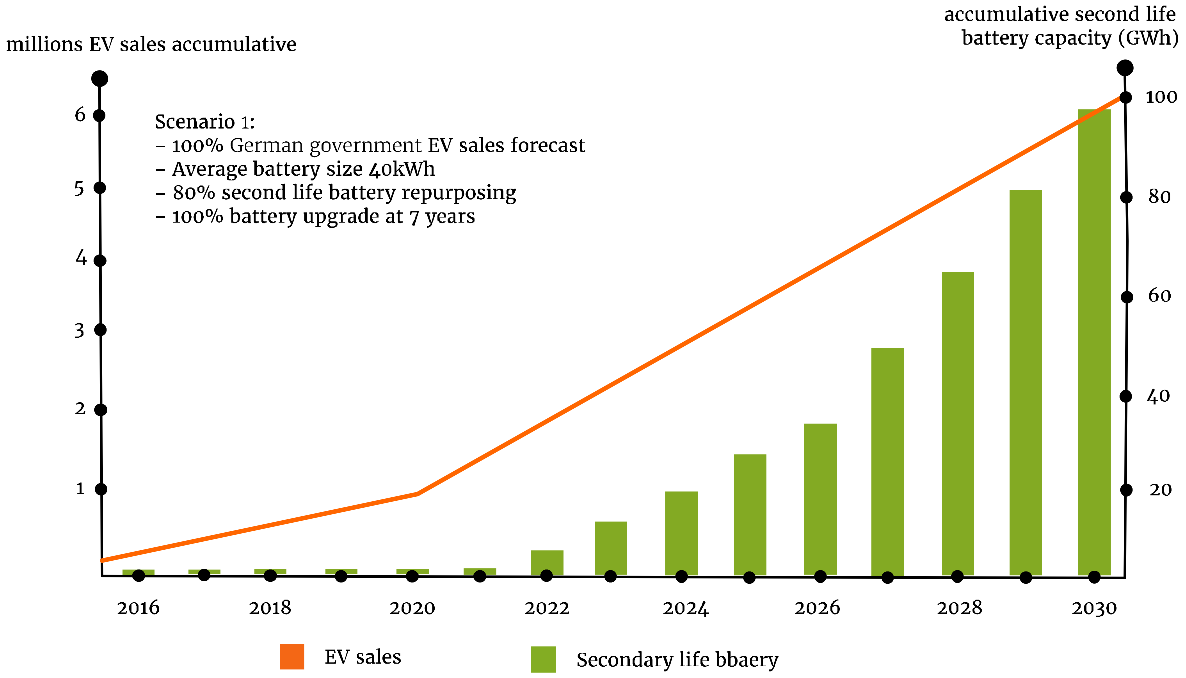


Global base scenario.

The most possible scenario for our point of view considers the EV sales assumptions set by Bloomberg Finance as most plausible; that means 6.7 million EV cumulative sales by 2020 and 88 millions by 2030. We consider the battery size to be 40kWh in average and a secondary life rate of 80% with a battery upgrade after 7 years. In this scenario by 2025 there will worldwide

Exhibit 16

Base scenario: Accumulative sales of EV and second life batteries in Germany



a cumulative installed capacity of secondary batteries of 230 GWh. By 2030 the capacity will have increase over four times achieving up to 1000 GWh.

Germany base scenario.

The most possible scenario from our point of view considers the target of EV set by the German government as achievable, that mean one million EV cumulative sales by 2020 and six million by 2030. We consider the battery size to be 40kWh in average and a secondary life rate of 80% with a battery upgrade after 7 years. In this scenario by 2025 Germany alone can have a cumulative installed capacity of secondary batteries of 25 GWh. By 2030 the capacity will have increase four times achieving up to 100GWh. This secondary capacity would be enough to power the whole Germany for two hours.

Exhibit 17

Barriers and solutions for secondary life batteries

Factors which could slow down second life batteries	2016	2025
1.- Economic return and storage market conditions	◑	◔
2.- Future competition from new batteries	◔	◑
3.- Remanufacturing costs	◕	◔
4.- Battery data availability	◔	●

Factors which could boost second life batteries	2016	2025
1.- Adapt regulation for secondary life battery	◑	◑
2.- Increase pilot projects and Goverment support	●	●
3.- Set re-manufacturing standards	○	○
4.- Make battery data available	◔	◔

Four factors which could slow down second life batteries

- Uncertain economic return and market for storage applications. The actual regulation blocks many of the different benefits which storage can offer to the energy system as a whole. Many of these benefits include applications most suited for second-life batteries, such as energy arbitrage to facilitate renewables integration, ancillary services and T&D grid investment deferrals. Further complicating matters, different applications have financial benefits that are not yet monetized properly in the regulated world of energy utilities.

- Potential future competition from cheap new energy storage. Second life batteries must compete with new batteries technologies on price and performance. While we expect second life batteries will be cheaper than other forms of energy storage, second-life batteries will have to compete with new lithium ion batteries and their future chemistries. Project developers face difficulties given the uncertainty around how well the second-life batteries will perform compare to new batteries.

- **Potentially expensive repurposing of the battery pack for second life applications.** The repurposing process of batteries requires dismantling the used batteries, re-design them and to reconditioned for the new application. These remanufacturing process together with the logistics cost have to be controlled. Actual cost of processing the battery is currently €50 per kilowatt hour. In order for second-life markets to thrive, the cost of the battery, plus this processing fee, must be lower than the expected revenue to attract financial backing and encourage deployment. In addition the original battery owners will also need to transfer responsibility for recycling them, as well as any liability costs.

- **Lack of data on battery life performance in first and second use applications.** The performance data of the batteries is basic to evaluate the state of health of the battery for a second use application. Lithium batteries in the market today don't have enough historical performance data for either their first life. At the same time due the small amount of secondary life projects, there is lack of data about the performance of second life batteries. This lack of data reduces the bankability and the finance opportunities of second life battery projects. In addition as battery chemistries is continue evolving, data from one specific chemistry in a given application could not be consistent for a different chemistry and or application

Four factors which could give impetus to second life batteries

- **Improve Regulatory Environment and market conditions.** Policy makers should remove regulatory barriers for batteries and monetize of all the different benefits that batteries can provide to the energy system as a whole. The energy ministry should fund an expert panel to inventory, monitor, and address the most pressing agency regulations that affect second life battery deployment. Government should offer rebates and other financing support for second-life demonstration efforts and ensure that grid-related incentive programs include second-life batteries as eligible.

- **Encourage demonstration projects.** Government should encourage more demonstration projects by improving grant support and reducing administrative barriers to implementation. Creating business case easy to replicate around the country. Reducing project uncertainty is translated in increased investors' confidence and lower cost of capital.

- **Standardization of remanufacturing process.** Automotive companies and industry participants should develop technical performance standards and best practices for second life batteries.The standardization of quality and remanufacturing process together with scale effects will reduce the repurposing costs. Industry leaders should identify and replicate existing liability models for automotive parts for application to second-life battery liability.

- **Improve battery data and project access.** Industry leaders should identify the type of data that is most useful for repurposing second-life batteries, based on chemistries and future applications. This would include work close with the automotive industry to make battery data available from first battery life uses. Automotive companies should introduce processes to collect all necessary data to establish the state of health of the batteries. In addition the energy ministry should make available utility, government, and grid data to help industry actors understand promising second-life revenue opportunities, via an accessible database with incentives for participation. State leaders should consider using data as a basis for reducing electric vehicle ownership costs by quantifying the monetary benefits of second-life batteries.

SECTION 4: SECTOR COUPLING MOBILITY AND ENERGY

The electrification of the transport and in particular the automobile will not only bring about massive changes in the automobile industry but also the power and utility industry and the oil industry. Currently, 95% of all transport globally relies on fossil fuel liquids as its energy source and in fact there is no other sector which is so dependent on a single primary energy source. The main reason for this is the success of the internal combustion engine which powers nearly all our vehicles across the world, and the fact that there has been no real cost competitive alternative technology available. That is now changing due to the falling costs of batteries which are making electric engines affordable and effective alternatives. They are also more fun to drive and their greater efficiencies mean that they are also better for the environment.

Battery powered EVs change everything, as for the first time in history, automotive companies can control not only the production of vehicles, but the energy source that will move them. On doing so they are positioning themselves to compete within two of the biggest industries on the planet: the utility and oil industry. Electro mobility is going to revolutionize both of them; the impact on oil demand in the medium term will be substantial and devastating in the longer term.

Industry shakeup

Electric cars are already in our streets and we are seeing car companies such as Daimler and Tesla moving into offering stationary storage solutions for homes and businesses. We are also seeing them putting in their own stationary storage solutions with which they can learn while at the same generate money.

The prospect of connecting lots of bi-directional EVs in a controlled manner to the grid is a tantalising one and enables the car batteries to act as distributed energy storage devices which can be used for providing lots of different services ranging from using automotive batteries to power home appliances during peak hours, to feeding the grid during peaks of demand as well as providing other services to power users and grid operators which are now performed by incumbent utilities. These include peak power substitution, energy arbitrage, spinning reserve, and frequency control among many others.

The convergence of power and transport around energy efficient electrons as opposed to oil will enable grid operators to better manage the grid by using the potential of EV batteries. They can be used to smooth the peaks and troughs of cyclical electricity demand and intermittent renewable supply, thereby enhancing the efficiency of the energy system as a whole. What is also transformative is that these traditional energy functions can also be performed by cost effective second life batteries.

For the power industry, the electrification of transport is an enormous opportunity. Not only will demand for power increase but there will be a need for new charging infrastructure and intelligence across the grid. If every automobile, for instance, in Germany, uses one battery charger then putting this infrastructure in will be the equivalent of building the German housing fleet again in terms of meter and connection points (over 40m) to the grid. And each new EV will give the owner or the equipment manufacturer the opportunity to become a potential supplier of power to the grid as well as our homes and businesses. And the numbers are enormous. If Germany's car fleet was all to go electric it would have close to 1,000GWh of storage capacity which would be enough to power Europe for a whole hour!

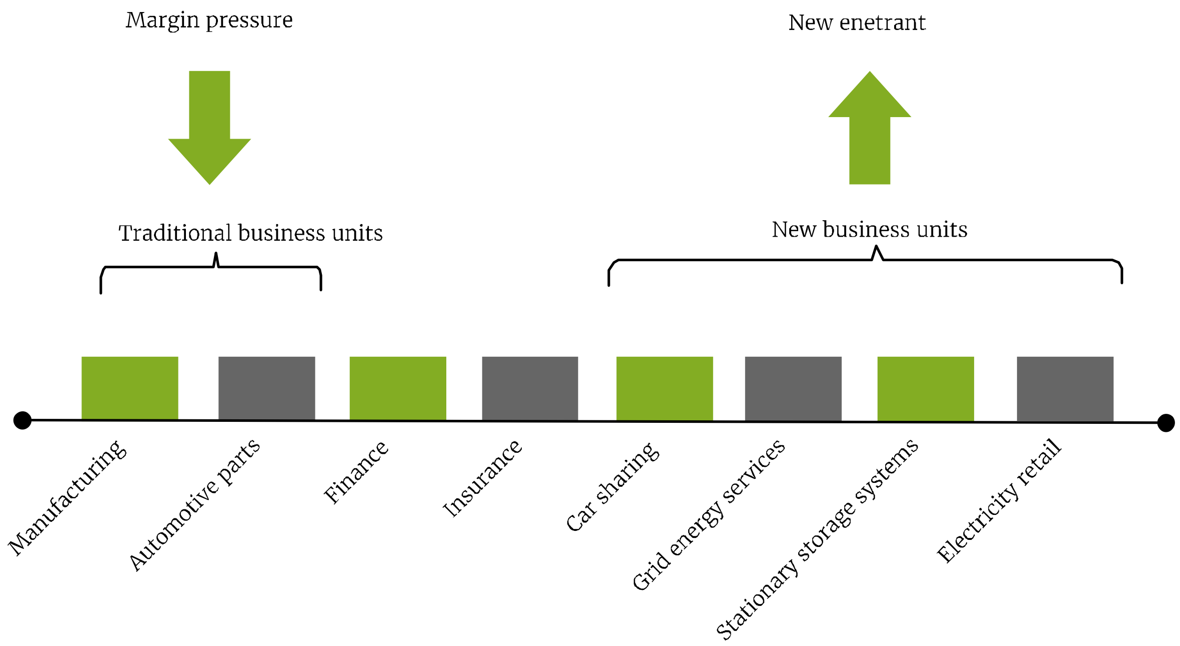
It is also a great opportunity for European electrical equipment suppliers such as Siemens, ABB and Schneider Electric. But it also a challenge for these companies as the grid of the future will need software rather than hardware and the former is not where the strength of those companies lie. That all said there is a big question mark over what role the automobile manufactures will play in this future? And then there is also the oil industry noting that EVs will canabilise oil demand. How will they react? What will oil exporting countries do?

The role of the automobile industry

There will be huge changes in the value chain of the automobile industry. The coming of EVs will mean that the battery will become the most important component of the car. Given that Europe does not have one major lithium-ion cell producer there must be serious concerns that Europe will be locked out of batteries. For the automobile manufacturers the move to EVs is not only going to be expensive in terms of the need to reequip factories and acquire other technical knowhow.

To make things works a move to the electric motor simplifies the manufacturing and logistic process and reduces considerably the number of engine parts. With less parts EVs will require less servicing which will in turn undermine the profitability of after-market servicing. As it now stands circa 10-15% of total industry profitability comes from after sales services including the sale of spare parts. The big question is whether the industry can offset these falls in margins not to mention the increased competition from the Chinese automobile manufacturers such as Chery and BYD and new players such as Tesla.

Exhibit 18
Automotive industry revenue sources



Addressing these challenges is what BMW is attempting to do with the i-series and projects such as the Drive Now car sharing program. In addition, BMW offers an extensive range of services for i3 which they label, their 360° ELECTRIC package. This includes the installation of the BMW i Wallbox in the customer's garage, a renewable energy supply offer, to the charging card for user-friendly access to the public charging infrastructure and additional driver assistance services from BMW ConnectedDrive. But this is only the start.

Once the total cost of ownership (TCO) of an EV comes to parity with that of a combustion engine car (by 2020) we will see the automobile manufacturers lock those costs including energy into leasing type agreements which should cause exponential growth in EV sales. It also allows the OEM to control the charging of the battery which means less wear and tear on that battery and thus lower warranty and customer satisfaction problems.

Then there is the second life batteries, the monetization of which will be very important to the automobile manufacturer, which is why Daimler and BMW have already battery offerings for the residential customer. They need to learn and develop channels for selling batteries and in the even these companies with their development of electric cars and of battery factories will no longer be just automobile or even a Li-ion battery manufacturer.

The widespread adoption of EVs will create an enormous and widely distributed energy storage capacity, which if managed properly will have a very positive impact. If managed poorly it could create unnecessary stresses and strains on the whole power system. An EV will draw roughly 1-4 KW of power while charging, roughly the same as a clothes dryer. This is clearly manageable but if everyone on a street does at the same time (for instance at night) then peak demand will rise and distribution equipment may become strained.   This is why smart technologies such as 'Vehicle to grid' (V2G) and 'Vehicle to home' (V2H) are very necessary.

V2G - From liability to asset

Through new charging strategies and EV swarm aggregation, electric vehicles will transform the operative management and structure of the power grid, as we have never seen before. And one of the implications may be that we move to renewables based economy faster than the German government plans envisage.

The big commercialization opportunity of EV is vehicle to grid integration (V2G) and describes the situation that all electric cars parked in our garages can sell power back to the grid during peak times, smoothly integrated renewables or power our homes during outages. A V2G platform consists of communications, control technologies, batteries and high power electronics between the vehicle and the grid. Using these tools effectively will enhance grid stability, both benefiting the grid to the greatest extent and the vehicle owner at the same time. Because car normally cars are stranded assets 95% of time, V2G allows to extract two value streams from the battery concurrently, one when the car is being driven and the other when the vehicle is parked and plugged in and the battery is on call to the grid. The capital costs of this approach are much smaller, probably factors of ten smaller than large centralized storage to integrate smoothly the increasing rates of renewables.

The big question is whether it is possible to extract value from the battery without leaving the car owner with a worn-out battery and a bad driving experience. The advantage to the driver is that he will not have to pay as much for his battery if somebody else is using it. This is exactly what Munich based company The Mobility House is doing successfully. Different business models exist where the owner gets a check every month or whether he leases his battery at a preferred rate because somebody else is leasing it at the same time. The fundamental economic assumption is that the battery creates two revenue streams, which reduces the cost of the primary function, which is transportation. And what seems to be clear is that the added cost due to battery degradation can be more than offset by revenues obtained through the second application.

The second application grid is key to the future German energy system. If Germany's milestone of one million new electric cars by 2020 were to be achieved, Germany could have close to 25GWh of storage capacity, which would be enough to power whole Germany for half an hour. Considering actual large scale battery prices of €500 kWh, this is translated in an equivalent investment of €12.5b in large scale storage. What is more important this accumulative capacity is going to offer invaluable grid services to allow smoothly integration of renewables and the deferral of investments in both the distribution and transmission grids.

BMW one of the leading German automotive companies is already starting to pilot these advantages with BMWi Charge Forward Pilot Program in California. Where innovative market conditions allows the participation of smaller storage units in their demand response program and allows to save the energy utility money by delaying the need to upgrade power lines and helping utilities to manage and smooth out the intermittent flow of energy from renewable sources. The 18 months pilot program rewards the participants with $1,540 and leads to lower total costs of EV ownership. Participants EV are bundled together into swarm of EV creating a virtual bigger storage unit that can be tapped as grid resource.

Energy storage pilot projects

.German companies have been developing and supporting pilot projects to test energy storage in the marketplace and initiated several commercial second life battery projects. For example, The Mobility House and Daimler have created in


Current second life battery projects in Germany

Lünen (North Rine Westfalia) the world's largest 2nd-use stationary storage with 13 MWh output made from around 1,000 used vehicle batteries. In addition they are planning to inaugurate a second one in Hannover in 2017 made from 3,000 new batteries. What makes this last project particularly special is the fact that this is a spare parts storage facility for electromotive battery systems.

Other automotive companies like Nissan have begun to experiment as well with second life batteries to develop a commercial-scale energy storage system, while other like Toyota and General Motors are using second- life batteries to develop a micro-grid backup system. These pilots indicate growing investment, experimentation and interest with energy storage systems, indicating the beginnings of new market opportunities and new business units for the car manufactures that will benefit second-life batteries

V2H-Optimizing on site production

While early attention related to using EVs for grid energy balancing purposes has been focused on V2G, a variation of that concept is vehicle-to-home (V2H) and vehicle to building (V2B). V2H describes the concept when a battery of an EV can supply electricity to residential homes why providing a sustainable and worthwhile alternative for times when electricity is in short supply. In addition they system maximize solar on site production and helps to create and market the energy flexibility. In a larger scale, V2B defines the concept of several EV aggregated and controlled together so that their combined energy storage can be used to deliver energy balancing and demand limiting services to nearby buildings. These options create another option for automotive companies to enter and revolutionize another industry, in this case, the building energy management space. This industry is currently the province of companies like Johnson Controls, Honeywell, Siemens and Bosch. A fleet of EV in the parking lot of a commercial building, properly controlled could offset most or all of the daily peak demand of the office building and still have enough energy to safely drive home. At peak hours, the building draws power from the cars, then, during off-peak hours when electricity is cheaper, it flows the other way. The system ensures the EVs are fully charged by the end of the working day. Savings will come from very different sources, the reduced demand charges and peak shaving. It’s easy to see how automotive companies could structure a service offering that creates a win-win for the EV owner, building owner, and themselves.

Digital Energy Solutions a joint venture of BMW and the Viessmann group are targeting the residential and C&I segment to provide complete energy solution to provide not just electricity but heat as well. A system made of solar panel, storage, mini CHP and electric vehicles create a micro grid that create and market energy flexibility. Flexibility arises from our intelligent coordination of energy generation and consumption.

SECTION 5: RECOMMENDATIONS & CONLUSION

New lithium-ion battery technology developments and scale production of new battery factories around the world is reducing the cost of batteries. As the performance and financial of batteries continues to improve, batteries will revolutionize the energy and mobility sector. In addition to the new batteries the market will be flooded with reconditioned second hand batteries from the first generation of EVs. In order to maximize the opportunities from batteries for the future we need to create a supportive regulation and lay the policies groundwork for batteries today.

We envisage expanded second-life battery deployment opportunities and suggest strategies and policies to begin developing a market for these batteries. Ultimately, we expect a thriving future market for second-life batteries, taking advantage of the lower cost and remaining battery life for a range of applications. The reuse of these batteries in the coming decades will help countries achieve its renewable energy and greenhouse gas reduction goals faster and cheaper than initially thought possible, while at the same time reducing the cost of electric vehicle ownership.

Five Main Recommendations:

The establishment of a positive policy battery framework will help both an affordable Energiewende and the establishment of a new industry. German companies could strongly benefit from this know how and technology advantage. The policy framework is divided in five main recommendations areas.

Embrace storage as a key component of the Energiewende.

- Energy storage needs to be redefined as a new category on its own, besides generation, distribution and transmission. Storage today has assigned end users network and renewables taxes as they where an end user, although they do not consume energy but shift the loaded electricity for a later use. This also relates to EV, which should also be classified as end user. As we have seen with the different V2G and V2H strategies, EV can be used to integrate renewables and to defer grid investments.

- The actual regulation endangers the existing storage projects and prevents investment in new capacities and the development and field-testing of new technologies.

Accelerate the development of flexible markets

- The present regulation provides few incentives for the use of storage to increase the systems flexibility. Most use cases of batteries that we have seen in section 2 are not economical as storage can only bid into one specific service and it cannot provide its myriad of benefits. In order to provide the full potential the new market design should provide with more auctions, smaller bids and shorten timeframes. Therefore batteries could apply to several of the auctions and have 1st application, 2nd application, 3rd application, 4th application.

- In addition to short-term improvements a new market design must be set where flexibility and cost are rewarded, in order to provide long-term investment security and prospects for existing and new storage technologies. Apart from frequency control and reserve control, batteries can also provide system relevant services like voltage control, reactive voltage, balancing, redispatch and black start. These services necessary to ensure security of supply and system stability are not rewarded with their significance.

Support the rollout of EVs and aggregators

- Support the rollout of EV across the country before the competitive advantage of the German automobile industry is lost to new startups such as Tesla and countries such as China.

- A key challenge in expanding the use of second life lithium ion battery modules for residential energy storage systems is the ability to efficiently and accurately determines the state of health (SOH) and remaining capacity of used battery modules. These characteristics are affected by a variety of factors connected with the original use of the battery, such as operating temperature, average driving distances, and the habits of individual drivers. In order to reduce the remanufacturing costs of second hand batteries, is from utterly importance the establishment of a battery management system in EV with the ability to store all data at individual battery cell level regarding especially, temperature, voltage, deep of discharging (DoD), overcharging (S0C) and short circuits. We are aware that many actual battery management systems are already collecting this datasets. But for this process become mainstream it should be establish as a de facto requirement by all of them.

- Allow electric vehicle automakers or customers to monetize the residual second-life battery value upfront to reduce purchase costs or monthly charging costs

Support the rollout of second life batteries

- Establish policy support and an enabling regulatory framework to facilitate further commercial deployment of second life battery technologies.

- As a long-term goal, policy makers should consider developing clear regulations on second-life batteries that businesses can rely on for an extended period of time.

- An industry-led regulatory working group to identify and address regulatory conflicts and needs that limit market development

- Industry-developed technical performance standards for second-life battery certification that policy makers can use to clarify product liability

- Increased funding and incentives for data collection and dissemination on second- life battery projects

- A five- or ten-year period following 2018 that avoids changing the basic rules governing second-life batteries would help encourage market development.

Support the true potential of decentralise storage

- Work with transmission and distribution system operators as well as regulators to help quantify and realise the true potential value of storage for the grid

- Batteries can finally woke utilities up to the understanding that the way they have been doing resource planning is not working. Traditional planning, which just meant building more power plants and expanding transmission and distribution to accommodate them, is starting to break down in a world where customer-sited generation can compete with traditional resources.

- Grid operators and utilities should provide energy data to an independent, transparent database on promising second-life applications to give investors an opportunity to gauge potential revenue and costs.

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