Repurposed EV Batteries Integration in Smart Energy Grids to Facilitate a Greener Energy Sector

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Abstract - The global fleet of electric and hybrid vehicles (EVs) is predicted to grow immensely over the next decade, leading to lower CO2 emissions in road transportation but higher demand for lithium-ion batteries. Battery manufacturing and even battery recycling are both very carbon and energy-intensive processes. Having environmental sustainability in mind, reusing is the preferable technique to the production of waste and recycling since it provides an opportunity to extend the EVs batteries' lifespan by reusing them in different second-life applications. Reusing batteries in battery energy storage systems (BESS) complements the idea of a smart grid by allowing energy storage at periods of low demand at night and release during the grid peaks, grid frequency regulation and levelling peaks in renewable energy generation, thereby alleviating the intermittent nature of renewable energy sources and decreasing the carbon footprint of the energy sector. The aim of this paper is to conduct an analysis on the benefits of reusing and repurposing EV batteries in smart BESS compared to direct recycling by using available data and case studies. A careful review of the materials shows that the benefits outweigh the disadvantages of repurposing vehicle batteries into secondary applications considering the carbon-intensiveness of the battery recycling process. The benefits of using repurposed battery packs have a major potential to facilitate a greener energy sector by shifting electricity purchases to off-peak times, more efficient use of the energy grid by providing constant energy reserves and storage for meeting changes in supply and demand, emission reductions, integration of renewable power and supporting their expansion, as well as more effective use of original materials.

I. MOTIVATION

Efforts to reduce CO2 emissions in road transportation will lead to an estimated thirtyfold increase of the number of electric vehicles (EVs) by 2030 [1]. An EV battery ends its automotive life the moment its metric state of health drops to 80% [2]. Thinking of what comes next and with environmental sustainability in mind, recycling is obviously preferable to the plain production of battery waste, but as far as benefits are considered it should come second to reuse.

Lithium-ion (Li-ion) batteries pack a significant amount of remaining energy that can still be put to use and reusing, or repurposing provides an opportunity to extend the battery's lifespan. Some second-life applications include: powering low-speed electric cars and bikes, being used as portable charging devices, and forming the basis of both large and small-scale battery energy storage systems (BESS) in back-up power supply solutions [3].

Introducing IC technology to the energy supply sector, and concepts such as Internet of Things (IoT) could contribute to robust and efficient energy management solutions lacking in the existing infrastructure [4]. An IoT smart grid enables two-way communication between connected devices and hardware that sense and respond to fluctuations in electricity production and user demand. Reusing EV batteries in BESS is of particular interest to this paper as they have the potential to allow for energy efficiency management and grid frequency regulation by meeting changes in supply and demand, and leveling peaks and lows in renewable power generation [3]. Since renewable energy is by nature intermittent, being able to store energy is critical to support the expansion of renewables and ultimately decrease the carbon footprint of the energy sector.

With that said, the aim of this paper is to review reusing and repurposing used battery packs and their potential to facilitate a greener energy sector. This will be achieved with a thorough analysis of Circular Economy and the respective places of recycling and repurposing, then a review of the benefits and shortcomings of repurposing old EV batteries in smart BESS in Europe and globally, and finally, an analysis of the potential for a successful integration of IoT concepts within the Energy sector.

II. RESEARCH QUESTIONS

A. Battery Waste Management

Correlatively to global efforts to reduce CO2 emissions in the transportation sector, it has been estimated that the use of EVs will increase thirtyfold by 2030 [2]. At the same time, Green Peace East Asia calculated that 12.85 million tons of Li-ion batteries from EVs will go offline between 2021 and 2030 [5], and even though EVs account for a low, local CO2 footprint, battery manufacturing is a very energy-intensive process.

High consumption and throw-away, waste-oriented economies cause climate change and resource exploitation. That's why to make EVs sustainable, battery manufacturers and automotive companies have a social responsibility to support circular economies, just as governments have a responsibility to mandate recycling and repurposing systems for batteries. The circular economy concept implies that production resources, waste, waste emissions and energy outflow are significantly reduced by slowing down, rounding off and extending the energy and material life cycles. Therefore, circular economy stands for retaining value and should not be viewed as a process that revolves around waste management, but rather resources management and how to maintain a product's value prior to recycling.

With environmental sustainability in mind, recycling is obviously preferable to the plain production of landfill battery waste, but as far as benefits are considered it should come second to reuse. This is because it saves the energy that comes with having to dismantle and re-manufacture products. Furthermore, Green Peace's calculations showed that repurposing batteries can save 63.34 million tons of carbon emissions compared to new battery manufacturing [6]. Seeing as the need for raw materials is reduced waste and pollution are also reduced.

B. Repurposing Batteries

Compared to their first life, the technical requirements for secondary use are usually less demanding on a battery's performance. This provides an opportunity for the industry to extend the EV batteries value and lifespan through reuse. A report titled "Remanufacturing, Repurposing, and Recycling Post-Vehicle-Application Li-ion Batteries", suggests that reusing EV batteries will help create a modern commercial reuse industry, which by 2035 will achieve a $3-billion-a-year profit [6]. Some second-life applications include: powering low-speed electric cars and bikes, being used as portable charging devices, and forming the basis of both large and small-scale BESS in back-up power supply solutions [3]. The idea of giving EV batteries a second life dates to the 1990s, but large-scale implementation of this idea did not take place until the early 2010s when a number of projects were launched (see Appendix 1). A further analysis of Appendix 1, leads us to four main conclusions:

a) The number of projects regarding second-life battery applications has been increasing rapidly in the past 3 years.

b) Almost all the major automotive equipment manufacturers have launched or plan to launch second-life application projects, whether jointly with their battery supplier or a different partner company.

c) The popularity of large-scale stationary BESS applications (particularly for grids) is increasing.

d) The types of second-life applications are diversifying.

C. Vehicle manufacturers on handling EV's battery waste

The fact that there are environmental upsides does not exclude the fact that there is one potentially big downside on cars using electric-drive systems, and that is: how to dispose EVs batteries once they fail to store and deliver adequate power? Many major car brands, including Bentley, Ford, Opel and Volvo, have already outlined plans to switch to entirely electric fleets in Europe by 2030. Subsequently, in the last decade, vehicle companies have been partnering with battery, recycling and electronics firms to figure out and develop post-automotive markets for Li-ion battery packs. At the same time, the original equipment manufacturers are facing tougher recycling mandates as the years go by. For instance, several major power utilities are working with companies - including General Motors, Ford, Toyota and Nissan - to explore the use of the batteries for stationary storage. Li-ion packs are being tested as backup power storage systems for retail centers, restaurants, and hospitals, as well as for residential solar systems.

As a company who sold 1.95 million hybrid electric vehicles (HEVs) globally in 2020, in 2015 Toyota donated 208 Camry hybrid battery packs used in conjunction with a solar array to provide sustainable, zero-emission power to Yellowstone National Park's LBR Ranger Station and Education Center. As this car company wrote on their official website, Toyota retailers in Japan are using a similar approach to provide power for their showrooms. Furthermore, the company launched an initiative to pair used batteries with solar panels to power "7-Eleven" stores in Japan. Toyota is currently investigating the possibilities of this kind of activity in Europe, where the number of used batteries available is still limited.

With money to be made in repurposing batteries, finding second-use applications has overtaken efforts to recycle. For instance, in 2010 Toyota has put efforts in recycling their EV nickel-metal hydride (NiMH) car batteries. Back then, Toyota established a battery recycling program with Toyota and Lexus dealerships. In 2019, they expanded the recycling program to include Li-ion batteries as well. However, latest news from Toyota, regarding the issue of batteries handling involves reusing them in BESS systems. In May 2021, Toyota agreed to partner with the Asian company Jera, in a bid to transform old batteries into a power storage system for renewable energy. The new storage system will consist of Li-ion and NiMH batteries. The two companies' objective is to enable storage batteries to operate more efficiently by combining different kinds of batteries. Toyota and Jera will target developing the storage battery by the end of 2021. Then, in 2022, the companies aim to connect the storage to the power grid so that they can conduct technical verification for practical use. By being connected to renewable-energy power plants, the storage system can store and supply electricity flexibly according to the changing levels of supply and demand.

Nissan was one of the first major automakers to pilot second-life batteries in a grid-scale storage installation in 2015. Nowadays, Nissan puts used batteries into automated guided EVs (AGVs). In car manufacturing plants, these AGVs travel on magnetic tracks and deliver parts to workers in factories. Other companies, like Daimler AG, announced their plans as well. Daimler's plan included building a 13MWh second-life battery storage unit at a recycling plant in Lünen, Germany. In 2020, this company controlled by Mercedes-Benz Energy, teamed up with the Asian company Beijing Electric Vehicle to build an energy storage system that uses retired batteries.

There are numerous examples of companies teaming up to find batteries a second use, just as there are numerous types of applications for batteries. However, automakers are aware that the current batteries' design does not allow easy application of old batteries in different types of systems and the process of repurposing batteries is complex. For example, American electric truck startup Rivian designed its battery packs to make EOL repurposing as easy as possible. Other companies, like electric bus manufacturer Proterra and General Motors, took the same approach. General Motors said that it designed its new Ultium battery pack with second-life applications in mind and the company is currently working with partners to develop a business case around battery reuse. Experts say that repurposing is actually very viable, and especially if batteries are designed with that purpose – it becomes much easier to integrate them later.

The automakers are interested in repurposing the old batteries because they know they have this huge store of value that is potentially going to come back to them when they have to take batteries out of cars. However, they prefer repurposing them since they are familiar with the costs of recycling.

III. METHODOLOGY – BESS APPLICATIONS IN EUROPE AND THE WORLD

A. Smart BESS in Europe

One of the ways to ensure Europe's sustainable future is improving the electrical grid and buffer capacities (as units that provide power for short periods of time). This involves making the grid more flexible to integrate increased electricity generation from renewable sources and more efficient and reactive to meet future demands from increased electrification, especially from the transport sector. However, investing in new grid infrastructure or upgrading the existing one requires a big budget. Buffer capacities, though, help smooth supply and demand profiles and relieve grid fluctuations. They are mainly found as centralized, large-scale power plants, but unfortunately, are limited by infrastructural considerations. Therefore, additional systems are needed to compensate for supply and demand imbalances. BESS have been investigated as an alternative to solve the grid and buffer capacity challenges and it was concluded that, by using batteries, it is possible to balance demand, and by that, ensure that renewable energy can be used when needed, not just when generated [7].

In Europe, BESS are being developed, implemented, and tested by industries, private consumers, and research projects (see Appendix 2). Industrial-scale second-use systems have a capacity ranging from several kWh up to several MWh, whereas smaller research and development projects have a capacity of several kWh. The larger storage systems are often built by industry partnerships consisting of vehicle manufacturers, utility companies and technology developers, and their solutions are based on battery packs. These are mostly used for primary frequency control and demand charge reduction. On the other hand, BESS for private consumers are often used in combination with a photovoltaic system to increase their self-consumption. Such systems are mainly based on battery modules and are often available on the market as out of the box solutions or may be custom built.

In Europe, second use, especially smaller systems (meaning those on the battery cell level), are uncommon due to the high effort and labor costs for repurposing. Appendix 2 maps second use storage systems being researched in the EU and the European Free Trade Association, showing that nearly all systems are based on Li-ion batteries, mostly coming from Nissan, Renault, or Volkswagen EVs. Some systems may combine used and new battery cells, but the capacities and power inputs/outputs are always lower when compared to industrial storage systems. Most storage systems are developed for "behind-the-meter" applications, most commonly to increase self-consumption.

Experts have already investigated legislation on repurposing batteries as stationary storage systems in the European Union [8]. The main conclusion is that a harmonized policy framework needs to be developed based on existing automotive and energy binding legislation. Since the analyses were published, the European Commission updated the Batteries Directive (2006/66/EC), which aims to minimize the negative impacts of batteries on the environment. A working document of the European Commission showed some of the shortcomings of the current Battery Directive such as not addressing second use, labelling measures, extended producer responsibility, and recycling efficiencies of Li-ion based batteries [9]. By doing this, the Commission engaged in an Inception Impact Assessment to modernize the EU's batteries legislation, in particular the Batteries Directive [10]. Second use of batteries, as part of the EU Circular Economy strategies, will reduce the need for extraction of raw materials for BESS and/or the costs for importing them, and will also extend the life of the EVs' batteries. Furthermore, developing BESS technologies allows gaining time for developing appropriate battery recycling technologies. This obviously leads to a more efficient and sustainable use of resources and also addresses short term battery waste issues.

B. Smart BESS in North America and Australia

The US Department of Energy published a report under the name "Solving Challenges in Energy Storage" which describes the critical need for energy storage in the electrical grid [11]. It mentions that advanced energy storage systems such as second use smart BESS built from old batteries provide a solution to some of the most critical issues associated with all stakeholder groups. Stationary second use storage systems are also considered a cost-efficient solution in the electrical grid in Canada [12]. The governments of Australia and New Zealand have announced that they support repurposing batteries for second use storage systems [13], and therefore various projects and applications can be found across the mentioned regions; the applications of these projects are often similar to the ones in Europe. BESS in these geographical areas are used for:

a) Commercial home applications – For the first time, in 2014, General Motors and a company that works in the field of automation technologies - ABB, repurposed old Chevrolet Volt batteries into a modular unit capable of providing hours of electricity. The idea of this pilot project was to explore an application that in the future will be used to power a group of homes or small commercial building during a power outage. Today, a company called Relectrify offers every home a chance to implement a similar system scalable from 120kWh to 2.4MWh [14].

b) Industrial applications – Chevrolet in 2015 combined old batteries, solar array and two wind turbines in order to achieve net zero energy at a data center in an IT building [15]. The 74 kW ground-mounted solar array and two 2 kW wind turbines generate approximately 100 MWh of energy annually, enough power to provide all of the energy needs for the office building and lighting for the bordering parking lot.

Existing data show that most second use projects in these areas rely on entire battery packs or battery modules (depending on the storage size) due to the high repurposing effort and labor costs.

C. Smart BESS in Asia

Second use of batteries in Asia is dominated by China, South Korea, and Japan with many application areas supported by research activities regarding second use of BESS. Applications range from private consumer to industrial applications. Unfortunately, detailed information about ongoing activities regarding second use of batteries is limited, especially for China – even though they are the largest battery manufacturer and consumer in the world. However, China's second use market is developing very quickly, mainly due to government policies and the rapidly growing EV market. When compared to other parts of the world, the application range in China is significantly larger.

The Chinese government is stepping up the development of relevant policies on reusing power batteries; the frequency and content of recent relevant policies are getting higher. Experts say that these and other signs indicate that China will issue regulations and policies on the reusing and/or mandatory recycling of old vehicle batteries soon.

Experts are claiming that China currently has a wide range of demand for energy storage batteries [16]. For example, the renewable energy power stations (photovoltaic power generation, wind power generation, etc.), the microgrid of the distributed independent power sources and communication base stations all have considerable demand for energy storage batteries. Researchers point out that the demand of storage batteries will continue to further expand with the optimization of the energy structure and the upgrading of information infrastructure.

GEM, China's largest recycling center for waste batteries, among others, is working on battery pack regeneration and has developed its own second use modules which can be used in various applications. Due to low labor costs compared to the battery costs, battery cells are being repurposed for numerous consumer applications. Also, a large number of "old' batteries has been redistributed in telecommunication infrastructure to back up transmission stations. Therefore, the high-quality repurposed batteries are replacing lead-acid based backup power systems [17].

Some projects point out that batteries in Japan are being reused for communities' purposes. One of those projects was announced in 2018, as Japanese auto manufacturer Nissan teamed up with the town of Namie (Japan) to install new streetlights powered by a combination of solar panels and used Nissan Leaf batteries as a battery storage system.

D. Smart BESS in South America and Africa

In these regions most storage projects are based on backup power and off-grid applications to power critical infrastructure. This means that facilities such as hospitals and schools, and basic needs like electric lighting in homes are a priority. In order to counter power outages (which occur quite often), back-up power systems are set up locally, in urban areas. In areas where suitable grid infrastructure is lacking, off-grid solutions, comprised of an energy source such as a photovoltaic system and a battery storage system, offer remote electricity supply [18]. Several projects, supported by EU and US Department of Energy grants, have aimed to establish off-grid solutions based on second-use battery modules with a low-capacity range. One of those projects involved off-grid solar energy system that used previously discarded Li-ion batteries [19]. The project's aim was to provide continual access to affordable power for rural communities in sub-Saharan Africa. The ultimate vision was to develop the micro-grid model to an extent where it can outcompete expansions of national power grids, since they are often set back by regulatory and financial issues.

On account of their high initial prices and due to limited electrical grid infrastructure, EVs containing the mentioned types of batteries, are less common in South America and Africa, and prices wise cannot yet compete with vehicles driven by an internal combustion engine. Therefore, just as the above-mentioned project showed, developing countries are currently dependent on second use batteries and technologies from Europe, North America, Australia, New Zealand, or Asia.

IV. DISCUSSION

A. Benefits of Smart BESS

The most obvious environmental benefit of BESS is lengthening a battery's lifespan by postponing recycling (or even worst landfill) and ensuring the most efficient use of individual components. At some point, the batteries should still be recycled, however, reusing is preferable since it exhausts the currently available resources. Another reason to postpone recycling is the fact that the time of batteries being reused, is the time needed for industries to further develop the technology of recycling in order for it to be as efficient as possible.

When discussing environmental benefits, the fact that repurposing batteries reduces the need for new batteries in BESS goes without saying, but it additionally saves on raw materials and reduces the negative environmental impact. Furthermore, at the World Economic Forum (2019), the Global Battery Alliance estimated that when using Li-ion batteries for peak flattening in BESS, instead of natural gas fueled power generation, a 56% reduction in CO2 has been achieved making repurposing a low-carbon strategy that contributes in decreasing GHGs.

Economic gains from repurposing include discounts on EV battery costs, reducing the costs of BESS, reducing energy costs, and creating new employment opportunities. The high cost of batteries is one of the main deterrents to fully electrifying transportation and repurposing would reduce the life cycle costs of an average battery pack by 4.6 €/kWh in 2030 (according to the World Economic Forum, 2019). When it comes to reducing the costs of BESS, a pilot project which included companies like Nissan, American Electric Power and Relectrify (which were or will be mentioned again), proved that BESS costs were reduced from 250€/kWh (when using new batteries) to 130€/kWh (when repurposing old batteries).

Smart BESS would also lead to economic benefits to both homes and companies by enabling cost savings achieved through storage of power purchased off-peak, more efficient use of the energy grid by providing constant energy reserves and storage for meeting changes in supply and demand. Furthermore, a new industry branch is being developed, which has huge human resources potential by creating new employment opportunities.

B. Challenges of repurposing batteries in BESS

Even though research in the field of BESS has delivered promising results, there are some issues remaining to the widespread adoption of these systems. Policy measures can help minimize uncertainty over the performance of repurposed batteries as BESS, not to mention increasing the commercial allurement for the new market. The process of repurposing comes with certain challenges, but the right policy instruments can provide solutions. Some of the barriers that delay the uptake of battery repurposing in BESS, developed from uncertainties over its implementation, as well as technical and legal risks can be found below.

Engineers working on repurposing and recycling lack data due to the fact that the batteries were not standardized in the time of production. Researchers suggest that the battery reuse industry could learn from the successes of dealing with other battery-reliant products, such as mobile phones, whose market has seen massive variability in designs. Standardization of the designs of the battery packs is, therefore, very important and would allow experts to plan ahead second-life applications early in the design stage. Controversy also exists over the expected lifespan from these batteries in their new stationary use. Residual capacity depends on aging, charge and discharge rates, temperature, and state of health (SoH) of the battery. Recording data on a battery's history can allow accurate predicting of the SoH of used batteries and help in estimating the value of each battery by modeling its performance in different second-life scenarios such as repurposing in BESS.

Furthermore, Li-ion batteries may come with a risk of thermal event so safety and liability concerns also present themselves. Regulatory safety frameworks and safety certifications barely exist, so legal norms clarifying safety standards and liability for vehicle batteries used in secondary applications and consulting the insurance sector are all steps that need to be taken to ensure a safer transition to secondary use. Additionally, even after years of introducing BESS, they face regulatory barriers. Since the BESS which contain repurposed batteries will be sold as new, separate products, legal liability measures to ensure safety, quality, and warranty from the producer of such systems will be needed. Policies regulating handling and ownership of waste, recycling, etc. are critical for fair and transparent market conditions, and to guarantee the circular economy of batteries. This will lead to increased battery reusing and battery recycling rates.

Reusing batteries for secondary applications is possible, but finance demonstrations and projects are needed to clear the uncertainties regarding economic usefulness of BESS. Such projects should also target decentralized energy systems in contents of lacking or limited access to electricity. Any action of this type should be supported by direct funding or any form of grants, subsidies, or financial incentives. Any administration barriers should be eliminated, in order for implementation of BESS with second-use batteries to be stimulated. However, criteria to select the relevant type of secondary uses and technical and economic feasibility will always depend on a large number of parameters (active stakeholders, penetration of EVs in the local market, conditions of e-waste collection and volumes, access to the grid and reliability of the distribution network, regulatory environment and other factors).

V. CONCLUSION

A careful review shows that the benefits far outweigh the disadvantages (or rather challenges) of repurposing vehicle batteries in Smart BESS. The Battery Global Alliance estimates that in 2030, 61% of car batteries could be repurposed after the end of their automotive use, substituting to 20 GWh of new energy storage systems, an amount corresponding to 6% of that year's demand for energy storage systems [20]. Repurposing a battery pack in BESS, seems to be most useful for stationary storage applications as grid support or storage of renewable energy and integration in the grid.

BESS allow storing energy at periods of low demand at night and release it during the grid peaks, which usually takes place in the early evening. Furthermore, BESS enables individual decisions to charge and discharge at specific times depending on the different electricity tariffs, with corresponding economic gains. Modern Smart BESS can also support grid frequency regulation. The use of new batteries for load shifting has been studied in a lot of research papers, but the high cost of new Li-ion battery packs makes this option not so smart. On the other hand, repurposed packs (retired vehicle batteries) will be available at low cost, making the potential BESS option much more economical.

BESS can be also used as back-up power systems in residential or commercial buildings, and particularly in contexts of instability and limited reliability of the generation or distribution networks, substituting to polluting fuel generators. Initially, users may need to be encouraged to re-use battery systems, but it is no doubt a positive policy measure because of the potential environmental benefits. A decrease in energy transfer fees and a higher payment for feeding into the electrical grid would further encourage homeowners to use smart BESS. Industrial use of BESS has an added incentive for storing power purchased off-peak, because they can directly benefit economically. Furthermore, a good use of BESS is supporting decentralized energy solutions, in contexts of low access or no access to the local grid.

Since renewable energies are by nature intermittent, being able to store energy is critical to support their expansion and ultimately decrease the carbon footprint of the energy sector. By alleviating the issue of the intermittent nature, it supports the expansion of these energy sources and provides answers to challenges affecting the electric grid such as generation intermittency and asynchrony of generation and demand peaks. Smart BESS allow levelling peaks in renewable energy generation ("over-generation"), a peak that takes place around noon for solar and generally during the night for wind power generation. The International Energy Agency has identified a Sustainable Development Scenario where renewables reach a share of two-thirds of electricity generation output and 37% of final energy consumption by 2040 [21], so one might say it is a clever move to further develop this energy storage technology.

In conclusion, properly configured battery packs as a part of BESS can decrease monthly energy costs of an industry or a home by simply shifting electricity purchases to off-peak times and can favor renewable energy sources. The benefits include cost savings, more effective use of the transmission grid, emission reductions and integration of renewable power. Additionally, using repurposed packs allows more efficient use of the energy grid by providing constants energy reserves and storage for meeting changes in supply and demand. Furthermore, there's the ability to easily integrate intermittent renewable energy (such as wind or solar). In regard to effective use of the original materials and manufacturing, repurposed batteries add a separate life cycle to the manufactured battery, by extending the effective useful lifespan of a battery pack by a decade when repurposed for stationary use [22].

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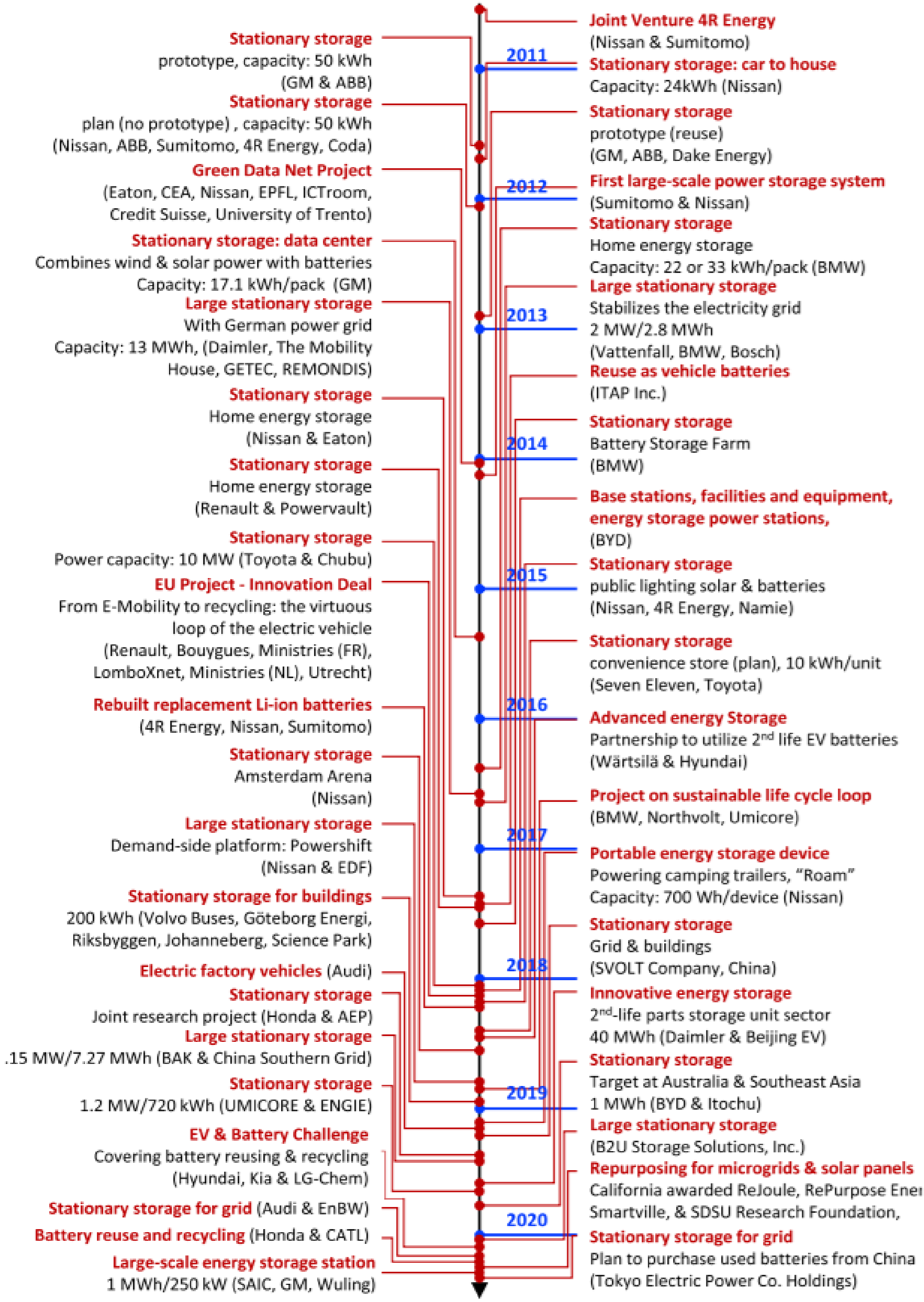
APPENDICES

Appendix 1 Second-life battery application projects



Appendix 2 European projects on second use of batteries in BESS

State	Project	Duration	Battery Technology	First Use	Applications	Comment	Capacity (kWh)	AC Power in/out (kW)	New/Old
Austria	Smart City Rheintal	2012-2015	Sodium-nickel chloride	Think City	Energy arbitrage	Two storage systems	28.2	1.5/8.2	0/100
							28.2	1.5/8.2	0/100
	SCORES	2017-2021	Lithium-ion	Formula E charging stations	Increased self-consumption		31.95	80/80	0/100
Denmark	READY	2014-2019	Lithium-ion	Nissan Leaf	Increased self-consumption	Hybrid storage using spent and new batteries	130	40/40	60/40
France	ELSA	2015-2018	Lithium-ion	Renault Kangoo	Energy arbitrage Demand charge reduction Resource adequacy (sim)	Applications tested and simulated	88	80/80	0/100
	ELSA	2015-2018	Lithium-ion	Nissan Leaf	Energy arbitrage Demand charge reduction		192	144/144	0/100
	SCORES	2017-2021	Lithium-ion	Formula E charging stations	Increased self-consumption		63.9	160/160	0/100
	IRIS	2017-2022	Lithium-ion	Renault Kangoo	Increased self-consumption		30	10/10	0/100
Germany	ELSA	2015-2018	Lithium-ion	Renault Kangoo	Increased self-consumption		66	72/72	0/100
	ELSA	2015-2018	Lithium-ion	Renault Kangoo	Energy arbitrage (sim) Frequency control (sim) Transmission congestion relief (sim) Increased self-consumption	Applications tested and simulated	66	18/72	0/100
	NETficcient	2015-2018	Lithium-ion	Nissan Leaf	Increased self-consumption	Two storage systems	24	5/5	0/100
							24	5/5	0/100
	Mobility2Grid	2019-	Lithium-ion	Audi e-tron	Different "in-front-of-the-meter" and "behind-the-meter" applications are planned	Applications planned	1900	1250/1250	0/100
Italy	ELSA	2015-2018	Lithium-ion	Renault Kangoo	Frequency control Increased self-consumption Demand charge reduction	Applications tested in two different scenarios	66	72/72	0/100
Netherlands	Pampus Project	2015	Lithium-ion	Custom made electric – VW Golf	Off-grid	System upgrade from 24 kWh to 40 kWh, recently replaced	24 to 40	30/30	0/100
Spain	Sunbatt	2014-2015	Lithium-ion	VW Golf GTE	Increased self-consumption	System setup further used in simulation studies	35.2	40/40	0/100
	Stardust	2017-2022	Lithium-ion	Nissan Leaf	Increased self-consumption	Three storage systems, partly under development	60	60/100	0/100
							200	40/40	0/100
							60	-	0/100
	EV-Optimanager	2015-2019	Lithium-ion and lead-acid	Lithium-ion from renewable facilities, lead-acid from forklifts	Time-of-use bill management Increased self-consumption	Two lithium-ion storage systems	12 each	10/10 each (DC/DC converter)	0/100 each
						One lead-acid storage system	12	10/10 (DC/DC converter)	0/100
	REFER Project	2016-2019	Lithium-ion	Renault Kangoo	Increased self-consumption		23	10/10	0/100
Sweden	IRIS	2017-2022	Lithium-ion	Volvo Bus	Increased self-consumption Demand charge reduction		196	84/84	0/100
United Kingdom	ELSA	2015-2018	Lithium-ion	Nissan Leaf	Resource adequacy Increased self-consumption Demand charge reduction (sim)	Applications tested and simulated	48	10/36	/100
Norway	ReLIEVe	2018	Lithium-ion	Nissan Leaf	Energy arbitrage		3.5	3.3/3.3	0/100
	Energipakkle Borg Havn	2018-2020	Lithium-ion	Different EV manufacturers (Mitsubishi, VW, Tesla)	Increased self-consumption	Each storage system is built from different EV battery	120	20/20	0/100
							90	10/10	0/100
							120-150	60/60	0/100
	INVADE	2017-2019	Lithium-ion	Nissan Leaf	Increased self-consumption	15 storage systems	4.6 each	6/6 each	0/100 each
						6 storage systems	10.08 each	6/6 each	0/100 each
Switzerland	Second Life	2017-	Lithium-ion	KYBURZ DXP vehicle	Increased self-consumption	Several pilot storage systems	6	3/3	0/100
							8	3/3	0/100