SOLUTIONSPLUS TOOLKIT

REPURPOSING ELECTRIC VEHICLE BATTERIES
Secondary applications as energy storage systems
## Contents

1  Project Information .................................................................................................................................................... 5

2  In Brief ........................................................................................................................................................................ 6

3  Results ........................................................................................................................................................................... 9

4  Technical and financial considerations ......................................................................................................................... 10

5  Policy/legislation .......................................................................................................................................................... 11

6  Institutions and Transferability .................................................................................................................................... 12

7  References .................................................................................................................................................................... 13
1. Project Information

Integrating Urban Electric Mobility Solutions in the Context of the Paris Agreement, the Sustainable Development Goals and the New Urban Agenda

The SOLUTIONSplus project enables transformational change towards sustainable urban mobility through innovative and integrated electric mobility solutions. The project boosts the availability of electric vehicles, fosters the efficiency of operations and supports the integration of different types of e-mobility in large urban areas and addressing user needs and local conditions in Europe, Asia, Africa and Latin America.

The project SOLUTIONSplus has set up a global platform for shared, public and commercial e-mobility solutions, and to kick start the transition towards low carbon urban mobility. The project has encompassed city level demonstrations to test different types of innovative and integrated e-mobility solutions, complemented by a comprehensive toolbox, capacity development and replication activities.

SOLUTIONSplus brings together highly committed cities, industry, research, implementing organisations and finance partners. Through numerous synergistic projects, networks and a strong technical experience, the project will be able to deliver its highly ambitious goals. Direct co-funding contributions will be provided by partner cities and SOLUTIONSplus works closely with UN Environment and the International Energy Agency (IEA) on a joint global urban e-mobility programme that will significantly boost replication and impact of this Innovation Action. Through the regional platforms, a global programme and local teams, the project aims to develop highly effective and innovative approaches to urban e-mobility ensuring that mobility systems and interventions from this project deliver on the Paris Agreement, meet the Sustainable Development Goals and address the New Urban Agenda.

- **Boost capabilities** of local and national authorities, public transport operators and entrepreneurs about innovative urban e-mobility solutions across various transport modes by **informing them about tools** to plan, assess, implement and operate e-mobility solutions.

- **Foster the take-up** of e-mobility innovations by businesses, start-ups, local and national governments and transport operators by **inspiring** officials, operators, industry and businesses through peer-to-peer exchange on innovative e-mobility products and services.

- **Strengthen** policy and business **collaboration** by **initiating** partnerships between local and national governments and local and European entrepreneurs and supporting the development of new e-mobility models business implementation plans.

- **Create reference models** for e-mobility innovation by **implementing** demonstration actions to test innovative e-mobility technologies and services, foster their **replication** and ensure their long-term **sustainability**.
2. In Brief

As the number of electric vehicles (EV) rapidly increases, the question of the end of life (EoL) management of their batteries becomes critical. Their EoL management can be separated in three main steps: repurposing or reusing batteries, repairing and refurbishing and finally recycling them (Figure 1). This factsheet covers repurposing also termed as the “second life” of the battery, corresponding to the following process: once a lithium-ion battery has reached the end of its automotive use (“first life”), usually estimated at a loss of between 20% and 30% of the initial capacity, it still has enough power (70%-80%) to be used for secondary applications as energy storage systems (ESS). Such uses cover a variety of purposes, including support for the integration of renewable energies in the grid, grid management including levelling demand peaks (“peak shaving”), back-up power or micro-grids. Hence, using second-hand EV batteries as ESS can be done in a variety of large and small-scale facilities including residential and commercial buildings, telecommunication towers, utilities.

Using retired EV batteries as ESS brings in manifold environmental and economic gains. Delaying the stage of recycling, this innovation preserves natural resources and reduces the need for production of new batteries in ESS, hence contributing to GHG abatement. The creation of a new market for retired batteries provides new economic opportunities for vehicle and battery manufacturers as well as e-waste companies, which can help reduce the upfront costs of EV batteries. By alleviating the issue of the intermittent nature of renewable energies (solar, wind), 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.

Repurposing EV batteries is seen as a promising practice: in an ideal target scenario, the Battery Global Alliance estimates that in 2030, 61% of EV batteries can be repurposed after the end of their automotive use in 2030, substituting to 20 GWh of new ESS which would have been installed, an amount corresponding to 6% of that year’s demand for ESS (World Economic Forum, 2019). Yet, at present both ESS and the use of EV batteries in these systems are still nascent practices, which explains a lack of information and data. In addition, this practice is not without technological and economic challenges including financial viability, safety, performance and liability concerns.

This factsheet is therefore conceived as a practical tool to disseminate knowledge on characteristics, challenges and solutions already identified around EV battery repurposing. It describes the different reuse options of EV batteries and related technical requirements, lists their benefits, identifies key challenges and points out to innovative models and policy options to support the uptake of this innovation.
Examples
Several options exist to make use of the substantial residual life of EV batteries, as depicted in Table 1.

Table 1. Typology of secondary applications of retired EV batteries

<table>
<thead>
<tr>
<th>Grid support and management</th>
<th>Support of decentralized energy solutions (e.g. micro-grids) in contexts of low to no access to the grid.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage of renewable energies and integration in the grid. Since renewable energies are by nature intermittent sources of power, being able to store energy is critical to support their expansion and ultimately decrease the carbon footprint of the energy sector. 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 (IEA, 2019). To balance fluctuations in the grid stemming from an ever-increasing share of renewables in electricity generation, BESS are an alternative option to additional generation sources. Smart BESS also 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. Retired EV batteries can help bring down the costs of BESS.</td>
<td></td>
</tr>
<tr>
<td>Power (load) backup, for instance in residential or commercial buildings, and particularly in contexts of instability and limited reliability of the generation or distribution networks, substituting to polluting diesel generators.</td>
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</table>

This innovative practice is relatively nascent; projects have been implemented worldwide over the last years. Involved stakeholders cover a broad range of private and public industry sectors, including large car manufacturers, battery manufacturers, e-waste management companies, energy stakeholders, software designers etc. In addition, projects deal with a constellation of aspects, ranging from the creation of new facilities such as large integrated photovoltaic (PV) and batteries systems (Case Study 1) to innovative business models (Case Study 3), battery management software, or smaller scale implementation at individual or company levels.
Case Study 1: Amsterdam stadium “Johan Cruijff Arena”

Composed of 590 battery packs (340 new and 250 second-life Nissan Leaf batteries with initial capacity of 24 kWh batteries), an energy storage system of 3 MW (power capacity) and 2.8 MWh (storage capacity) has been installed in 2018 at the Johan Cruijff Arena in Amsterdam (Pagliaro and Meneguzzo, 2019; Lambert, 2018). This ESS entails multiple benefits by leveraging the existence of solar energy generated at the stadium (4,200 rooftop PV modules), supporting grid shaving and making use of differentiated electricity tariffs (charging from the grid at night). Batteries have been certified for a duration of 10 years.

Case Study 2: Second life of Volvo Buses batteries

Volvo Buses is engaged in several initiatives where retired bus batteries are used as energy storage systems. These secondary applications include storage of locally produced solar power, power management when charging electric vehicles, power management for residential areas, support of needs in power grids etc. Projects are deployed in Gothenburg’s Fyrklövern and Viva residential areas, and in cooperation with the Swedish property manager Stena Property and BatteryLoop, a subsidiary of Stena Recycling.

Case Study 3: New business models, the case of Yinlong Energy (YLE)

YLE is an EV and battery manufacturer producing electric buses, which has set an innovative system tying first and second lives of batteries (Jiao and Evans, 2016). E-buses are sold to a financial entity, responsible for renting them to transport companies. YLE provides maintenance services during the 10-year contract, upon which expiration the company takes back the EVs, including batteries. This way, two of the main challenges of EV battery repurposing, namely battery collection and knowledge over the state of batteries are solved (see section below on “Technical and financial considerations” and identified hurdles).
3. Results

Multidimensional gains can be expected from repurposing EV batteries into secondary applications, mainly providing environmental and economic benefits.

**Benefit 1: Environmental gains**

Repurposing EV batteries:

- postpones the moment where the battery needs to be recycled, hence making a longer and more efficient use of the materials present in lithium-ion batteries, which have substantial environmental impacts. Cusenza et al. (2019) indicate that it delays the recycling stage to up to 10 years and point out to the additional benefit that recycling techniques and facilities will be more developed by then. According to the Australian company Relectrify Pty., repurposing extends the productive use of a li-ion battery to circa one third (Stringer, 2020).

- reduces the need for new batteries in ESS, saving on raw materials and its negative impacts on the environment.

For these reasons, repurposing has been identified as a low-carbon strategy contributing to GHG abatement: Ahmadi et al. (2014) calculate a 56% reduction in CO2 emissions enabled by an EV li-ion battery used for peak flattening, compared with natural gas fuelled-electric power generation. The Global Battery Alliance estimates a potential to reduce life cycle GHG emissions for medium-size vehicles in China by 2.2 g/km through battery repurposing, i.e. a higher environmental benefit than recycling assessed at 0.5 g.km (World Economic Forum, 2019).

- reduces the costs of ESS. In a project piloted by the American electric utility company American Electric Power, together with Nissan North America and the Australian battery management system (BMS) company Relectrify, ESS costs were reduced from $289 per kWh (new batteries) to $150 per kWh (Stringer, 2020). More generally, ESS (new or retired EV batteries) entail economic advantages at individual level (household, company) by enabling cost savings in buildings, through the storage of PV power or the replacement of diesel back-up generators. Such replacement may be financially interesting from the start if provided on a leasing or rental basis. ESS can also enable profits if the battery is charged at time of lower tariffs and discharged at time of higher prices (“energy arbitrage”). In addition, ESS are key to allow access to electricity in regions with low or no access to the grid.

**Benefit 2: Economic gains**

Repurposing EV batteries:

- may enable discounts on the EV battery cost. By extending the value of the battery and creating new revenue streams, repurposing can reduce its life cycle costs. Companies may factor in the resale EV battery value by passing it on the EV battery purchase price. Such a discount could have a significant impact on the EV market as the high capital cost of the EV battery is one of the main deterrents to the uptake of electric mobility. The World Economic Forum (2019) states that reuse/second life could decrease the cost of an average battery pack for a passenger car by 5.3 US$/kWh in 2030. The gain is higher than what enables vehicle-to-grid (4.7) and just slightly lower than the gain of recycling (6.1).

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- creates employment opportunities, locally by installing and operating facilities, dismantling and analysing the state of health of the EV batteries, and on a broader level by reengineering as well as creating new economic models crossing over distinct sectors and stakeholders (e.g. mobility/energy, OEM/operator etc.).
4. Technical and financial considerations

EV batteries are usually considered to come to the end of their automotive (first) use when reaching a threshold of circa 20% use of the initial capacity, but this is an approximate delimitation which actually varies between 10 to 30% (Sanghai et al., 2019; Pagliaro and Meneguzzo, 2019). Deterioration results from battery aging and degradation process which are accelerated by high charge and discharge rates, extremely temperatures and high depth of discharge (DoD), among other factors.

Repurposing EV batteries requires battery collection and transport, an existing facility with testing equipment, technical knowledge and skills, all together inducing capital and labour costs. It follows a seven-step process:

1. Removing the battery from the vehicle and assessing its history (if available),
2. Sorting batteries according to similarity (chemistry, module dimensions, number of cells, power and capacity, type of BMS, state of health),
3. Physically examining modules,
4. Testing the battery and module, sometimes the cell, and consequently assessing the residual capacity,
5. Possibly removing faulty modules,
6. Reassembling as such or in a new battery pack composed of packs having similar power and life. As batteries do not face the same constraints in size and weight as in EVs, they can be grouped together.
7. Finally, a certification process covering performance and safety aspects is desirable.

The following three key barriers hinder the uptake of EV battery repurposing, stemming from uncertainty and anxieties over the easiness of its implementation, as well as technical and legal risks. Yet, answers to these challenges have been identified, as developed in the next section on policy measures.

- **Safety and liability concerns.**
  As repurposing is a recent practice and li-ion batteries may present a risk of thermal event, uncertainties over safety aspects exist especially at stages of removal, testing and disassembly (Hossain et al., 2019). This is also linked to the lack of data on their SoH mentioned above. In addition, regulatory frameworks barely exist on safety procedures, nor safety certifications. The question of liability in case of possible events caused by the battery in the ESS poses a further challenge as the use of EV batteries in such systems has not been anticipated by manufacturers.

- **Uncertain financial viability.**
  To be preferred to new batteries of a similar capacity, repurposed EV batteries need to be available at a lower price. This may prove challenging as repurposing involves the following costs: purchase cost of the retired battery (if not owned by the company itself), collection and transport costs, and processing costs. Furthermore, the price of new batteries is expected to further decrease in the coming years (BNEF, 2019).

Economic feasibility is disputed and is likely to vary depending on case uses (Derousseau et al., 2017). The latter indicate that repurposing costs could go down to US$20/kWh, enabling repurposed EV batteries prices to be lower than new ones, even in the future. Sanghai et al. (2019) find out that repurposing can enable a 7% discount on EV batteries, taking into account forecasts on future prices.

Collecting batteries and sorting the diverse types can be a costly and complex step. Organisational schemes easing collection (e.g. OEM keeping ownership over the batteries before repurposing, as highlighted in the case of YLE described above), reducing the heterogeneity of the battery types collected, and streamlining the repurposing process, can all enable economies of scale. These economies of scale are likely to play a substantial role as large EV and battery manufacturers will be able to set up required facilities, gather data, and scale-up pilot projects. Volumes also play a role with regard to the necessity to ensure sufficient and reliable e-waste collection streams. This may prove a significant hurdle in countries with limited automotive knowledge and production, as well in the situation of nascent, limited or inexistent e-waste management policies, institutions and facilities.
5. Policy/legislation

Policy measures can help reduce anxieties over the technical performance of second-hand EV batteries repurposed as ESS, as well as increase the financial attractiveness for this new market, as shown in Figure 2.

**Figure 2:** Policy measures to challenges posed by EV battery repurposing

### Uncertainty over the battery state of health and future lifespan:
- A “battery passport”, supported by the Battery Management System (BMS) and recorded data displaying and sharing information on the battery’s origin, chemistry, performance and history;
- Support business models where the entity in charge of repurposing has been closely monitoring the battery’s performance during its automotive life, for instance by providing maintenance services, and has remained owner of the battery;
- Foster exchange of data.

### Safety and liability concerns:
- Design technical performance standards on safety practices covering all stages and retired EV battery certification; legal provisions on the labelling of batteries and their removal from equipment (e.g. European Battery Directive 2006/66/EC, Article 11 on removal);
- At international level, dialogue on product design and technical specifications enabling disassembly; work towards harmonization of rules to transport batteries;
- Legal norms clarifying liability for EV batteries used in secondary applications; develop liability standards and involve the insurance sector.

### Economic feasibility:
- Finance demonstration and scale-up projects to clear uncertainty regarding economic and technical characteristics and disseminate data, through direct funding or financial incentives (e.g. tax rebates). Such projects should also target decentralized energy systems (mini grids, microgrids) in contexts of lacking or limited access to electricity;
- Decrease repurposing costs: disseminate best practices to streamline repurposing processes to bring down their costs; address limited economies of scale by fostering regional integration of the battery market; promote closed industrial loops to track batteries and facilitate economies of scale; reducing administrative barriers;
- Improve economics of renewable energies generation through grid-related incentivization, such as net metering, feed-in tariffs, grid tariffs incentivizing charging when the demand is the lowest i.e. at night (residential peak-valley electricity price spread);
- Increase e-waste collection rates and design enabling policies, e.g. Extended Producer Responsibility (EPR), clarifying responsibilities.
6. Institutions

Repurposing EV batteries represents a substantial opportunity to break silos between the three battery, transport and energy sectors. Multi-stakeholder partnerships and innovative models going beyond one single sector are desirable to share knowledge and extend value proposition and creation.

With regards to public institutions, a large array of ministry and agencies, as well as parastatals, can be usefully involved:
- Energy Ministry and utilities in charge of the grid network;
- Ministry and agencies in charge of Environment;
- Ministry and agencies in charge of Transport;
- Ministry and agencies in charge of Industry;
- Ministry in charge of R&D; research institutions.

7. Transferability, replicability

Repurposing EV batteries for secondary applications is replicable as a pilot project or a large-scale one. Criteria to select the relevant type of secondary uses, identify technical and economic feasibility will depend on a large number of parameters including 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 especially for ESS etc.
7. References

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