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D2. 1 – BENCHMARK DEPOSITORY OF 2ND LIFE PRONE LIB & ACCEPTANCE CRITERIA AND GUIDELINES

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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List of Abbreviations

EOL	End of Life
BMS	Battery Management System
CMU	Cell Management Unit
OEM	Original Equipment Manufacturer
CAN bus	Controller Area Network
HV	High Voltage
LV	Low Voltage
EV	Electric Vehicle
BEV	Battery Hybrid Electric Vehicle
MHEV	Mild Hybrid Electric Vehicle
PHEV	Plug in Hybrid Vehicle
BESS	Battery Energy Storage System

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1 EXECUTIVE SUMMARY

To streamline the process of EV battery 2nd application development, criteria for module selection and database of existing battery packs have been compiled. Criteria have been selected basing on the inputs of 2nd life partner input and are adapted on module level. Database has been compiled with 200 commercial and passenger vehicles that are classified as BEV, MHEV and PHEV. From partner inputs it has been possible to identify the necessary acceptance criteria to help selecting the best modules for 2nd life BESS applications. Therefore, modules for HV and LV systems have been selected based on the selected criteria.

This document is created for RHINOCEROS project Task 2.1. EoL batteries characterisation and selection, within Work Package 2- Selection, characterisation and supply.

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2 INTRODUCTION

CO_2 neutral future is unimaginable without electrically powered transportation. Battery powered vehicles market share is exponentially growing, but the circular recycling strategy is yet lagging behind. Scarcity of raw materials, costs of new batteries and productions emission are some of the biggest indicators that put 2nd life applications as the forerunners of circular battery strategy. EV battery and BESS battery typology is really similar, that makes it possible to dismantle EV batteries to module level. Cells as well are really similar to the commercially available battery energy storage cells, so their second life in BESS can create price advantage, where not only modules-cells are retrieved and reused, but also contactors, fuses, CMU, wirings and bridges can be utilized. To streamline the efforts of circular economy and battery reuse, a database of existing EV battery packs has been compiled. Dismantling and 2ndlife integration process has a lot of challenges and these processes can be streamlined by having an adequate foresight of the EV Pack size, hardware and chemistry. For an example, size and weight are important criteria when acquiring the equipment for starting to handle the packs. Different OEM's produce different packs, but to handle these packs dismantling facility has to account for the size of batteries they are going to process. PHEV packs are smaller and require less space on workbench, while also put less stress on logistical and moving process chain. Yet these packs also provide less value for the dismantler as the capacity is smaller, while weight, size and dismantling time is still considerable.

On the other hand, dismantling of battery packs is a dangerous risk for the operators because of the HV architecture. With different voltages, different safety equipment is needed with different chain of process dismantling to mitigate the risk of arch fire or other damage.

While size, weight and pack architecture are considerable criterias for dismantling operations, battery modules specification are determining 2ndlife application possibilities. Starting from chemistry, we already see that the market is dominated by NMC modules, while LFP and NMA have a considerably smaller market share. 2ndlife applications are possible with NMC and NMA chemistries, but for indoor application of ESS, LFP is more desired because of the safer and more stable operation.

Battery module integration in 2ndlife application matter on their size, capacity, voltage and communications. To create ESS from battery modules, builders of these systems have to accommodate for their space and weight. Big battery modules are usually integrated in HV, containerized systems, while smaller ones serve perfectly in rack mounted solutions, where space/power density is a considerable factor.

A lot of work is also needed to integrate battery management system that can communicate with the battery module cell voltage and temperature sensors. OEM battery pack BMS is unusable without the OEM support and custom-made solutions are required to use these battery modules.

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3 METHODOLOGY

Database is created by using Watt4Ever and Accurec insights from 2nd life integration and recycling perspective. After basic template with physical and operational parameters have been developed and agreed on, the partners divide the duties on data entry.Partners have used different data sources to put in necessary makes, models and parameters on different level, thus, there is a lack of data consistency as some of the parameters are left blank, project partners agree to do their best to acquire information to fill the missing information. Database is kept updated till 2025.

Database of 200 BEV/PHEV/MHEV batteries and their characteristics is created have an overview and technical data of each model. Parameters such as size; capacity; CMU; casing; cell configuration are chosen as criteria for the 2*nd* Life applications because of the mechanical, technical and software challenges that have to be resolved for efficient module integration in deployable LV and HV BESS. Database snapshots available in Annex Figure 6. and Figure 7.

Criteria is compiled by analysis of parameters and experience factor input from partners participating in EV battery pack dismantling operations and partners participating in second life battery module integration in energy storage systems. Selected criteria should advance the ease and safety of dismantling and time spent per pack to get to module level, while also selecting criteria's that ease the 2*nd*life modules integration in battery energy storage or other systems.

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4 PARAMETERS

Database is built up with Pack-Module-Cell architecture in mind where necessary physical, electro-mechanical, chemical and nameplate specifications and properties are logged in as parameters. Data from this database is combined by using various sources of information such as internal dismantling analysis and publicly available information.

4.1 GENERAL 1ST LIFE APPLICATION INFORMATION

This section of the database identifies the first life application of battery pack. By using this information, it's already possible for dismantlers and 2*nd* life battery builders to source necessary data inputs based on the battery that they are about to do operations on.

Table 1. 1st life identification section

Type	Make	Model	Model Year
PHEV	FORD	KUGA	2019
BEV	PORSCHE	TAYCAN	2020

Starting with **Type**, we indicate what application the battery pack was used in. **Make** and **Model** is corresponding with the OEM assigned market name and model year. For battery integrators it's interesting to what is the **Model Year**, as most probably the newer the model is, the technologically advanced it will be with bigger power and capacity density.

4.2 PACK LEVEL PARAMETERS

Table 2. Pack Level section

Physical properties				Nameplate specifications					
Weight	**Length**	**Width**	**Height**	**Nominal voltage**	**Nominal energy content**	**Nominal capacity**	**Cooling Type**	**# modules**	**Module configuration**
530	2830	1772	127	375	80	15	Liquid	30	15s2p
213	1200	1723	143	350	14	3	Forced Air	7	7s1p

Pack level physical properties indicate **Weight** and **Size** that are important criteria when acquiring the equipment for starting to handle the packs. Different OEM's produce different packs, but to handle these packs dismantling facility has to account for the size and weight of batteries they are going to process. PHEV packs are smaller and require less space on workbench, while also put less stress on logistical and moving process chain. Yet these packs also provide less value for the dismantler as the capacity is smaller, while weight, size and dismantling time is still considerable.

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Nameplate specifications are corresponding with the values found on OEM data labels usually printed on the battery packs. This information contains the **Nominal Voltage**, **Energy Content** and **Capacity**, but sometimes also may include **Cooling type (Forced Air, Liquid)**, **module amount** and **configuration**. These details are important, as it may already introduce a picture for dismantler and operator on the dismantling effort and 2*nd* life integration possibility.

4.3 Module level parameters

Module physical properties are indicating the possibility of 2*nd* life integration. Usually bigger the module is, the more capacity it will have. Market is saturated with shoebox sized modules that can perfectly fit in server rack type of application where weight and space is an important factor. While bigger modules, are usually integrated in HV systems, due their size and nominal voltage/capacity.

Table 3. Module level section

Physical properties							Electro mechanical properties		
Weight	**Length**	**Width**	**Height**	**# cells**	**Cell config.**	**Casing**	**CMU**	**Communication protocol**	**Busbar connector**
12	35	15	11	12	12s1p	Open top	External multi module	CAN	M6
13	39	15	11	444	6s2p	Alu jacket	Internal	CAN	M6

Table 4. Module level section

Nameplate specifications			
Nominal voltage	**Nominal energy**	**Nominal capacity**	**Cooling type**
44	2.05	108	Heatsink
22	2.86	240	Heatsink

Cell amount, **Configuration**, **Voltage**, **CMU** and **Communications protocol** are the main factors of any battery module integration in 2*nd* life energy storage system. Also, these parameters are a great help in to understanding if modules can go in to LV or HV system.

Every battery energy storage system needs Battery Management System that controls the Cell Management Unit that is always connected to the module itself within specific communications protocol. There are different types of topologies that OEM use, like internal CMU unit that is connected to the BMS directly, while in many of the battery packs, the CMU is external from module. Module has a can connector that is connected to CMU, where one CMU is responsible for one module or it can also be multichannel CMU, where multiple modules are connected in the same CMU.

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On most cases battery pack BMS is OEM IP and can't be reused due scarce information about it, but on some cases the CMU units can be used to integrate with 3rd part BMS solution. Meaning, that if CMU also can't be used- communications protocol has to be reverse engineered to use also 3rd party hardware of CMS and BMS. Module level communications port most of the time is CAN bus, that is wired to cells that sends Cell Voltage and Temperature data over to the port via wire.

Busbar connector – Disassembling time and safety is influenced by the busbar connector setup, while in some cases propriety OEM connector is used, such as in BMW case.

While recyclers of batteries would often like to receive only the cell level batteries, often it's not possible due casing of the batteries. Cells are put in metal casing under pressure and either have an open lid or are in Alu jacket without any possibility to see or connect to the cells, except using the CANbus communications.

4.4 Cell Level parameters

Cell level properties are interesting for EOL material recyclers to adjust their metal reclaiming processes. Shape and size is important parameters for grinding machine selection, but chemical properties play a role in the Pyrometallurgy or Hydrometallurgical processes to retrieve lithium, cobalt, cooper.

Currently, cell swapping for 2*nd* life reuse is not popular among industry partners, but to work on such projects, **Size**, **Voltage** and **Chemistry** is needed to mix and match different cells to assemble new modules and battery packs.

Table 5. Cell level section

Physical properties						Chemical properties		
Weight	**Length**	**Width**	**Height**	**Cell shape**	**Diameter**	**Cathode**	**Anode**	**Ratio**
914	30	80	123	Prismatic	-	External multi module	CAN	-

Table 6. Cell level section

Nameplate specifications	
Nominal voltage	**Nominal capacity**
3.75	21

Nevertheless, Cell level parameters such as **Chemistry** and **Nominal Voltage**, **Capacity** is crucial information when selecting the BMS for 2*nd* life applications.

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5 SELECTION CRITERIA

Selection criteria is compiled by analysis of parameters and experience factor input from partners participating in EV battery pack dismantling operations and partners participating in second life battery module integration in energy storage systems. Every batter module from any OEM can be integrated in 2nd life application, but selected criteria should advance the ease and safety of dismantling and time spent per pack to get to module level, while also easing the 2*nd* life modules integration in battery energy storage or other systems.

5.1 MECHANICAL DESIGN CRITERIA

For 2nd life applications, module level parameters are the ones that give insight on the desirability. First set of parameters are the **Physical Properties,** 2*nd* life integrators already have knowledge of module integration and have specific designs to accommodate the battery modules, if the module sizing is the commonly used roughly the size of a shoe box 350*150*120 mm, it already makes the integration a lot easier, faster and cheaper. By adding **Capacity**, power density can be calculated, and the technical design improved to maximize the capacity of the system.

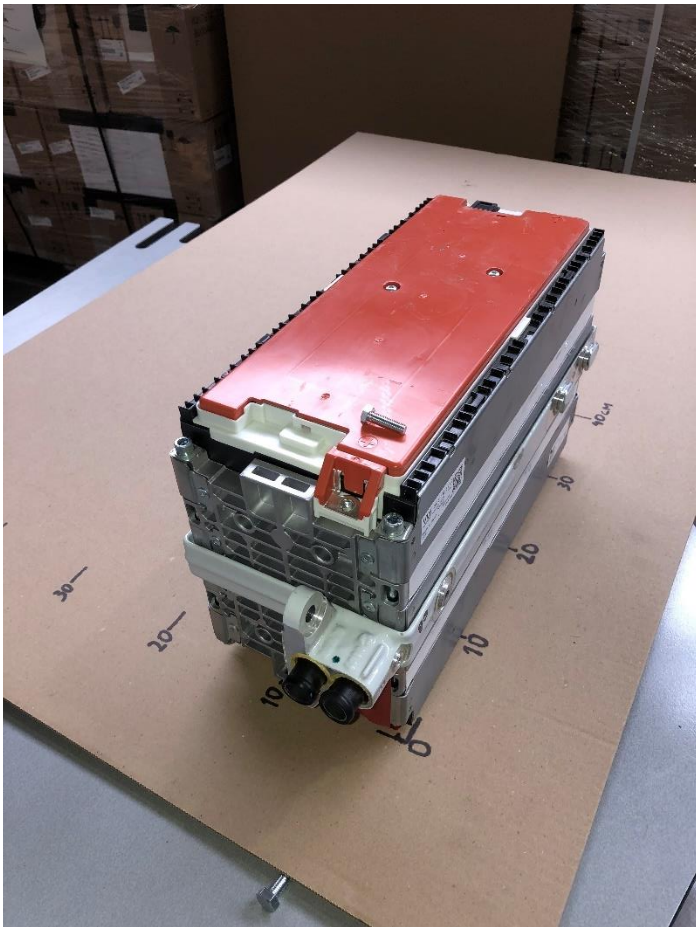

Figure 1. VAG group module with two bonded battery modules

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For an example this AUDI A3 ETRON battery module is made out from two shoebox sized module fused together with cooling plate in-between and metal bracket around it that can only be removed with angle grinder. First constrain to use these modules is their shape and size, additionally, their capacity of 1kwh per block nowadays is not enough to make sense in terms of power density as there are modules with twice the capacity in same size available. These modules have internal CMU unit that is hard to use and has little to no third-party hardware available.

Figure 2. Nissan Leaf module

Nissan Leaf battery module sizing also makes it not favourable for 2nd life application streamlining into unified design.

5.2 ELECTRICAL DESIGN CRITERIA

Cell Configuration give an insight in to the voltage of the module, but also allows to wonder about the possible BMS use in the battery, for an example, modules with 16s1p configuration are way harder to integrate, because of hard-to-find BMS/CMU solution. So, it’s better to aim for lower Cell amount.

Casing protects the cells from puncture, grinding, shorting out, but most importantly, expansion. There is a variety of designs to maximize power/capacity, but there are some that have a full Aluminium jacket casing (LG CHEM), and in case of internal CMU breakthrough, it becomes challenging to work with them. Open top design is more popular in industry and allows second life

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integrators to connect their own cell taps to the modules for faster integration without custom wiring harness development. Yet, to streamline design, custom wiring harness are being made.

BMS/CMU on some cases, we see that OEM integrate internal CMU on the module level. This makes life for second life easier, if there are third party solutions on the market that make these CMU units usable. In case of no CMU, external CMU has to used, from OEM or 3rd party.

Case examples:

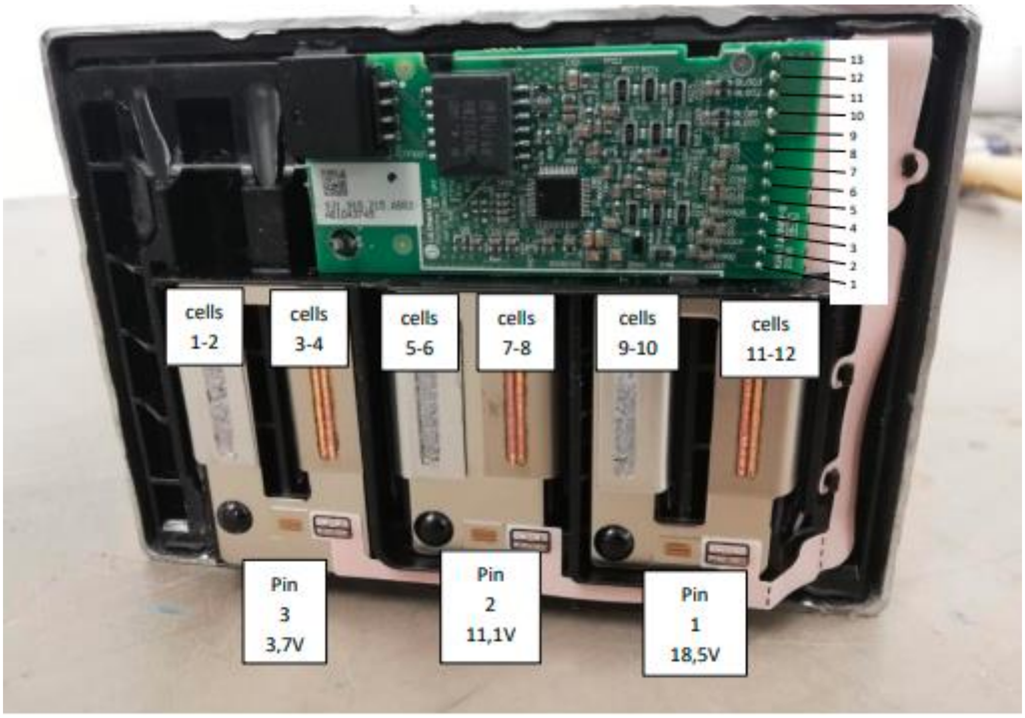

Figure 3. Porsche Taycan VAG group module

This is a LG CHEM 6s2p modules from Porsche Taycan. These modules are in a Aluminium welded casing in regular shoebox size. With internal CMU unit, it would almost be impossible to reuse these modules without support of OEM, but company in Netherlands has acquired the necessary information to communicate with the internal CMU board to make this module reusable in 2nd life application. This power dense module also has a low cell count that makes it both good in LV and HV systems.

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Figure 4. BMW group battery module

BMW SAMSUNG SDI modules are also in a shoe box size parameters and have external CMU unit. Here we can see the open-top battery module where it is also possible to connect 3rd party CMU solution. What is unfavourable with BMW modules is their proprietary bridge connection terminals, that are almost impossible to use without acquiring OEM parts.

Figure 5. Ford Kuga battery module

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Some OEM such as Ford also use SAMSUNG SDI modules, but with a different design of PCB on top of cells to minimize wiring. Also, take into account that these modules have screw terminal that are easier to work with.

5.3 MODULE ACCEPTANCE CRITERIA FOR LV 48V SYSTEM

One of the proposed 2nd life BESS LV systems is server rack design integration.

This design would allow to accommodate shoebox size modules from different OEM, while also keeping the same design of the box with small adjustments.

Mechanical Design criteria:

- **Casing-** Open top or Alu Jacket
- **Size**: 350*150*120 mm ± 100 mm on all axis
- **CMU:** External multimodule, external single module or internal and all can be reused if OEM CMU unit communications gateway is possible.
- **Cell amount:** 3s-12s
- **Voltage:** 10V-30V
- **Chemistry**: NMC with risk mitigation or LFP.

5.4 MODULE ACCEPTANCE CRITERIA FOR HV SYSTEM

For High Voltage battery energy storage system, modules that have higher voltage and size have a priority. This allows to save time and money on wiring and building expenses. Also, no internal CMU is recommended, and external CMU from 3rd party is preferred to be used to minimize any interference and bug risks with the Energy Management System.

- **Size**: >350*150*120 mm ± 100 mm on all axis
- **Cell amount:** 12s-30s
- **Voltage:** 40V-100V

DISCLAIMER: First and most important criteria is SoH of the battery. Any battery module that has at least 80% of the original capacity after 3 charge-discharge cycles and stable cell balance should be reused in BESS. What matters for the integration is the associated expenses to design and manufacture the necessary hardware and software integrations.

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6 CONCLUSION

Based on the DB, a Benchmark depository was obtained, giving an overview of the most relevant parameters for 2*nd* life. The most important parameters as module size, capacity, cell amount, CMU and power terminals were selected. Researched have tried to gather as much data as possible, but for some entries in the Module and Cell parameter level no publicly available information was found to fill. Yet database provides insights on Pack – Module - Cell level sizing, capacities and chemistries for dismantling optimization, while also providing necessary information for second life integration.

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7 ANNEX

Snapshot from Automotive Battery benchmark table.

Figure 6. Automotive Battery Database screenshot

General					Pack level parameters				
	1st application				ID				
Sort	Type	Make	Model	Model Year	Partnumber	Serial number	Bar/QR code	Producer	Weight (kg)
pack	PHEV	Ford Kuga				1222212322		SAMSUNG SDI	
pack		sla	S	2014				Panasonic	5[illegible]
pack		BMW	i3	2014				SAMSUNG SDI	2[illegible]
pack		Nissan	Leaf	2014				AESC	2[illegible]
pack	EV	Porsche	Taycan	2021				LG CHEM	
module	EV	Volkswagen	E-golf	2019				SAMSUNG/SDI	
pack	EV	Hyundai	Kona	2018				LG CHEM	4[illegible]
pack	MHEV	Acura	ILX	2014					
pack	MHEV		RLX	2014					[illegible]
pack	HEV		MDX	3rd gen					
pack	HEV		NSX	2nd gen					

Figure 7. Automotive Battery Database Module Parameters screenshot

Module level parameters														
Physical properties							Electro mechanical properties			Nameplate specifications				
Weight (kg)	Length (cm)	Width (cm)	Height (cm)	# cells	cell configuration	Casing	BMS/CMU	Comm	Busbar c	Nominal voltage (V)	Nominal energy content	Nominal capacity (Ah)	Coolingtype
12	35	15	11	12	12s1p	Open top	External multi module	CAN		44	2.05		
25	665	302	79	444		Open	External single module						
29.8	410	311	150	12		Open top	External single module			44	5.27	120	
3.8	303	225	35	4		Alu Jacket	External multi module			14	1.67	112	
13	39	15	11	6	6s2p	Alu Jacket	internal	CAN		22	2.86		
11	335	150	105	12	4s3p	open top	External single module	CAN	m6	15	1.6	108	

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