BATSS
Safe efficient BATtery SyStem based on advanced cell technology

D6.1 Safe-by-design output (I)

Author: I. Cendoya (CID), M. Arrinda (CID)

Date: 08/03/2024

Funded by the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101103821.

Project General Information

Project Acronym	BATSS
Project Title	Safe efficient BATtery SyStem based on advanced cell technology
Grant Agreement Number	101103821
Call	HORIZON-CL5-2022-D2-01-05
Project Coordinator	Fundación CIDETEC
Project Duration	1 January 2024 – 31 December 2026 (36 months)

Deliverable General Information

Deliverable No.	D6.1 Safe-by-design output (I)
Dissemination level*	PU
Work Package	WP6 - Battery system safe-by-design approach in a circular economy
Task	T6.1 - Safety for design, assembly, testing and disassembly
Lead beneficiary	I. Cendoya (CID), M. Arrinda (CID)
Contributing beneficiary/ies	M. Koller (AIT), J. Bangerl (MIBA), R. Stachl (MBS), Z. Wang (ACC)
Reviewers	M. Koller (AIT), J. Bangerl (MIBA), R. Stachl (MBS), H. Popp (MBS), Z. Wang (ACC)
Date of deliverable	08 March 2024

*PU – Public, fully open, (Deliverables flagged as public will be automatically published in CORDIS project's page)
SEN – Sensitive, limited under the conditions of the Grant Agreement

Document History

v	Date	Summary of Main Changes
1	29/01/2024	Initial version
2	09/02/2024	Overall review
3	12/02/2024	Correction of some wording for more accurate statements and correction of typos. Modification of reviewers list.
4	01/03/2024	Grant nr. corrected and logo included in cover page; section 2.1 incorporates an additional explanation of the SbD methodology; section 3.1 includes how failure modes will be categorized; section 4 contains a more specific description on how the gender dimension will be considered in the SbD methodology; some typos corrected.
5	08/03/2024	Executive Summary includes information about the outputs achieved in this report and the ones that will be included in its follow-up, D6.2

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them

Index

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them

List of Figures

List of abbreviations

WP	Work Package
SbD	Safe-by-Design
BS	Battery System
R&D	Research & Development
TRL	Technology Readiness Level
BMS	Battery Management System
FMEA	Failure Mode and Effect Analysis
R&I	Research & Innovation
EOL	End Of Life
TMS	Thermal Management System
SOC	State of Charge
TRA	Thermal runaway
SW	Software
IoT	Internet of Thing
US	Ultrasonic
PC	Personal Computer
WBG	Wide Bandgap
DC/DC	Direct Current/Direct Current
HW	Hardware
SiC	Silicon Carbide

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them

Executive Summary

This document is the deliverable "D6.1 Safe-by-design output (I)" of BATSS project (contract no. 101103821) prepared within the scope of WP6 "Battery system safe-by-design approach in a circular economy" and collects the SbD principles to be fulfilled in every step of the BS design, assembly, testing and further disassembly phases.

The purpose of this document is to define the preliminary SbD methodology to be applied in BATSS project: principles will de defined in this report. It will be the guide for the BS designers, (dis)assemblers and testers. This will be a live methodology that will be enriched and detailed until close to the end of the project (M33), since it covers the whole cycle life and value chain of the BS. The fine-tuned SbD methodology will be assessed towards the end of the project to spread the good practice in the European industry and reported in the deliverable "D6.2 Safe-by-design output (II)". This D6.1 report includes as an output a preliminary brainstorming related to the key innovations proposed in the project and their associated challenges. In D6.2, the analysis will cover both, innovative and necessary aspects of the BS in a structured FMEA and will emphasize, in this structure, gender related and hazardous materials related topics. The FMEA methodology includes the evaluation of the prevention, mitigation and protection measures to avoid or minimize the impact of any potential event.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them

1. Introduction

1.1. Purpose of the document

The deliverable 6.1 aims to define a SbD methodology in order to ensure that every step of the BS design phase follows the safety principle as soon as the project is launched. Safety must be also considered during the assembly, testing and further disassembly. Hence, each step of the BS value chain will include a customized safety overwatch program, led by CID.

The BATSS project will develop a specific SbD approach to guide the whole R&D process, aiming at identifying and mitigating (even eliminating) safety risks across the life cycle of the battery, while allowing to counteract possible performance and cost trade-offs linked to the implementation of safety barriers in the BS.

CID (WP leader of the BS mechanical design) will lead the customization of this methodology in close collaboration with WP leaders in charge of the electrical (AIT) and thermal (MIBA) design on one hand, MBS as BS assembler and ACC as leader of the disassembly procedure.

Sex differences when it comes to work safety will be carefully assessed.

1.2. Structure of the document

The document is structured into 5 sections and 1 annex:

- Section 1. Introduction
- Section 2. Safe-by-design approach
- Section 3. Preliminary identification of hazards, risks and mitigation measures
- Section 4. Gender dimension in SbD
- Section 5. Conclusions
- Annex I. References.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them

2. Safe-by-design approach

BATSS consortium will develop, up to TRL5, the different thermal, electric and mechanical innovations to meet (and improve) the industry use cases performance and safety requirements, guided by a SbD approach and supported by cutting edge modelling and simulation tools for the battery system design and predictive maintenance functionalities of the BMS. These SbD principles will be applied not only to the design phase but also to the (dis)assembly, tests and final use stages. This will be done through a methodological approach based on FMEA rules. Simulation of extreme conditions in the BS is a core activity of the SbD approach in order to avoid any dangerous event and implement countermeasures; special care will be taken to fire related events.

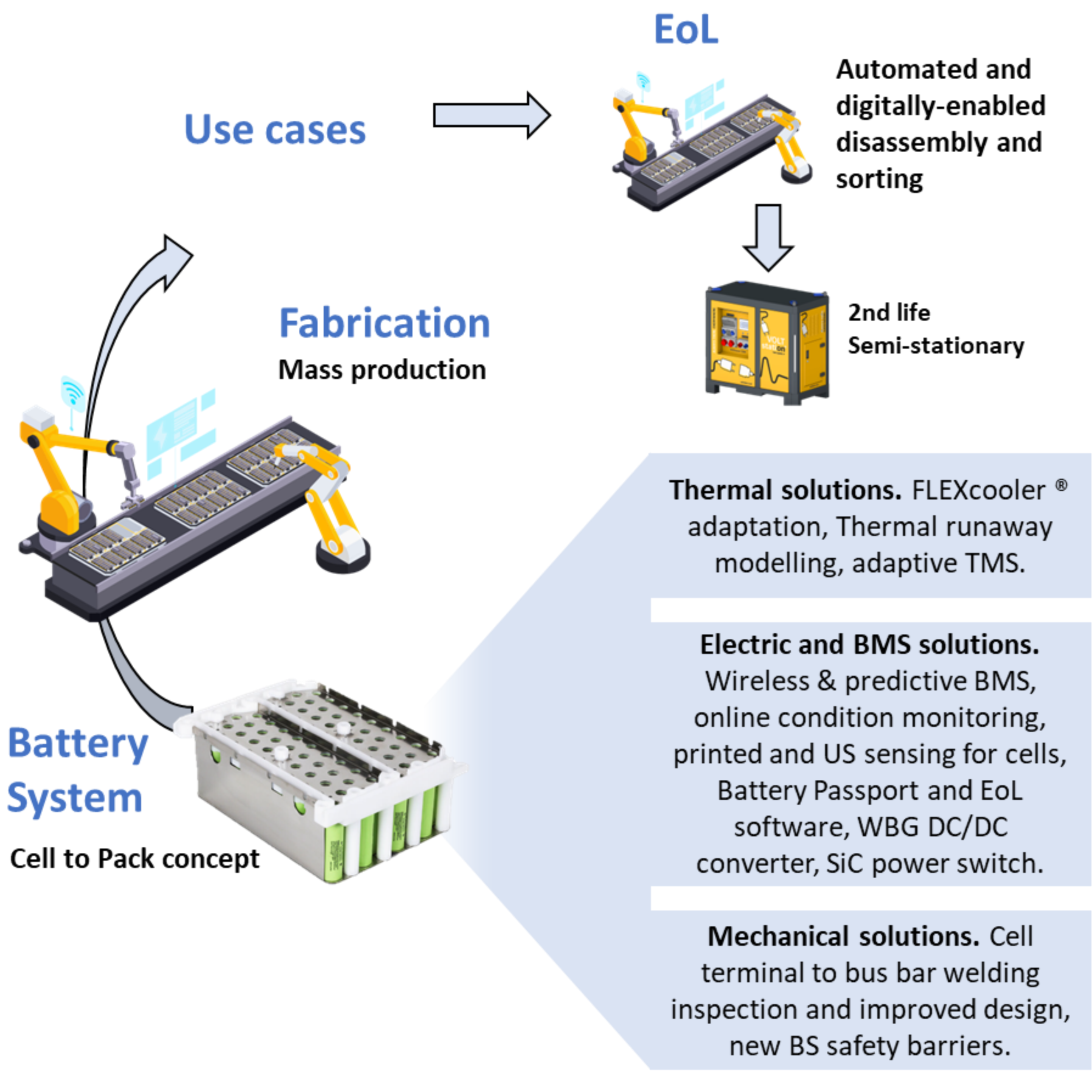

Figure 1 BATSS project concept in a nutshell

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them

2.1. The SbD concept

The SbD concept refers to identifying the risks and uncertainties concerning humans and the environment at an early phase of the innovation process to minimize uncertainties, potential hazards and/or exposure. The SbD approach addresses the safety of the material/product and associated processes through the whole life cycle: from the R&D phase to production, use, recycling and disposal.

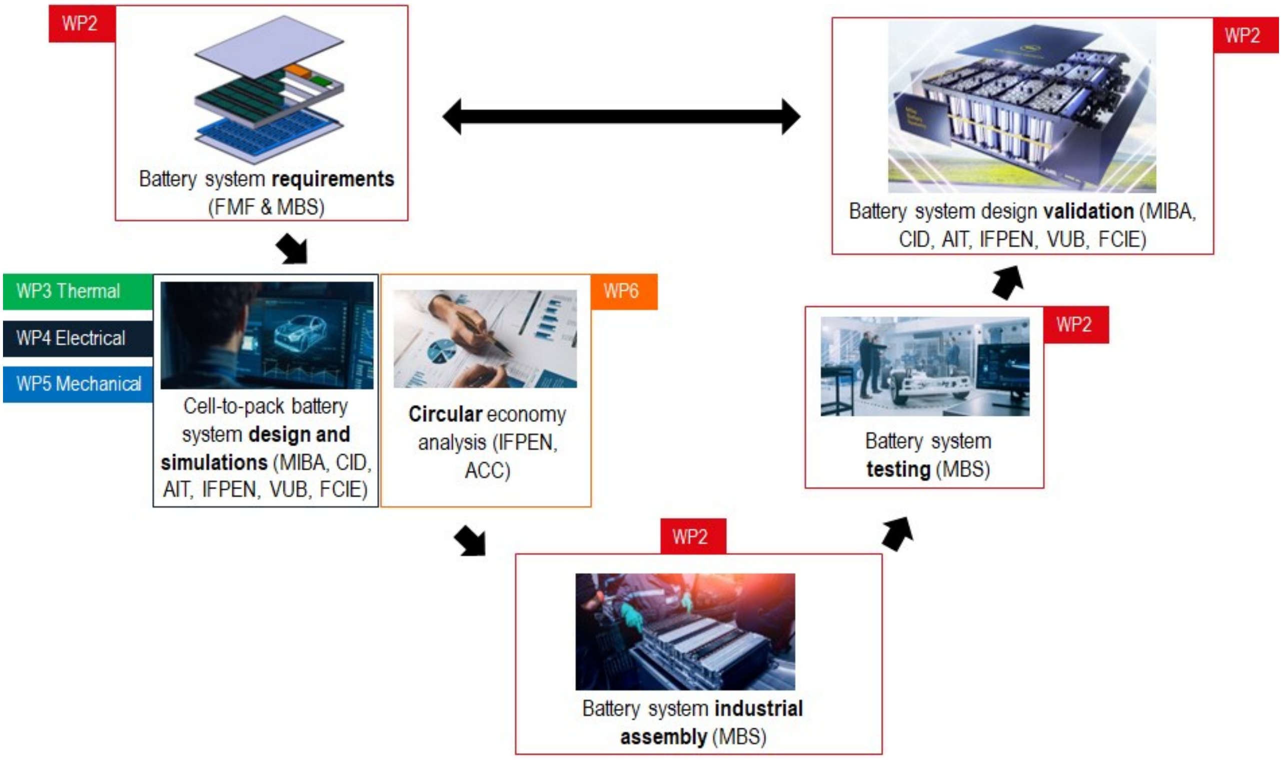

Figure 2 V-model adopted for BATSS project development cycle

During the first stages of BS R&D, designers usually focus on the technical characterization of the BS, whereas parameters as cost, environmental impact and safety are studied in detail just at later stages of the process, in the best case. This usually leads to several rework and/or the achievement of suboptimal products that do not satisfy with the same degree all the mentioned aspects. BATSS is taking a holistic approach in which all these parameters (specially safety) are equally considered intrinsically in the ideation, design, (dis)assembly (including purchase, shipment, storing and handling of components), testing and further use phases.

The SbD methodology will initially consists in the:

- Identification of **hazards** (chemical, electrical, etc.)
- Identification of root-causes and failure modes through **FMEA** analysis
- Definition of **prevention, mitigation and protection** measures via simulation and **countermeasures**.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them

This SbD process will be guided and based on a traditional FMEA multidisciplinary analysis, where the identification of hazards will have a prominent place. In the he same way, as a result of the fulfilment of the FMEA, the proposed countermeasures will be double checked with the different actors of the BATSS value chain to confirm its suitability. Depending on the failure mode under analysis, the countermeasure could have nature of prevention, mitigation or protection. When feasible, simulations and/or tests will be executed to prove the success of the countermeasures.

BATSS is executing this approach to the whole life of the BS, although a more intensive analysis is dedicated to the ideation and design phases due to the scope of the project and expected TRL5. In this sense, the SbD methodology includes electrical, mechanical and thermal simulations to cover thermal runaway, cell ageing, thermal propagation and fire related safety countermeasures, mechanical failures and BMS miscommunication.

2.2. Impact of the SbD approach

The SbD approach implemented by the project will contribute to a systematic R&D process which incorporates safety criteria to the usual product development process carried out by R&I departments. The SbD approach implemented by the project will contribute to a systematic R&D process which incorporates safety criteria to the usual product development process carried out by R&I departments, ensuring safer manufacturing process steps, and that end products used by the final customer are reliable and safe for their use. An increased trust of end-users in the safe and reliable operation of the product can also determine their market uptake. BATSS' SbD and improved safety measures will contribute companies to outstand their competitors.

BATSS' battery concept is counteracting the usual increased costs associated to safety barriers through several SbD strategies that manage to increase or maintain safety while reducing manufacturing costs (resources/time) and improving the performance,

The commercial sector places higher demands mainly on energy density and cost of battery packs. When optimizing those parameters, often safety does suffer, but as in private sector this is a must. A reliable, SbD high energy density battery pack can propel various applications for BATSS's potential customers and increase the market competitiveness of the product.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them

3. Preliminary identification of hazards, risks and mitigation measures

3.1. Initial list of aspects to be considered

This is an **initial brainstorming on key innovations** proposed from the thermal, electrical and mechanical point of view of the BATSS BS design. This initial approach is not fully considering the production and EOL of the product yet, but both will be considered as soon as the picture of the BS is clarified and inputs from partners on the production and disposal of the BS are shared. Once the brainstorming is finished it will be classified in a FMEA structure, where failure modes are identified, severity and likelihood are discussed and countermeasures proposed. Criticity of the failure in case of occurrence will be also considered and together with the likelihood and severity, each failure mode will be classified by evaluating (numerical score) these concepts. The expected success rate of the proposed countermeasure might be also included to conclude the evaluation. All these aspects will be collected and showed in a table mode.

Thermal aspect

- FLEXcooler ® adaptation
  - Electric hazard if leakage appears.
    - The FLEXcooler integration needs to be done through detailed and expert process.
    - The production process must verify unitarily that there is no leakage.
    - The BS needs to detect the leakage as soon as it happens. The design may need to add some leakage detection elements.
    - Alternative low conductivity coolants (e.g. Glysantin G22) could be used to reduce hazard.
  - Thermal hazard if proper contact between FLEXcooler and the cells is not met.
    - The design must assure the proper contact.
    - Some partial assembly or prototype must validate the contact between cells and the FLEXcooler.
    - Operation checkups should be done regarding the thermal homogeneity so as to check that the defined thermal contact between cells and FLEXcooler is maintained. Temperature sensors on cells from MBS.
  - Chemical hazard if leakage appears. The coolant may be toxic.
    - The design of the BS must avoid leakage from the BS as much as possible.
    - The manual of maintenance should have integrated the steps to be followed when there is a coolant leakage.
    - Personnel should be properly trained regarding not only electric and thermal aspects, but chemical aspects as well.
    - Check the compatibility and toxicity of new low conductivity coolants.
- Thermal runaway modelling
  - Possible failure in detecting thermal runaway due to defects/lack of sensors (inputs) or defects in the model itself (output).
    - The integrity of the sensors must be detected and reported.
    - The lack of thermal sensors cannot be a problem. This should be taken into account in the thermal runaway modelling.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them

    - The model must be validated through experiments.
- Adaptive TMS
  - Thermal hazard if the algorithm is not robust.
    - The robustness of the algorithm must be verified through extensive simulations.
    - The robustness of the algorithm must be validated through extreme operation conditions.

Electric and BMS aspect

- Wireless BMS
  - Electric hazard if loss of voltage/current measurements happens. The lack of voltage/current measurements affects the SOC estimation and therefore, it could lead to an overcharge or over-discharge.
  - Thermal hazard if loss of voltage/current/temperature measurements happens. An overcharge can trigger a TRA. The loss of temperature information can make the BMS blind to a TRA.
    - Robust SW must be developed where losses of measurements will not trigger immediate alarms, but that will point the seriousness if extended in time.
    - Perturbation robustness of the sensors. The BS design should provide it.
    - The sensors should be regularly checked in order to avoid critical issues in operation.
- Predictive BMS
  - Electric and thermal hazard if wrong predictions.
    - The SW should be robust to avoid cases where due to a bad prediction a problem could arise. An expert logic should be added between the predictive BMS and a traditional BMS. This SW should be verified with extensive simulations and validated through experiments.
- Online condition monitoring
  - Electric hazard could arise from electric perturbances.
    - The design of the IoT device must be taken into account when designing the electro-magnetic noise.
    - The perturbance levels at pre-production must be validated as appropriate with all the electric elements + the IoT device used for the monitoring purpose.
- Printed and US sensing for cells
  - Electric hazard if printed sensors change properties or suffer mini-cuts in their contact roads.
    - Robust SW design to detect those cuts.
    - Verification of the SW through extensive simulations.
    - Validation of the SW through experiments.
    - Aging tests to the printed samples so as to validate their characteristics through time.
  - Chemical hazard when recycled.
    - Appropriate recycling considerations must be done at design state.
    - A recycling plan should be done.
- Battery Passport
  - Possible future legal issues if not considered at design level. Production and operation data must be gathered and saved somewhere (standalone PC, cloud, standalone vehicles or/and …).

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them

    - Possible troubles when recycling if not considered when designing the BS.
- EoL management
    - To be discussed.
- WBG DC/DC converter
    - Electric and thermal hazard if defects appear. The transformers can produce a short cut and a TRA in consequence.
        - Proper safety HW and SW measurements should be considered when designing the BS.
        - Electric failures must be prevented by checking the integrity of the converter before connection and while working.
- SiC power switch
    - Electric hazard if defects appear. The power switch must act when needed. If not, it could lead to a TRA.
        - Robust SW. Extensive simulation to verification. Experiments to validate.
        - Integrity verifications in operation.

Mechanical aspect

- Cell terminal to bus bar welding inspection and improved design.
    - Thermal hazard if the cell is pierced too deeply.
        - The welding must be start with dummy cells, verified with simulations and validated with experiments.
        - The welding properties should be observed in a pre-production process.
        - The welding would take into consideration application operation conditions (vibrations, climatic conditions etc.)
- New BS safety barriers.
    - These barriers respond to the mitigation of TRA. They must be verified through extensive simulations and validated through experiments.
    - They should be considered in the recycling plan for old ones but also for damaged ones due to TRA.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them

4. Gender dimension in SbD

BATSS' consortium has undertaken a preliminary sex and gender analysis to define how the gender dimension can be addressed in each stage of the project lifecycle (ideation – proposal – research – dissemination), according to the checklist recommended by the HE guidelines. BATSS focuses on developing a novel BS concept, attached to SbD rules and EoL practices, whose end-users will not be individuals subject to gender, sex and other definitory conditions, but rather specific companies. Thus, gender and sex are not envisioned as a primary topic influencing the technical activities carried out in the project, and vice versa.

Nevertheless, it will be a factor to consider in other tasks carried out throughout the project. For instance, when considering the safety at work as a step of the SbD methodology, it is well known that women can be prone to suffer more from the exposure to specific chemicals than their male colleagues. This is a clear case, for instance, when using NMP solvents in the cell manufacturing step. Thus, the safety analysis in the project will take into account possible sex differences especially in the manufacturing and recycling steps of the value chain, when workers can be exposed to different risks. The FMEA analysis will keep in mind a fair and inclusive approach in order to consider the gender dimension. Once this analysis is fulfilled, the final D6.2 Safe-by-design output (II) will report any specific gender/sex issues detected in this regard.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them

5. Conclusions

This document defines the three pillars of the SbD methodology that will be applied in BATSS project (hazards identification, FMEA, prevention/reaction to issues) and addresses preliminary aspects of the BS design to be discussed guided by this approach. These aspects, as a starting point, mainly focus on the key innovations proposed by BATSS project but the whole SbD analysis will consider every step of the cycle life of the BS. During the lifetime of the project, this SbD methodology and content will be improved and updated according to the development of the project.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them

6. Annex I: References

The following references included below are helpful to answer any query related to this Safe-by-design output (I) report.

- Approaches to implement safe by design in early product design through combining risk assessment and Life Cycle Assessment, Vrishali Subramanian, Willie J.G.M. Peijnenburg, Martina G. Vijver, Carlos F. Blanco, Stefano Cucurachi, Jeroen B. Guinée, Chemosphere, Volume 311, Part 1, January 2023, 137080
https://www.sciencedirect.com/science/article/pii/S0045653522035731

- JRC Publications Repository - Safe and Sustainable by Design chemicals and materials Review of safety and sustainability dimensions, aspects, methods, indicators, and tools, Patinha Caldeira, C., Farcal, R., Moretti, C., Mancini, L., Rauscher, H., Rasmussen, K., Riego Sintes, J. and Sala, S., EUR 30991 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-47560-6, doi:10.2760/879069, JRC127109.
https://publications.jrc.ec.europa.eu/repository/handle/JRC127109

- JRC Publications Repository - Safe and Sustainable by Design chemicals and materials - Application of the SSbD framework to case studies, Caldeira, C., Garmendia Aguirre, I., Tosches, D., Mancini, L., Abbate, E., Farcal, R., Lipsa, D., Rasmussen, K., Rauscher, H., Riego Sintes, J. and Sala, S., , Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/329423, JRC131878.
https://publications.jrc.ec.europa.eu/repository/handle/JRC131878

- General principles of the use of safety factors in design and assessment, F.M. Burdekin, Engineering Failure Analysis, Volume 14, Issue 3, April 2007, Pages 420-433
https://www.sciencedirect.com/science/article/abs/pii/S1350630706000938

- A step forward towards to safe and sustainable by design chemicals and materials, ECP, 4 Annual Conference May 4 2023, Javier Sanfélix Industrial Transformation Unit, Directorate General Research and Innovation
https://emiri.eu/wp-content/uploads/2023/05/EMIRI-General-Assembly-2023-1-Slides_SSbD_Javier-Sanfelix-2.pdf

- The international ecosystem for accelerating the transition to Safe and Sustainable by design materials, products and processes, Anne Chloe Devivc FOR Cefic, WP4 leader, 21 Nov 2023: Workshop on Sustainable Materials (San Sebastian)
https://www.ami2030.eu/wp-content/uploads/2023/12/IRISS-presentation-Sustainable-Materials-WS.pdf

- Checklist for Gender-Sensitive Research
https://equal4europe.eu/checklist-for-gender-sensitive-research/

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them