

Circular economy in the automotive industry

A Cross-Consortia Use Case from Materials, Engineering and Chemical Sciences

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Abstract

Against the background of the vision of 'One NFDI', consortia are increasingly faced with the question of overarching metadata models, common metadata standards, and interoperable workflow solutions. Research in Engineering Sciences currently involves several consortia. They have set up a standing working group with the aim of finding concrete solutions in transdisciplinary research data management. One such use case addresses the reuse of components in the automotive industry, reacting to the economic and environmental challenges of our society. This applies to steel components as used in the drive technology, similarly as to components composed of (mixtures of) polymers as used in seats bumpers and armatures, as well as critical raw materials as used in car batteries.

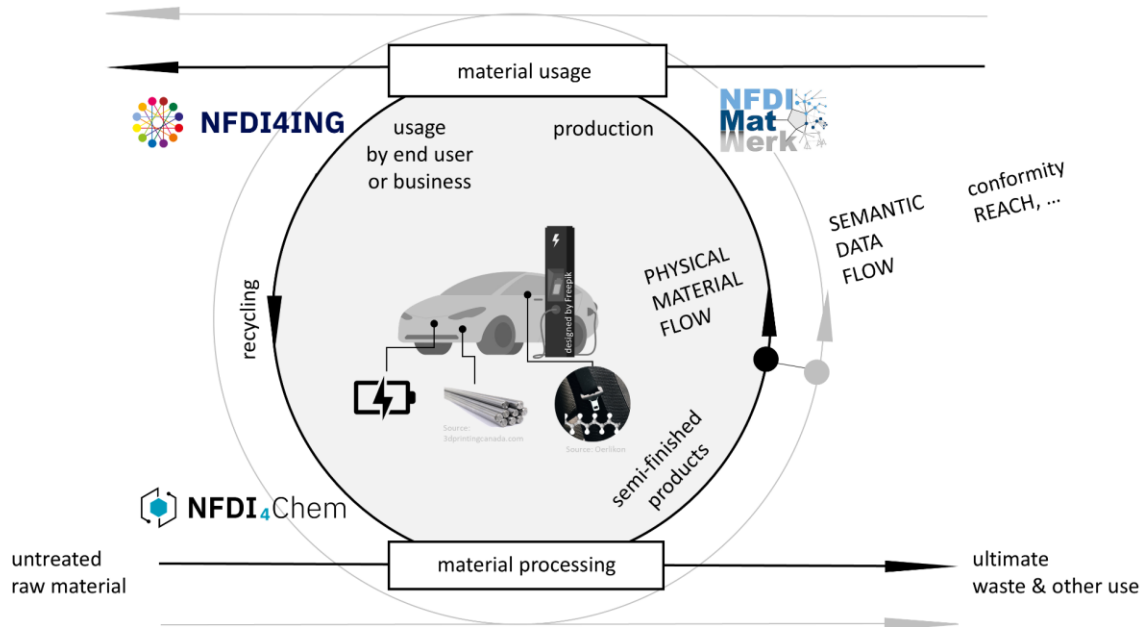


Fig. 1: Material flow and the different life cycle phases in the circular economy

However, the heterogeneity of these components, and unknown status and previous usage are a challenge. To make the reuse strategies sustainable and efficient, the systematic recording of data throughout the whole life cycle of the material is therefore mandatory, including the raw material, the processing, the product development, the manufacturing, the operational life in products and the recycling process. Batteries, for example, are disassembled in an automated way once reaching end of life, then refurbished and tested for a new lifecycle. Similarly, certain steel and polymer components in vehicles can be reused or recycled in terms of scrap material. These procedures involve a large number of stakeholders, which can interact optimally if the data are FAIR. With the present contribution, we demonstrate how a combination of tools can enable such a FAIR data exchange between several NFDI consortia for a few typical components in automotive applications.

An important challenge remains ensuring that the exchange of data, metadata, semantic data, and concepts for data processing between several NFDI consortia can be performed without the loss of information [4,5]. There are joint efforts towards standardizing software tools in order to help tackle this challenge. We demonstrate this for the exchange of workflows in computational materials design, by combining the integrated development environment pyiron from NFDI-MatWerk [4] with the workflow system KaDI4Mat used in NFDI4ING [6]. The progress of this development is shown for the semantic simulation of the steel processing [7]. Furthermore, the concept of the digital product passport is meanwhile an established concept to digitally collect the product's information along the life cycle, including data on the environmental impact. Here, the interoperability of heterogeneous data sources has been identified as the main enabler [8]. The performance of this approach is demonstrated for the digital battery passport, highlighting similarities with other relevant concepts such as digital data sheets (NFDI4ING, NFDI4Cat) [9, 10]. The digital availability of data is impacting the real world when battery data is used to decide for battery recycling or remanufacturing, and to physically disassemble it (like in the project REVAMP). The FAIR Digital Object approach [11] is followed in all consortia to provide data as well as related metadata and code in an encapsulated and FAIR way. In many cases, a minimum information standard helps to ensure FAIR data for every used methodology, as exemplified in NFDI4Chem [12]. When it comes to recycling of polymers, the composition of the polymers (e.g. colorants, additives) but also the

side reactions during their recycling need to be represented in a machine-readable way. Here, the International Chemical Identifier (InChI) can help [13].

We will discuss the advantages and challenges of these solutions and their transferability to the other components within the framework automotive industry. In this way, the added value of collaborations between Materials, Engineering and Chemical Sciences will be highlighted.

Keywords: Circular economy, Recycling, Steel, Polymers, Workflow environment, Battery, Remanufacturing, Digital Product Passport

Resources

The contribution makes uses of the following resource:

- The integrated development environment pyiron: <https://github.com/pyiron>, which allows the interoperable combination of simulation tools along the process chain.
- The ontology <https://github.com/materialdigital/stahldigital-ontology-public> of StahlDigital, which ensures that the description of steel processing is semantically interoperable.
- Technical solutions of the REVAMP project (Remanufacturing of high-variant batteries with automated disassembly and inspection processes), in which, where possible, batteries are traced as digital twin.

Author contributions

The authors contributed in different roles to this project: CE Conceptualization, Writing, Funding. ML: Conceptualization, Writing. TH: conceptualization of the simulation part of this demonstrator and corresponding software development of the workflow environment, Writing, Funding. M.M.: Conceptualization, Writing - original draft. R.S.: Conceptualization, Funding acquisition. PP: Conceptualization. SHP: Conceptualization, writing - original draft, writing - edits

Competing interests

The authors declare that they have no competing interests.

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References

- [1] Janssen, J., Surendralal, S., Lysogorskiy, Y., Todorova, M., Hickel, T., Drautz, R., & Neugebauer, J. (2019). pyiron: An integrated development environment for computational materials science. *Computational Materials Science*, 163, 24-36. <https://doi.org/10.1016/j.commatsci.2018.07.043>

- [2] Kühbach, M., Menon, S., Saxena, A., Forti, M., Kružikova, P., Hammerschmidt, T., Draxl, C., Hickel, T.: IUC 09: Infrastructure interfaces with condensed matter Physics, <https://10.5281/zenodo.12594061>
- [3] Brandt, N., Griem, L., Herrmann, C., Schoof, E., Tosato, G., Zhao, Y., Zschumme, P. and Selzer, M., 2021. Kadi4Mat: A Research Data Infrastructure for Materials Science. *Data Science Journal*, 20(1), p.8. DOI: <http://doi.org/10.5334/dsj-2021-008>
- [4] Roters, F., Aslam, A., Bai, Y., Büschelberger, M., Bulert, K., Butz, A., ... & Helm, D. (2025). StahlDigital: Ontology-Based Workflows for the Steel Industry. *Advanced Engineering Materials*, 2402148. <https://doi.org/10.1002/adem.202402148>
- [5] Nazeri, A., & Rezapour, M. (2024). WS: Preventing Data Silos in the Circular Economy – Data Spaces and Data Interoperability as Key Factors. Zenodo. <https://doi.org/10.5281/zenodo.14033069>
- [6] S. P. Lamm, P. Wetterich, I. Dietrich, S. Sommer and P. F. Pelz, "Semantic PEA Data sheet (SPEAD)". Zenodo, Apr. 14, 2025, doi: 10.5281/zenodo.15187664.
- [7] Logan, Kevin T. ; Meck, Marvin M. ; Preuß, Nils ; Wetterich, Philipp ; Pelz, Peter F. (2024): Data Management as an Enabler of Sustainability – Discussion Using the Example of a Digital Data Sheet. 13. International Fluid Power Conference, IFK 2022. Aachen (13.06.2022-15.06.2022). doi: 10.26083/tuprints-00026610
- [8] K. De Smedt, D. Koureas, and P. Wittenburg, "FAIR Digital Objects for Science: From Data Pieces to Actionable Knowledge Units," *Publications*, vol. 8, no. 2, 2020, ISSN: 2304-6775. DOI: 10.3390/publications8020021.
- [9] Herres-Pawlis, Sonja; Bach, Felix; Bruno, Ian J.; Chalk, Stuart J.; Jung, Nicole; Liermann, Johannes C.; McEwen, Leah R.; Neumann, Steffen; Steinbeck, Christoph; Razum, Matthias; Koepler, Oliver
Minimum Information Standards in Chemistry: A Call for Better Research Data Management Practices
In: *Angewandte Chemie / International edition*, Volume 61, Issue 51, Page(s) e202203038 (2022)
[DOI: 10.1002/anie.202203038]
- [10] Blanke, Gerd; Brammer, Jan C.; Baljovic, Dorde; Khan, Nauman Ullah; Lange, Frank; Bänsch, Felix; Tovee, Clare A.; Schatzschneider, Ulrich; Hartshorn, Richard M.; Herres-Pawlis, Sonja
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In: *Faraday discussions*, Volume 256, Page(s) 503-519 (2024, 2025)
[DOI: 10.1039/D4FD00145A]
- [11] K. De Smedt, D. Koureas, and P. Wittenburg, "FAIR Digital Objects for Science: From Data Pieces to Actionable Knowledge Units," *Publications*, vol. 8, no. 2, 2020, ISSN: 2304-6775. DOI: 10.3390/publications8020021.
- [12] Herres-Pawlis, Sonja; Bach, Felix; Bruno, Ian J.; Chalk, Stuart J.; Jung, Nicole; Liermann, Johannes C.; McEwen, Leah R.; Neumann, Steffen; Steinbeck, Christoph; Razum, Matthias; Koepler, Oliver
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- [13] Blanke, Gerd; Brammer, Jan C.; Baljovic, Dorde; Khan, Nauman Ullah; Lange, Frank; Bänsch, Felix; Tovee, Clare A.; Schatzschneider, Ulrich; Hartshorn, Richard M.; Herres-Pawlis, Sonja
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