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Working group vision and contribution to catalaix

In the ANTS subproject, intelligent use of sensor-based data is to enable characterization and monitoring of carbon-containing residual material flows, making data available to increase the transparency of the carbon cycle for the entire value chain. The accuracy of the data will be continuously improved by self-learning systems and used on different levels. Finally, this should enable evaluation and control of different process routes and decision making as well as a national material flow model for sustainable management of carbon-containing residues.

Current & Previous Positions

Since 2021	**Rectors Delegate for Sustainability**, RWTH Aachen University, Germany
since 2020	**Director and Full-Professor**, Department of Anthropogenic Material Cycles, RWTH Aachen University, Germany
2018-2019	**Research group leader** at INZIN Institute, Düsseldorf, Germany
2013-2020	**project coordinator** at Wuppertal Institut für Klima, Umwelt, Energie gGmbH, Wuppertal, Germany
2010-2013	**research fellow** at Wuppertal Institut für Klima, Umwelt, Energie gGmbH, Wuppertal, Germany
2008-2009	**research and teaching assistant** at the Technical University of Munich, Germany
2006-2008	**research fellow and assistant** at the German Advisory Council on the Environment (SRU), Munich and Berlin, Germany

Education

2006-2010	Phd with Prof. Dr. Martin Faulstich, Technical University of Munich, Germany
2003-2006	Graduation in Environmental planning and engineering ecology, TU Munich, Germany
2000-2003	Graduation in Molecular Biotechnology, Munich, Germany

Fellowships and Awards

2018-2019	**habilitation scholarship** at INZIN Institute, Düsseldorf, Germany

Contributions to the science system

2023	reviewer for “Dialogplattform Recyclingrohstoffe” initiated by the ministry for economy
Since 2022	member of scientific committee of the World Resource Forum.
since 2022	Jury member for HumboldthochN Award, sunstainability initiative of the Universtities in Northrhine Westfalia
Since 2021	Member of advisory board for the research focus "Energy, Environment & Sustainability" of the FernUni Hagen

since 2021 Rector's Delegate for Sustainability of the RWTH with a focus on research
since 2021 member of International Society for Industrial Ecology (ISIE)
since 2021 member of expert committee Resources&Agrobusiness for the "Zukunftsagentur" Rhenish mining area.
since 2020 member of the German Society for Waste Management (DGAW)
since 2020 Cofounder of the center of Circular Economy at RWTH Aachen University
Since 2020 member in the DIN Standard committee NA 172-00-14-01 AK "Circular Economy".
since 2018 member of the NaRess Network, which is the national platform for resource efficiency, initiated by the Federal Environment Ministry

Selected Projects

Since 2019 Core PI of the national Cluster of Excellence "Fuel Science Center"
2019-2022 Coordination Committee of *Kopernikus Project P2X*
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Most important scientific contributions

Bayram, B., & Greiff, K. (2023). Life cycle assessment on construction and demolition waste recycling: A systematic review analyzing three important quality aspects. The International Journal of Life Cycle Assessment, 1-23. DOI: 10.1007/s11367-023-02145-1.
Life cycle assessment (LCA) is increasingly being applied to construction and demolition waste (CDW) recycling. But what is the current state of LCA studies on CDW recycling? In the context of circular economy, several aspects become important in LCA, such as avoided impacts and consideration of the quality of recycled materials. The aim of this study is to identify inconsistencies and best practices, and then provide recommendations for future LCA studies focusing on CDW recycling.

N. Kroell, X. Chen, B. Küppers, J. Lorenzo, A. Maghmoumi, M. Schlaack, E. Thor, C. Nordmann, K. Greiff (2022). Near-infrared-based determination of mass-based material flow compositions in mechanical recycling of post-consumer plastics: Technical feasibility enables novel applications, 06 November 2022, PREPRINT (Version 1) available at Research Square. DOI: 10.21203/rs.3.rs-2241246/v1.
Mass-based material flow compositions (MFCOs) are crucial to assess and optimize mechanical plastic recycling processes. While MFCOs are determined by manual sorting analysis today, in the future MFCOs could be determined inline through near-infrared-based material flow characterization. This study aims to quantify the accuracy of near-infrared-based MFCO determinations to assess its technical feasibility. Binary mixtures of plastic flakes and post-consumer packaging were pixel-based classified at different material flow presentations, and mass-based MFCOs were predicted from the resulting false-color data using different data processing techniques. The results show high correlations between near-infrared-based false-color data and mass-based MFCOs. Through regression models and data aggregation, it was possible to predict mass-based MFCOs with mean absolute errors of 0.5% and 1.0% and R2-scores of 99.9% and 99.4% for plastic flakes and packaging, respectively, across all material flow presentations. The demonstrated technical feasibility thus paves the way for new sensor technology applications in plastic recycling.

W. Hagedorn, A. Gramlich, K. Greiff, U. Krupp (2022). Alloy and process design of forging steels for better environmental performance. Sustainable Materials and Technologies, 150, 141-150. DOI: 10.1016/j.susmat.2022.e00509.
In material development processes, the question if a new alloy is more sustainable than the existing one becomes increasingly significant. Existing studies on metals and alloys show that their composition can make a difference regarding the environmental impact. In this case study, a recently developed air hardening forging steel is used to produce a U-bolt as an example component in automotive engineering. The production process is

analyzed regarding the environmental performance and compared with the standard quench and tempering steels 42CrMo4 and 33MnCrB5–2. The analysis is based on results from applying the method of Life Cycle Assessment. It is seen that the air hardening forging steel has environmental savings as it enables skipping a heat treatment process. Superior material characteristics enable the application of lightweight design principles, which further increases the potential environmental savings. The present work shows that the question of the environmental impact does not end with analyzing the raw material only. Rather, the entire manufacturing process of a product must be considered. The case study also shows methodological questions regarding the specification of steel for alloying elements, processes in the metalworking industry and the data availability and quality in Life Cycle Assessment.

W. Hagedorn, S. Jäger, L. Wieczorek, P. Kronenberg, K. Greiff, S. Weber, A. Röttger (2022). More than recycling - The potential of the circular economy shown by a case study of the metal working industry. Journal of Cleaner Production, 377, 134439. DOI: 10.1016/j.jclepro.2022.134439.

The steel industry is responsible for a quarter of all industrial greenhouse gas emissions. So far, the environmental savings are mainly due to steel recycling. Besides recycling, the circular economy offers strategies to increase material efficiency and thus decrease the primary raw material demand. However, the potentials remain unexploited because circular economy concepts with a higher degree of circularity are not considered. The presented case study of an industrial machining knife illustrates how the production process can be improved by implementing various circular strategies. The environmental performance is analyzed by calculating and comparing the carbon footprint, the cumulative energy demand and the material footprint, and the material efficiency indicator. The results show that the implementation of the three overarching strategies of the circular economy - narrowing, closing, and slowing – contributes to a significant increase in material efficiency. The implementation also has a positive effect on the overall environmental performance. The circular production processes require less energy and resources and cause fewer emissions. Auxiliary processes such as additional transport routes are relevant, as they can reduce or even overcompensate for savings. These processes must be adequately considered and designed.

J. Schleier, M. Simons, K. Greiff, G. Walther (2022). End-of-life treatment of EPS-based building insulation material - An estimation of future waste and review of treatment options. Resources, Conservation and Recycling, 187, 106603. DOI: 10.1016/j.resconrec.2022.106603.

Expanded Polystyrene (EPS) used in External Thermal Insulation Composite Systems (ETICS) is mainly disposed of in waste incineration plants. However, alternative recycling options need to be identified as capacities for this waste treatment are limited and the amount of EPS-based ETICS waste is expected to increase. Herein, it is necessary to quantify the future waste masses with regard to regional distribution as EPS-based ETICS waste is generated decentrally. Furthermore, consistent information on alternative treatment options for EPS-based ETICS waste is lacking. First, we estimate the amount of upcoming EPS waste from ETICS in Germany with a high spatial resolution. Second, we evaluate state-of-the-art waste management options regarding economic, legal and environmental aspects. We find that waste masses will increase from 3 to 33 kt (2020-2040) with large spatial deviations. We conclude that solvent-based recycling seems promising, but more sophisticated analyses are required, i.e. planning of the future waste treatment infrastructures.

N. Netsch, M. Simons, A. Feil, H. Leibold, F. Richter, J. Slama, S.P. Yogish, K. Greiff, D. Stapf (2022). Recycling of polystyrene-based external thermal insulation composite systems –

Application of combined mechanical and chemical recycling. Waste Management, 150, 141-150. DOI: 10.1016/j.wasman.2022.07.001.
The material recycling of complex waste streams such as external thermal insulation composite systems (ETICS) is challenging, which is why their recycling in the sense of a circular economy is currently hardly established. Therefore, the combined mechanical and thermochemical recycling of ETICS based on expanded polystyrene (EPS) is investigated experimentally and by simulating full process chains in order to evaluate circular economy opportunities. Model ETICS as example for building and construction waste is pretreated mechanically, followed by either pyrolysis and / or gasification steps, and full mass and energy balances are derived. By the combined recycling, inorganic compounds can be separated to a large extent allowing a pre-concentrate generation. The plastic-rich pre-concentrate is converted into either pyrolysis oil with a high styrene monomer content of 51 wt% or to synthesis gas in the subsequent thermochemical conversions. The holistic approach enables a high carbon recycling rate between 53 and 68 wt%. In addition, the investigation reveals technology limitations and opportunities to be further developed and optimized.

N. Kroell, X. Chen, K. Greiff, A. Feil (2022). Optical sensors and machine learning algorithms in sensor-based material flow characterization for mechanical recycling processes: A systematic literature review. Waste Management, 149, 259-290. DOI: 10.1016/j.wasman.2022.05.015.
Digital technologies hold enormous potential for improving the performance of future-generation sorting and processing plants; however, this potential remains largely untapped. Improved sensor-based material flow characterization (SBMC) methods could enable new sensor applications such as adaptive plant control, improved sensor-based sorting (SBS), and more far-reaching data utilizations along the value chain. This review aims to expedite research on SBMC by (i) providing a comprehensive overview of existing SBMC publications, (ii) summarizing existing SBMC methods, and (iii) identifying future research potentials in SBMC. By conducting a systematic literature search covering the period 2000 – 2021, we identified 198 peer-reviewed journal articles on SBMC applications based on optical sensors and machine learning algorithms for dry-mechanical recycling of non-hazardous waste. The review shows that SBMC has received increasing attention in recent years, with more than half of the reviewed publications published between 2019 and 2021. While applications were initially focused solely on SBS, the last decade has seen a trend toward new applications, including sensor-based material flow monitoring, quality control, and process monitoring/control. However, SBMC at the material flow and process level remains largely unexplored, and significant potential exists in upscaling investigations from laboratory to plant scale. Future research will benefit from a broader application of deep learning methods, increased use of low-cost sensors and new sensor technologies, and the use of data streams from existing SBS equipment. These advancements could significantly improve the performance of future-generation sorting and processing plants, keep more materials in closed loops, and help paving the way towards circular economy.

Patents