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## Material Flow Analysis of the Recycling Pathways for Advanced (Nano)Materials

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**Faculté :** Faculté des Sciences appliquées

**Diplôme :** Master : ingénieur civil en chimie et science des matériaux, à finalité spécialisée en Advanced Materials - Innovative Recycling

**Année académique :** 2023-2024

**URI/URL :** <http://hdl.handle.net/2268.2/21036>

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# EXECUTIVE SUMMARY

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AUGUST 21, 2024

## Short summary

The EU's circular economy strategy pushes more and more post-consumer waste toward recycling facilities, in an attempt to achieve the highest possible material or energy recovery. Its strategy is represented by targets for collection and recycling rates in multiple waste categories, or if not specific numbers, then extensive guidelines as to how to handle such waste. With technological advancements and material science and engineering coming up more and more advanced materials, it is uncertain what happens to these products when they enter their end-of-life stage. To a particular concern of this study are advanced (nano)materials (ANM) which are either coated or embedded in a matrix, hence they will end up following the matrix in the recycling streams. To assess the flow of ANM throughout various recycling streams a prospective dynamic probabilistic material flow analysis (pDPMFA) is done. This is a computational method used to determine current and future mass flows of ANM (or other materials) within a system. A knowledge gap specifically in the recycling sector was noticed and therefore a compilation in the form of diagrams of recycling technologies for all types of gathered post-consumer waste and their relevant side processes, those in use now and those with high probability to be implemented in the near future, was made. This compilation includes relevant process parameters which could induce change in an ANM. A decision tree is provided to help navigate the recycling the diagrams. Finally, a case study was performed to showcase how the system should be used. Graphene was selected as an ANM because of its enormous utilization potential in various products. Three seemingly unrelated waste categories were selected for the study, namely tires, batteries and concrete, all of which hold high potential to hold graphene. The compiled overview of recycling technologies as well as the case studies let to multiple conclusions. It was shown that a big fraction of the waste, particularly tires and batteries, is in fact improperly disposed, for reasons such as economics and criminal activity of the waste management sector; or because of convenience or lack of awareness and education of the consumers. On the other hand, concrete has achieved almost perfect collection, going well above its targets. However, transparency in terminology such as recycling are lacking and therefore the reported numbers for recycling rates are not a fair representation of current trends. Another thing represented was those multiple recycling treatments may exist at the same time and flows should be distributed to each, with dynamic change for environmental and economic trends. Lastly, research in recycling technologies showed that is it possible to perform close-loop recycling even for ANM such as graphene, and even that recyclers are aiming for the production of ANM during their processes such as pyrolysis, in an attempt to make them more economical. However, it is unclear what happens to the graphene that entered the system beforehand. Additionally, even though some economic and environmental analysis were done on the matter, further economics, LCA and energy flows should be studied in depth before the implementation of these processes.

As part of the EIT chapter, the business opportunity posed by this study was presented. According to multiple financial, entrepreneurial and technical analysis, it was found that the market is currently a promising opportunity for development.