The Safe and Sustainable by Design Framework applied to Graphene-based Materials

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1. Introduction

In 2022, the proposal for a framework that connects safety and sustainability aspects was disclosed by the European Commission with the main objective to boost innovation towards a toxic-free environment and retain the position as a frontrunner in this regard.[1] This safe and sustainable by design (SSbD) framework aims to identify and substitute the chemicals of high concern as well as point out safe and sustainable chemicals and materials to continue developing them. The years 2023 and 2024 are the periods of testing the framework and submitting feedback to improve and further develop the framework.[1] In this context, we performed a case study involving graphene-based materials (pristine graphene, graphene oxide, and reduced graphene oxide). Graphene and its relatives have gained interest after their discovery in 2004 thanks to their enhanced properties counting exceptional thermal and electrical conductivity, flexibility, and mechanical strength that are very desirable in the electronics and energy sectors.[2]

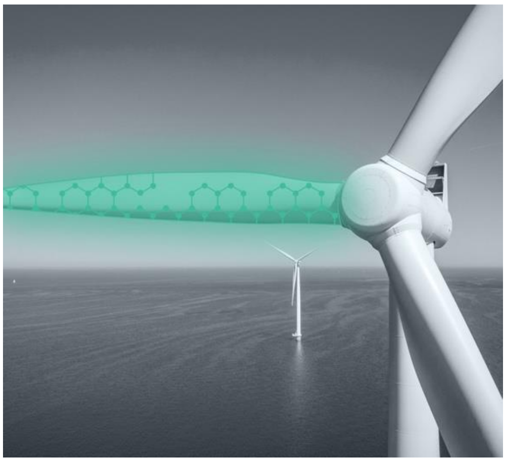

Figure 1: graphene-based additives in wind turbine blades are beneficial especially in harsh environments as they increase the strength and durability of coatings. Picture retrieved from sparctechnologies.com.au.

2. Methodology

To assess the operability of the framework applied to materials instead of conventional chemicals, the proposed approach was followed in this case study of graphene-based

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materials (GBM). The primary focus was placed on the evaluation of the applicability of the suggested models and tools to novel materials. Secondly, the framework was applied to the materials as the final product instead of predefining an application to evaluate to what extent the framework can be used if it is independent of a final application.

In Step 1 of the SSbD framework, a hazard assessment was conducted for each of the three GBM forms. The primary classifications were collected from the ECHA database and the missing hazard classes were evaluated and justified by data obtained from published papers and studies. For the occupational safety and health (OSH) assessment in Step 2, the Stoffenmanager Nano Module was used to perform an inhalation risk assessment of six different techniques to produce GBM. In Step 3 of the framework, the risk assessment during the final application phase, GBM in wind turbine blades was chosen as specific application. To conduct a complete environmental risk assessment, a published prospective material flow analysis (MFA) of graphene-based materials was used.[3] The MFA considers all flows along the life cycle and from all expected uses and allocates them into different compartments. To evaluate the impact of GBMs coming solely from the application in wind turbine blades, all other flows were set to 0. This approach allows us to estimate the exposure to humans and the environment by deducting the information from the overall consumption data and put in relation. Lastly, in Step 4, the environmental sustainability assessment was done by a function-based life cycle assessment where the reference product was a wind turbine blade without the addition of GBM. Finally, the scores of each step (1-4) are summed up to get an SSbD score.

3. Discussion and Results

Starting with the hazard assessment, graphene-based materials have not been fully classified under CLP. Based on the classifications available, all three forms pass the cut-off criteria suggested in Step 1. Nonetheless, the classification of respiratory sensitization and endocrine disruption (environment) was not possible due to a lack of data. These potential hazard classifications could change the final scoring of the GBM, and they wouldn't pass the cut-off criteria. While the hazard assessment step is resource- and time-demanding, it provides an overview of (eco)toxicological properties of the material and identifies data gaps and needs to allow a more accurate assessment.

The results obtained with the Stoffenmanager Nano Module show a risk priority level for the six production techniques. The chemical vapor deposition route resulted in the least risky one. Information requirements for this step are very extensive and data concerning the production of a material is often not given due to confidentiality reasons. Additionally, exposure estimation models for materials are not as developed as for conventional chemicals.

Continuing to Step 3, the environmental exposure of graphene-based materials present in wind turbine blades was estimated starting from a prospective MFA by Hong *et al*. To get the relevant PEC and PNEC values, all data from flows other than into wind turbine blades was removed. Compared to the overall exposure of all combined uses the environmental release is a very small amount since the majority of the GMB remains in in-use stock. From the human health perspective, the GBM are considered not to be hazardous since they are embedded into a polymer and hence lose the hazardous properties that come from the dusty nature of the material. On the other hand, the exposition is set to be zero since no clear information about possible abrasion of the graphene content is known. Additionally, there is no direct contact between consumers and the final application. The availability of a MFA is beneficial to conduct a risk assessment that considers various uses and life cycle stages because it shows not only an absolute score but also relative amounts.

The LCA conducted in Step 4 show the changes in environmental impacts that come from the addition of GBMs in wind turbine blades respective to the blades that are GBM-free. This assessment requires a lot of different information and is not accurate until a certain degree of data certainty is achieved.

4. Conclusion

Overall, the SSbD assessment incorporates many safety and sustainability aspects that provide an overview of challenges, data gaps and other features of the GBM throughout their life cycle. Until there is no planetary boundary for novel entities to use the absolute sustainability concept, to evaluate the safety and sustainability of the GBMs, one specific application needs to be selected. Hence, the effort in terms of time, knowledge, and other resources for a single application is very high. To increase the efficiency of the framework especially when applied to non-conventional chemicals, models and tools need to be further developed.

5. References

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