LIFE-CYCLE RISK ASSESSMENT OF GRAPHENE FUNCTIONAL FABRICS

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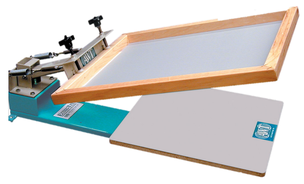
Raw Material → Product Manufacture → Product Application → Product Use → Re-use/ Recycling → Disposal






1. Identify and Characterize Potential Hazards

2. Assess Exposure Potential and Risk

3. Prioritize Data Gaps

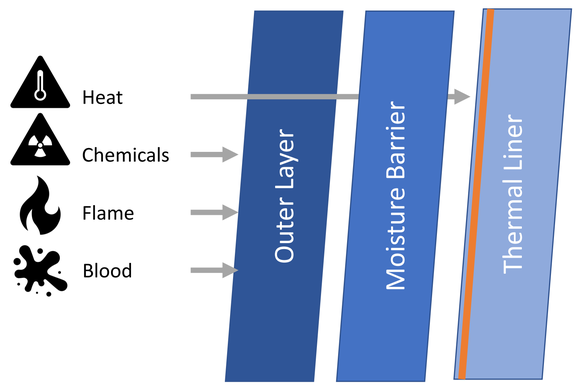
4. Address Data Gaps (E.g., Toxicity Studies)

Output: EHS Strategy

PROJECT SUMMARY

- Performed a nano life-cycle risk assessment (NANO LCRA) of a graphene-enabled textile for heat and fire-resistant PPE.
- Developed the graphene toxicity database, evaluating state of knowledge.
- Exposure scenarios associated with inhalation of graphene powder rank highest.
- Priority research gaps: long-term, low dose graphene exposures; potential release and hazard characterization of graphene-acrylic nanocomposites.
- Development of Safe(r) and Sustainable-by-Design (SSbD) strategies.

CASE STUDY



APPROACH

1. Case Study Development

Assumptions for GrapheneXT Industrial Partner Case Study
Textile nanocomposite targets thermal dissipation, fire resistance, and antistatic properties
No PPE used across product life
Use of graphene nanoplatelets produced by liquid exfoliation
Production of graphene-acrylic paste according to XT method (5-10%wt GBM)
Applied to textile via XT method (screen printing) to innermost thermal liner, out-facing
Garment follows NFPA and CSN design & care standards

2. Exposure Scenario Development Across Life-cycle Stages

For each life-cycle stage, possible scenarios that could lead to occupational, public or environmental exposure are identified.

1. Raw Material
2. Product Manufacturing
3. Product Application
4. Product Use
5. Re-use/Recycling
6. Disposal

3. Scenario Ranking

Scenarios are ranked by applying four exposure criteria (relative scores: 1-3). Highest cumulative scores become the top-ranked scenarios.

- Directness of exposure
- Magnitude
- Likelihood
- Frequency

4. Exposure and Hazard Literature Review

Literature about hazards (inhalation, dermal, ingestion, eye, ecological) and potential exposures to graphene (and other GBMs, where data is limited) in the workplace, to the public, or in the environment is collected and analyzed.

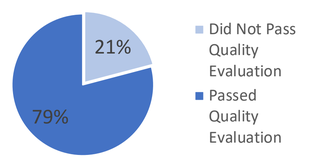
5. Risk Characterization and Data Gap Analysis

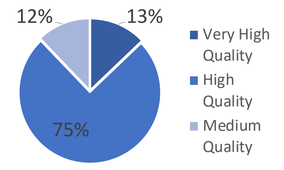
The potential risks associated with the top-ranking exposure scenarios at each life-cycle stage are characterized on the basis of available information on exposure and hazard. This multi-angle approach exposes the strengths and shortcomings of current knowledge. The analysis contributes key findings toward the development of Safe(r) and Sustainable-by-Design (SSbD) strategies by identifying the key potential human and environmental hazards and exposures of the products across the product life-cycle.

RESULTS

The Graphene Toxicity Database

A literature review, quality evaluation, and database development informs potential hazards associated with graphene-based materials (GBMs) across the product life-cycle. Studies evaluating human health (in vivo, in vitro) and ecotoxicity were collected [8] subjected to a quality evaluation following the GUIDEnano approach [9] with the following results:





Life Cycle Stage	LC Stage Code	LC Stage #	Scenario #	Scenario	Receptor	Exposure Route	Hazard Potential	Magnitude [1]	Likelihood	Frequency	Score	Rank
Raw Material	RM	1	1	Transfer graphene from synthesis facility to production facility (e.g.handling & bagging)	occupational	inhalation	3	3	2	3	11	1
Raw Material	RM	1	2	Transfer graphene from synthesis facility to production facility (e.g. handling & bagging)	occupational	ingestion/derm	3	3	2	3	11	1
Product Manufacturing	PM	2	1	Mixing graphene and acrylic to produce paste - graphene dust release	occupational	inhalation	3	3	2	3	11	1
Raw Material	RM	1	3	Incidental release from synthesis equipment	occupational	inhalation	3	2	2	3	10	2
Raw Material	RM	1	4	Incidental release from synthesis equipment	occupational	ingestion/derm	3	2	2	3	10	2
Raw Material	RM	1	5	Incidental release from synthesis equipment	environmental	direct contact	3	2	1	3	9	3
Raw Material	RM	1	6	Synthesis equipment cleanout	occupational	inhalation	3	2	2	2	9	3
Raw Material	RM	1	7	Synthesis equipment cleanout	occupational	ingestion/derm	3	2	2	2	9	3
Raw Material	RM	1	8	Synthesis equipment cleanout	environmental	direct contact	3	2	2	2	9	3
Raw Material	RM	1	9	Accidental release/spill during production	occupational	inhalation	3	3	2	1	9	3
Raw Material	RM	1	10	Accidental release/spill during production	occupational	ingestion/derm	3	3	2	1	9	3
Raw Material	RM	1	11	Accidental release/spill during production	environmental	direct contact	3	3	2	1	9	3
Product Manufacturing	PM	2	2	Mixing graphene and acrylic to produce paste; homogenization in roller-dermal contact with mix/paste	occupational	ingestion/derm	2	2	2	3	9	3
Product Manufacturing	PM	2	6	Accidental spill/release of graphene powder during handling	occupational	inhalation	3	3	2	1	9	3
Product Application	PA	3	1	Paste deposition on textile with screen print equipment	occupational	ingestion/derm	2	2	2	3	9	3
Product Use	PU	4	1	Contact with graphene on textile during firefighting garment assembly/detachment	occupational	dermal	2	2	3	2	9	3
Re-use/Recycling	RR	5	7	New use causes graphene release from textile	public	inhalation	2	1	3	3	9	3
Re-use/Recycling	RR	5	8	New use causes graphene release from textile	public	ingestion/derm	2	1	3	3	9	3
Re-use/Recycling	RR	5	9	New use causes graphene release from textile	environmental	direct contact	2	1	3	3	9	3
Product Manufacturing	PM	2	3	Equipment cleanout	occupational	inhalation	2	2	2	2	8	4
Product Manufacturing	PM	2	4	Equipment cleanout	occupational	ingestion/derm	2	2	2	2	8	4
Product Manufacturing	PM	2	5	Equipment cleanout	environmental	direct contact	2	2	2	2	8	4
Product Application	PA	3	3	Screen print equipment cleanout	occupational	ingestion/derm	2	2	2	2	8	4
Product Application	PA	3	4	Screen print equipment cleanout	environmental	direct contact	2	2	2	2	8	4

Exposure Scenario Development and Ranking

CONCLUSIONS AND RECOMMENDATIONS

- Occupational exposure scenarios associated with inhalation during raw material and product manufacturing ranked highest.
- Available information suggests graphene has a relatively low pulmonary hazard. Data gaps exist in our understanding of potential hazards from long-term, low dose graphene exposures typical of the workplace. These data gaps are important priorities to fill for SSbD.
- Once incorporated into coating, there is a much lower potential for graphene exposure to workers, the public, and the environment. However, very limited data was located characterizing the hazard and potential release from graphene-acrylic composites.
- Studies to understand (1) potential inhalation and dermal hazards of graphene-acrylic composites; and (2) release characteristics from graphene-acrylic composites would allow iteration of these scenarios and reduce current uncertainty.