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Sustainable Nanotechnology: Life Cycle Thinking in Gold Nanoparticle Production and Recycling

Paramjeet Pati

Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
In
Civil Engineering

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Sean P. McGinnis (Co-chair)
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Sustainable Nanotechnology: Life Cycle Thinking in Gold Nanoparticle Production and Recycling

Paramjeet Pati

ABSTRACT

Nanotechnology has enormous potential to transform a wide variety of sectors, e.g., energy, electronics, healthcare, and environmental sustainability. At the same time, there are concerns about the health and environmental impacts of nanotechnology and uncertainties about the fate and toxicity of nanomaterials. Life cycle assessment (LCA), a quantitative framework for evaluating the cumulative environmental impacts associated with all stages of a material or process, has emerged as a decision-support tool for analyzing the environmental burdens of nanotechnology. The objective of this research was to combine laboratory techniques with LCA modeling to reduce the life cycle impacts of gold nanoparticle (AuNP) production. The LCA studies were focused on three aspects of AuNP synthesis: 1) the use of bio-based ('green') reducing agents; 2) the potential for recycling gold from nanomaterial waste; and, 3) the reduction of the life cycle impacts of AuNP production by conducting the synthesis at reduced temperature. The LCA models developed for AuNPs can inform future nanotechnology-focused LCA studies. Comparative LCA showed that in some cases, the environmental impacts associated with green synthesis methods may be worse than those of conventional synthesis approaches. The main driver of the environmental burdens associated with AuNP synthesis is the large embodied energy of gold, and so-called green synthesis methods do not offset those impacts. In addition, the reaction yield, which is seldom reported in the literature for green synthesis of nanomaterials, was found to greatly influence the life cycle impacts of AuNP synthesis. Gold from nanomaterial waste was successfully recovered by using host-guest inclusion complex formation facilitated by α -cyclodextrin. This recycling approach involved room temperature conditions and did not require the toxic cyanide or mercury commonly used in the selective recovery of gold. A major advantage offered by this approach for selective gold recovery over conventional approaches is that the recovery does not involve the use of toxic cyanide or mercury. To reduce the energy footprint of citrate-reduced AuNP synthesis, the synthesis was conducted at room temperature. LCA models showed significant reduction in the energy footprint. The findings of this research can inform future LCAs of other nanomaterials.