# Outwitting the Uncertainty of Nanotechnology Risks Through Environmental Life Cycle Assessment

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## ABSTRACT

Life cycle thinking, in the context of risk assessment and management, is a “cradle-to-grave” approach for comprehensively accounting for the total cost of a product or technology. The goal of this study was to evaluate a carbon nanotube (CNT) product in terms of life cycle phases representing points where resources are expended and emissions are created. The study described here is important and unique because it is an example of a real commercialized CNT technology where environmental risks are evaluated and process engineering solutions identified to manage risks.

***Keywords***: life cycle assessment, carbon nanotube, process engineering, by-product streams

## 1 LIFE CYCLE APPROACH

Advanced materials such as engineered nanoscale particles offer significant opportunity for advancing medical, consumer, and military technologies. While most nanoscale technologies are still early in development, there are many that are in prototype or small-scale production. The unique properties of these advanced materials has raised concern regarding the potential hazards of the technologies. Therefore, the environmental health and safety risks of these materials must be considered for the technology to be safely produced and used. One of the leading questions in the decision to produce a technology is the potential for nanoscale particles to be released from the application during production, use, or end of life. The life cycle perspective (see Fig. 1) or value chain has been recommended by the National Research Council [1] to identify potential releases and evaluate exposure for the purposes of predicting potential effects. This cradle-to-grave approach can be used to inform the manufacturer where improvements in the process can be made to improve efficiencies and minimize risk of the technology.


Figure 1. Cradle-to-grave approach considered in life cycle assessment.

## 2 CARBON NANOTUBE ELECTRONICS

Single-walled carbon nanotubes (SWCNTs) are used for a variety of applications in the electronics industry, including chemical and physical sensors, computer memory, and flexible printed electronics. To apply SWCNTs in these applications, a stable aqueous suspension is required. Powdered SWCNTs (obtained commercially) are processed and dispersed in an aqueous system. The product is used internally as well as marketed to other manufacturers to use in electronics manufacture.

## 3 APPLICATION OF LIFE CYCLE APPROACH

### 3.1 Life Cycle Assessment

Utilizing a general LCA methodological framework [2] (see Fig. 2), we calculated the gate-to-gate environmental impacts from a model developed to represent a company’s CNT technology production including derivatization, product manufacturing, packaging, and waste disposal. This case study focused only on life cycle stages associated with CNTs used for manufacturing of a specific electronic device, yet was bound to reflect a company’s particular environmental stewardship. We emphasize the value of this approach for its application to various other advanced materials to be developed for use in consumer products, environmental monitoring, sensors, and electronics.

### 3.2 Modeling

A life cycle inventory (LCI) was constructed using data collected from the manufacturer, where raw materials, energy, transport, and disposal inputs and outputs to the technosphere associated with CNT technology production were defined in terms of the EcoInvent v2.0 database [3], to calculate environmental emissions. Emissions from CNT synthesis were not included because nanotubes were received separately. Characterization factors for standard impact categories such as human health, climate change, and natural resource depletion were calculated using the life cycle impact assessment methods IMPACT 2002+ [4] and EPS 2000 [5]. The LCA results indicated the environmental impacts were dominated by emissions from the incineration of CNT-containing waste streams. Thus, we concluded that efforts to improve production efficiencies that minimize the quantity of by-product streams would substantially reduce these impacts.

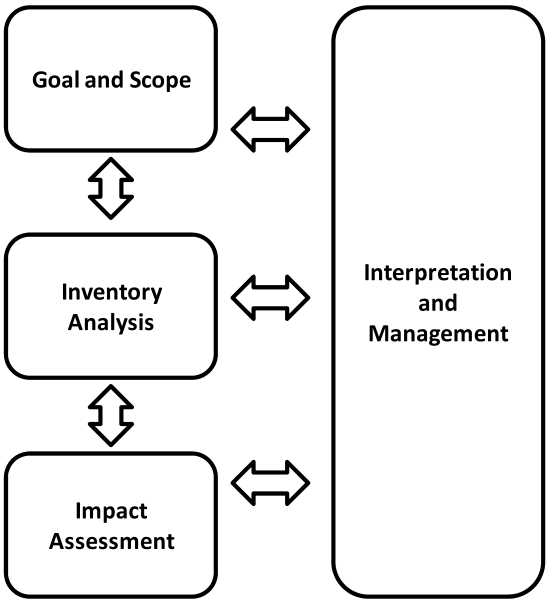


Figure 2. General LCA methodological framework [2].

## 3.3 Carbon Nanotube Characterization

We undertook studies to thoroughly characterize CNTs and the production of the CNT technology in an effort to develop appropriate process engineering solutions. Characterizations included aggregate size and charge distributions via dynamic light scattering (see Fig. 3) and suspension turbidity. Suspension number density was calculated using an online tool developed at ERDC [6] from mass density (mg/L), aggregate radius (nm), and ionic strength of the CNT mixture. Results showed the product is a polydisperse, concentrated SWCNT suspension (intensity-averaged aggregate size of approx. 125 nm) that is electrostabilized by its high negative charge.

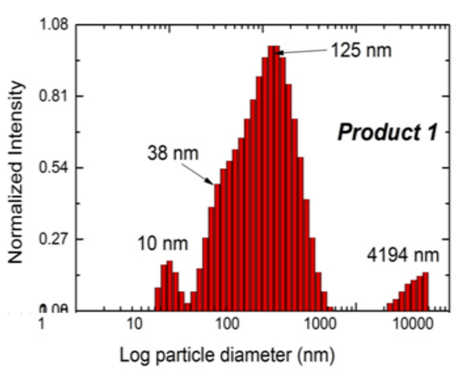


Figure 3. Particle size by dynamic light scattering of the SWCNT product.

## 3.4 Process Optimization

Using this information, we identified process engineering improvements to substantially decrease the environmental impact of this technology, particularly as part of production scale-up for increased manufacture levels. The LCA methodology identified specific waste streams in the manufacturing process that can be optimized. For example, liquid by-product containing highly agglomerated SWCNTs is currently disposed of through incineration. Alternative means of re-use or disposal besides incineration are being sought. Additional studies to better understand the potential environmental and human health effects will also support decisions regarding the safe development of the SWCNT product and resulting technologies.

## REFERENCES


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