Michigan DEQ
2016 Sustainability Webinar Series

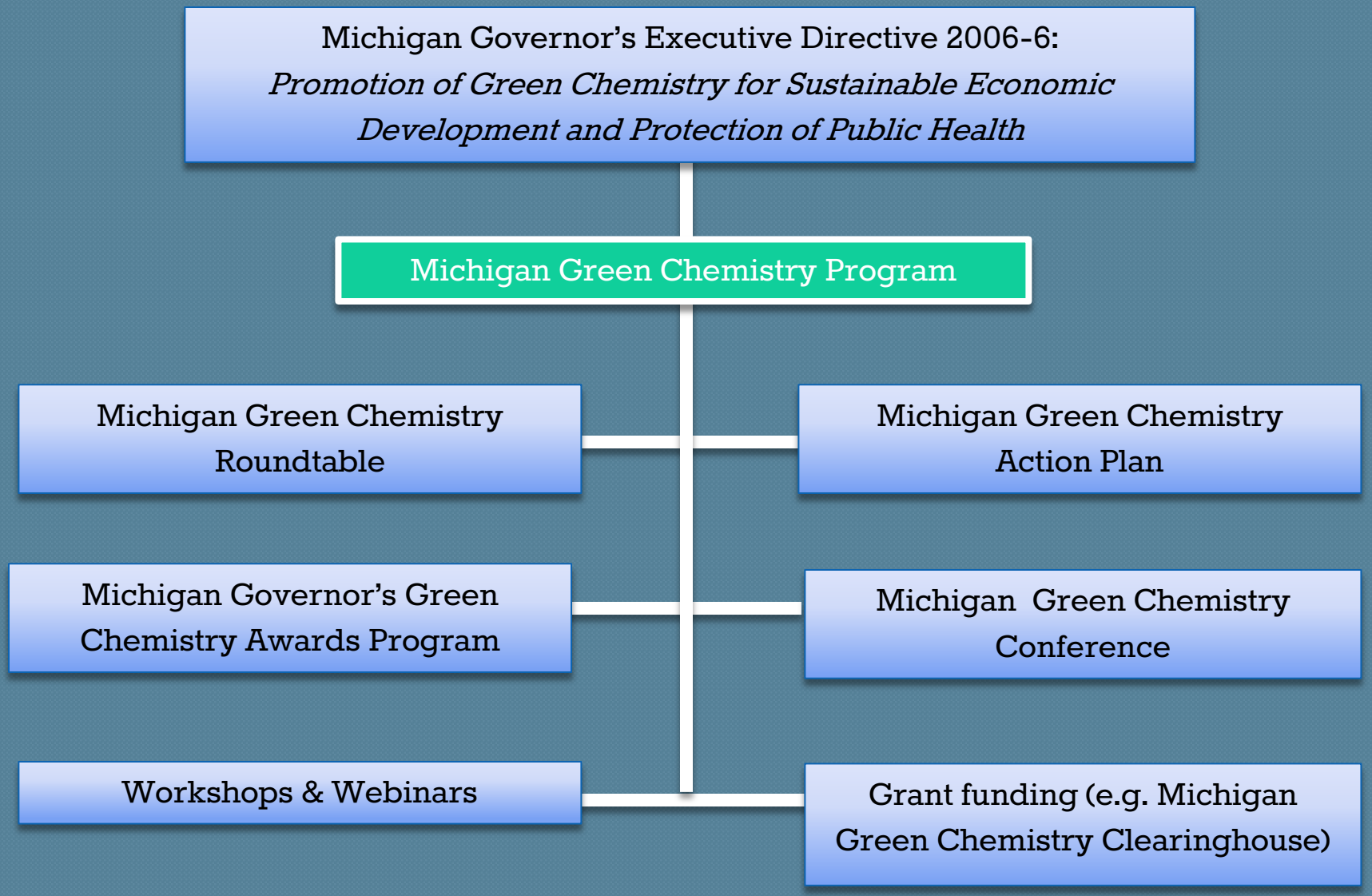
Introduction to Green Chemistry

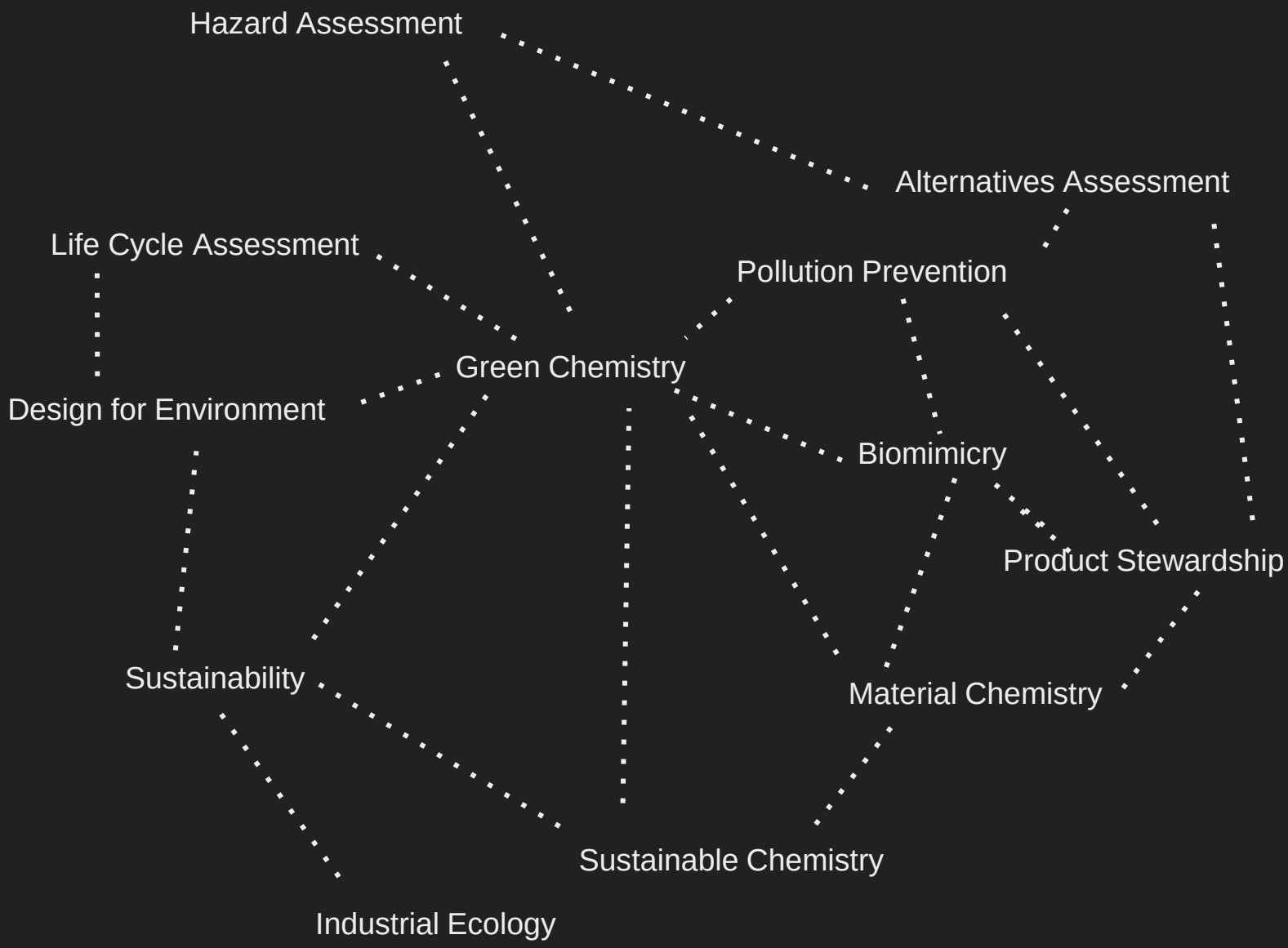
Clinton S. Boyd, PhD

Principal Scientist, Green Chemistry & Sustainability

steelcase inc

July 21, 2016


Michigan Governor's Executive Directive 2006-6:
Promotion of Green Chemistry for Sustainable Economic Development and Protection of Public Health
Michigan Green Chemistry Program
Michigan Green Chemistry Roundtable
Michigan Green Chemistry Action Plan
Michigan Governor's Green Chemistry Awards Program
Michigan Green Chemistry Conference
Workshops & Webinars
Grant funding (e.g. Michigan Green Chemistry Clearinghouse)

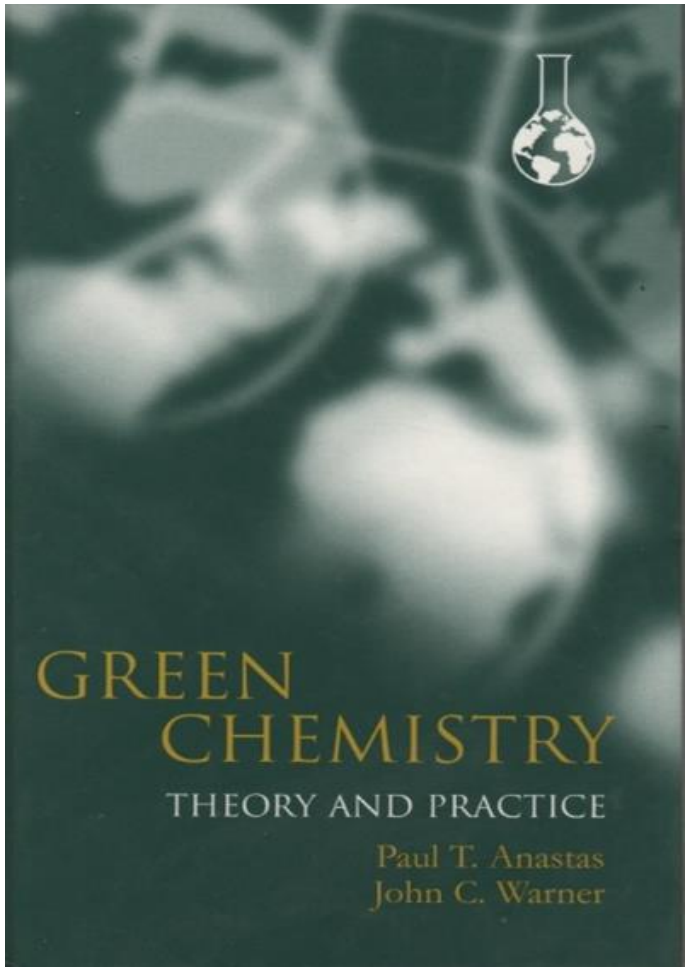

Hazard Assessment
Alternatives Assessment
Life Cycle Assessment
Pollution Prevention
Green Chemistry
Design for Environment
Biomimicry
Product Stewardship
Sustainability
Material Chemistry
Sustainable Chemistry
Industrial Ecology

What is Green Chemistry?

Green Chemistry is the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and applications of chemical products.[1]

Principles of Green Chemistry[1]

1. Prevent waste
2. Design safer chemicals and products
3. Design less hazardous chemical syntheses
4. Use renewable feedstocks
5. Use catalysts, not stoichiometric reagents
6. Avoid chemical derivatives
7. Maximize atom economy
8. Use safer solvents and reaction conditions
9. Increase energy efficiency
10. Design chemicals and products to degrade after use
11. Analyze in real time to prevent pollution
12. Minimize the potential for accidents



1: Anastas, Paul T., and Warner, John C. Green Chemistry Theory and Practice, Oxford University Press, New York, 1998.

❑ Definition of Hazard / Hazardous

➢ Hazard is the inherent potential for a chemical, substance or waste to:

(1) be toxic

(2) be corrosive, ignitable, explosive, or chemically reactive ,or

(3) adversely impact humans and the environment.

❑ Definition of Green

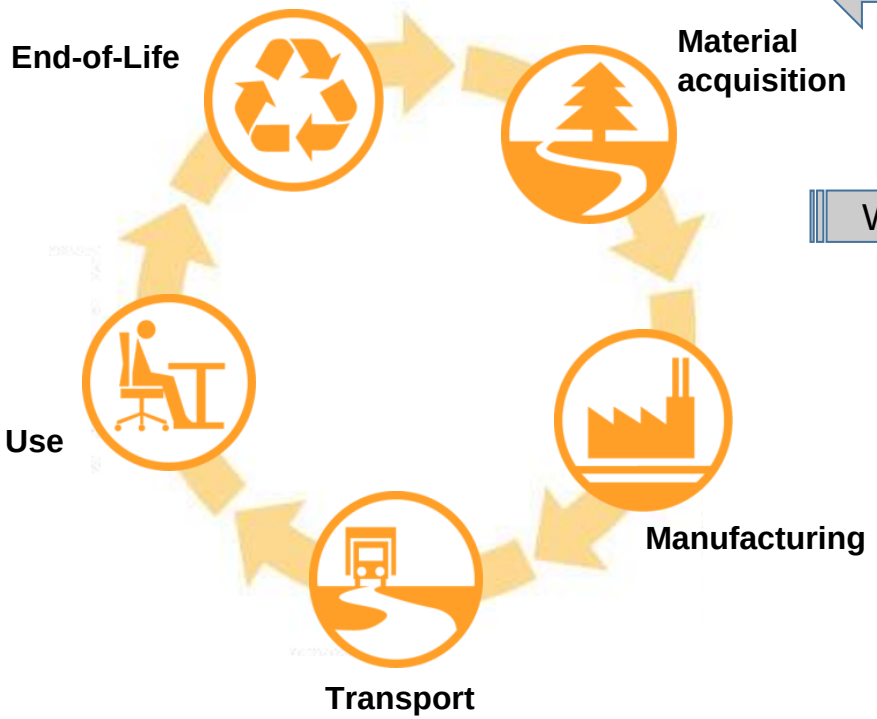
"…greener refers to the relative measure of ecosystem and human health impacts of a chemical and its process when compared to the same or similar chemical and its process"

Source: NSF /GCI /ANSI 355

"not harmful to human health and the environment"

Life Cycle Thinking / Life Cycle Assessment (LCA)

System

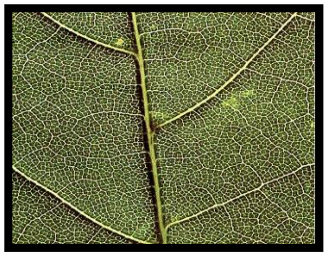


Materials

Energy

Waste

Surroundings



Product *Life Cycle Stages*

Life Cycle Impact Categories

- ***Life Cycle Impact Categories*** represent a standardization (categorization) of the different types of negative impacts on **human health** and the **environment**
- Broadly, impacts result from:
  - The **amount** of matter
  - The **kind** of matter
- Almost all the life cycle impact categories are the direct result of **chemicals** released to and interacting with the environment (both geophysical and living systems)

- **Resource depletion**
- **Land Use**
- **Global warming**
- **Stratospheric ozone depletion**
- **Acidification**
- **Eutrophication**
- **Smog formation**
- **Ecotoxicity**
- **Human health**

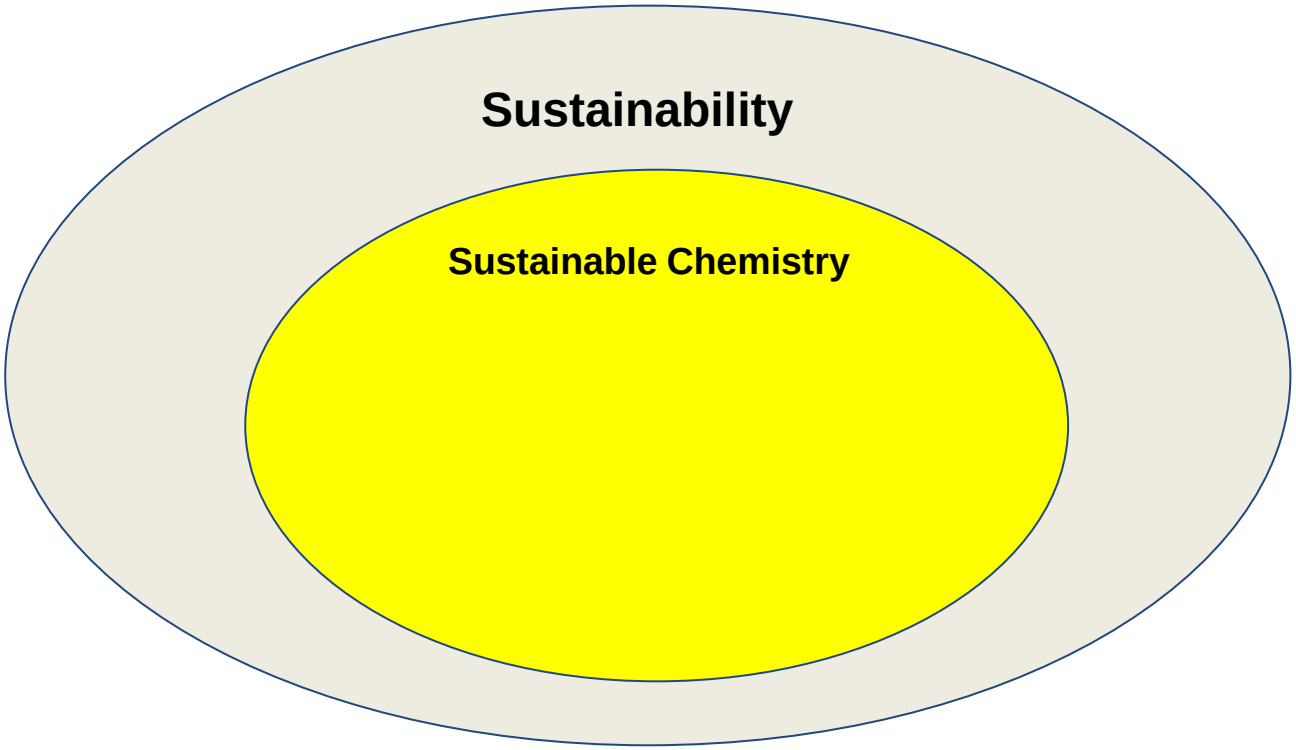
12 PRINCIPLES OF GREEN CHEMISTRY

	E	1.	Prevent waste
	H	2.	Design safer chemicals and products
	H	3.	Design less hazardous chemical syntheses
H	E	4.	Use renewable feedstocks
	E	5.	Use catalysts, not stoichiometric reagents
	E	6.	Avoid chemical derivatives
	E	7.	Maximize atom economy
	H	8.	Use safer solvents and reaction conditions
	E	9.	Increase energy efficiency
E	H	10.	Design chemicals and products to degrade after use
E	H	11.	Analyze in real time to prevent pollution
	H	12.	Minimize the potential for accidents

Broadly, Principles address:

- **Efficiency of matter consumption and energy consumption (amount of matter)** — E
- **Hazard of matter (type of matter)** — H

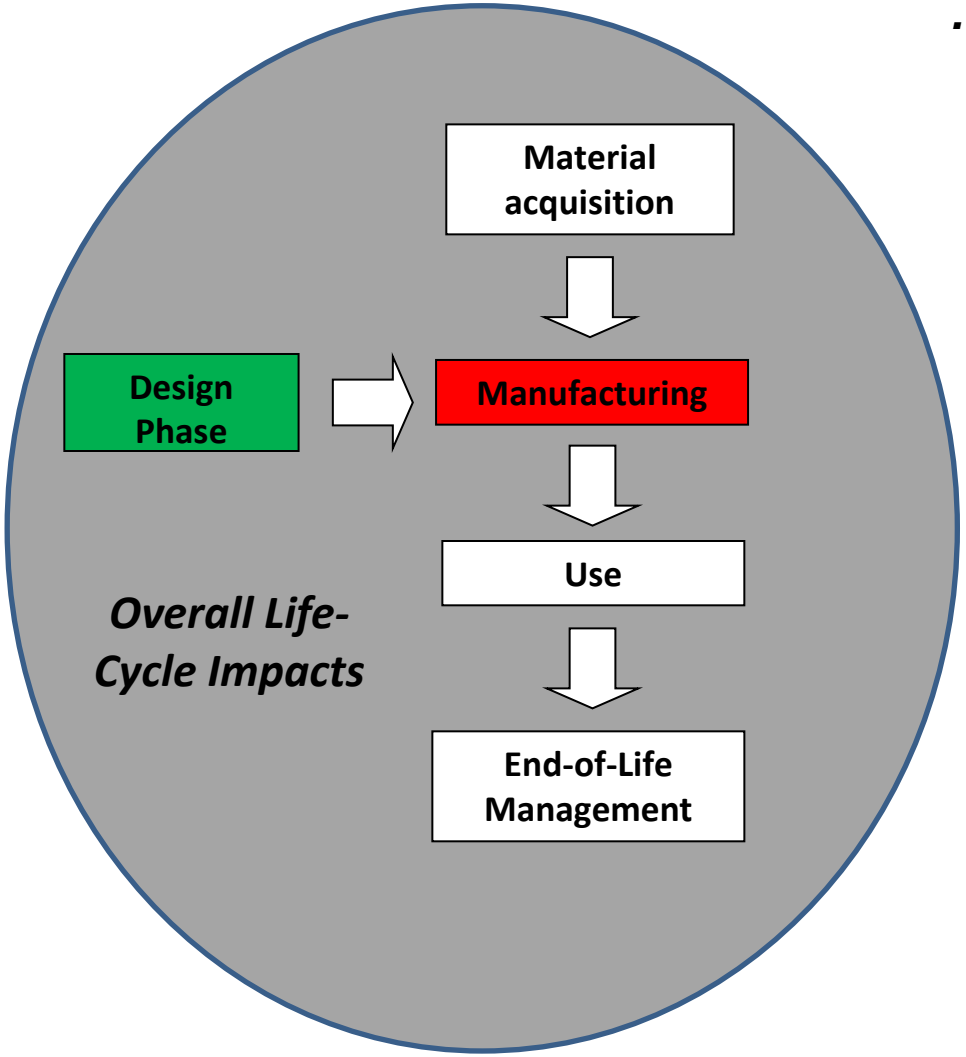
Source: Modifedf from Anastas, Paul T., and Warner, John C. Green Chemistry Theory and Practice, Oxford University Press, New York, 1998.



Macro-scale	**Production Systems, Community, Ecosystems**	**Industrial Ecology**
Meso-scale	**Products**	**Product Stewardship**
Micro-scale	**Chemicals, Materials**	**Green Chemistry**

What is Design for Environment?

Integration of environmental considerations into the <u>product design</u> and development process to reduce environmental impact of product over <u>entire life-cycle</u>



More than 75% of the environmental impact of a product during its lifecycle is determined and "locked-in" at the **DESIGN STAGE**

Synonyms:

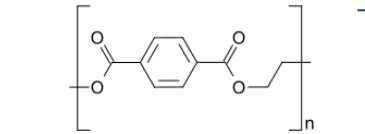
- Eco-Design
- Green Design
- Environmentally Conscious Design

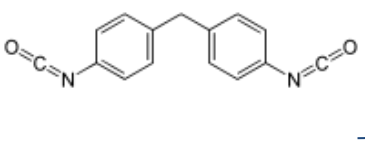
Chemicals

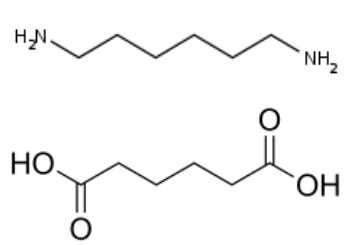
Homogeneous material

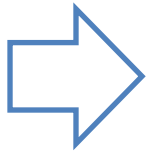
Part and/or assembly

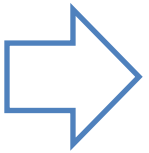
Product











Design for Environment: Take 2

More than 75% of the environmental impact of a product during its lifecycle is determined and "locked-in" at the **DESIGN STAGE**

Many environmental impacts are chemical in nature, resulting from inherent properties of the chemicals

Green Chemistry can be viewed as the application of the concepts and strategies of **Design for Environment** at the **molecular level**

Green chemistry aims to make chemicals, materials, products less hazardous throughout the entire life cycle by **applying the Principles** at the design stage of product development

➢ **Hazard is a "design flaw"**

➢ **"Benign by Design"**

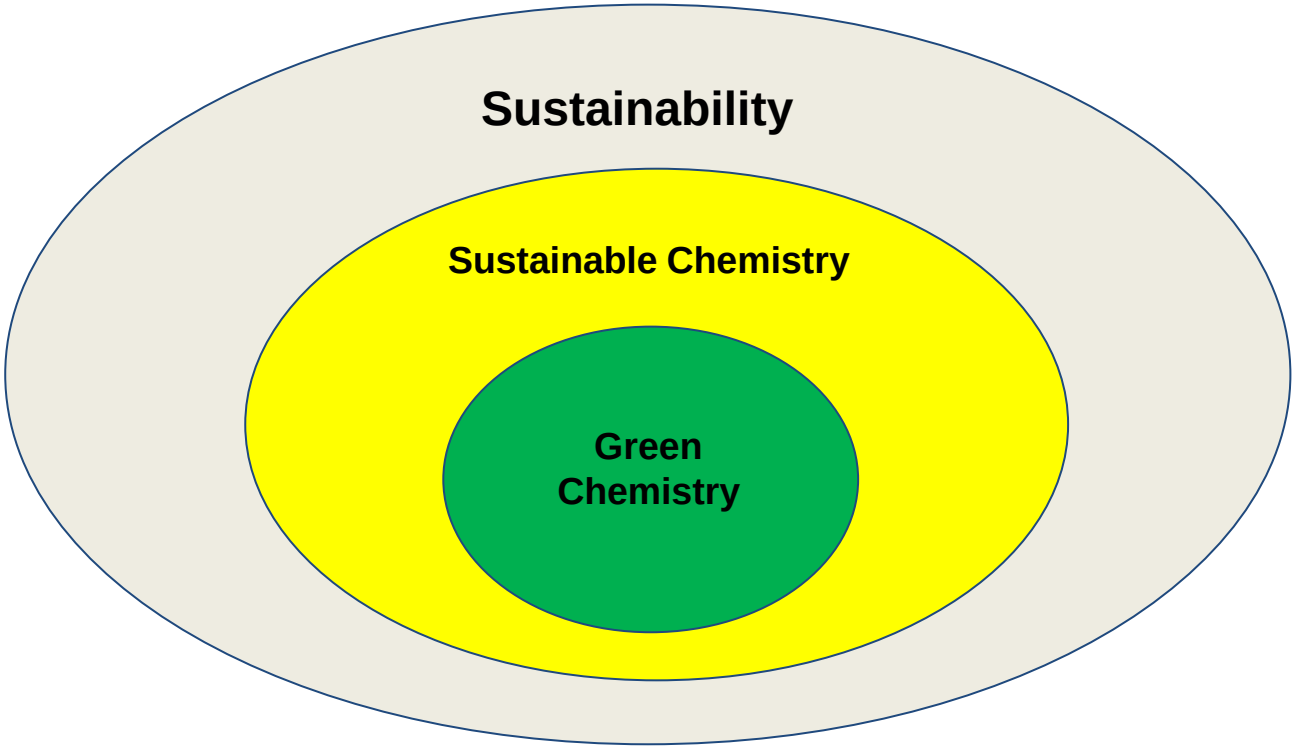
❑ **Life Cycle Assessment**

Impact = Σ (Mass x Impact Potential)

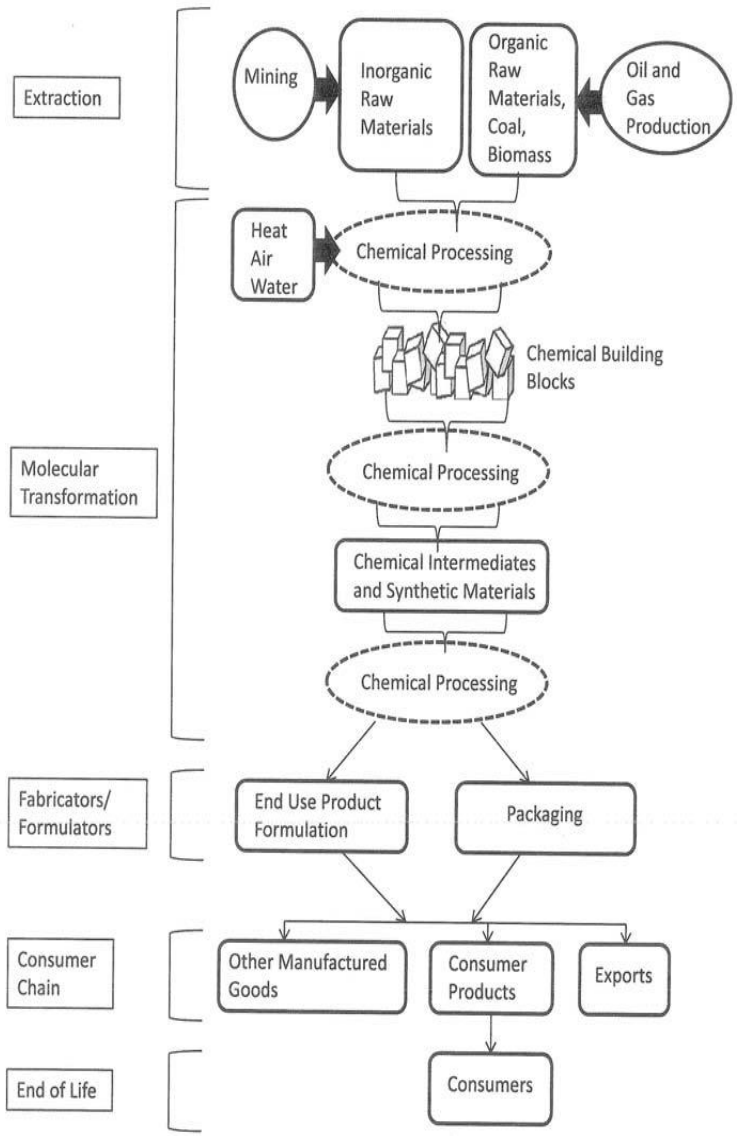
❑ **Toxicology**

Risk = *ƒ* {Hazard, Exposure}

❖ Since “Hazard” is an inherent property of a chemical due to its molecular structure, Green Chemistry emphasises the potential to minimize risk by treating “hazard” as another property that can be controlled by the chemist.


Sustainability
Sustainable Chemistry
Green
Chemistry

Scope of the Chemical Enterprise



Molecular Transformers

Bulk, Fine & Specialty Chemicals

- Chemical manufacturers
- Pharmaceutical industry

Formulators

Physical mixing/blending of chemicals

Fabricators

Manufacturers of consumer goods:

- Component manufacturers (tier suppliers)
- Final product manufacturers (Original Equipment manufacturers (OEMs)

Source: NSF/GCI/ANSI 355 – 2011: *Greener Chemicals and Processes Information* Standard

steelcase inc

Global leader in the office furniture industry offering a comprehensive portfolio of workplace products, furnishings and services

"Victor"

"601" desk

Founded as **Metal Office Furniture Company**, 14 March 1912

- The idea to make metal furniture is born of necessity
- "The development of the spot welder..was very important to our history...Spray painting was another important development."

Source: *Steelcase The First 75 Years*;Steelcase, Inc. 1987 ©

Seating | Furniture | Storage | Tables | Technology | Worktools & Accessories

steelcase inc

Love how you work.

Influencers

Regulations

Customer Needs

Cost

Disclosures

Labels

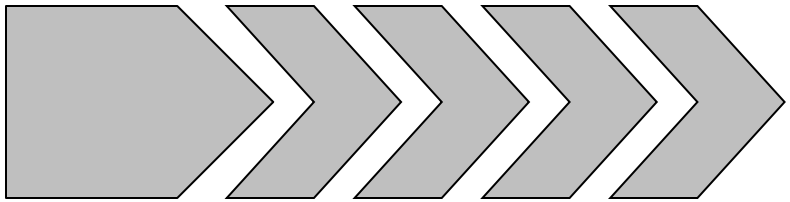
Product Environmental Profiles

Certifications

LCA

EPD

Product Development



Sustainability Platforms

Performance

Supply Chain

Materials Chemistry

Life Cycle Assessment

Reuse, Recycle

Chemical Dimension of a System

Chemical Management

- Acquisition
- Inventory & Tracking
- Storage
- Use
- Disposal & Treatment
- Transfer, Transport & Shipment

Chemical Assessment

- Risk Assessment
- Hazard Assessment
- Alternative Assessment

Chemical Substitution / Reduction

- Pollution Prevention
- Waste Minimization
- Green Chemistry

New Design Concepts | New Materials | New Processes

Form follows Function – "physical" solutions

New Green Chemicals / Materials

Materials Innovation & Exploration

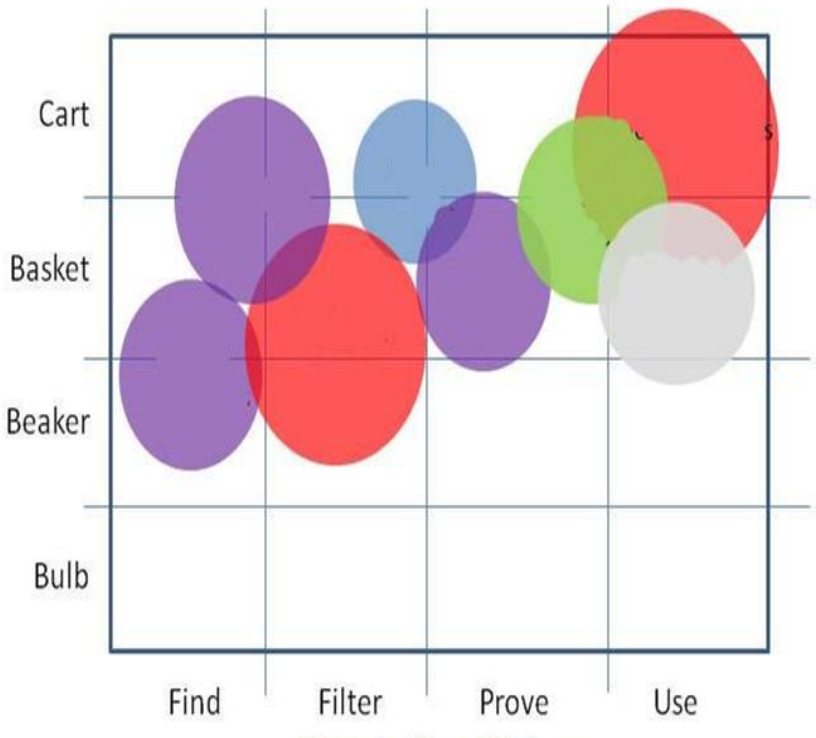
materiality & process

Material chemistry and **material process** are components of a **material experience** and in the design process these **cannot be separated** **from the consideration of material choice**.

materiality *ethos*

preserve & compel

Humanizing... **preserving** the **planet** and **protecting** the **human experience**. We seek material and process decisions that **benefit** the planet rather than simply reduce harm done. We seek material and process solutions that are **compelling** and create **lasting emotional connection**



Principles of Green Chemistry[1]

1. Prevent waste
2. Design safer chemicals and products
3. Design less hazardous chemical syntheses
4. Use renewable feedstocks
5. Use catalysts, not stoichiometric reagents
6. Avoid chemical derivatives
7. Maximize atom economy
8. Use safer solvents and reaction conditions
9. Increase energy efficiency
10. Design chemicals and products to degrade after use
11. Analyze in real time to prevent pollution
12. Minimize the potential for accidents

1: Anastas, Paul T., and Warner, John C. Green Chemistry Theory and Practice, Oxford University Press, New York, 1998.

Green Chemistry Pocket Guide

The 12 Principles of Green Chemistry

Provides a framework for learning about green chemistry and designing or improving materials, products, processes and systems.

1. Prevent waste
2. Atom Economy
3. Less Hazardous Synthesis
4. Design Benign Chemicals
5. Benign Solvents & Auxiliaries
6. Design for Energy Efficiency
7. Use of Renewable Feedstocks
8. Reduce Derivatives
9. Catalysis (vs. Stoichiometric)
10. Design for Degradation
11. Real-Time Analysis for Pollution Prevention
12. Inherently Benign Chemistry for Accident Prevention

www.acs.org/greenchemistry

ACS Chemistry for Life® | ACS Green Chemistry Institute®

The Chemistry of Nature

Green Chemistry Definition: *The design, development and implementation of chemical products and processes that reduce or eliminate the use and generation of hazardous substances.*

Green Chemistry is doing chemistry the way nature does chemistry – using renewable, biodegradable materials which do not persist in the environment.

Green Chemistry is using catalysis and biocatalysis to improve efficiency and conduct reactions at low or ambient temperatures.

Green Chemistry is a proven systems approach.

Green Chemistry reduces negative human health and environmental impacts.

Green Chemistry offers a strategic path way to build a sustainable future.

To catalyze and enable the implementation of green chemistry and engineering throughout the global chemical enterprise

Contact us: gci@acs.org

A *New* Kind of Chemistry!

Green Chemistry — Sustainable Chemistry in Sync With Nature

The design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances.

- Smarter
- Safer
- More Efficient
- Saves Money
- Conserves Energy
- Prevents Pollution
- Designed for Reuse or Recycle
- Enhances Chem's Public Image

"The best way to predict the future is to create it."
- Peter Drucker

Green chemistry can create a better future.

www.acs.org/greenchemistry

ACS Chemistry for Life® | ACS Green Chemistry Institute®

The Chemistry of Nature

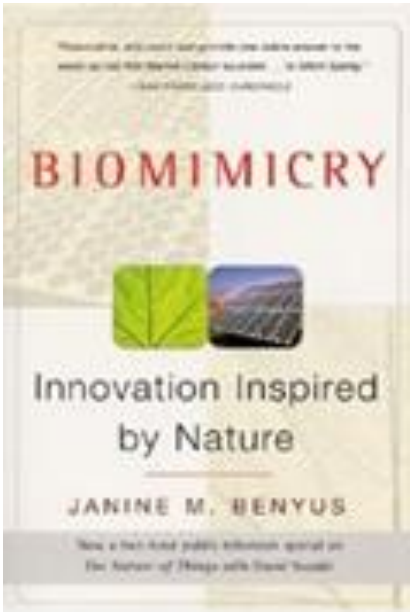
- Green Chemistry emulates nature by using renewable materials that biodegrade easily in the environment.
- Green Chemistry uses materials more efficiently with less energy.
- Green Chemistry respects the environment, preventing pollution before it can happen.
- Green Chemistry helps build a sustainable future.
- Green Chemistry fosters innovation, creates jobs and inspires the next generation of chemists.

To catalyze and enable the implementation of green chemistry and engineering throughout the global chemical enterprise

Contact us: gci@acs.org

Biomimicry

The design and production of materials, structures, and systems through the study and imitation of biological entities, processes and strategies.



The Biomimicry Institute

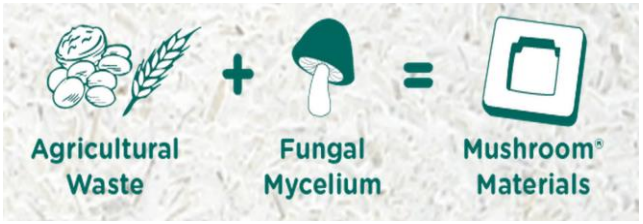
Biomimicry 3.8

Biomimetic Chemistry

- A method of scientific inquiry that involves mimicking the laws of nature to create new synthetic compounds
- procedures designed to imitate a natural chemical process
- compounds that mimic a biological material in its structure or function

Sources: www.coca-colacompany.com; www.dasani.com; www.wikipedia.com; www.treehugger.com

ecovative



Source: http://www.ecovativedesign.com/

Burr

Velcro®

Source: Stock images from www.freeimages.com

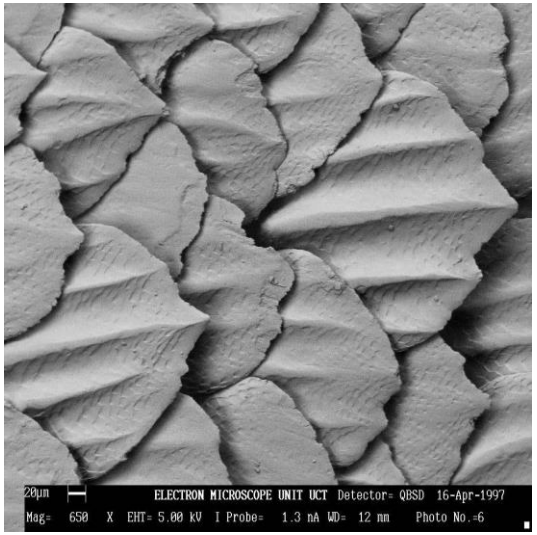
Structural Color

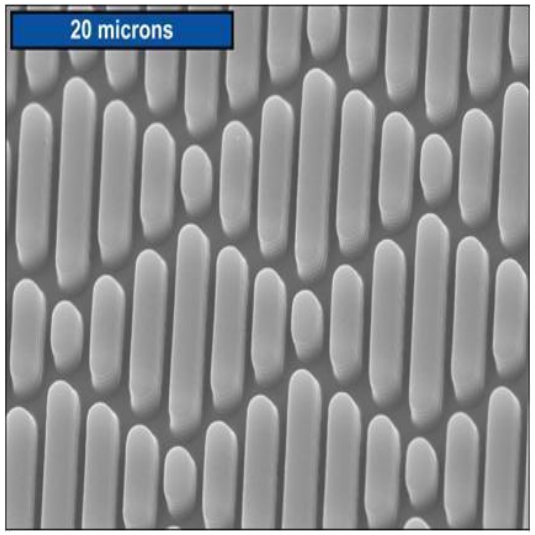
Photo credit: Clinton S. Boyd

Morphotex®
(Teijin Fibers Limited)

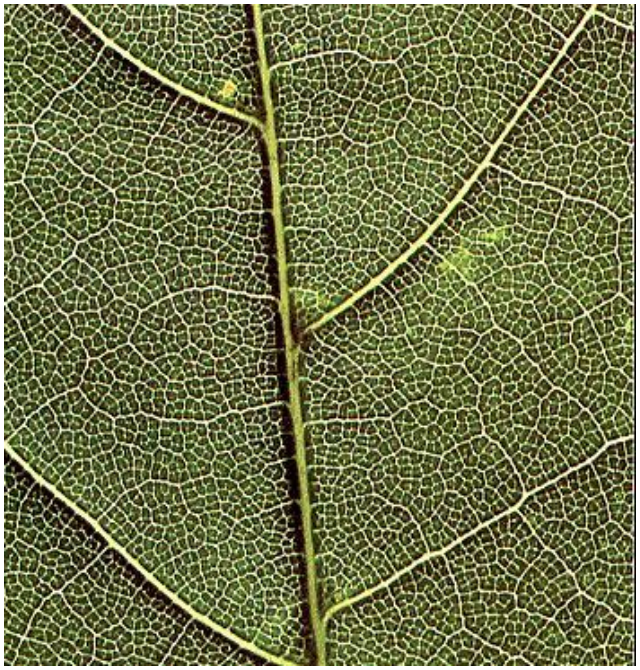
Image source: http://transmaterial.net/morphotex/

Sharklet™
Technologies, Inc.





Source: http://sharklet.com



NEWLIGHT
TECHNOLOGIES

NOVOMER
Catalyzing Green Chemistry

Source: https://vimeo.com/112761863

Source: MIT Self-Assembly Lab

CLIP Technology:
Continuous Liquid Interface Production

Source: http://carbon3d.com/

Thank you.

Clinton S. Boyd, PhD

Principal Scientist, Green Chemistry & Sustainability

Global Sustainability Initiatives

Steelcase, Inc.

616.954.1002
cboyd6@steelcase.com

Please read the **2015 Corporate Sustainability Report** to learn more about Steelcase's efforts.

www.steelcase.com