Green Chemistry:

Innovation and Commercialization with the 12 Principles

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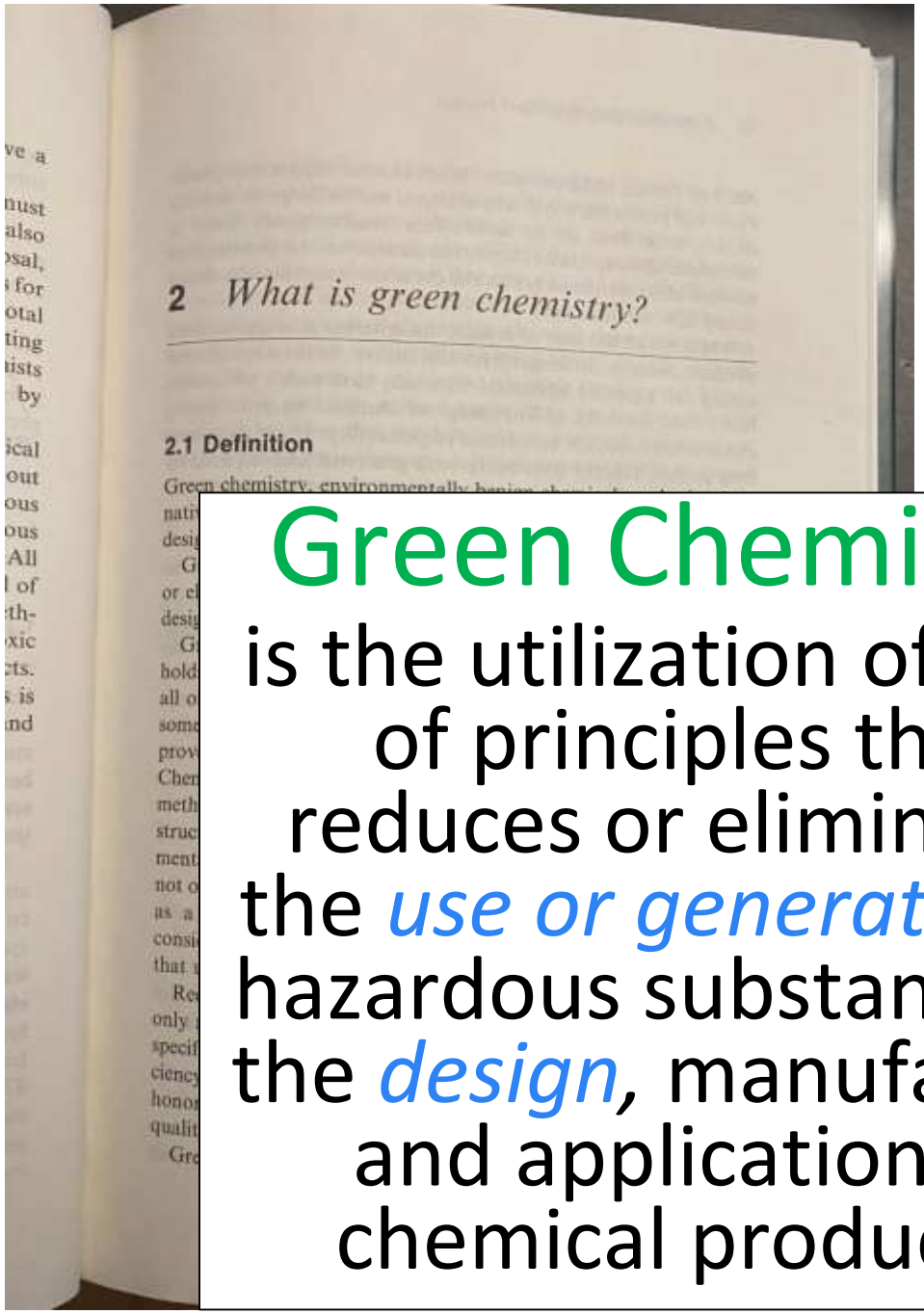
John@johnwarner.org

warnerbabcock
institute for green chemistry, LLC

beyondbenign
green chemistry education

Many Approaches

1998



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 application of chemical products.

The Twelve Principles of Green Chemistry

1. **Prevention.** It is better to prevent waste than to treat or clean up waste after it is formed.

2. **Atom Economy.** Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

3. **Less Hazardous Chemical Synthesis.** Whenever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

4. **Designing Safer Chemicals.** Chemical products should be designed to preserve efficacy of the function while reducing toxicity.

5. **Safer Solvents and Auxiliaries.** The use of auxiliary substances (solvents, separation agents, etc.) should be made unnecessary whenever possible and, when used, innocuous.

6. **Design for Energy Efficiency.** Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure.

7. **Use of Renewable Feedstocks.** A raw material or feedstock should be renewable rather than depleting whenever technically and economically practical.

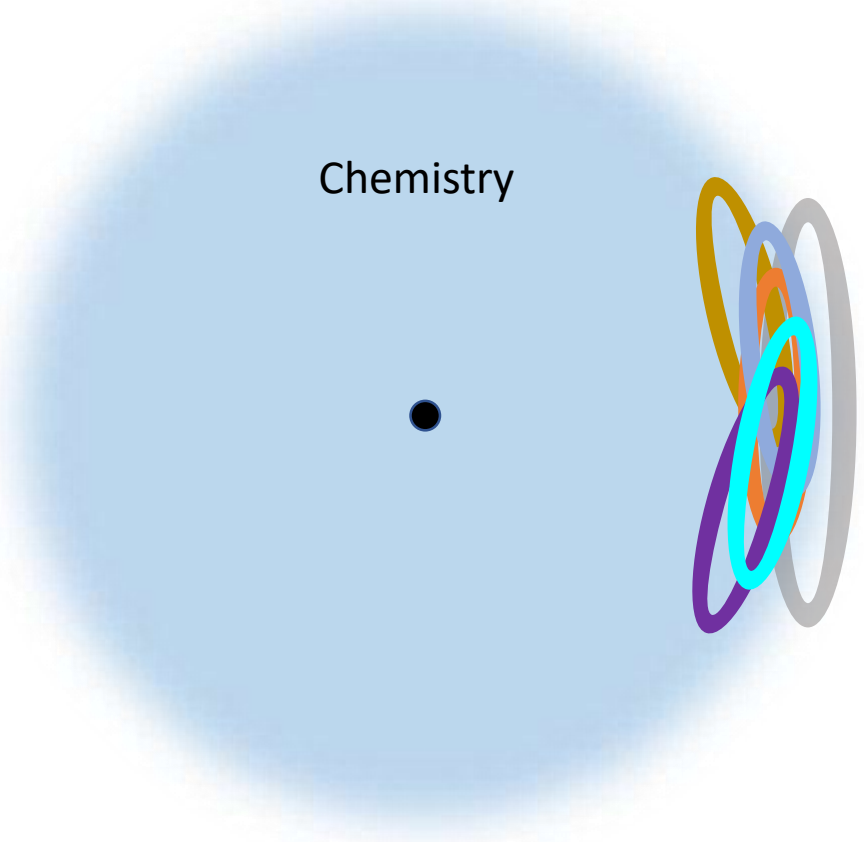
8. **Reduce Derivatives.** Unnecessary derivatization (blocking group, protection/deprotection, temporary modification of physical/chemical processes) should be avoided whenever possible .

9. **Catalysis.** Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

10. **Design for Degradation.** Chemical products should be designed so that at the end of their function they do not persist in the environment and instead break down into innocuous degradation products.

11. **Real-time Analysis for Pollution Prevention.** Analytical methodologies need to be further developed to allow for real-time in-process monitoring and control prior to the formation of hazardous substances.

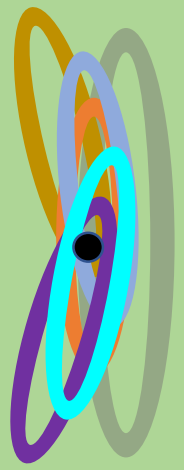
12. **Inherently Safer Chemistry for Accident Prevention.** Substance and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.



Clean Chemistry
Safe Chemistry
Sustainable Chemistry
Circular Chemistry
Regenerative Chemistry

Chemistry

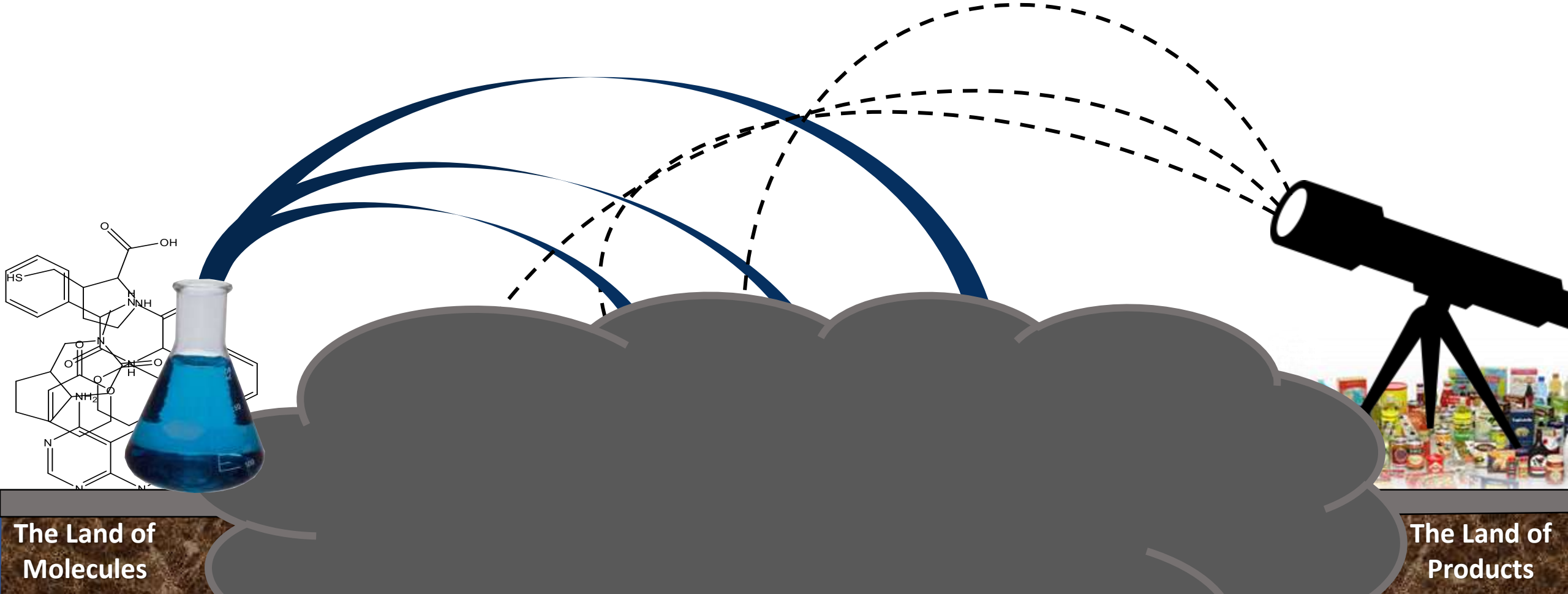
Green Chemistry



Clean Chemistry
Safe Chemistry
Sustainable Chemistry
Circular Chemistry
Regenerative Chemistry

Invention

The Islands of Innovation



The Islands of Innovation

Molecule 1
Molecule 2
Molecule 3
Molecule 4
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Molecule 39
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Molecule 45
Molecule 46
Molecule 47
Molecule 48

Infinite molecules

Molecular Mechanism

An intramolecular process within a single molecule or within a polymer that occurs under 1nM of through-molecule distance.

Bond Rotation Barrier
Van Der Waals Surface Area
Molecular Topography
Hydrogen bonding potential
Enthalpy of formation
Aromatization Potential
Stabilization of cation
HOMO/LUMO Energies

Materials Mechanism

An intermolecular process between more than one molecules, or an intramolecular process within a polymer that occurs over 1nM of through-molecule distance.

Polymer Crystallinity
Polymer chain mobility
Young's modulus
Hanson Parameters
Joule-Thomson Coefficient
Intermolecular Bond Energy
Enzyme Active Site Binding
Molecular Mobility

Materials Property

A quantifiable consequence of molecular and materials mechanisms that has direct relationship to a performance characteristic of a product.

Color
Flexibility
Hardness
Repellency
Flammability
Toxicity
Bioactivity
Thermal Conductivity

Infinite Products

Cosmetics 1
Cosmetics 2
Cosmetics 3
Cosmetics 4
Cosmetics 5
Cosmetics 6
Electronics 1
Electronics 2
Electronics 3
Electronics 4
Electronics 5
Electronics 6
Ag 1
Ag 2
Ag 3
Ag 4
Ag 5
Ag 6
Energy 1
Energy 2
Energy 3
Energy 4
Energy 5
Energy 6
Materials 1
Materials 2
Materials 3
Materials 4
Materials 5
Materials 6
Personal Care 1
Personal Care 2
Personal Care 3
Personal Care 4
Personal Care 5
Personal Care 6
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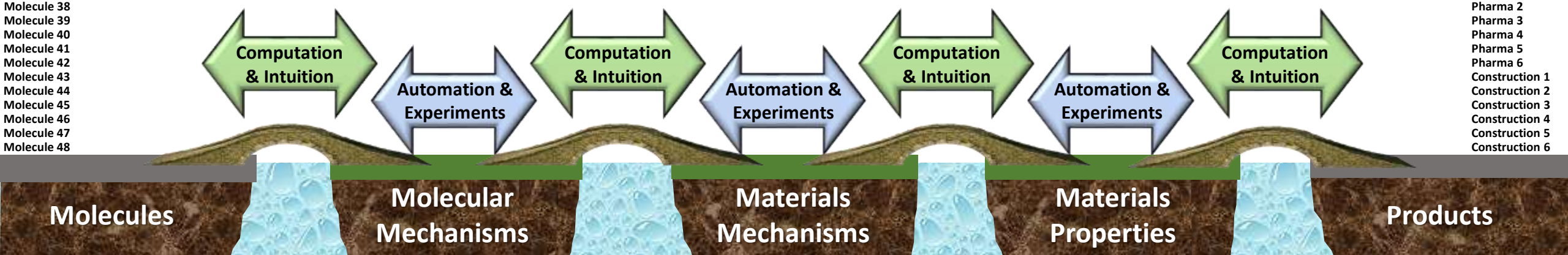
Construction 6



345 Patents and Patent Applications

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WO 1995/029067
US 5,582,956
US 5,338,644
JP 2881072
EP 0523470
DE 69218312
CA 2070450
US 5,177,262

Companies with Licensed/Assigned Inventions (Publicly Viewable)

2010
John Masters
Enzymatic
Hair Color

2010
ATMI
Entegris
Fluoride Free
Semiconductor
Processing

2011
ONE SUN
Replenishable
Photovoltaics

2011
ATMI
Entegris
e-waste
Metal
Recovery

2012
NBD Nano
Henkel
Chemical
Resistant
Coatings

2013
Appvion
BPA Free
Thermal
Recording

2013
Empire
Fire
Retardants

2015
Solazyme
Algae based
Wood
Products

2015
Natura
Biopolymers in Hair
Coloring

2015
Naucity
Pharma
Synthesis of NACA

2017
Oncochell
Anticancer
Agents

2018
Nike
Debondable
Adhesives

2018
Chemtura
Lanxess
High Density
Brine Fluids

2019
NutJobs
Composites
From waste
Almond
Shells

2019
Covestro
Alternative
Polyurethane
Crosslinking

2021
Givaudan
Fragrance
Encapsulation

New Companies Based in Green Chemistry

HAIRPRINT®
[THE HAIR HEALING COMPANY]
www.myhairprint.com

ambient PHOTONICS
www.ambientphotonics.com

Technology Greenhouse
www.TheTGH.com

COLLABORATIVE MEDICINAL DEVELOPMENT LLC
www.colmeddev.com

Water Harvesting Technology

John C. Warner
Green Chemistry, LLC
www.johnwarner.org

COLLABORATIVE AGGREGATES LLC
www.collaborativeaggregates.com

warnerbabcock
institute for green chemistry, LLC
www.warnerbabcock.com

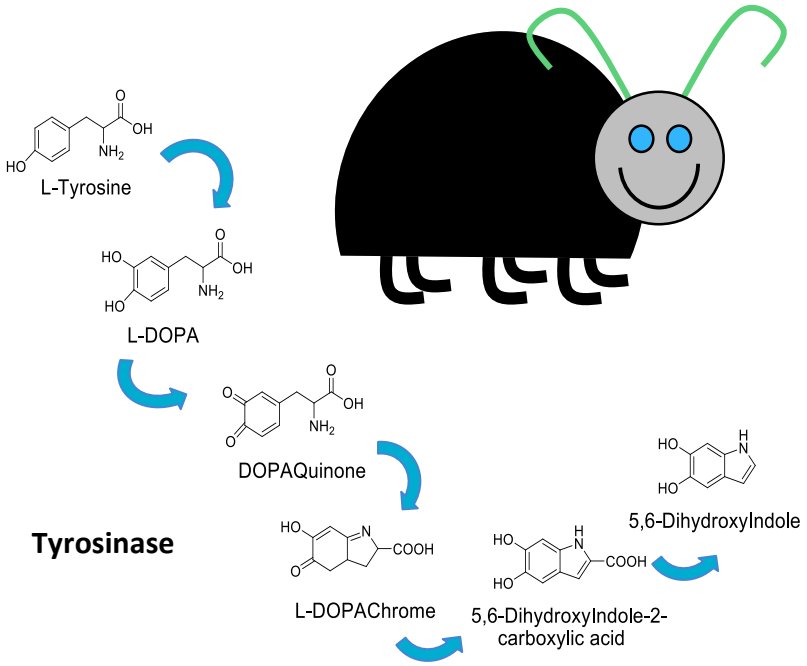
beyondbenign
green chemistry education
www.beyondbenign.org

Commercialized Examples

HAIRPRINT®

[THE HAIR HEALING COMPANY]

www.myhairprint.com



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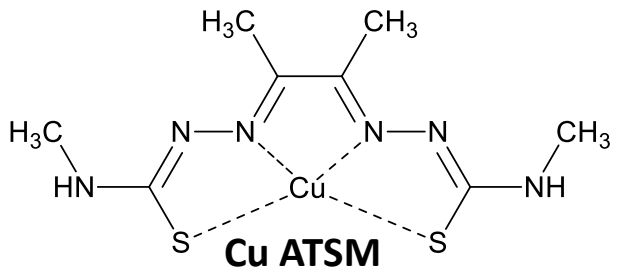
COLLABORATIVE MEDICINAL DEVELOPMENT LLC

www.colmeddev.com



Cu ATSM

NCD

Increased Bioavailability & BBB Penetration

Mechanochemistry

U.S. National Institutes of Health

ClinicalTrials.gov

NCT02870634	Phase 1	Motor Neuron Disease
NCT03204929	Phase 1	Parkinson Disease
NCT03136809	Phase 1	Amyotrophic Lateral Sclerosis (ALS)
NCT04313166	Phase 2	Amyotrophic Lateral Sclerosis (ALS)
NCT04082832	Phase 3	Amyotrophic Lateral Sclerosis (ALS)

ALS NEWS TODAY™

A BIONEWS™ BRAND

New Study Uncovers Mechanism of CuATSM, ALS Therapy Now in Trials

November 2022

US 11,266,686 Granted 2022-03-08, Published 2016-09-22, Filed 2014-11-10
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COLLABORATIVE AGGREGATES LLC

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Delta S

DeltaMist

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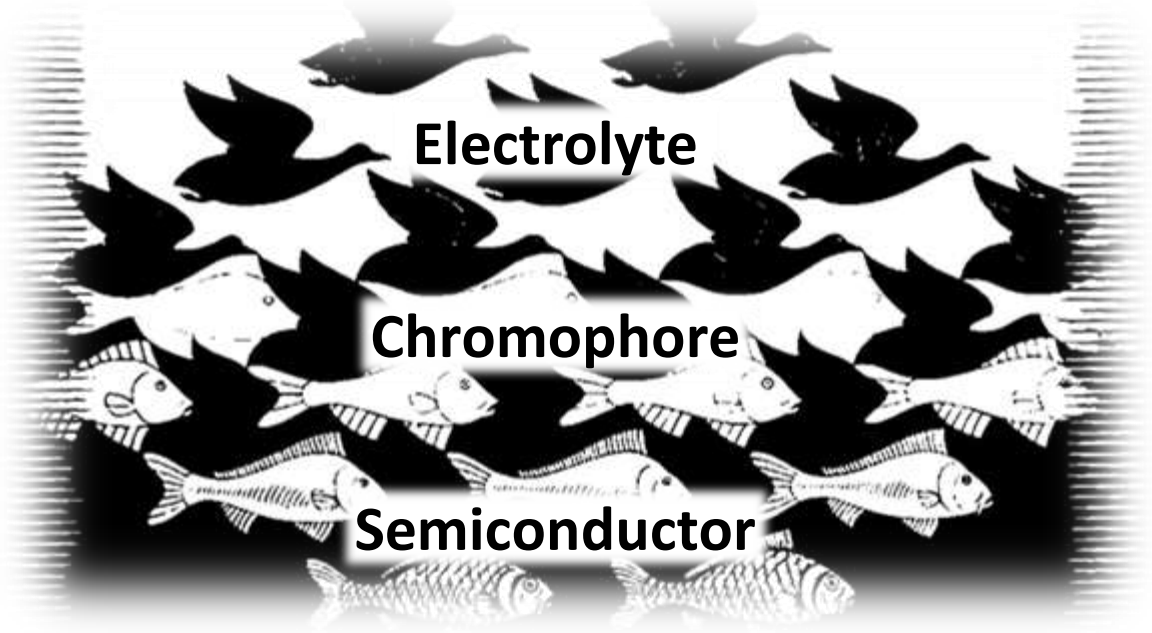
ambient PHOTONICS

www.ambientphotonics.com



April 2023 businesswire A BERKSHIRE HATHAWAY COMPANY

U.S.' First Climate Tech Factory for Low-Light PV Cells Comes Online in California from Ambient Photonics

Ambient achieves automated production of unique low-cost, high-density PV cell technology for powering battery-free electronics

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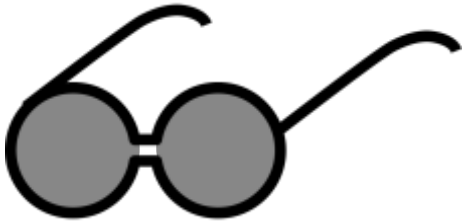
MistMiner



Photochromic water harvesting platform
John C. Warner, Srinivasa R. Cheruku and Sofia Trakhtenberg
The Warner Babcock Institute for Green Chemistry
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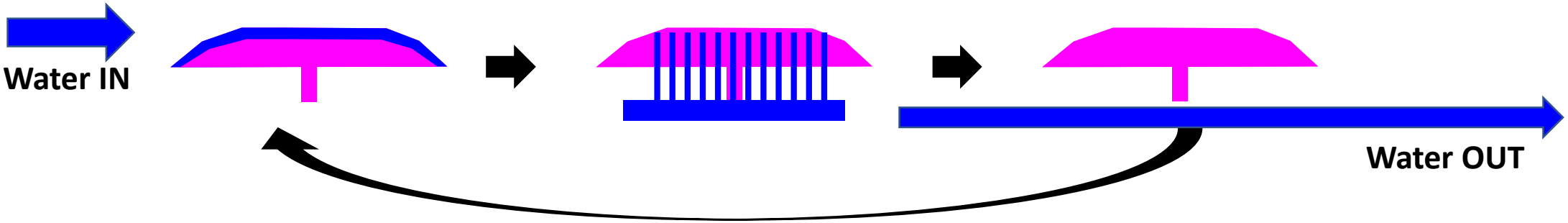
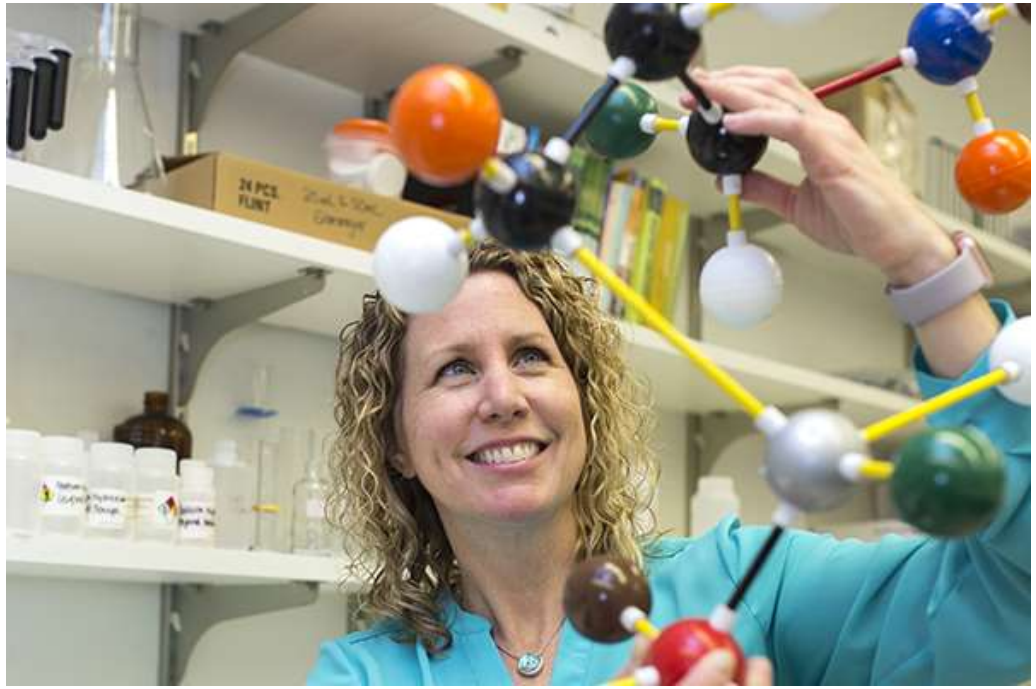


beyondbenign
green chemistry education

www.BeyondBenign.Org



Ambrose University
Berea College
Biola University
B State
Bluffton University
Bradley University
Bridgewater State University
Buena Vista University
California State University San Marcos
CNM Central New Mexico Community College
Chulalongkorn University
Claremont McKenna College
College of the Canyons
Drexel University
Earlham College
Eastern Mennonite University
Edgewood College
Elmhurst College
UFG
UFMS INQUI
The Technical University
Florida Gulf Coast University
Florida Southern College
Georgia Gwinnett College
Gordon College
Grand Valley State University
Green River College
Hampton University
Harrisburg University
Harvey Mudd
Humboldt-Universität zu Berlin
Instituto Federal
unesp
Iowa Lakes Community College
Kean University
Kingsborough
Las Positas College
Lawrence Tech
LMU|LA Loyola Marymount University
Loyola University Maryland
McGill University
McMaster University
McPherson College
Milligan University
Michigan State University
Michigan Tech
Millikin University
Monash University
Monmouth College
Montclair State University
Newcastle University
NC State University
North Park University
Northeastern University
Northern Essex Community College
Odessa College
Pacific Lutheran University
PennState Shenango
Pitzer College
Prairie View A&M University
Queen's University Belfast
RV Institutions
Ramapo College of New Jersey
Randolph College
Rhodes University
Rose-Hulman Institute of Technology
St. Catherine University
Saint Francis University
Salem
Scripps College
Seton Hall University
Siena Chemistry and Biochemistry
Siena Heights University
Simmons
South Dakota State University
Southern University
St. Edward's University
Guttman Community College
Stockholm University
Stonehill College
SUNY Fredonia
Tabor College
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Texas A&M
Texas Woman's University
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Innovation and Commercialization with the 12 Principles

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