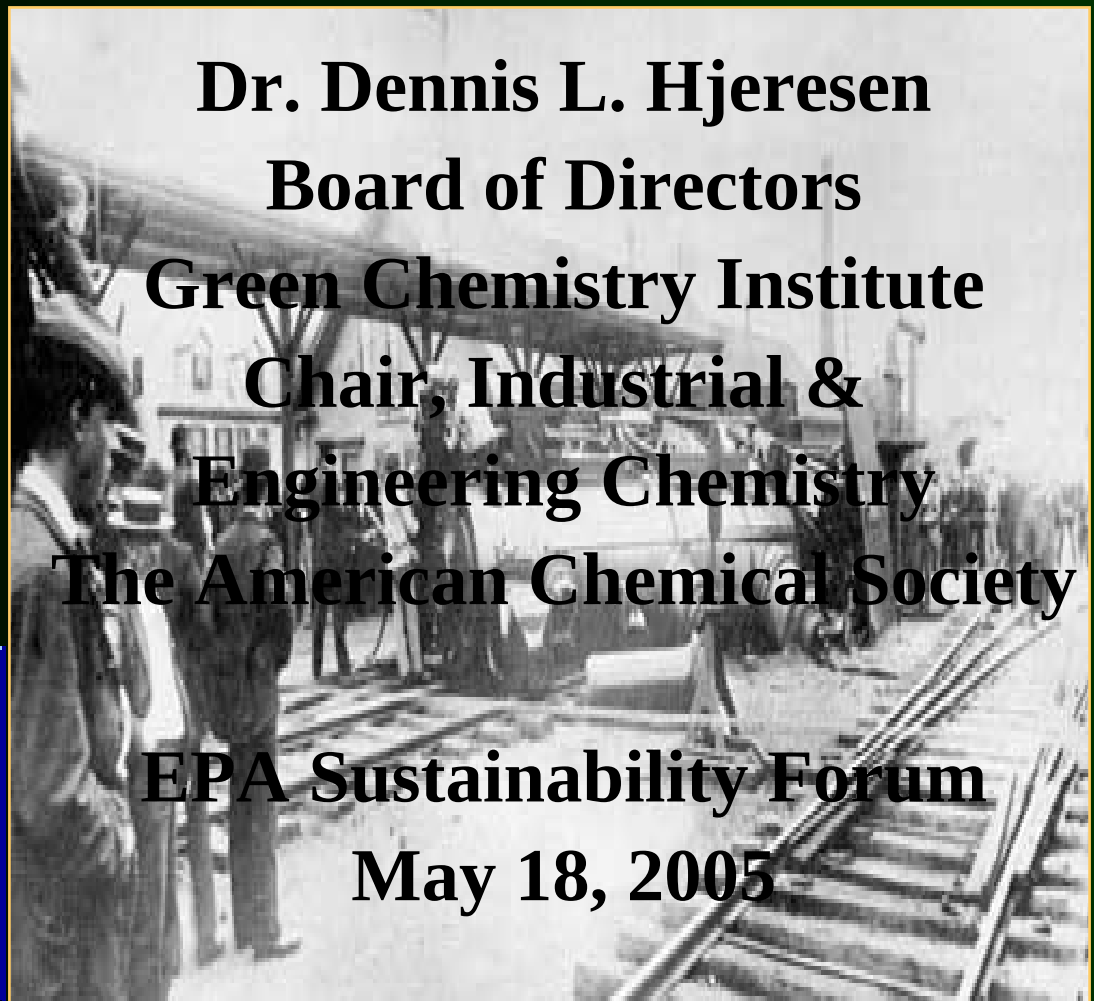
Green Chemistry:
The Impact on Water Quality and Supplies



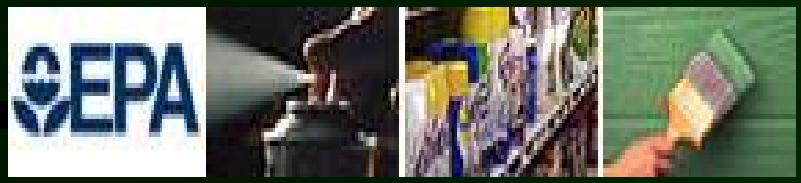
Dr. Dennis L. Hjeresen
Board of Directors
Green Chemistry Institute
Chair, Industrial &
Engineering Chemistry
The American Chemical Society

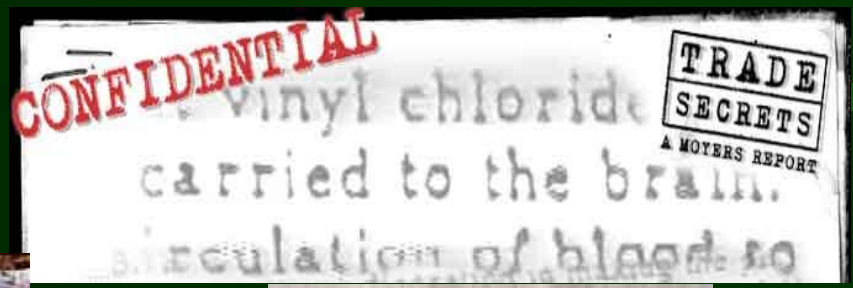
EPA Sustainability Forum
May 18, 2005

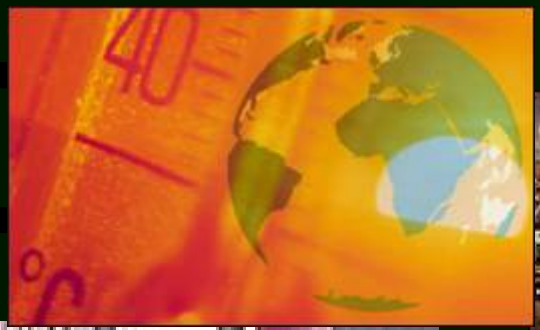
Negative Chemical Legacy

- The Surprises
  - CFC's and Ozone Depletion
  - Persistent Organic Pollutants
  - Bioaccumulation
    - PCB @ 1 x in H20, 6,400 in plankton, 240,000 in squid, 13,000,000 in dolphin and tuna
  - Atmospheric Distillation (esp. northern latitudes)
  - Endocrine disruption
- The Messes Left Behind
  - Thousands of tons of abandoned pesticides
  - Nuclear legacy with $300 billion price tag

Changing View of Chemistry







National Report on Human Exposure to Environmental Chemicals

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 application of chemical products.

Must Address Global Challenges

- Up to 4.7 billion people in next 50 years
- Tremendous resource demands
  - Energy, food, water, chemical goods and services
- Most population growth and economic expansion will occur in developing world
  - Pollute and clean up option
  - Green Chemistry option
- Water, agriculture, and energy at heart of sustainability
  - Chemistry supports and threatens all

Global Freshwater Crisis

- Population outstripping resources
  - 8.9 billion people by 2050
- 2025 global freshwater shortfall equals 2,000 km3
  - Equal to the annual flow 10 Niles or 110 Colorado rivers
- Chemistry plays role in global economy, manufacturing, food production and water contamination
- How can Green Chemistry help?

Industrial Waste Treatment

- World chemical market = $5 B/yr.
  - Infrastructure protected = over $1T
- Nalco Approach - Green Chemistry
  - Systematic analysis of facility use
  - Substitution chemistry to decrease toxicity
    - Corrosion, scaling and anti-bacterial products
  - Precision control of chemical metering
  - Profit comes from more than chemical sales
- Green Chemistry issues extend far beyond traditional chemical industry

Water Conservation

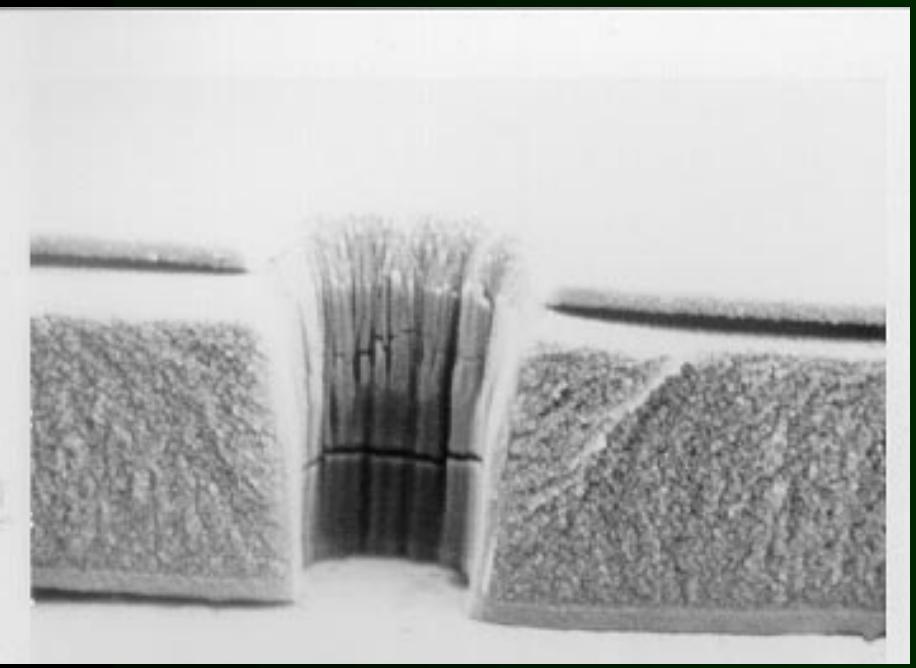
- Semiconductor fabrication and cleaning is chemical, energy and water intensive
  - Chemicals: 45 g per cm2 = 280 kg per kg of chip
  - Water: 2-3 M gal/day = 18-27 L per cm2
    - 32,000 g per 2 g chip
  - Energy: 1.45 MJ per cm2
  - Total: 1.7 kg of chemicals and fuels to produce a 2 gram 32 MB DRAM chip
- But until industry hit a rate-limiting technical problem there was no change
  - The physics of surface tension

Source: Williams, Ayres, Heller, In Press, ES&T

Photoresist Removal

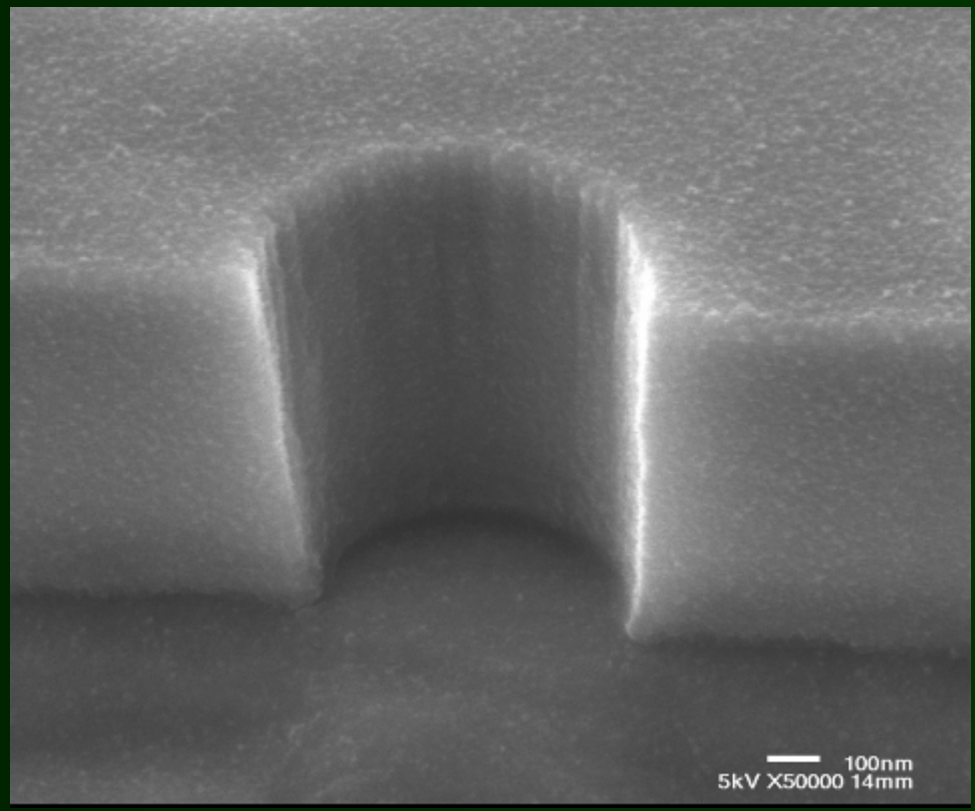
- Semiconductor fabrication and cleaning is water intensive
  - 500,000 gal/day in modern fabrication facility
  - Deionized water is also energy intensive
  - Surface tension problem rate-limiting
- Los Alamos Supercritical Resist Removal uses CO2 with propylene carbonate additive
  - Non-toxic additive in tunable medium
  - Eliminates water-based cleaning system while lowering operating costs
- Solved rate-limiting technical problem

Semiconductor Photoresist Removal



Semiconductor component showing sidewall polymer prior to cleaning

Semiconductor component After SCORR cleaning



Carnegie Mellon

Environmentally Safe Technologies

Institute for Green Oxidation Chemistry

- Dr. Collins research has developed a new set of catalysts for the activation of hydrogen peroxide called TAML® (Tetra Amido Macrocyclic Ligand) activators.
- TAML® activators promise a revolution in industrial peroxide chemistry. The goal is to achieve as general a greening of oxidation technology as is possible with catalyzed hydrogen.
- Applications in many fields-of-use; wood pulp bleaching and effluent treatment, laundry science, surface cleaning, water-borne dye effluent treatment, toxic chemicals destruction and decontamination, and water disinfection.

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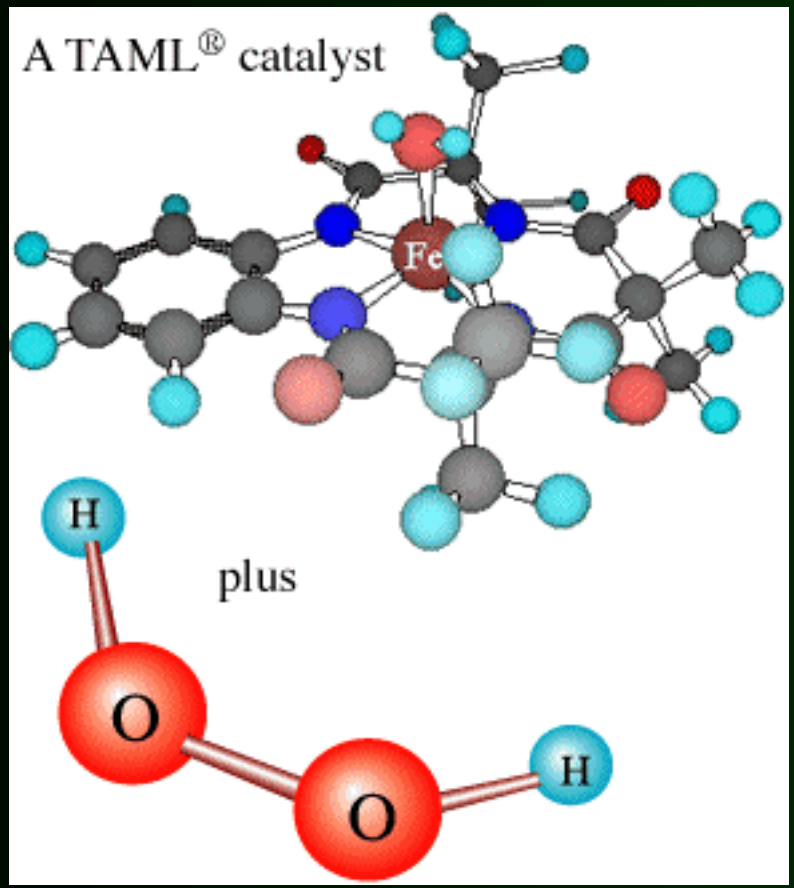

Pulp and Paper
Pulp delignification and effluent decolorization

Textiles
Dye bleaching and effluent decolorization

Laundry
Dye transfer inhibition and stain bleaching

Water Cleaning
Halogenated aromatics and organics destruction

Photographic Processing

- Billions of photos yearly with silver halide process
  - US release = 1200 M gal. of water with15 million gal. of chemical developer and contaminants such as hydroquinone, ammonia and silver.
- DuPont DuCare™ Photochemical Film System
  - Replaces hydroquinone developer with erythorbic acid
  - 99% of developer and fixer recycled Provide and recycle all containers
  - Potential 395 M gal. H20 savings per yr. in US
- Illustrates multi-dimensional approach to complex problems

Marine Fouling a Major Economic and Environmental Issue

Marine Antifoulants

- Organisms on ships surfaces increase drag and fuel costs - $4 B/yr. if untreated
    - Reduced fuel usage
    - Longer dry-docking intervals and less maintenance
- Tributyltin used in 70% of treatments
  - Bioaccumulates and is chronically toxic
    - Immune, reproductive and mutagenic effects
- Rohm & Haas Sea-Nine® Antifoulant
  - 4,5-dichloro-2-*n*-octyl-isothiazolin-3-one (DCOI)
  - Metabolic breakdown products non-toxic w/o bioaccumulation
  - Cost competitive

Agriculture and Green Chemistry

Pesticide waste is disappearing into the environment

Obsolete pesticides leaking and contaminating groundwater

Local citizens have little choice despite knowledge of contamination

All photos: www.fao.org

Biomimetic from Dow

- Dow Spinosad® is a biomimetic pesticide
  - Derived through the fermentation of a naturally occurring organism;
  - Targets chewing insects on cotton, fruits, vegetables
  - Highly active at low use rates;
  - Active by ingestion and contact exposure with a mechanism unique among known insect pest control compounds;
  - Has less impact on predatory beneficial insects.
- Illustrates chemistry mimicking nature

Molting Accelerators

- Organophosphates and carbamates used to combat caterpillars, cutworms, and beetle grubs
  - Disrupt nervous system enzyme function
  - Toxic to humans and non-target insects
- Rohm and Haas developed diacylhydrazines to mimic 20-hydroxycdysone found in molting insects - different compounds for specific species
  - CONFIRM® and MACH2® arrest molting and stops feeding
  - Non-toxic to other nonlepidopteran insects
  - EPA classification as reduced risk pesticides

Harpin Proteins

- Harpin Ea is a natural protein produced by the plant pathogen Erwinia amylovora, or fire blight.
- When applied to a plant, the harpin Ea protein tricks the plant into thinking it is under attack.
  - Triggers a cascade of gene responses stimulating several distinct biochemical pathways within the responsible for growth and disease and insect resistance.
  - The gene expression also stimulates nutrient uptake and photosynthesis.

Harpin Proteins

- Marketed as Messenger® by Eden Biosciences.
- Simultaneous activation of natural plant systems to:
  - Enhance plant growth, crop yield and quality,
  - Array of viral, fungal and bacterial diseases,
  - Enhance resistance to attacks by insects, decreasing potential for damage.
- Effectiveness across a wide array of crops.
- Improved food safety
- Reduced risk of environmental damage.
- Increased worker safety

Summary

- Sustainability issues can’t be a choice between food, clean water and the environment
- Green Chemistry is a viable approach to global environmental problems
- Success requires an effective and complex blend of technical, social, economic and political contributions
  - No environmental problem can be solved without all factors being addressed