Green Engineering – Principles and Applications in Modern Society

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- Sustainable Design Aspects of Waste Management
- Green Engineering in Industrial Processes
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What is green engineering?

- Green engineering is the design, commercialization, and use of processes and products in a way that reduces pollution, promotes sustainability, and minimizes risk to human health and the environment without sacrificing economic viability and efficiency.
- Green engineering embraces the concept that decisions to protect human health and the environment can have the greatest impact and cost-effectiveness when applied early, in the design and development phase of a process or product.

Characteristics of Green Engineering

Green engineering processes and products:

- Holistically use systems analysis and integrate environmental impact assessment tools.
- Conserve and improve natural ecosystems while protecting human health and well-being.
- Use life-cycle thinking in all engineering activities.
- Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.
- Minimize depletion of natural resources.
- Strive to prevent waste.

Additionally, green engineering:

- Develops and applies engineering solutions while being cognizant of local geography, aspirations, and cultures.
- Creates engineering solutions beyond current or dominant technologies; improves, innovates, and invents (technologies) to achieve sustainability.
- Actively engages communities and stakeholders in the development of engineering solutions.

12 Principles of Green Engineering

- **Inherent Rather than Circumstantial**
  Designers need to strive to ensure that all materials and energy inputs and outputs are as inherently nonhazardous as possible.
- **Prevention Instead of Treatment**
  It is better to prevent waste than to treat or clean up waste after it is formed.
- **Design for Separation**
  Separation and purification operations should be designed to minimize energy consumption and materials use.
- **Maximize Efficiency**
  Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.

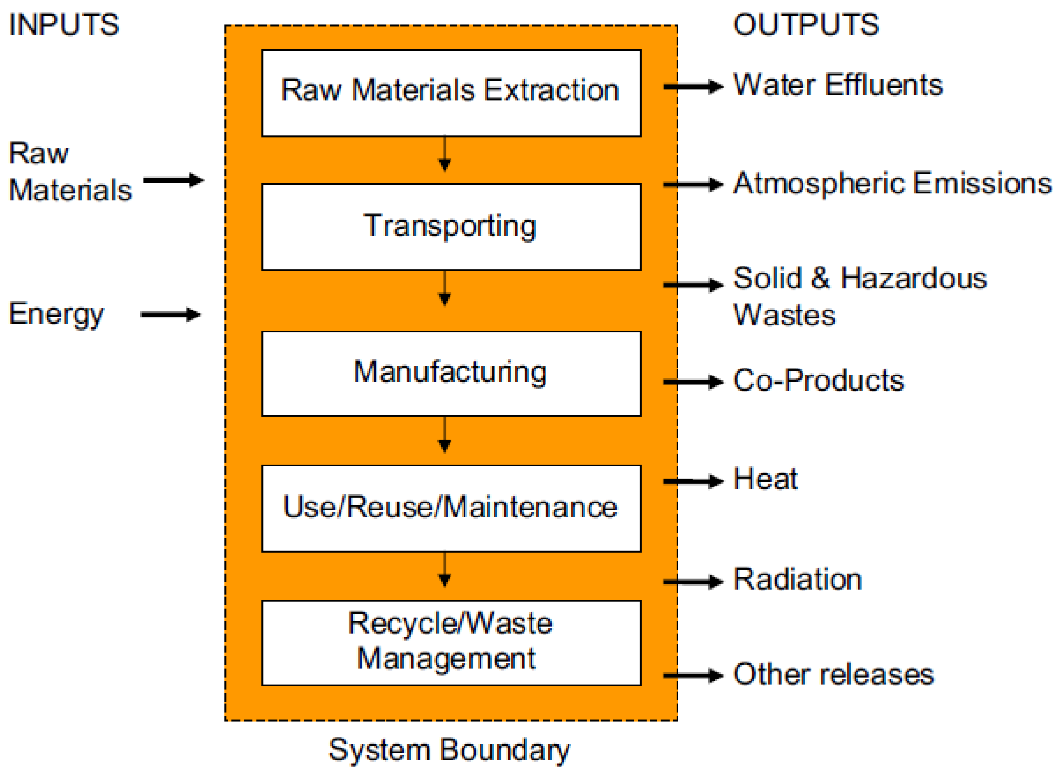
12 Principles of Green Engineering

- **Output-Pulled Versus Input-Pushed**
  Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials.
- **Conserve Complexity**
  Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
- **Durability Rather Than Immortality**
  Targeted durability, not immortality, should be a design goal.
- **Meet Need, Minimize Excess**
  Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw.

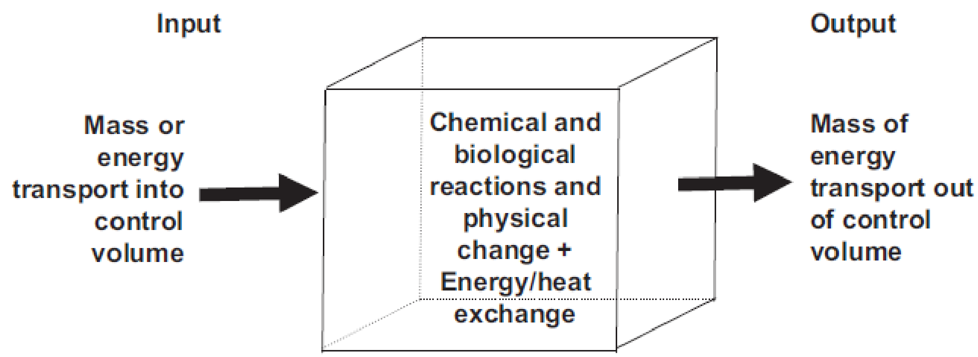
12 Principles of Green Engineering

- **Minimize Material Diversity**
  Material diversity in multicomponent products should be minimized to promote disassembly and value retention.
- **Integrate Material and Energy Flows**
  Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.
- **Design for Commercial "Afterlife"**
  Products, processes, and systems should be designed for performance in a commercial "afterlife."
- **Renewable Rather Than Depleting**
  Material and energy inputs should be renewable rather than depleting.

Green Engineering and Sustainable Design Aspects of Waste Management

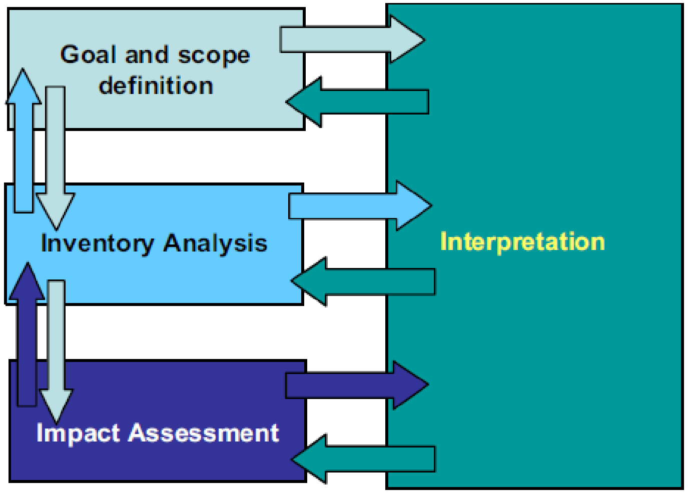


Life cycle stages of a process



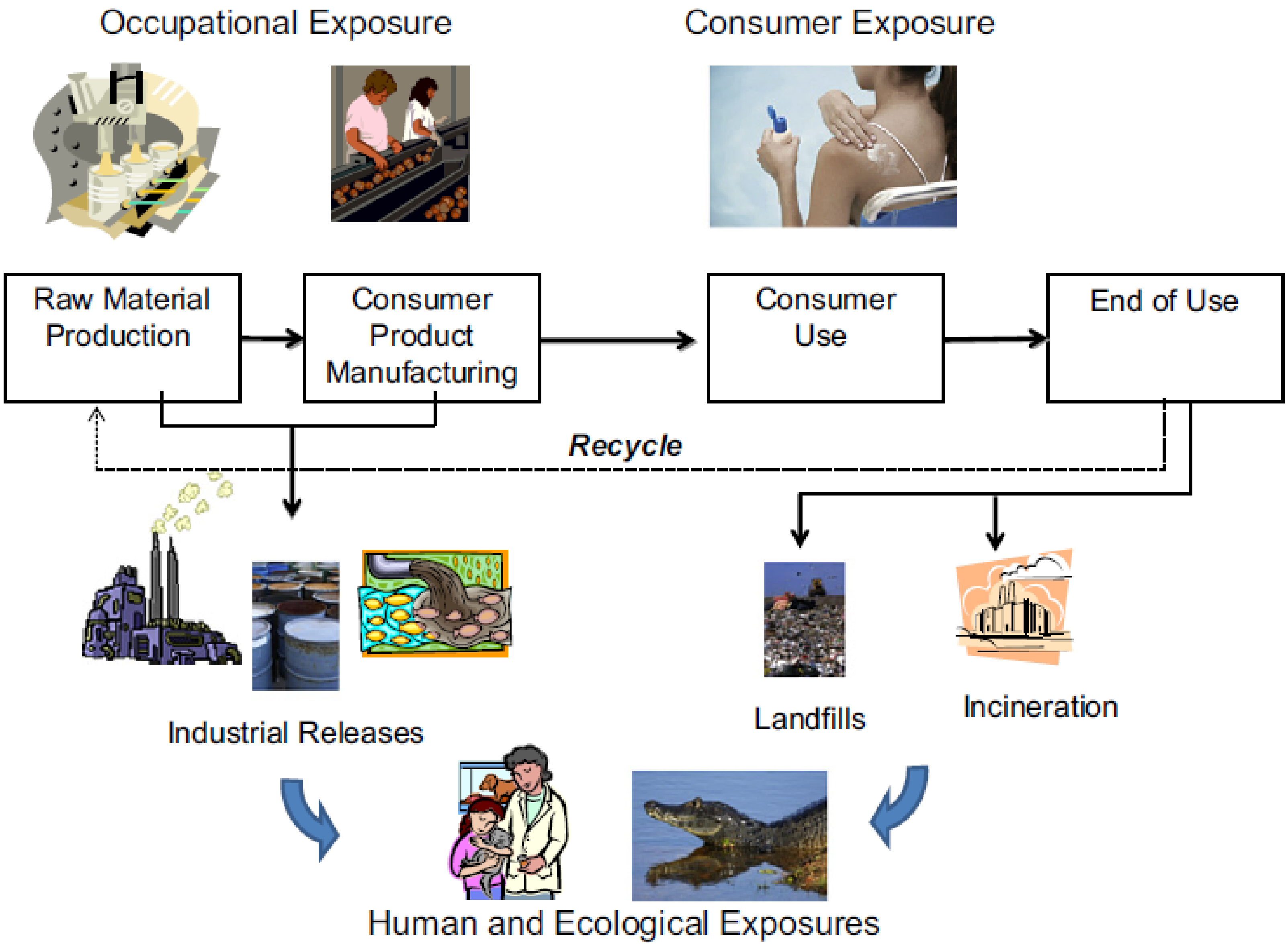
$$\text{Efficiency} = \frac{E_{\text{in}} - E_{\text{out}}}{E_{\text{in}}} \times 100$$

Life Cycle Assessment Framework

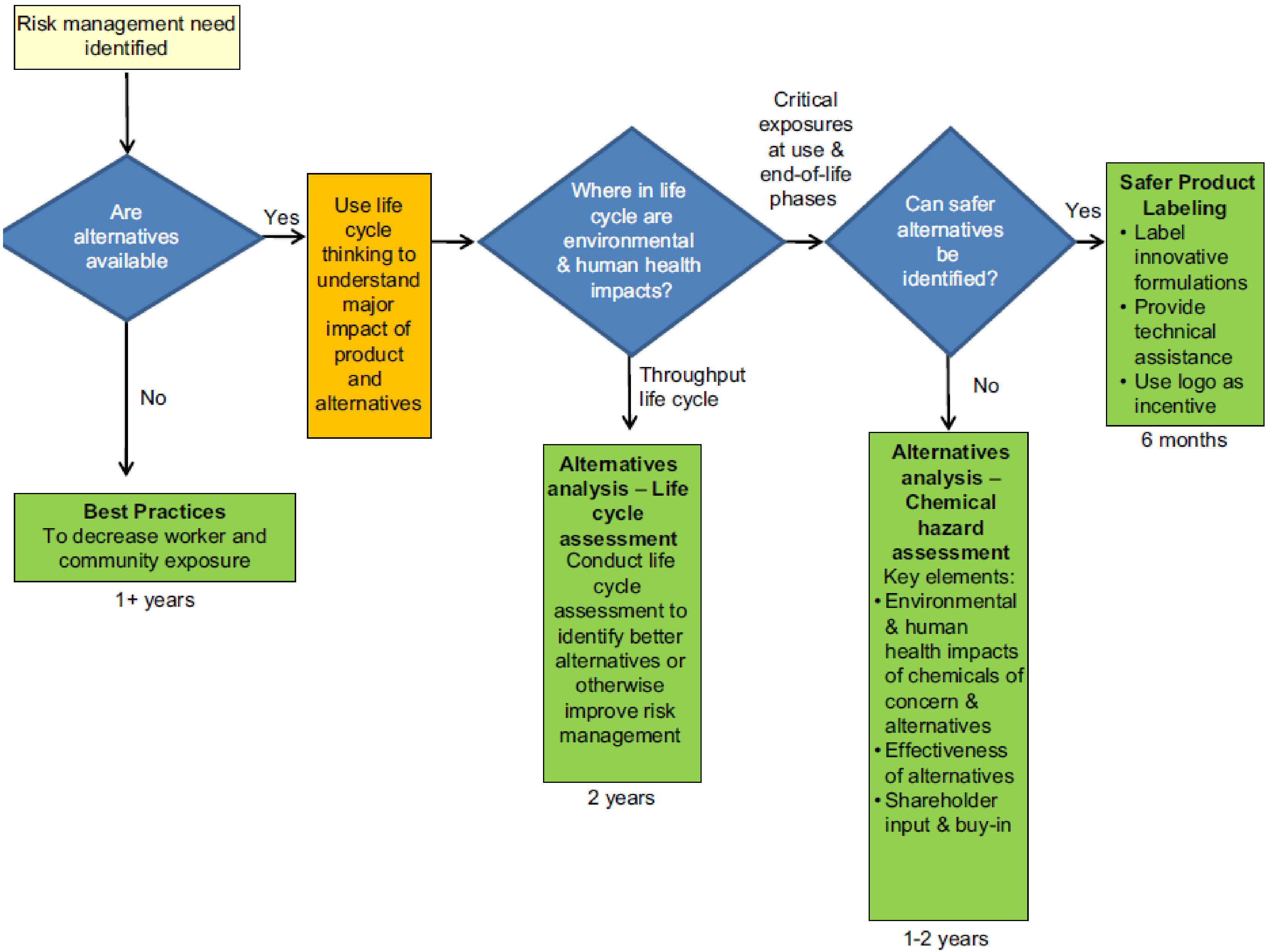


- Goal Definition and Scoping -Define and describe the product, process, or activity. Establish the context in which the assessment is to be made and identify the boundaries and environmental effects to be reviewed for the assessment.
- Inventory Analysis - Identify and quantify energy, water, and materials usage and environmental releases (e.g., air emissions, solid waste disposal, and waste water discharges).
- Impact Assessment - Assess the potential human and ecological effects of energy, water, and material usage and the environmental releases identified in the inventory analysis.
- Interpretation - Evaluate the results of the inventory analysis and impact assessment to select the preferred product, process, or service with a clear understanding of the uncertainty and the assumptions used to generate the results

Life cycle of product, showing points of exposure and potential risk, including after the useful life of the product



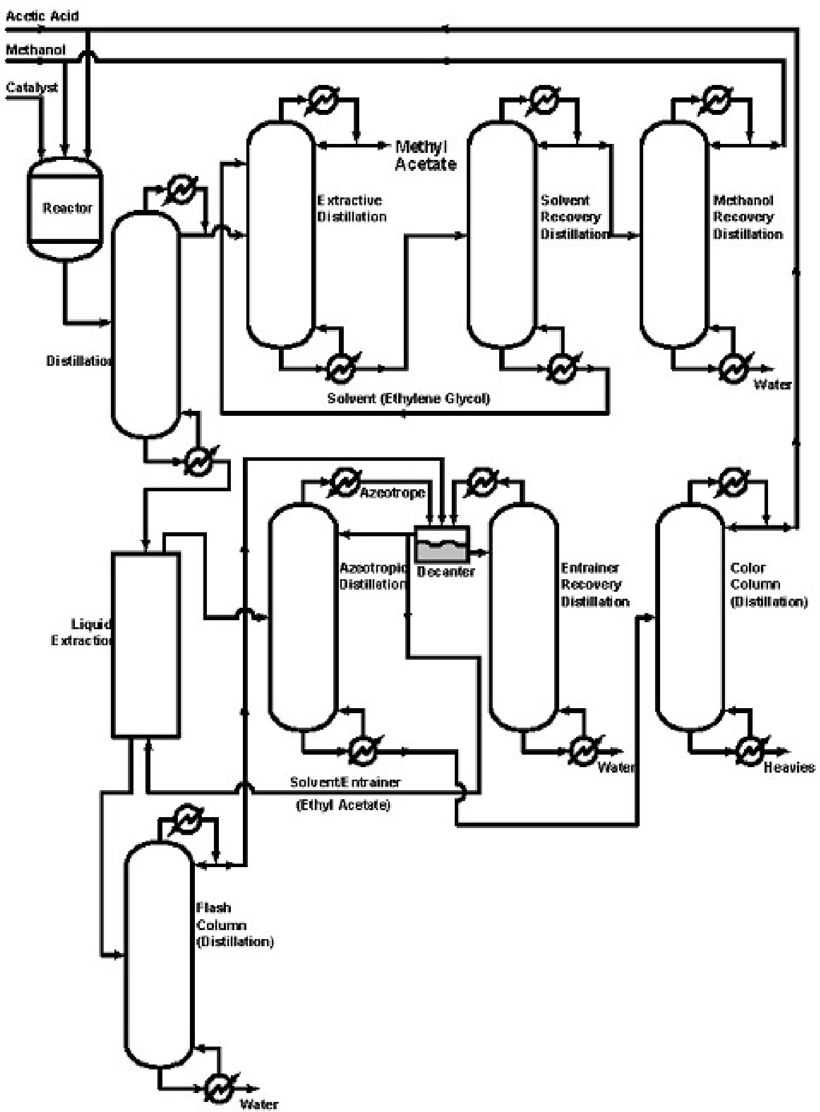
Decision logic for DfE approaches



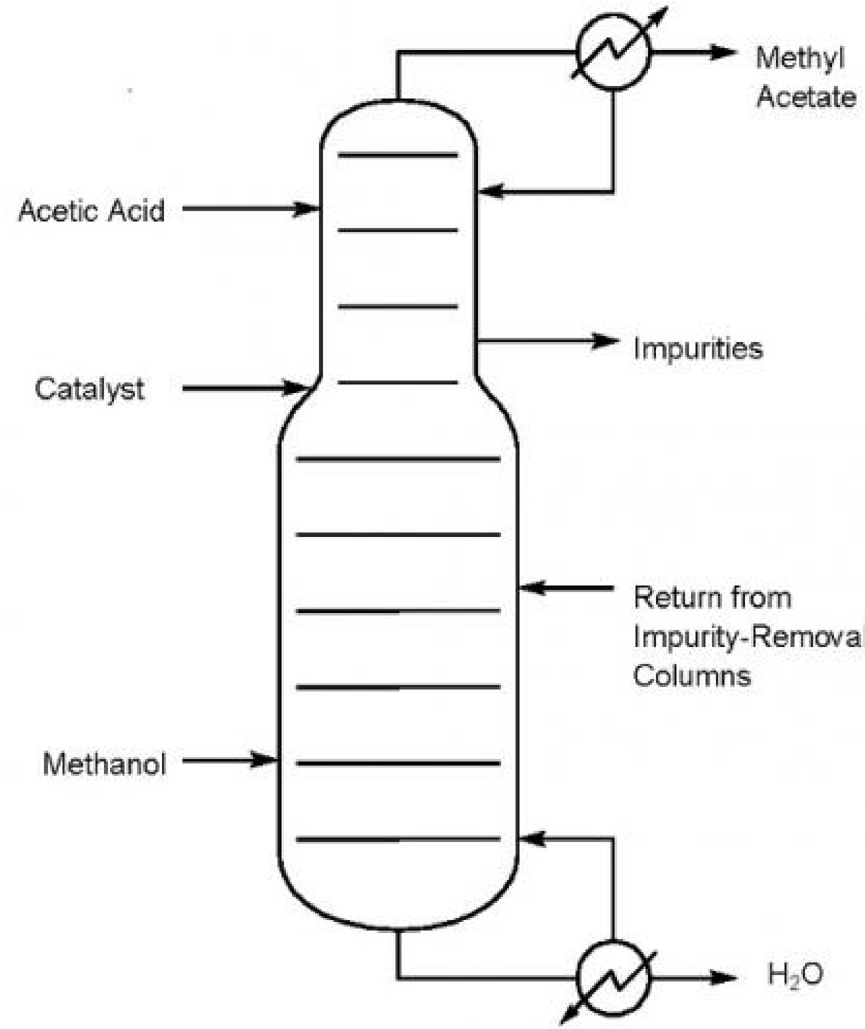
Green engineering in industrial processes: Reactive distillation

For production of methyl acetate, reactive distillation is beneficial compared to traditional distillation process:

- Improve selectivity
  - Reduce raw materials usage
  - Reduce byproducts prevent pollution
- Reduce energy use
- Handle difficult separations
  - Avoid separating reactants
  - Eliminate/reduce solvents
- Enhance overall rates
- "Beat" low equilibrium constants



Traditional Distillation Process



Reactive Distillation Process

Green engineering in industrial processes:
Reducing automobile emissions and saving energy

- Case study on the UltraLight Steel Auto Body-Advanced Vehicle Concepts (ULSAB-AVC), in which reductions in automobile emissions and improvements in gas mileage were observed as a result of using lightweight steel in the construction of cars.
- The ULSAB-AVC is a complete conceptual design for steel intensive compact and mid-size sedans.
- The designs were developed by a consortium of 33 steelmakers from around the world.

	U.S. C.A.F.E. standard	ULSAB-AVC Gasoline	ULSAB-ABC Diesel
U.S. combined [mpg]	27.5	52	68
CO_2 emission [g/km]	204	108	92

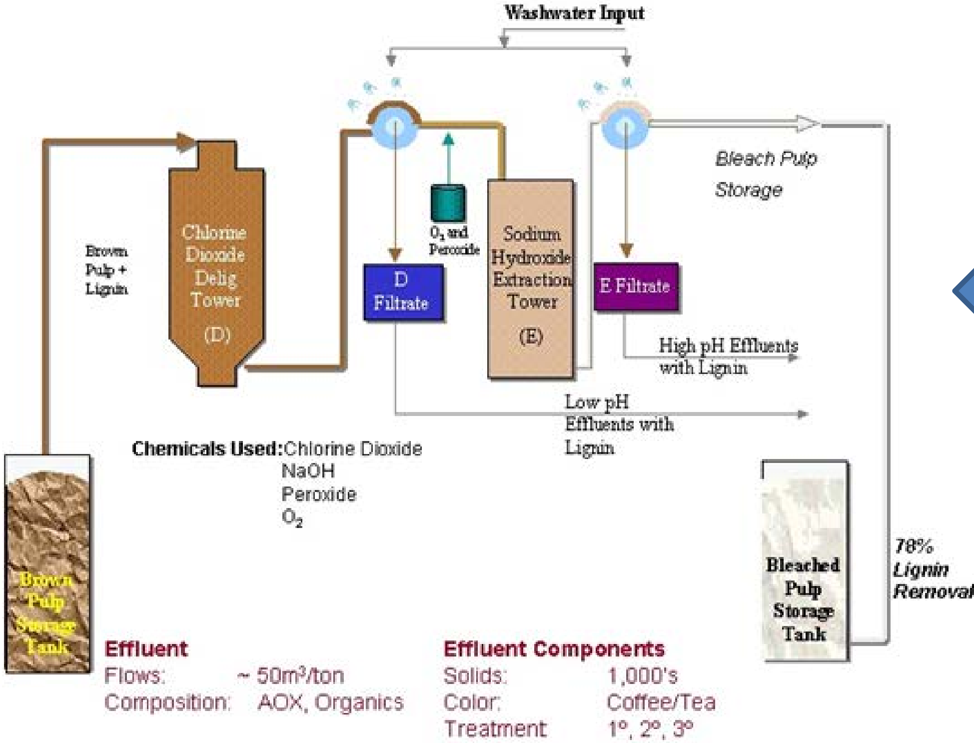
1 mpg = 0.425 kmpL

CAFE = Corporate Average Fuel Economy Standards for automobiles and trucks

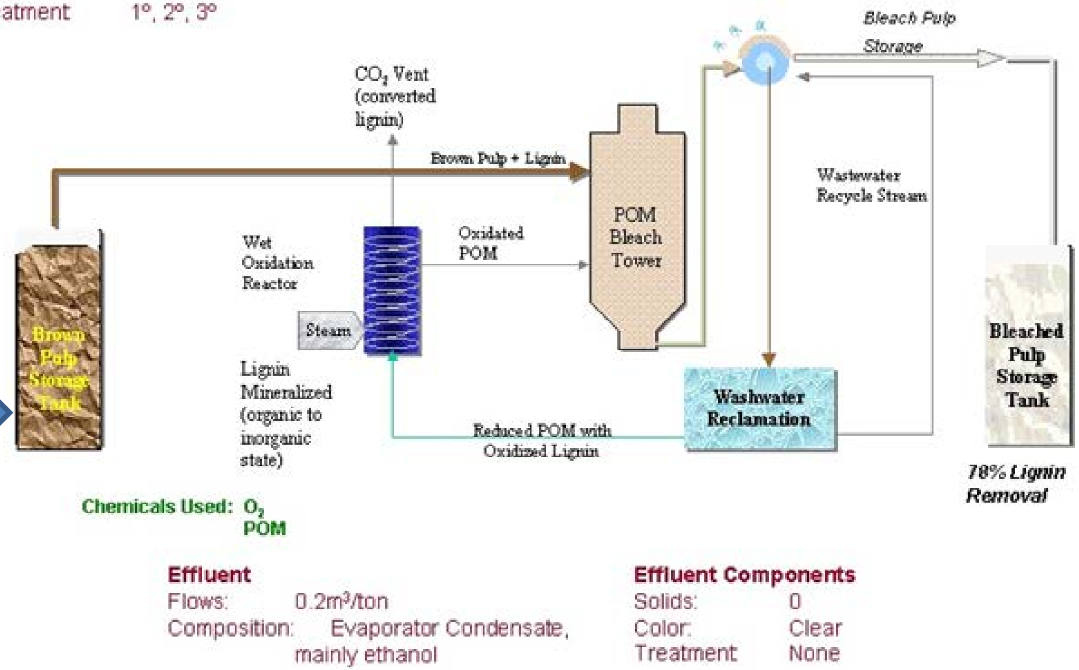
Green engineering in industrial processes: Minimizing hazardous chemicals in the paper industry

- To eliminate the use of and exposure to hazardous chemicals in the bleaching process, a new delignification agent (a polyoxometalate, or POM) is used to provide the basis for closed-mill bleaching technology.
- This technology eliminates the use of a hazardous chemical while maintaining effective lignin removal.

Traditional bleach process for lignin removal from wood (delignification) - DEop process



"Green" process for lignin removal from wood via polyoxometalate (POM)



Paper bleaching: comparison of process stream and energy inputs

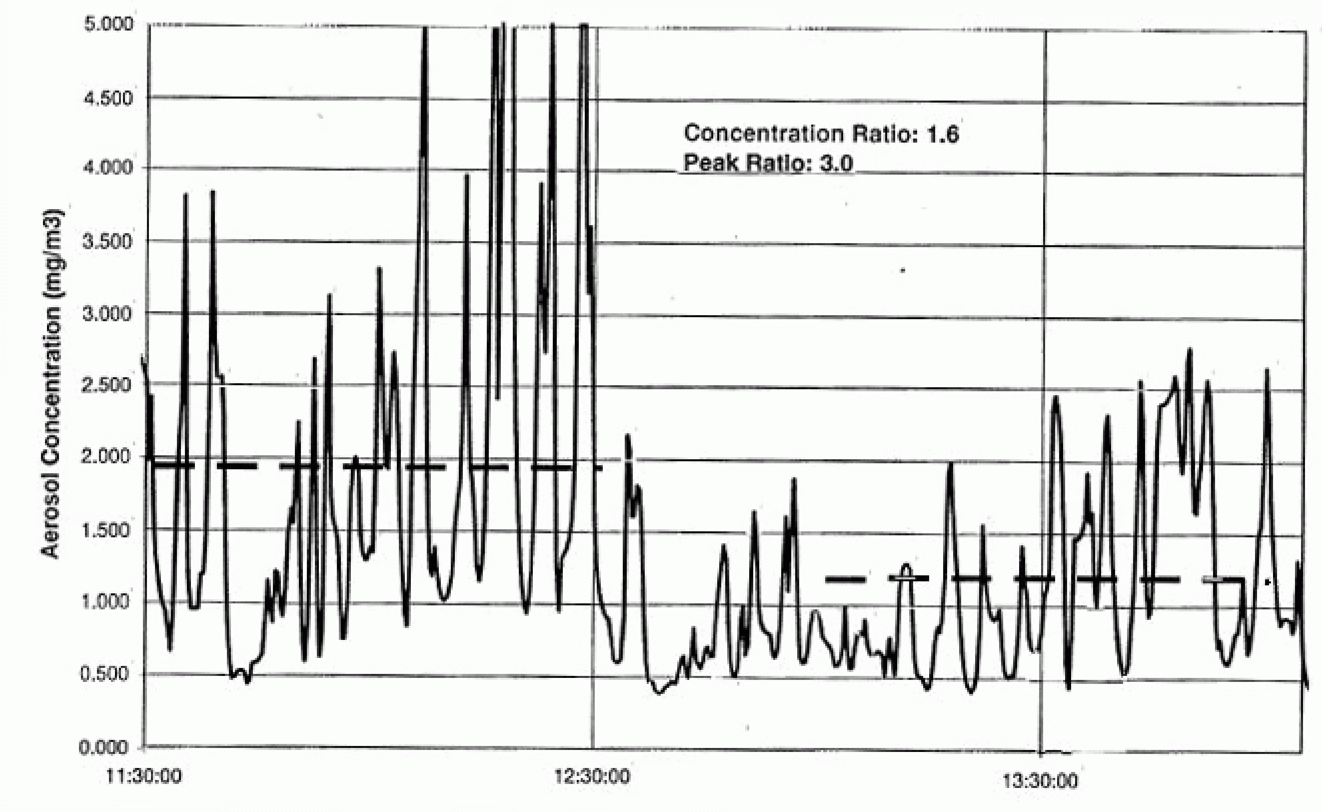
	Process Stream Inputs						Energy Inputs	
	NaOH	O_2	H_2SO_4	ClO_2	H2O2	POM	Electricity (kW-hr/MT)	Steam (kg/MT)
POM		137				0.27	277	2,858
DEop	24	5	5	18.3	6		281	1,693

- While this delignification process completely eliminates bleach plant effluent, it requires increased steam and energy usage as well as new capital equipment.
- The trade-offs are that the POM process requires higher process flow temperature and has a high steam requirement to run the oxidative reactor.
- The challenge will be to reduce process temperature and to eliminate the oxidative reactor to decrease steam requirements.

POM = polyoxometalate process, uses no ClO_2 or NaOH
DEop = traditional method of bleaching

Green engineering in industrial processes: Minimizing worker exposure to mist in the auto industry

- Exposure to mist from machining fluids can cause serious health problems, including cancer, respiratory problems, and allergic reactions.
- A cost-effective method of reducing mist from oil-based fluids has already been widely implemented in the auto industry.
- For straight oil fluids, polyisobutylene (PIB) can be added to control mist. An addition of 70 ppm of PIB results in a 40 percent reduction in average mist levels and a 67 percent reduction in peak mist levels.
- This additive has been used extensively in auto manufacturing facilities. Its costs are relatively low and only weekly replacement is required.



- **70 ppm of PIB added to machining oil**
- **40% reduction in average mist levels**
- **67% reduction in peek mist levels**
- **24 hours plus service life**

- polyethylene oxide (PEO) being tested-results are promising
- high treatment levels are needed (up to 500 pm), the polymer is relatively costly, and daily replacement is required.
- optimization of polymer-surface interactions and synthesis of "designer" antimisting systems

NASA & Green Engineering

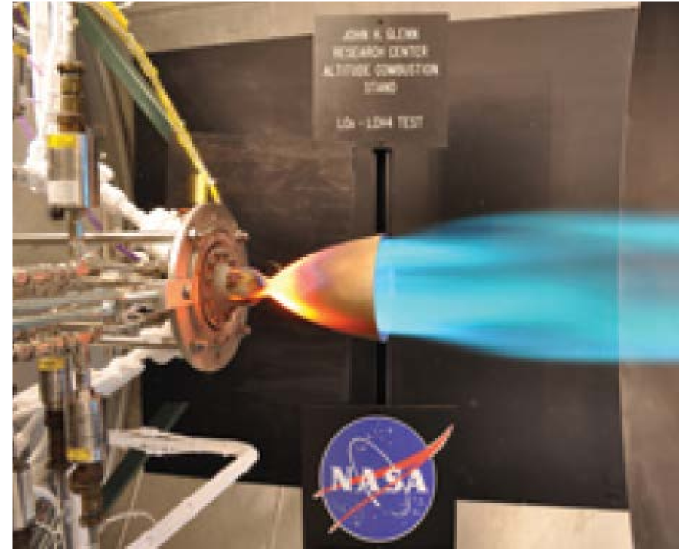
- Helping NASA Design a Successful & Sustainable Future

- To accomplish its mission by minimizing and mitigating risks, especially those from materials that are obsolete or restricted by national and international environmental regulations.
- To enhance effectiveness and efficiency by increasing multiple uses of materials and the reuse of wastewater and air in closed systems, while reducing weight and minimizing exposure to hazardous materials on long-term missions.
- to promote strategic life cycle management
- NASA's Technology Evaluation for Environmental Risk Mitigation Principal Center (TEERM) works with other stakeholders, such as the Department of Defense (DoD), U.S. Air Force (USAF) and U.S. Navy (USN) – and aerospace industry partners.
- NASA tested lead-free electronics assemblies in space.
- It could be used on low-Earth orbit space flight applications if tin whisker mitigation is incorporated into the design of these electronics assemblies.
- NASA is developing "green propellants" as alternatives to hydrazine.

NASA's approach

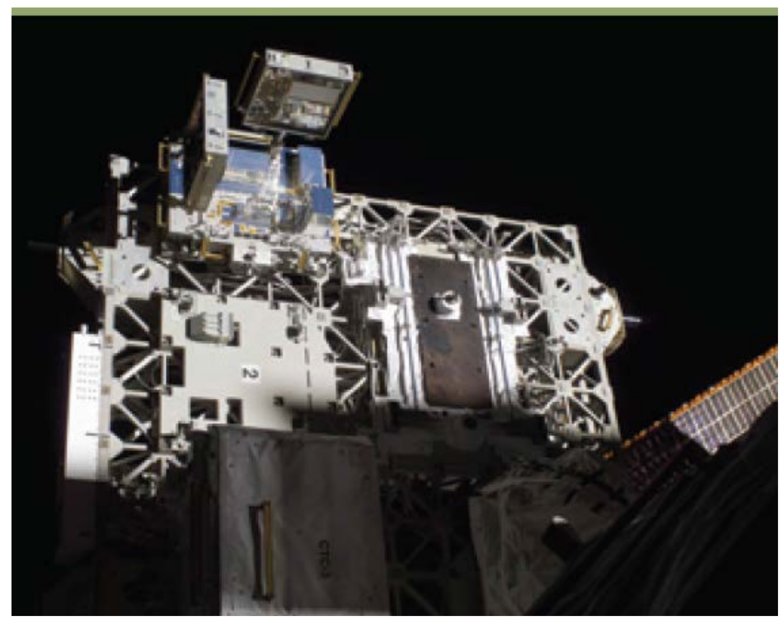
- **Improving** decision making in system development by promoting the adoption and use of green engineering methodologies within the decision making.
- **Influencing** procurement actions within the supply chain to acquire and use sustainable materials and products.
- **Inspiring**, motivating and incentivizing designers, engineers and managers by facilitating a change in NASA's culture and improving NASA policies. This change involves managers, engineers and designers, encouraging them to ask questions about where materials and products originate, how much energy they use and their eventual disposition.
- **Communicating** with and educating students and space personnel by sharing techniques, methodologies and tools.
- **Collaborating** and sharing resources with national and international partners.
- **Reducing** the use of energy, water and other resources, as well as project life cycle costs.
- **Increasing** the applicability of energy and other exploration technologies for use on earth.

Hexavalent Chromium-free Pretreatments
Project, a new coating is tested



“green propellant” as a hydrazine replacement

an inspector checks the condition of panels



NASA tested lead-free electronics assemblies in space

Integrating Education into the Design Process - NASA offers three-day Green Engineering course

- Identifying and communicating NASA engineering challenges and opportunities regarding environmental impacts – and future risks, requirements and potential solutions
- Designing and developing materials, products, processes, hardware and systems that are inherently safe, generate less waste and use energy more efficiently
- Describing and applying basic life cycle assessment techniques for engineering new products, considering environmental and energy impacts throughout the life of the project from design through operation to its eventual disposal

Academic programs in Green Engineering

Undergraduate programs

- Virginia Tech Green Engineering Minor
- University of Texas at Austin

Graduate programs

- University of Pittsburgh Mascaro Center for Sustainable Innovation
- University of Michigan College of Engineering & School of Natural Resources and Environment
- Yale University Center for Green Chemistry & Green Engineering
- Carnegie Mellon University
  - Environmental Engineering, Sustainability, and Science
  - Department of Engineering and Public Policy

Undergraduate and graduate programs

- Arizona State University
  - School of Sustainability
  - School of Sustainable Engineering and the Built Environment

Conclusion

- This presentation talked about Green engineering and principles.
- An overview of environmental issues and risk management assessment was discussed.
- Application of green engineering in industrial processes such as reactive distillation, reducing automobile emissions, minimizing hazardous chemicals in the paper industry, minimizing worker exposure to mist in the auto industry has been discussed.
- Advances of NASA in designing a successful and sustainable future has been presented.
- Opportunities for engineers to enhance their learning on green engineering has been explored.

Thank you
for your
Kind Attention!