Pollution Prevention Techniques Module
Module Objective

- Apply pollution prevention techniques to various industrial processes in order to eliminate or reduce the emission of toxic and/or hazardous substances into the environment.

- This would be done by globally analyzing the industrial process as well as the process emissions and wastes while keeping in mind environmental laws and regulations.
CHAPTER 1

Introduction to Environmental Aspects Related to Pollution Prevention
Introduction

- Pollution Prevention and Waste Management Hierarchy
- Introduction to Environmental Issues
  - Impact of chemical production on the environment
  - Waste stream impact and life cycle analysis
  - Important aspects of the environment
    - energy use
    - water quality issues
    - natural resources
    - economics and feasibility
    - air quality issues
    - ecology
    - solid waste
What is Pollution Prevention?

Any action (or actions) that prevents the release of hazardous and/or toxic substances into the environment – source reduction.
North American PP Regulations

CANADA

The Canadian federal government defines pollution prevention as: The use of processes, practices, materials, products or energy that avoid or minimize the creation of pollutants and waste, and reduce overall risk to human health or the environment.

Source: Environment Canada
Pollution Prevention means “source reduction,” as defined under the Pollution Prevention Act, and other practices that reduce or eliminate the creation of pollutants through: increased efficiency in the use of raw materials, energy, water, or other resources, or protection of natural resources by conservation.

Source: EPA
http://www.epa.gov/opptintr/p2_97/append-c.pdf
MEXICO

See the *Ley General del Equilibrio Ecologico y la Protección al Ambiente* which defines pollution protection for air, water and land.

Source: Semarnap

http://www.semarnat.gob.mx/wps/portal
Benefits of Pollution Prevention

– Improved environmental protection in all aspects (air, water, soil, ecology, human health)

– Reduced costs of raw material, energy, water, waste handling, waste treatment and disposal

– Improved worker health and safety, public image and product quality.
Waste Management Hierarchy

- Direct Release into the Environment
- Secure Disposal
- Waste Treatment
- Off-Site Recycle
- In-Process Recycle
- Source Reduction
- Pollution Prevention (Encompasses the first 4)
Environmental Issues Concerning Pollution Prevention

Energy Use
Air, Water and Soil Quality
Ecology
Natural Resources
Solid Waste
Economical Issues
Production of a Chemical

It is important to not only look at the effects of the waste streams, but to also consider all the steps of production when implementing pollution prevention techniques into a process. One must use an holistic approach.
Overall View of Chemical Production

- Natural resources and other processes required
- Waste heat, energy and emissions from all processes
- Pollution from waste streams as well as product and by product disposal

* It is also important to consider all possible sources of pollution, from the initial natural resources required to the final disposal of the product.
Waste Stream Impacts

The production of a chemical has an impact on many different aspects of the environment, including natural resources, air, water, arable land, ecology and human populations.
Primary Impacts

Pollutants from waste streams can directly impact the air, water and land, and can also have an adverse effect on the environment and on humans through dermal contact, ingestion or inhalation.
Secondary Impacts

Pollutants from waste streams can also react after being discharged to create adverse effects in the air, water, land, on the environment or to humans.
Environmental Issues

Energy use

• It is important to consider:
  – The Renewable and Non-Renewable Sources,
  – The Efficiency of the Sources,
  – The Primary and Secondary Sources,
  – The Associated Environmental Impacts.
Example: Electricity Generation

Utility and non-utility electricity power producers operate several types of electric generating units, powered by a wide range of fuel sources, including:

- Fossil Fuels (coal, natural gas, and petroleum)
- Nuclear “fuels” (uranium)
- Renewable fuels (water, geothermal, wind, and other renewable energy sources).

Source: www.acnatsci.org/research
Example: Electricity Generation

U.S. Net Electricity Generation, 2000

Fuel Source

Source: Energy Information Administration,
Finite (non-renewable) energy sources include fossil fuels.

Renewable energy sources include water (hydropower), biomass, wind, heat from the earth (geothermal), and the sun (solar energy).

"Green" renewable energy sources contribute much less to global warming, and climate change in comparison with fossil fuels.
Renewable energy is not a new concept.

Five generations ago, **wood** supplied up to **90 percent of our energy needs**. Due to the convenience and low prices of fossil fuels, wood use has virtually been replaced.

Many different industries are **converting waste biomass into electricity**.

**Examples** of such processes/substances include manufacturing wastes, rice hulls, and black liquor from paper productions.
Example: Renewable Energy

Total Energy = 96.935 Quadrillion Btu
Renewable Energy = 5.668 Quadrillion Btu

- Natural Gas: 24%
- Coal: 23%
- Petroleum: 39%
- Nuclear Electric Power: 8%

- Renewable Energy: 6%
  - Solar: 1%
  - Biomass: 50%
  - Geothermal: 6%
  - Hydroelectric: 42%
  - Wind: 1%

Source: http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea_sum.html
Environmental Issues

Ecology

It is important to consider the effects of pollutants on ecosystems that may cause damage by:
- Disrupting the cycling of elements (i.e. nutrients).
- Entering the food chain.

Ecology is *the study of material flows and energy utilization patterns in communities of living organisms in the environment, termed ecosystems.*

Source: Green Engineering, Allen and Shonnard, pp. 23
Example: Organisms Stressors

Organisms are subjected to a number and variety of stressors in the environment, therefore multiple measures of health are needed to help identify and separate anthropogenic-induced effects of stress from those effects caused by natural stressors.
Example: Organisms Stressors

Source: www.esdornl.gov/programs/bioindicators/
Environmental Issues
Natural Resources

• It is important to consider the following in the design of a process:
  – Availability of the natural resource (material).
  – Sustainable use of the material.
  – Ability to recycle, conserve and/or use improved technologies to maintain the availability of the material.
Environmental Issues: Air Quality

Mobile Sources:
Are automobiles, other transportation vehicles, and recreational vehicles such as snowmobiles and watercraft.

Stationary Sources:
Include factories and other manufacturing processes.

Area Sources:
Are emissions associated with human activities that are not considered mobile or stationary including emissions from lawn and garden equipment, and residential heating.
Environmental Issues: Air Quality

**Primary:**
Those emitted directly to the atmosphere.

**Secondary:**
Those formed in the atmosphere after emission of precursor compounds.
Environmental Issues: Air Quality

Criteria Air Pollutants

- Carbon Monoxide
- Lead Particulates
- Particulate Matter (2.5 and 10 microns)
- Sulfuric Oxide (SOx)
- Ozone
- Nitrogen Oxides (NOx)
- and
- Volatile Organic Compounds (VOCs)
- Hydrocarbons (HCs)
Carbon Monoxide

Carbon monoxide is readily absorbed into the body from the lungs. It decreases the capacity of the blood to transport oxygen, leading to health risks for unborn children and people suffering from heart and lung disease.

Nitrogen Dioxide

Nitric oxide reacts with hydrocarbons in the presence of sunlight to form nitrogen dioxide.

In the summer months NO₂ is a major component of photochemical smog.
**Environmental Issues : Air Quality**

**Ozone**

Ozone is not emitted directly into the atmosphere but is primarily formed through the reaction of hydrocarbons and nitrogen oxides in the presence of sunlight.

**Sulfur Dioxide**

Sulfur Dioxide is emitted directly into the atmosphere and can remain suspended for days allowing for wide distribution of the pollutant.

Source:  http://www.arb.ca.gov/aaqm/criteria.htm
Environmental Issues: Air Quality

Adverse Effects of Air Pollution

- **Stratospheric Ozone Depletion**
  - Ozone depleting chemicals (CFCs, HCFCs) and light.

- **Smog (creation of tropospheric ozone)**
  - Reaction of VOCs or HCs with NOx and light.

- **Acid Rain and Deposition**
  - Reaction of NOx and SOx with water molecules in the atmosphere.

- **Global Warming** (or greenhouse gas effect)
  - Caused by emission of “greenhouse gases” (CO$_2$, CH$_4$, N$_2$O, etc.).
Acid Rain and Deposition

Acidification may lead to reduced health of trees and eventually death of whole forests. Some soils contain chalk which neutralizes the acid and hence keep the effects of acidification invisible for a period of time.

Smog

Tropospheric ozone is absorbed by plants through the leaves. In the leaves, ozone degrades chlorophyll. The loss of chlorophyll inhibits photosynthesis and hence growth of the plant.
Global Warming

The concentrations of greenhouse gases are continuously increasing in the atmosphere due to human activities:

1) By emissions of naturally occurring greenhouse gases such as \( \text{CO}_2 \), methane \( \text{CH}_4 \) and nitrous oxide \( \text{N}_2\text{O} \), and,

2) By emissions of new substances such as halogenated carbons (CFCs, HCFCs and PFCs).

The possible increase of the earth’s temperature due to these emissions is often referred to as the “greenhouse effect” or “global warming."

Source: http://www.howproductsisimpact.net
Environmental Issues

Water Quality

- Contamination of surface water (lakes, rivers, seas, oceans) and groundwater can occur from point or non-point sources.
- Contributors to water pollution include:
  - Industrial sources
  - Municipal sources
  - Agricultural sources
  - Forestry
  - Land and water transportation
OXYGEN DEPLETION

All plants and animals in the water need oxygen for their respiration and the concentration of oxygen in the water is a limiting factor for many species of fish and bottom animals.

A mild degree of oxygen depletion may cause a shift in the composition of life in the water towards less oxygen demanding species. Stronger oxygen depletion may kill plants, fish and bottom animals and leave only robust plankton, insect larvae and bacteria.

Source: http://www.howproductsimpact.net
NITROGEN

The waterborne emission may arise from agriculture, industry and households in forms such as ammonia (NH₃), ammonium (NH₄⁺), nitrite (NO₂⁻), nitrate (NO₃⁻), urea (CO(NH₂)₂) and organic-bound nitrogen.

Excessive emissions of the nitrogenous substances can change the balance in the aquatic and terrestrial environment cause serious problems known as nutrient enrichment.

Source: http://www.howproductsimpact.net
Environmental Issues: Solid Wastes

**Non-Hazardous Waste:**
- Represents the largest contribution to the industrial waste picture.
- Important contributions come from the manufacturing, oil and gas and mining industries.

**Hazardous Waste:**
- Residual materials which are ignitable, reactive, corrosive and toxic.
- Small quantities but high treating cost in comparison to non-hazardous waste.
- Very little is recycled.
Environmental Issues: Economics

Example: Economical Aspect of Recovering Wastes

Waste Recovery is a cost-effective waste management alternative.

- Effective Recovery depends on the segregation of the recoverable material from other process wastes or extraneous material.

- Potential Advantages:
  - Eliminate waste disposal costs
  - Reduce raw material costs
  - Reduce energy use (and therefore costs)
  - Providing income from salable wastes

Source: es.epa.gov/techinfo/facts/nc/tips8.html
Examples of Waste Reduction Through Recovery and Reuse - Industry Technique

**Mirror manufacturer**
- Recover spent xylene using a batch-distillation system.

**Printed circuit boards**
- An electrolytic recovery system used to recover copper and tin/lead from process wastewater.

**Power tools**
- Recover alkaline degreasing baths using an Ultra-filtration system, etc.
Example: Wet Spray Booth Wash Water Recycling

Thomson Crown Wood Products, Mocksville, NC

Original System: Dispose of contaminated wet spray booth wash water as hazardous waste.

New System: Separate paint solids from the waste wash water and recycle the recovered water back to the spray booth

Result: Reduction of hazardous waste disposal costs by $92,500 per year

Source: es.epa.gov/techinfo/facts/nc/tips8.html
Sources and Impacts of Pollution in Chemical Production

In the face of growing political and public concerns, the pulp and paper industry began to research and implement ways of reducing organochlorine formation and discharge from mills reported as AOX in addition to COD and BOD discharges. These can be broadly categorised as process internal and process external measures.

FIGURE 2: Diagrammatic representation of the production of pulp and paper using bleach processes.
Process Internal Measures

Process internal measures to reduce mill organochlorine and other polluting outputs centre around increased removal of lignin before the pulp is sent to the bleach plant. Enhanced lignin removal allows modification of the bleaching process and agents and reduces the charge of bleaching chemicals used.

This processes has been intensively investigated and now seems established as the future system of choice for eliminating chloro-organics from the waste stream.
Process External Measures

Process external measures largely refer to the design and construction of various types of treatment plants. Treatment of bleach plant effluents can reduce toxic effects, depending upon the bleach chemicals used and the type of treatment employed, while the move towards chlorine dioxide as a bleach chemical has also contributed.

The ability of treatment systems to reduce the AOX component varies markedly, but wastewaters discharged from such plant invariably contain AOX if chlorine based chemicals are used while sludges may contain up to 50g AOX per kg of dried material.
Life Cycle Analysis (LCA)

What is Life Cycle Analysis?

Is the examination of the total environmental impact of a product through every step of its life, often quoted as being the “cradle to grave” analysis of a product.

Examples

Paper bags vs. Plastic bags  Styrofoam cups vs. Paper cups

Source: www.acnatsci.org/research/kye/big_picture.html
For example, after a flurry of state legislation regulating plastic shopping bags, makers of both plastic and paper grocery bags performed life-cycle studies comparing the two types of bags. The study by a plastics trade group claimed that the net environment impact of plastic shopping bags is less than that of paper bags.

Source: www.acnatsci.org/research/kye/big_picture.html
Even the often criticized polystyrene foam cup has been defended by LCA. A study published in the respected academic journal Science compared the environmental impact of polystyrene foam hot drink cups with that of paper cups.

The manufacture of paper cups was estimated to consume 36 times as much electricity and to generate more than 500 times as much wastewater as the manufacture of polystyrene foam cups.

Source: www.acnatsci.org/research/kye/big_picture.html
A Life-Cycle Analysis consist of Four Major Steps:

1) The **System Boundaries**.

2) Life-Cycle Inventory.

3) Life-Cycle Impact Assessment.

4) Improvement Analysis or Interpretation Step.
Life Cycle Analysis Steps

System Boundaries

What the limits of the investigation will be

The *system boundaries* define the processes and/or operations (e.g. manufacturing, transport, and waste management processes), and the inputs and outputs to be taken into account in the LCA.

The *functional unit* defines what is the basis for comparison between two similar products.

Source: www.dk-teknik.dk/ydelser/miljo/LCA%20guide/3rd_ed/kap334.htm
Paperboard plays an important role in packing because of its strength, low price, and flexible properties.

Paper sheets above 0.3 mm thickness are classified as paperboard and paperboard is produced in single-ply or multi-ply structure.

Source: http://www.howproductsimpact.net/box/
Indicator of paper and LDPE bag life cycles

Source: www.pre.nl/life_cycle_assessment/impact_assessment.htm
Life Cycle Analysis Steps

Life Cycle Inventory

The goal of is to clearly determine and quantify the inputs and outputs of the process boundaries.

This accounts for the use of raw materials, energy as well as effluent wastes (air, water, solid), emissions and by-products for the entire process.
Resources
Coal in the ground

Materials
Explosives

Energy uses
Diesel for machinery
Electricity

Extraction Of Coal

Air emissions
CH4 CO2 CO NOx
VOC SOx Particulates

Products
Extracted coal

Emissions to water
Metals
Inorganic salts
Suspended solids (SS)

Generation of waste
Mine waste

Source: http://www.howproductsimpact.net
Electricity used in all processes is obtained from the national grid. Thai electricity is derived mostly from coal, oil, natural gas, and hydro power.

Electricity is produced in power plants by combustion of fuels such as coal, oil and natural gas. During combustion many substances are emitted to air, for example carbon dioxide, nitrogen oxide, volatile organic compounds, methane, sulphur oxide.
## Exchanges per kWh (year 1999)

### Inputs

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<tr>
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### Outputs

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<table>
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Source: www.howproductsinpact.net/box/systemboundaries/systemboundarieselectricitygeneration.htm
Life Cycle Analysis Steps

Life Cycle Impact Assessment

The goal of this step is to **compile the environmental impacts** of the Life Cycle Inventory items. It can be done in three major steps:

- **classification**: of the substance into a category relating to the impact it may pose

- **characterization**: of the potency of the environmental impact

- **valuation**: relative indexes determined and an overall impact assessment can be determined
The phases of Life Cycle Assessment

Source: www.uneptie.org/pc/pc/tools/lca.htm
Goal and Scope Definition

The product (s) or service (s) to be assessed are defined, a functional basis for comparison is chosen and the required level of detail is defined.

Inventory of Extractions and Emissions

The energy carriers and raw materials used, the emissions to atmosphere, water and soil, and different types of land use are quantified for each process, then combined in the process flow chart and related to the functional basis.
Impact Assessment

The effects of the resource use and emissions generated are grouped and quantified into a limited number of impact categories which may then be weighted for importance.

Interpretation

The results are reported in the most informative way possible and the need and opportunities to reduce the impact of the product(s) or service(s) on the environment are systematically evaluated.
Life Cycle Analysis Steps

**Improvement Analysis or Interpretation Step**

The fourth step is to interpret the results of the impact assessment, suggesting improvements whenever possible.

This step might consist of recommending the most environmentally desirable product.

Source: Green Engineering, Allen and Shonnard, pp. 425