POWER ENGINEERING

Fourth Class

Edition 3.5

Introduction to Plant Operations and the Environment

Part A

Unit A-5

PanGlobal
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March 2026

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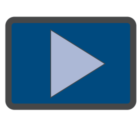
MEDIA 	Media icons show that some form of supporting medium is available. These media may include videos, animations, 2D and 3D models, multi-views of cutaways, simulations, and more. Media elements are available to registered textbook purchasers online via MyPower Study.
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4th Class Edition 3.5 • Part A

UNIT A-5

Introduction to Plant Operations and the Environment

Unit Introduction

What makes up the environment? News reports often highlight environmental issues surrounding climate change, carbon emissions, petroleum spills, and acid rain. But what actually is "the environment?"

Simply put, the environment is everything that surrounds us. It is not just a collection of individual, unrelated objects or processes. The interactions that occur are equally important.

The Earth's environment is made up of objects that interact and change through water, air, carbon, and soil cycles. This unit will examine these cycles, their interactions and interdependencies, and the need for ecological balance to preserve the Earth's environment.

The actions of the Power Engineer can influence the generation of emissions and pollution caused by facility operation. The activity or inactivity of Power Engineers can impact the environment. This unit will look at how to reduce or eliminate human impact on the environment. Topics include:

- Solid liquid and gaseous emissions
- Water consumption
- Thermal pollution

This unit will also examine specific effects human emissions have on the eco-system. Topics include how greenhouse gases affect global temperatures, and how noise affects the environment.

Perhaps the most important concept in this unit is "attitude": both individual and collective. The best way to perform a job is not necessarily the "way things have always been done." The proper attitude towards plant operation and the environment is one of continuous examination and improvement.

These and other related topics are covered in the following chapters.

Unit Rationale

Historically, the main concerns of Power Engineers have been twofold:

1. Operate equipment so personnel, equipment, and facilities are protected.
2. Operate equipment efficiently, to minimize production costs.

However, there is increasing awareness of how vulnerable the environment is, and how human activity can damage it. Because of this, there is now a greater push for environmental controls and protection. This has added a third priority:

3. **Operate equipment in such a way as to protect the environment.**

It is no longer acceptable to dump polluted liquids into waterways, or allow gaseous pollutants to escape to the atmosphere. These old procedures are no longer allowed, nor should they be.

Energy plants have the ability to produce solid, liquid, noise, and thermal pollution. Power Engineers have the ability to mitigate these problems through conscientious energy plant operation.

It is essential for Power Engineers to know the types of wastes and pollutants that cause environmental impacts, where the pollutants originate from, and how to minimize or eliminate their production.

Related procedures and regulations affect how Power Engineers operate their plants. These procedures and regulations vary from plant to plant, and between jurisdictions. Power Engineers need to be aware of the procedures and regulations that apply to their plants.

Chapter 1

Introduction to the Environment

Learning Outcome

When you complete this chapter you should be able to:

Identify environmental considerations and how they relate to an operating plant.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Describe four important Biogeochemical Cycles that operate within the environment.*
2. *Describe typical interdependencies seen among elements within an "ecosystem."*
3. *List the types of impacts that operating facilities can have on the environment.*
4. *Describe the alert processes related to environmental problems of plants.*
5. *Explain the importance of "attitude" in limiting environmental impacts of plants.*
6. *Describe the long-term environmental impacts after the decommissioning and abandonment of plants.*

Chapter Introduction

The environment is made up of everything that is living and non-living. Atoms and molecules are the fundamental units of matter. Matter cannot be destroyed. However, when these units are rearranged, energy is consumed or released. When combined, atoms and molecules create compounds and mixtures that everyone recognizes. Various collections of substances may provide resources such as food, air to breathe, water to drink, or shelter. These resources are maintained in a complex web of relationships that connects everyone to the environment they live in.

As people consume or interact with the resources in the environment, the makeup of those resources will change. Usually, chemical processes of human origin alter the chemical makeup of natural resources to create a desirable energy release. The end products of human consumption may be utilized elsewhere in the environment and may be converted again in further reactions, possibly through an addition of energy (such as sunlight).

These additional chemical processes may recreate the original substances, thus renewing the process. These cycles rely on complex relationships between biological, geological, and chemical components of the environment. The cycles of interaction are often called Biogeochemical Cycles.

All human activity has either a positive or negative impact on the environment. Some examples of activities with a positive environmental impact are wetland preservation, water purification, and reforestation. An activity with a negative impact would be chemical spills that pollute bodies of water and kill aquatic life.

Ecosystems, by definition, are self-balancing. Human activities can interfere with this balance. An imbalance can cause lasting, significant effects on the ecosystem, both positive and negative. These effects can be seen either immediately or over a long period of time. The way Power Engineers manage facilities can have lasting positive or negative effects on the ecosystems, within both local and regional environments. As a profession, Power Engineers may collectively influence the global environment.

This chapter will look at how the operation, decommissioning, and abandonment of plants can impact the environment both short term and long term. It will discuss how the Power Engineer's attitude can create positive or negative environmental impacts. It will also look at what can be done by Power Engineers to reduce or prevent negative effects through their attitudes and actions.

Objective 1

Describe four important Biogeochemical Cycles that operate within the environment.

Biogeochemical Cycles

Biogeochemical Cycles describe the movement of materials and substances through the environment. In these cycles, substances move through both living (biotic) and non-living (abiotic) segments of the environment. Through this movement, the atoms and molecules that make up these substances often change due chemical or physical reactions, which either release or consume energy.

"**Biogeochemical**" combines the terms "biological," "geological," and "chemical", in recognition that the cycling of matter essential to life involves all three segments. Critical elements are recycled continuously, including:

- Oxygen
- Carbon
- Nitrogen
- Phosphorus
- Calcium
- Water

For example, water is continuously recycled through the water cycle. It evaporates (changes from liquid to vapour), condenses (changes from a vapour to a liquid), and precipitates (falls back to Earth). Elements and compounds are passed continuously between organisms, both directly and through abiotic processes, in ongoing biogeochemical cycles.

Biogeochemical processes always try to achieve equilibrium within the movement of matter. However, in some cycles there are stages (called *reservoirs* or *sinks*), where matter accumulates for a long period of time. These sinks include the atmosphere (which holds oxygen), oceans and lakes (which hold water), and sedimentary rock (which holds carbon). A closer look at the Oxygen, Water, Carbon, and Soil Cycles will show their close interrelationships.

Oxygen Cycle

Oxygen is a major element on the Earth. Most of it is contained within the Earth's silicate and oxide mineral deposits. As free atmospheric oxygen, it is critical in the support of terrestrial animal life. As dissolved oxygen, it supports aquatic animal life. Much of the atmospheric oxygen reservoir was originally created by the formation of the earth's continents, several billion years ago. The Oxygen Cycle is responsible for maintaining this oxygen.

Oxygen is a basic element of all life on this planet. Some organisms (animals) take in oxygen gas (O_2) from the air and water and release carbon dioxide (CO_2) in a process called respiration. Other organisms (green plants) consume CO_2 and release O_2 and water to the atmosphere as a function of photosynthesis. Ultimately, oxygen needs to cycle through the air if it is to be made available for those that require it.

The atmosphere also contains other gases. Table 1 shows an average composition of the air in percent volume.

Table 1 – Composition of Air

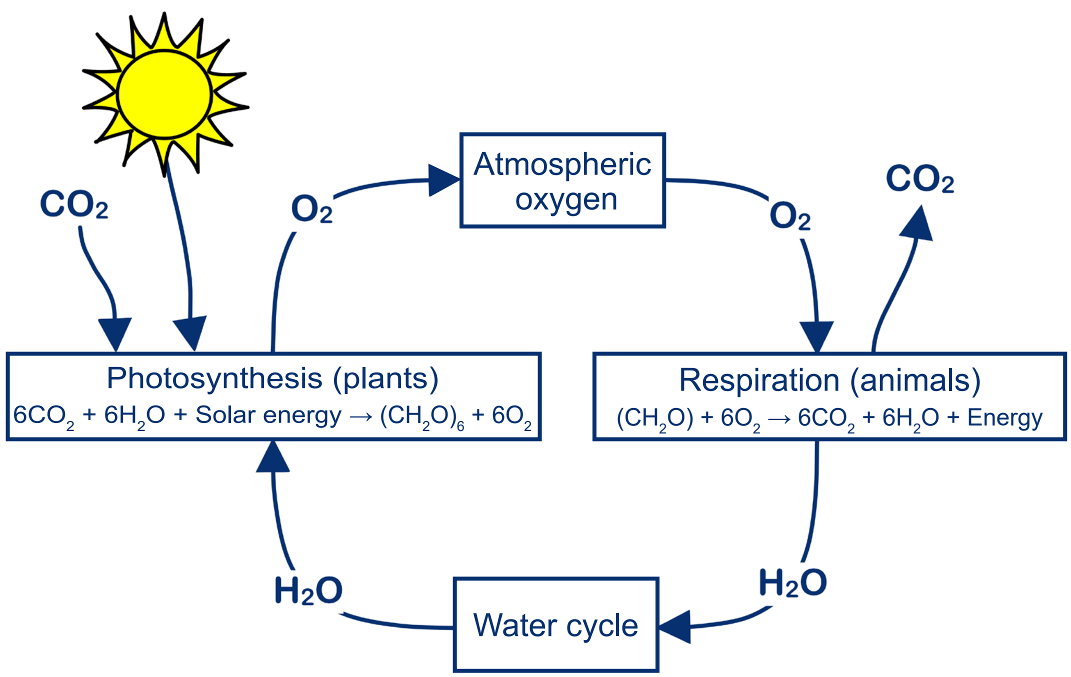
Gas	% Volume
Nitrogen (N_2)	78
Oxygen (O_2)	21
Argon (Ar)	0.9
Carbon dioxide (CO_2)	0.03
Traces of other gases	0.07

The composition of air is normally stable and is maintained through cycles of use and regeneration. Atmospheric O_2 is produced by photosynthesis. In this process, green plants use carbon dioxide, water, and solar energy to produce their own food and increase their mass (biomass). In doing so, green plants exhale oxygen. Photosynthesis is therefore very important for the lives of all organisms.

Animals use the oxygen byproduct from photosynthesis to convert biomass to energy. Because of animal respiratory processes, CO_2 and H_2O are released.

In Figure 1, the chemical formula for a simple sugar $(CH_2O)_6$ is used as a general form for biomass. Two simple chemical reactions illustrate the oxygen cycle.

Figure 1 – Oxygen Cycle



WATER CYCLE

Water is one of the most important natural resources on the planet. At least half the body weight of all living plants and animals is composed of water. About 70% of human body weight is water. Water covers around 71% of the earth's surface. The sun's energy moves the earth's water through its cycle, called the water or hydrologic cycle.

The important components of the water cycle include:

a) Storage Reservoirs:
   - Oceans
   - Ice and Snow
   - Lakes and Rivers
   - Groundwater
   - Atmosphere

b) Physical Reactions of Water
   - Evaporation
   - Condensation
   - Sublimation

c) Biological Functions
   - Respiration
   - Transpiration

d) Soil Filtration

Birds and land animals release water through respiration. Plants release water through "transpiration." Both of these processes release moisture into the atmosphere. As well, solar energy heats rivers and oceans, which causes evaporation. All water released to the atmosphere eventually condenses and forms clouds. When the condensed moisture collects to form larger particles, the moisture falls as precipitation (rain, snow, or hail). The moisture then flows back to the rivers and oceans, from surface water runoff and ground infiltration.

Much of the fresh water that is consumed comes from vital groundwater sources. Groundwater has a role in the formation of landscapes and in the migration and accumulation of minerals. The origin of groundwater and surface water is precipitation. From the land surface, water filters through a porous or aerated upper zone to the zones below.

In the upper zone, water shares the spaces between soil particles with air and provides moisture for plant life. Only a small portion filters down to the water-saturated zone bounded by the water table.

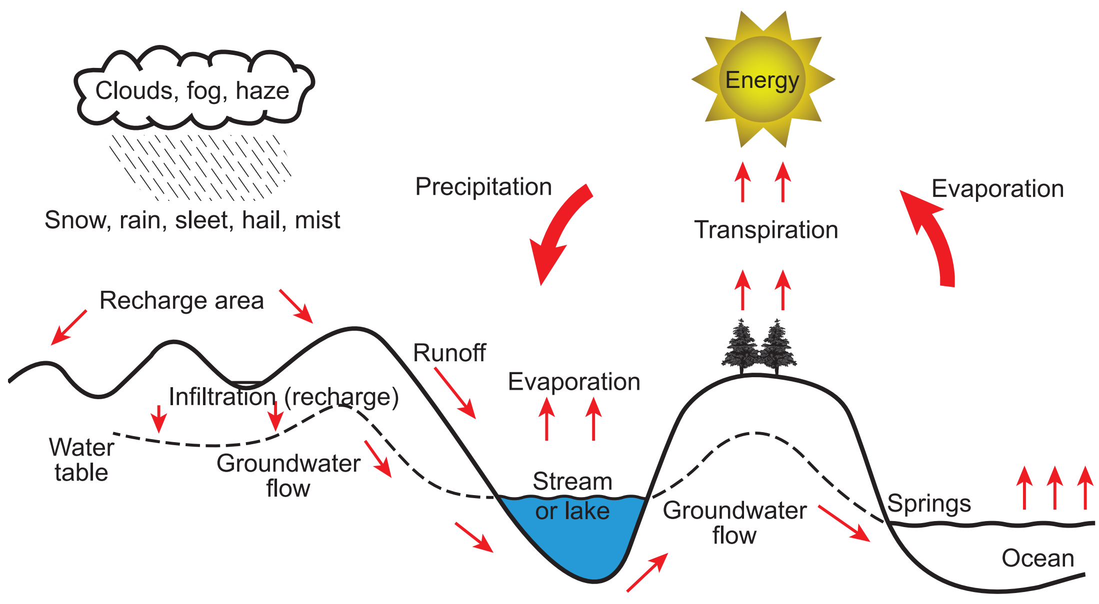
The direction of flow is generally from higher ground to lower lying areas, such as river or lakes. However, the direction of flow is sometimes more complex, depending on the water table configuration and geology.

Figure 2 shows an example of the direction of groundwater flow. At some locations, called discharge points, the water leaves the groundwater system to become surface water. Common discharge points are:

- Rivers
- Lakes
- Springs
- Sloughs

Sometimes rivers, lakes, springs, and sloughs feed into the groundwater system, and serve to recharge the groundwater.

Figure 2 – Water Cycle



The process of repeated evaporation, condensation, and soil filtration purifies the water. Evaporation is a distillation process: only the water evaporates, not what is dissolved in it. Soil filtration removes suspended matter from the water.

The water cycle also introduces impurities to water. When water vapour condenses, it dissolves gases (oxygen, carbon dioxide, and oxides of sulfur and nitrogen) from the atmosphere. Water also dissolves solids (various salts and silica) from contact with solid materials found in the earth's soil.

Carbon Cycle

Carbon is an important element in all living organisms and the entire biosphere. Carbon is also important in the creation of many non-living materials. The carbon Cycle describes the movement of carbon, in its many forms, between the three reservoirs that house it: rocks, oceans, and atmosphere.

Carbon dioxide and methane are the two main sources of carbon in the atmosphere. Carbon is removed from the atmosphere via photosynthesis. Also, CO_2 dissolves in atmospheric moisture. In this way, carbon returns to the land or bodies of water through precipitation. Carbon is found is all organisms, living or dead. Carbon is also stored in the soil.

When plants are consumed, carbon transfers from the plants to their consumers. When animals consume plants, the carbon is used for tissue growth, but some is released as carbon dioxide and methane. Carbon is returned to the atmosphere by processes such as respiration, the decay of dead organisms, and combustion.

Most of Earth's carbon is stored in rocks. The rest is in the ocean, atmosphere, plants, animals, and soil. As described below, carbon cycles through these reservoirs in different ways.

Carbon Rock Cycle

Most of the carbon on Earth is stored in sedimentary rocks within the planet's crust. These rocks are produced in two ways.

1. By the hardening of mud (containing organic matter) into shale.
2. By the collection of calcium carbonate particles from the shells and skeletons of marine organisms into limestone and other carbon-containing sedimentary rocks.

These slow processes occurs over tens of thousands of years, converting carbon from the atmosphere into carbonates and other sedimentary rock. Then, these materials continue to be moved and transformed by geologic processes. This can eventually result in the emission of gaseous carbon back to the atmosphere through volcanic eruptions, thereby completing the cycle.

Atmospheric Carbon Cycle

Carbon in the atmosphere exists almost exclusively as CO_2 with small amounts of methane (CH_4) carbon monoxide (CO) and chlorofluorocarbons (CFCs). All of these gases trap heat near the earth's surface. They can be described as "greenhouse gases." Changes in their atmospheric concentration have been implicated in "global warming."

Photosynthesis and respiration are the primary processes of rapid atmospheric CO_2 cycling. These processes, tied directly to the Oxygen Cycle, tend to balance out in nature, and create a stable concentration of CO_2 in the atmosphere. Volcanic activity, extreme weather events such as extensive droughts or floods, and changes in the icecap can produce dramatic changes in atmospheric CO_2 concentration, disrupting the equilibrium. The atmospheric CO_2 concentration is also affected by human activity:

a) Combustion of hydrocarbon fuels for power generation, heat, and transportation releases CO_2.

b) Large scale livestock production releases CH_4.

c) Deforestation releases CO_2 and reduces CO_2 absorption.

Oceanic Carbon Cycle

The oceans absorb and store much more carbon than the atmosphere. This stored carbon is made up of dissolved CO_2, carbonate ions (CO_3^{2-}) and bicarbonate ions (HCO_3^-). Near the surface, much of the CO_2 is consumed by photosynthesis (green algae), and eventually returns to the atmosphere through respiration and organic decay.

A small portion of the carbon is retained in the shells of shellfish and coral, which convert the carbon into calcium carbonate (the main component of their shells). These shells sink to the ocean floor and add to the ocean's carbon inventory. The carbonate and bicarbonate ions may react with natural calcium ions to produce insoluble calcium carbonate (a major component of feedwater system scale), which also adds to the ocean's carbon inventory.

Terrestrial Organism Carbon Cycle

Terrestrial organisms (land dwellers) such as plants, animals, bacteria, and fungi are carbon based organisms. Carbon is a fundamental component of their composition. Unlike rocks and oceans, this carbon exists in organic forms. In this context, the term "organic" refers to compounds produced by living things, including:

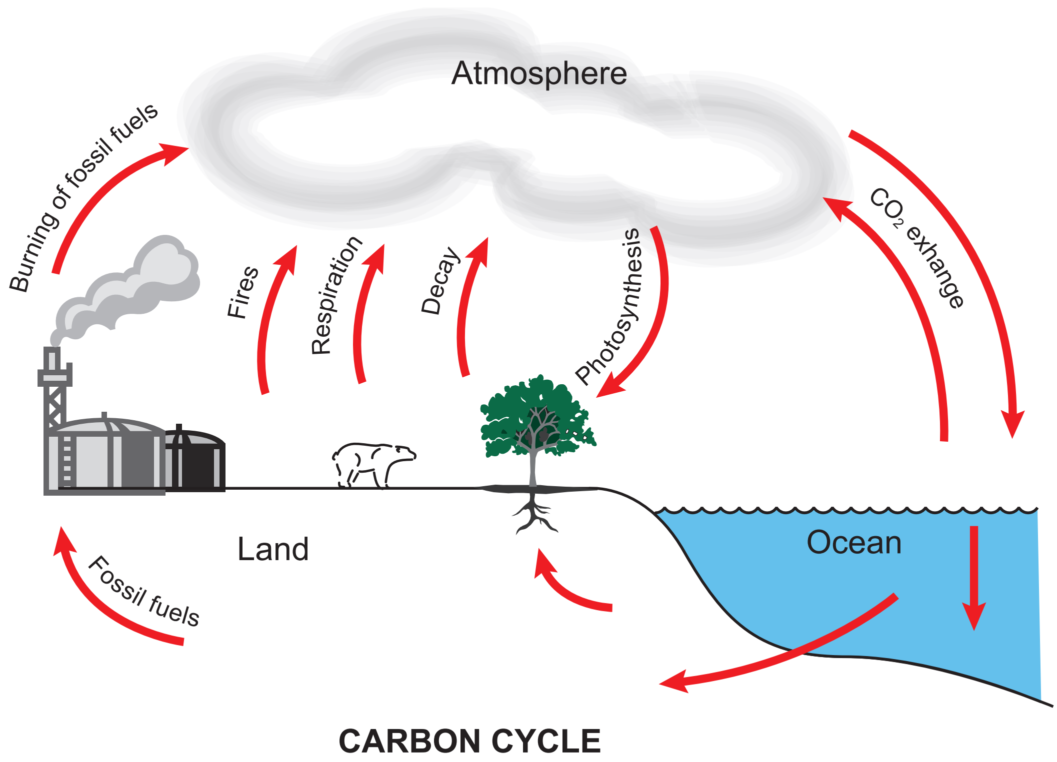
- Leaves
- Wood
- Roots
- Dead plant material
- The brown organic matter in soils (which is the decomposed remains of formerly living tissues)

Plants consume carbon from the atmosphere relatively quickly through photosynthesis, and convert carbon to tissue. Plants are the baseline food source for all other organisms. The carbon in their tissue eventually converts back to atmospheric CO_2.

If not consumed by other organisms, plant tissue may become trapped in sedimentary rock, where it eventually creates concentrations of carbon, which are the main source of hydrocarbon fuels. The release of CO_2 from the combustion of these fuels increases atmospheric CO_2, although the overall effect is unclear because of oceanic CO_2 absorption.

Figure 3 illustrates some of the more important processes within the Carbon Cycle.

Figure 3 – Carbon Cycle



Soil Cycle

Soil is a naturally occurring loose mineral or organic material at the earth's surface, which is capable of supporting plant growth. It is essential in the production of food.

The process of soil formation begins with a parent material. This may be a mineral or organic matter deposited on the landscape in a variety of ways. Mineral matter is often deposited by wind, water, or glacial activity. Organic matter is deposited primarily by vegetation. Soil development and composition depends on the:

a) Type of parent material
b) Topography of the area
c) Climate
d) Types of organisms present above and below the surface

The Soil Cycle is somewhat like a bank account. Plants and animals deposit nutrients and organic matter in the form of their dead tissues and wastes. Organisms within the soil break down and redistribute these deposits. Withdrawals are made as plants use soil nutrients for growth. Microscopic organisms in the soil (microbes) may withdraw nutrients from the soil as well. When plants and microbes die and decompose, deposits are made once again.

The process of soil development in most of the northern part of North America began on parent material deposited by glaciers that retreated about 10 000 years ago. Soils in other parts of the world are much older.

Like other cycles, the soil cycle:

a) Tries to establish a balance between materials that are added and withdrawn.
b) Is affected by both natural and human activity.

Objective 2

Describe typical interdependencies seen among elements within an "ecosystem."

Ecology

Many areas of study contribute to the understanding of the environment. Ecology is the study of plants and animals in relation to their environment. Ecosystems are complex systems that involve individual organisms, their physical surroundings, and interactions between the organisms and their surroundings.

Figure 4 shows a schematic diagram of an ecosystem. The dashed line represents the boundary of the system. The solid arrows indicate interactions within the system.

A viable and sustainable ecosystem depends on energy and chemical cycles. These two interdependent cycles are key components of an ecosystem.

The external environment provides inputs of:

- CO_2
- H_2O
- O_2
- Nutrients
- Radiant energy

The ecosystem puts the following back into the external environment:

- CO_2
- O_2
- H_2O
- Some nutrients
- Heat of respiration

Chemicals, such as nitrogen, carbon, and oxygen are continuously cycled between plants, animals, and the local environment (habitat). The sun's energy is the driving force of the ecosystem.

The major components in the system are:

- Producers
- Consumers
- Inactive Organic Matter

Producers

Producers are green plants. They collect energy from the sun and, through photosynthesis, create sugar from CO_2, and release O_2.

Consumers

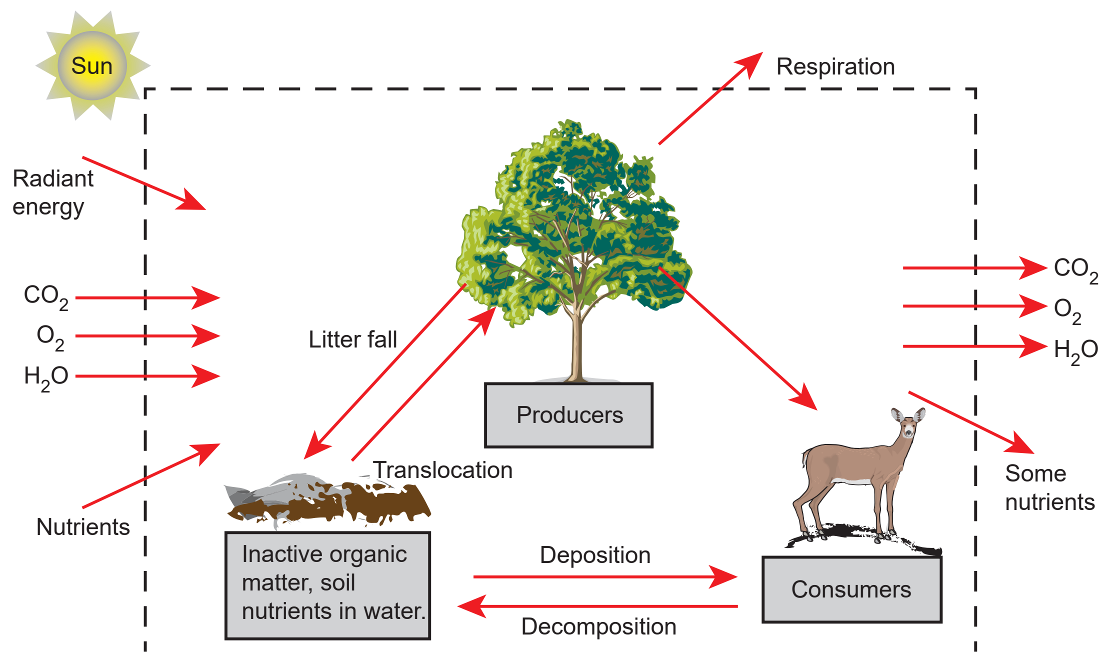
Consumers are organisms that feed on plants or animals to gain energy. They can be any one of the following:

- **Herbivores**, that feed exclusively on plants.
- **Carnivores**, that feed exclusively on herbivores.
- **Omnivores**, that feed on both plants and animals.
- **Decomposers**, such as microbes and fungi. Decomposers break down the complex compounds of dead plants and animals into more simple molecules that they can absorb.

Inactive Organic Matter

Inactive organic matter includes the soil, nutrients in water, and sediments. These are the physical surroundings that support the biological interactions of the producers and consumers in an ecosystem.

Figure 4 – Interactions within an Ecosystem



Food Webs

Producers and consumers interact in a complex web of relationships called a food web. The direct transfer of food from organism to organism is called a food chain. The long food chain of nutrients and energy passes from one organism to another.

The energy in a food web starts with the sun's energy. The sun continuously replenishes the food web's energy. However, a great deal of the energy that supports consumers and producers does not directly support their survival. Much of the energy is dissipated as heat.

Unlike energy, matter follows a sort of cyclic process. Matter is conserved in an ecosystem, and is constantly cycled throughout the ecosystem. Matter is taken in by producers from their physical surroundings. The matter is passed along to other organisms. When organisms – plants and animals – die, the decomposers break down the matter into its basic elements. This returns them to the physical surroundings to be used again. In the final stage, decomposers return only matter, not energy, back to the physical surroundings.

There are many interdependencies in ecosystems. **Symbiosis** refers to the interaction of two species that live together in close contact. Sometimes this interaction is a mutual benefit (**Mutualism**). Sometimes one organism benefits at the expense of the other (**Parasitism**).

All of the components of an ecosystem are connected. It is impossible to alter one component without affecting another. When outside events do not consider these relationships, an ecosystem can become unbalanced. This will cause changes in the environment which may become permanent. The release of components into an ecosystem that are not natural or are unnaturally concentrated can have major local or widespread impact on organisms.

Sometimes environmental effects do not occur immediately. It is also difficult to know what these final effects will be. Too often, air and water resources are presumed to belong to everyone, but no one takes responsibility for their conservation. These resources are often taken advantage of and undervalued. However, a more comprehensive approach to development and conservation is emerging.

All ecosystems are essential. Wise decision-making and long term planning are necessary for them to be maintained.

Objective 3

List the types of impacts that operating facilities can have on the environment.

Planning And Designing Facilities

Before an energy plant can be built, applications must be submitted to the provincial or territorial authorities to have the project design approved. Design requirements may vary but, in general, the following sections must be included.

Applicant Identification: the owner of the facility and along with their contact information.

Plant or Facility Identification: where the facility is located and what it will be doing.

Project Background:

a) **Regulatory**: Other requirements and relationships that must be considered. These include:

   i. The **National Resources Conservation Board (NRCB)**

   ii. The **Canadian Environmental Assessment Agency (CEAA)**

   iii. Provincial, Regional Authority or Municipal Jurisdictions

b) **Financial:** to identify the financial risks and benefits.

c) **Proposed Project Timelines and Public Consultation:** what the project plan is and who knows about it.

Current Setting for the Proposed Project and its Environmental Condition:

a) What effects the physical surroundings will have on the project.

b) What the environmental risks are and the objectives that must be achieved.

c) The pre-existing environmental conditions that need to be considered.

Energy Plant Design:

a) The environmental risks and risk factors.

b) How risks will be mitigated. Especially:

- Storage of potentially environmentally sensitive materials
- Wastewater treatment
- Emissions management

Some applications need to be modified to meet the regulatory requirements. Others may not be approved due to the:

a) Impact on the environment

b) Cumulative effects of the proposed facility and others already operating in the area.

Regardless of the design, an energy plant may impact the environment in a number of ways. The impacts can be planned and unplanned.

Planned and Approved Effects:

a) Normal stack emissions
b) Planned vapour and airborne particulate releases
c) Solid waste release and disposal processes
d) Noise generation
e) Odour Release
f) Surface disturbance during construction and subsequent mitigation after plant retirement

Unplanned Effects:

a) Non-optimal releases due to plant efficiencies
b) Increased stack emissions during process upsets
c) Hazardous or contaminated liquid releases
d) Airborne particulate matter not captured

These conditions can have both immediate and long-term effects on the environment around the plant and collectively over a broader area. Energy plant operators have the greatest influence on mitigating unplanned releases through the efficient and safe operation of the plant.

Stack Emissions

The Canadian government, and each jurisdiction, have specific regulations that limit stack emissions, such as:

a) Particulate Materials
b) Carbon Containing Compounds such as CO and CO_2
c) Nitrogen oxides (NO_x)
d) Sulfur oxides (SO_x)

Different fuels have distinct firing methods, and produce different emissions. For example, waste fuels such as coke from processing bitumen, waste organics from landfills, and black liquor from pulp mills all produce different emissions in both composition and concentration. Some fuels such as natural gas have low sulfur, so they produce lower sulfur emissions.

Fuels that burn very hot, such as pulverized coal, will produce higher nitrogen oxide emissions. Under certain conditions, this NO_x produces ground-level ozone, visible as a brown haze in the atmosphere.

Poorly optimized firing equipment produces excessive CO emissions, due to incomplete combustion. This lowers plant efficiencies. When combined with rain, CO and NO_x can form acids that harm the soil and waters upon which they fall. The release of the CO_2 alone in stack emissions minimizes the oxygen requirement for the combustion process. It also identifies the maximum efficiency that the energy plant thermal processes can provide in converting hydrocarbon fuels into heat.

Vapour/Water Emissions

Industrial water use has come under public scrutiny across Canada. Water is needed for drinking, irrigation, recreation, and ecologic preservation. Industry also has need of water. Industry may use water for cooling, processing feedstock, or steam generation. However, industrial water use is not permitted to reduce fresh water supplies or contaminate water resources.

The need for fresh, uncontaminated water has driven industry to find new ways to:

a) Reduce the need to use fresh water in the plant.

b) Reduce the amount process-water disposal.

c) Prevent source water contamination.

Provincial regulations on water consumption and disposal include different limits for different water streams. For example, since 2012, Alberta's **Steam-Assisted Gravity Drainage (SAGD)** plants in the oil sands have only been allowed to get 5% of their water from fresh water sources. This means SAGD plants must recycle and reuse 95% of their water. Before 2012, these facilities only had to reuse 10% of their water. For these same SAGD facilities in Alberta, the following disposal rules apply:

a) 3% of fresh water may be disposed of as a normal loss from within the process.

b) 10% of produced water (water recovered from the process of bitumen extraction) may be disposed.

c) 35% of brackish water (unpotable well water with high salt concentration) may be disposed.

This demonstrates how regulations change, and drive improvements in technology. Some SAGD facilities are working toward zero-discharge emissions for water, including water vapour and blow-down water.

Hazardous or Contaminated Liquid Waste

Power plant operation requires the use of chemicals for numerous reasons. These include:

a) Prevention of corrosion in boilers and heat exchangers.

b) Prevention of scale deposition in boilers and cooling towers.

c) Prevention of bacterial and algae growth in cooling towers.

As well, power plants produce liquid waste, such as:

a) Human waste.

b) Blowoff from cooling towers and boilers.

c) Waste from ion-exchanger regeneration.

d) Lime softener sludge.

e) Used lubricants and heat exchange fluids.

Chemicals and waste products may be stored in bulk on site. Even though they are in storage, these liquids can still be spilled or released.

Spilled liquids can travel great distances and are difficult to control. They can soak into and contaminate both the ground and the groundwater. Spilled liquids can travel over land and contaminate bodies of water. Under some conditions, they can also evaporate into the air.

Plans must be in place to prevent spills from occurring. If there is a spill or release, a plan must be in place to respond to the situation as soon as possible, to reduce the amount of damage to the environment.

Sometimes, engineers design ways to contain liquid spills if a container fails. For example, concrete containment berms are installed around above-ground fuel storage vessels. Containment volume requirements vary, but typically must exceed the storage vessel volume by at least 10%. Engineers can also specify equipment to reduce the likelihood of container failure, like **cathodic corrosion prevention systems**.

All waste from a facility must be disposed according to the jurisdictional regulatory requirements. Under most environmental laws, the person who is in charge of the material at the time of a spill is responsible for reporting the spill to the local jurisdictions.

Liquid waste or other chemicals must never be poured or released to a sanitary or storm sewer system.

Airborne Particulate Matter

Facilities that burn solid fuel will also produce **particulate matter** that can escape with flue gas. Particulate release is a problem because it can have adverse health effects on both people and animals. The small size of some particulates makes them easily inhaled causing asthma, lung cancer, and respiratory diseases. Each Canadian jurisdiction has an established amount of discharge that is allowed based on particulate size. This information will be stipulated in each energy plant's permit to operate.

Facilities should monitor their stacks for particulate matter emissions. As well, plants may monitor the local area to determine the particulate dispersal patterns. These measures are necessary to ensure plants meet their operating permit requirements.

Often, the jurisdictional authorities will conduct checks to ensure the reports from the facilities are accurate.

Solid Waste

Solid waste is generated from a number of industrial processes. These can include liquid wastes that have evaporated into dry materials, and dry ash from solid-fuel firing. It must be disposed of regardless of its source.

All jurisdictions have regulations that govern the:

a) Quantities of hazardous materials that can be stored.

b) Type of materials that can be stored.

c) Method of storage.

d) Length of time materials can be stored until they are disposed.

There are specific disposal requirements and transportation requirements for solid waste. Each plant is responsible for the waste it generates and its proper disposal.

The way companies and facilities manage hazardous solid waste can have long-term environmental impacts. The best way to manage hazardous waste is to avoid making waste in the first place. Reducing the production of hazardous waste is often more cost effective than treating or destroying it.

Hazardous material that cannot be eliminated must be securely contained and monitored to protect people and the environment. Long-term storage of hazardous material should be avoided where commercial treatment or disposal facilities exist. When an outside contractor is used for hazardous waste disposal, the following key points must be followed.

a) When hazardous waste is transported, it must conform to **Transportation of Dangerous Goods (TDG)** legislation.

b) Periodically assess the disposal company under contract to ensure they comply with all required legislation.

Hazardous materials that leak from storage facilities must be dealt with immediately.

Despite measures to prevent and contain leaks, some residual material may accumulate during the life of the facility. When a contaminated area is identified, the boundaries of the contaminated area must be defined. This will involve core sampling of the soil to determine the area and depth of the contaminated soil. Once these boundaries are established, the contaminated soil is removed, placed in sealed containers, and taken for disposal or destruction. The void made by removing contaminated material is then replaced by fresh fill.

Another area that may be cause for concern is the disposal of samples that are taken within a facility. If the samples contain hazardous material (for example, insulation that contains asbestos), they should be disposed of in a careful, responsible manner. This may involve collecting samples in appropriate containers and removing them to a disposal facility. The samples must never be poured or released to a sanitary or storm sewer system.

Noise

The federal government does not establish guidelines or regulations for noise levels. That is the responsibility of each province and territory. Some authorities will allow the municipality to set and enforce their own guidelines. However, every plant being proposed will have to identify and address noise level concerns.

The municipality is responsible for noise levels that impact the general public and the environment. Noise studies and statements must be submitted with applications for new facilities. The application has to address the noise concerns for its own proposal. It also has to address any cumulative noise problems that may arise due to multiple facilities being in one location.

Where there is an expectation of continuous noise generation, a noise impact statement is required. This statement must be submitted with the application for new permanent facilities, or for modifications to existing permanent facilities. The following are examples of facilities that require noise impact statements:

- Gas turbo-generators
- Compressor and pumping stations
- Gas processing plants
- Gas pipeline compressors

Odours

During the normal course of operation, plant upsets will occur. These upsets may release material into the atmosphere having a distinct odour.

For example, the smell of hydrogen sulfide or mercaptan is very noticeable. These products may or may not be harmful, depending on the concentration level. However, the presence of any of these products in the atmosphere can raise public concern.

Care must be taken in handling any material that may produce odours. For example, when injecting mercaptan into a load of propane, or offloading mercaptan, adequate measures need to be taken to minimize the chance of a release.

Canadian environmental law permits the public to complain about the operation of facilities. The majority of complaints are for odours. All complaints must be investigated. In some situations, the public can lay claims against the facility for damages. This may also be possible under the local jurisdictional legislation.

Surface Disturbance

All facilities disturb the ground surface with their physical footprint. This includes the facilities':

- Main and auxiliary buildings
- Work camps
- Roadways
- Trenches
- Ponds

There may be bridges to erect, pipelines to carry fuel, and railway lines for transportation of raw materials and product to and from the site.

The landscape may have been changed to ensure a level site for the facility. This could affect the precipitation run off. For oil and gas facilities, all run off must be collected and tested to determine whether it complies with safe release guidelines.

The pipelines for carrying natural gas, **diluent**, or diluted bitumen (**dilbit**) to and from facilities require forests to be clear-cut for line of sight to permit pipeline inspection, servicing and maintenance. Power transmission lines also require clear-cutting to allow service vehicle access. These de-forested "cut lines" provide easy hunting corridors for predators. Wildlife that enters cut-lines can be easily seen and hunted, thus reducing their population. Also, cut-lines divide continuous wildlife habitat into smaller areas. This reduces the amount of wildlife in that area and inhibits natural migration.

Roads and other activities also disturb the landscape. This may reduce the amount of water that can return to the **aquifer**. It will also affect:

- Vegetation
- Natural wetlands
- Large bodies of water used for cooling systems and water discharge

Objective 4

Describe the alert processes related to environmental problems of plants.

Alert Recognition

Different methods may be used to alert operators to the existence of a problem. For example, instrumentation can indicate:

- A change in level
- A change in flow
- A change in pressure
- Improper combustion

Other equipment may be used to monitor for conditions such as leaks, critical equipment integrity, or contaminated sewers. Early recognition of spills, leaks, or any unplanned condition can minimize their impact. This can be done through frequent, systematic, and comprehensive checks.

It is important for all employees to know the characteristics of the materials they work with in order to spot process upsets and releases, to protect themselves and the environment. Various sights, sounds, and smells become standard or normal as workers become familiar with their workplace. One way to detect possible trouble is to recognize conditions that are different from normal.

Operators should consider simple questions, such as:

- Does the operating area have an unusual sound?
- Should that vapour plume exist?
- What is the source of that unusual odour?

If any of these questions surface during the execution of duties, make sure the cause is followed to the source.

Some potential for release may not be obvious, especially to an inexperienced worker. For example, some facilities may have gaskets or valve packing with asbestos fibres. In a new, undamaged state, these materials are not hazardous; however, as they wear, some asbestos fibres may be exposed.

When removing this gasket or packing material, the worker must recognize the potential asbestos hazard, both for themselves and others. The material must be removed in a way that does not release fibres. Procedures for the removal and disposal of material that contains asbestos must be in place to ensure that asbestos fibres are not released into the atmosphere. As well, companies should have policies for using non-asbestos replacement materials.

It is important to be familiar with the facility that one operates and maintains. This makes it possible to identify design deficiencies. Seek alternate methods of doing the job to ensure minimal environmental impact.

Release Response: Reporting Requirements and Processes

It is of prime importance for facilities to eliminate (or at least minimize) the release of substances, especially when they are unplanned. To help deal with unplanned releases, facility owners must have approved Emergency Response Plans (ERP) in place. An ERP prepares a facility to respond to emergencies. It must meet the jurisdictional requirements for reporting, containment, cleanup, and disposal of environmentally harmful substances.

Uncontrolled releases require immediate action. They must be reported according to the jurisdictional requirements. This includes the toxic substances such as liquefied natural gas and gasoline, as listed in **Schedule 1** of the **Environmental Emergency Regulations** under the **Canadian Environment Protection Act** (available on the internet). Releases may be made to the air, water, or soil. A release can be defined as any of the following:

- Spills
- Discharges
- Leaks
- Venting
- Seepage
- Deposits

The person who causes, allows, or finds a release is responsible for putting the ERP into action. The immediate response is to stop any further release, if possible. Next, a report of the release must be made to the shift engineer, and action must be taken to stop and contain the release.

The person who releases, causes, or permits the release of an environmentally harmful substance is responsible for reporting. Reporting steps include:

a) Immediately call the 24-hour emergency phone line.

b) Written reports, which must be submitted as soon as possible or within 7 days, depending on the jurisdiction.

c) Notify members of the public who may be affected by the release. Facilities usually have strict guidelines about who may inform reporters or the public. Always follow company protocol.

Reports must include:

a) Date and time of the release

b) Description of the circumstances leading up to the release

c) Type and quantity of the substance released

d) Description of the responsive actions taken or proposed actions at the release site

e) Description of the release site and the immediate surrounding area

CAUTION

The above are only general guidelines. Please consult the facility Emergency Response Plan and jurisdictional requirements for specific response and reporting obligations.

OBJECTIVE 5

Explain the importance of "attitude" in limiting environmental impacts of plants.

ATTITUDE

The action taken by operating personnel is critical for minimizing the impact of an unplanned release or upset. An action may be as simple as the adjustment of airflow to ensure complete combustion. Other more complex situations may require the isolation of equipment and containment of a release.

For example, suppose a pump seal fails and releases liquid hydrocarbon. Prompt isolation of the pump will reduce the amount of material spilled. Containment to prevent the release from entering storm sewers or seeping into the ground will aid in minimizing the damage caused.

Perhaps the most beneficial and effective factor in the reduction of environmental impacts is the right attitude. Tasks should not be performed because ***"They were always done like that!"*** Power Engineers must always be conscious of the potential environmental impact of their actions. Questions, such as, ***"Is there a better way?"*** should be asked to raise awareness and potentially reduce negative environmental effects.

There are many ways for a Power Engineer to limit or eliminate releases, to reduce environmental damage. Below are some examples to take into consideration.

a) Consider a transmitter that requires regular blow down to clear its sensing lines. Does it need to be blown down to the ground, or can its output be routed to a collection system, such as a flare, a **closed hydrocarbon drain**, or simply a grounded metal pail?

b) Are there flange and valve packing leaks? Power Engineers can tighten joints to stop leaks, or ensure the leaks are reported to maintenance personnel for quick repair. Chronic leaks may need to be placed on a preventive maintenance schedule.

c) Care should be taken to minimize the release of harmful substances when isolating equipment for maintenance or preparing equipment for operation. Wherever possible, liquids should be retained in a closed system, and vapours should be purged to a container or flare.

d) Plans must be made to deal with residual substances, such as trapped liquids or sludge deposits. Procedures must be followed to contain and dispose these substances and to satisfy regulations that govern the use of personal protective equipment.

Power Engineers must respond to both unplanned events and routine situations. Before taking an action, consider other problems that may arise because of that action. Often, the most probable scenarios are already identified. Procedures (routine or emergency) should be available to address these scenarios. However, the employee should ask why each step of the procedure is being carried out, and what the impact on the environment is likely to be.

As facilities age, some original design aspects may no longer satisfy current environmental regulations. Changes may occur that require additional or replacement equipment. In some cases, existing equipment may need to be retrofitted. It is the responsibility of the owner and each worker to identify concerns and act on them promptly.

Each step of a change in design or operating procedure should be evaluated to assess the consequences of the change. Normally, a hazard analysis and risk assessment are included in the design stage to identify, minimize, and control any potential hazards. Prior to commissioning or operating a modified design, an additional hazard and operability study should be conducted to address the potential effects of the modifications.

The following three types of actions can be taken when a problem area is identified.

1. Permanent Action
2. Interim Action
3. Adaptive Action

Permanent Action

Permanent action is the most desirable since it deals with and eliminates the root cause of the problem. For example, a chemical tank may be purged through an atmospheric vent on a frequent basis. A permanent action would be to modify the vent piping so the vessel vents into a closed flare system.

Interim Action

An interim action allows an individual to live with the effects of a problem while making plans to address the cause. To ensure that this action is effective, it is critical to assign responsibility and establish a time frame for follow up.

Consider, for example, a section of pipeline that ruptures and spills emulsion. An interim action would be to repair the rupture. Responsibility would then be assigned to test and replace any suspect areas by a certain date, to prevent further leaks.

Adaptive Action

Adaptive actions allow the plant to operate with a problem condition indefinitely. For example, consider a remote transmitter that has been blown down to the ground twice a day since the facility started up. Because it is in a remote area, it is impractical to route the drains to a collection system. In this case, the frequency of blowdown can be addressed and the transmitter may only be blown down on an as-required basis. By recognizing and analyzing the operation, the blowdown frequency may be reduced. As well, it may be possible to blow the transmitter down into a grounded metal portable container. The contents can then be collected and properly disposed.

The ability to deal with abnormal conditions in a timely and efficient manner will significantly reduce adverse environmental impacts. Companies will generally have identified the most likely problems and have established emergency plans. It is important to question and develop contingency plans for those occasions when something could go wrong. This will assist in solving environmental problems.

The following are answers to ***"If something goes wrong, how will I handle it?"*** They will help to establish emergency procedures.

a) Know the properties and environmental potential of the released substances or upset conditions that are being dealt with.
b) Know where and how to isolate the substances and mitigate the upset.
c) Identify the actions required to contain a release, or eliminate the upset condition in a way that always protects personnel.
d) Identify other processes or problems for the environment that operational upsets may cause.
e) Inform others in the area of what is happening so they may either assist or keep clear.
f) Discuss the "what ifs" with others to gain their experiences in dealing with unusual occurrences.

CAUTION

The Power Engineer has to work with high pressures, high temperatures, large equipment, and moving parts. All of these can damage the plant, the operations, the environment, and personnel in the area.

The best way to be protected is to know how the equipment and systems are supposed to operate. Know what is "normal." Be proactive in recognizing changes in temperature, noise, vibration, and pressure. These are all signs that indicate problems. Being familiar with the equipment will ensure the Power Engineer knows what to do when these changes are observed.

Objective 6

Describe the long-term environmental impacts after the decommissioning and abandonment of plants.

Decommissioning and Abandonment

There are many historical examples of contaminated industrial sites. Minimizing the long term environmental effects of a large industrial facility is an on-going area of research. Plans to decommission a site and restore it to a prior condition are now part of the approval process for new projects.

When an existing facility is shut down and decommissioned, the site must be left in a condition suitable for alternate use. It must pose no future threat to public health or the environment, nor create any future liability for the company. In order for a new facility to be approved, an acceptable development and reclamation plan must be prepared prior to construction.

It is necessary to remove all contamination from the soil that results from on-site waste management, and the inevitable spills and leaks that occur in a facility. This process may involve the actual removal and cleansing of the soil, depending on the levels and types of contaminants that are present.

The highest practical reclamation standards must be established and met. The public must be provided with a full disclosure of all reports, and data generated during the reclamation project. Before a plant closure is announced, environmental impacts must be identified and appropriate remedial plans must be established.

The plans should address such details as:

- Closure
- Dismantling
- Site evaluation
- Reclamation procedures

The process of determining the history and location of potential sources of past contamination such as tank leaks, process spills, and landfills can begin even before shutdown. A history and records search, as well as, discussions with long-term employees will help with this process.

As areas are abandoned periodically over the life of the facility, the site and equipment should be dismantled and cleaned. While these steps are helpful in initiating the cleanup, the full scale of the project may expand as the shutdown progresses.

The cost of reclamation can be greatly influenced by the activities of the operations personnel. If people operate a facility in an environmentally responsible manner, there will be far less work to do in order to return the site to a condition suitable for alternate use.

In some jurisdictions, the owners of the facility must put up an insurance bond to cover the cost of remediation and reclamation in the event the owners cannot pay for it when the facility is shut down. The bond must be submitted with the application for development and operation of a facility. This ensures the land does not become "orphaned," and that it will be restored to its original or nearly original condition.

Long-Term Environmental Impact

The construction and operation of a facility can have a significant long-lasting impact on the environment. The water level in the aquifer will be affected when water is drawn for the cooling towers. The aquifer may not recharge for several years. Vegetation may take years to grow back. Animals that were displaced from their habitat may not return for many years. The landscape will never be able to return to its original contour, so water run-off could be affected, which can impact vegetation downstream.

The removal of the facility and all auxiliary equipment such as rail cars and tracks, transmission lines, fuel storage, and buildings takes time. The noise and dust generated will impact the air and vegetation as well as wildlife in the area.

If the ground is contaminated, there will need to be a plan to determine the extent of the contamination. Contaminated soil must be removed and disposed of as hazardous waste. Fresh dirt will need to be brought in and native vegetation must be planted. Care must be taken that a viable and stable ecosystem is the final result of any reclamation.

Chapter Summary

This chapter was an initial overview of how critical compounds move through the environment in Biogeochemical Cycles. It introduced the concepts of ecology and interdependence. It pointed out how the single actions of operating personnel can have complicated and long lasting effects on the environment.

This chapter identified the impact facilities have on the environment. It discussed how facility operation can affect the cycles of renewal that function within the ecosystem. Ultimately, energy plants disrupt the ecology of living organisms in the environment. The air, water, and soil around a plant can be impacted during any phase of the plant: construction, operation, and decommissioning.

Power Engineers are responsible for recognizing when systems are not functioning properly. They must take action to prevent system upsets and maintain efficient operation. This ensures that the approved development and operating plan can be maintained within regulated limits. If releases occur, Power Engineers must take steps to control and reduce the impact on themselves and the environment. By using their five senses, Power Engineers can recognize when systems are not operating properly.

Power Engineers should protect the environment in all they do. All damage must be cleaned up and the site must be returned to its natural state when decommissioned. All spills need to be reported and cleaned up immediately, to make it easier and less costly to decommission and reclaim. The right attitude will prevent long-term damage to the environment and increased costs later on.

Subsequent chapters will go into further detail on the effects facilities have on the environment, and how these effects can be minimized or eliminated.

CHAPTER 2

Gas and Noise Emissions

Learning Outcome

When you complete this chapter you should be able to:

Explain how gas and noise emissions affect plant operations.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Identify the sources and effects of common gases and vapours that have an adverse environmental impact.*
2. *Identify the common greenhouse and acid rain causing gases and describe their effects.*
3. *Describe the common methods for monitoring and reducing gaseous pollutants.*
4. *Describe the effects of noise pollution and methods of identifying, measuring, and controlling it.*

Chapter Introduction

The burning of fossil fuels generates a variety of gases. Some of these gases are removed by secondary processes. However, those that remain may leave the plant at concentration levels that are hazardous to human health and the environment. To protect the public and the environment, jurisdictions impose regulations to limit gaseous emissions. Consequently, technologies have been developed that monitor, document, control, and reduce gaseous emissions.

Gaseous emission levels are continuously reviewed and evaluated in light of current scientific research and emerging technologies. As a result, these emissions tend to become less and less acceptable, especially if there are detrimental effects on human health or the environment.

Noise emitted from a plant throughout its lifecycle (including construction, commissioning, operation, decommissioning and abandonment activities) can have harmful local effects on the people and wildlife in the surrounding area. These issues will also be discussed in the following chapter.

Objective 1

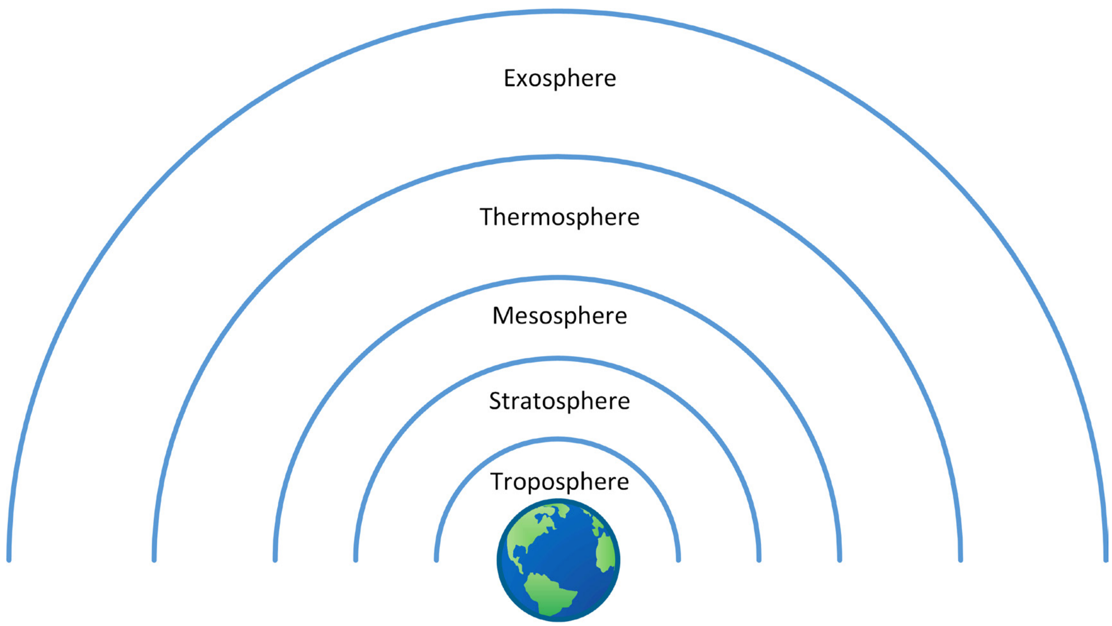
Identify the sources and effects of common gases and vapours that have an adverse environmental impact.

The Atmosphere

The Earth's atmosphere is divided into various layers. Each layer is comprised of various naturally occurring gases. Some gases, such as stratospheric ozone, protect the Earth. Others, such as CO_2 and O_2, directly support life.

The following diagram shows some of the layers of the atmosphere. Though the layers are bounded by transition zones, each layer is recognizable by its own unique characteristics. The transition zones have characteristics of the layers on both sides of the transition.

Figure 1 – Layers of the Atmosphere



The outermost layer is called the **exosphere**. It extends from about 500 to 10 000 km from Earth. The next closer layer is the **thermosphere**. This is the location of the Northern Lights. This layer absorbs much of the solar X-ray and UV radiation that the Earth receives. Temperatures in the upper thermosphere can range from about 500 to 2000°C or higher. This layer extends from about 85 to 690 km from the Earth's surface.

The **mesosphere** is found between the thermosphere and the **stratosphere** and is about 50 to 85 km from the Earth's surface. Meteors and other objects travelling through the mesosphere heat up by interacting with the thickening atmosphere. Some material from meteors lingers in the mesosphere, causing this layer to have a relatively high concentration of iron and other metal atoms. Temperatures in the mesosphere drop with increasing altitude from around 0°C to about –100°C at its upper limit.

The stratosphere is about 20 to 50 km above the surface of the Earth and is located between the **troposphere** and the mesosphere. The stratosphere is warmer at higher elevations than at lower elevations. Temperatures increase from about –60°C closer to the Earth to about 0°C at its outer region. This is due to absorption of **ultraviolet (UV) light** from the sun during the production of ozone. Ozone is created when ultraviolet rays react with oxygen molecules (O_2) to create ozone (O_3) and atomic oxygen (O). This process is called the **Chapman cycle**. Thus, harmful UV radiation is absorbed in the production of ozone.

The layer of the stratosphere where ozone accumulates is called the **ozone layer**. Recently, scientists have reported a noticeable depletion of ozone levels. This has been attributed to the action of chlorofluorocarbon based refrigerants (CFCs). Scientists claim that this depletion reduces the ozone layer's ability to protect the Earth from harmful UV radiation.

Ozone in the stratosphere is beneficial to the Earth. However, ozone that occurs at the lowest layer, the troposphere can trigger a variety of health problems, particularly for children, the elderly, and people with lung diseases such as asthma. This ground level ozone is not emitted directly into the air. Rather, it is created by chemical reactions between **nitrogen oxides** (**NO_X**) and **volatile organic compounds (VOC)** in the presence of sunlight. Industrial emissions, motor vehicle exhaust, gasoline vapors, and chemical solvents are some of the major sources of NO_X and VOC. Low level ozone is also made by lightning and electrical equipment.

The troposphere is found at the surface of the Earth. It reaches about 7 to 20 km in height. Its greatest thickness is near the equator and its least thickness is at the poles. Most atmospheric physical activity and almost all atmospheric water exists in the troposphere.

Gaseous Pollutants

Scientific research continues to raise awareness about the various gaseous pollutants that human activities emit, and concern about how these gases affect human health and the environment. Governments respond by enacting legislation and tightening emissions requirements. Researchers respond with technological advances in equipment and processes so that industry can comply with new regulations. Industry responds by using newer technology and processes to produce fewer or less harmful emissions.

Energy plants must comply with government regulations. Therefore, they must limit the amount and duration of gaseous emissions. One of the Power Engineer's most important responsibilities is to ensure compliance with regulatory requirements.

The gases and vapours that are responsible for environmental pollution are numerous. Below are some of the most common gaseous pollutants addressed by jurisdictional regulation.

- Carbon Monoxide
- Carbon Dioxide
- Sulfur Oxides
- Nitrogen Oxides
- Methane
- Ozone
- Chlorofluorocarbons
- Fluorinated Gases

Power Engineers must be aware of the effects of these pollutants, how to detect them and, most of all, how to control them.

This objective will describe the pollutants mentioned above. Control measures will be discussed later in this chapter.

Carbon Monoxide (CO)

Carbon monoxide is an extremely poisonous gas. It can be produced by any of the following:

a) When combustion occurs with insufficient air
b) Insufficient mixing of fuel with air
c) Insufficient time for combustion to be complete

One of the greatest producers of CO is the internal combustion engine, because it does not provide enough time for complete combustion in the engine cylinder. Forest fires, burning refuse, and poorly tuned boilers can also produce CO.

When fuel is burned, carbon reacts with oxygen. If there is enough oxygen, turbulence, and time for combustion, the carbon and the oxygen form carbon dioxide (CO_2). If these elements are insufficient, carbon combines with the oxygen to form carbon monoxide (CO).

Carbon monoxide is a serious pollutant because it is a deadly toxic gas. Its presence in stack emissions also represents an operating loss. The chemical energy in the fuel is not entirely converted to heat when the carbon element of fuel burns to carbon monoxide. This is because the oxidation process that releases heat is not completed.

In high concentrations, carbon monoxide is very explosive. If it accumulates in boiler fireside locations, where flue gas circulation is less vigorous, then a source of ignition will cause a furnace explosion.

Boiler-produced carbon monoxide is addressed by ensuring that:

1. There is adequate combustion air.
2. There is adequate turbulence.
3. The boiler fuel train is in a proper state of tune.

Burners and their control systems (fuel control valves, air registers, dampers, and oxygen trim systems) require regular "set-up" to ensure peak combustion efficiency throughout the entire boiler firing range.

To reduce the production of carbon monoxide, Power Engineers must be able to:

a) Operate burners cleanly and safely, with the combustion controls set to "manual." In this way, boiler emissions are minimized even during warm up, cutting-in, and cutting-out procedures.
b) Recognize when burners have insufficient oxygen (are burning "rich"), without relying on instruments.
c) Troubleshoot and take appropriate steps when burners are operating rich (such as reducing fuel flow, calibrating the O_2 analyzer, cleaning burner nozzles, etc.).
d) Recognize when a boiler is overloaded. When overloaded, there is insufficient time for combustion to occur in the furnace, and it is possible for fuel and air ratio to become rich.

Carbon Dioxide (CO_2)

Any time a hydrocarbon fuel is burned, CO_2 is produced. It is one of the most important gases on the planet because all plant life depends on it. Animal and plant life produce CO_2 naturally through respiration and decomposition in the presence of oxygen. Forest fires are also large natural contributors. CO_2 cannot be eliminated from the combustion process as long as the fuel contains carbon.

Carbon dioxide, unlike carbon monoxide, has not historically been classified as a gaseous pollutant. However, growing concern over the effects of increased levels of atmospheric CO_2 has prompted new interest in removing the gas from the smokestacks of large-scale sources. Jurisdictions across North America have been active in legislating limits on the production of CO_2 from industrial sources. CO_2 is now a commonly measured component of flue gases.

CO_2 is considered a **greenhouse gas (GHG)**. The carbon dioxide released into the atmosphere by human activity has been identified as contributing to climate change. Countries around the world who are major CO_2 emitters are recognizing more and more that regulatory steps must be taken to reduce and even eliminate CO_2 emissions.

Coal-burning central heating plants, industrial plants such as steel mills and electrical generating stations are large contributors of CO_2 emissions. Plants that burn fossil fuels other than coal also release CO_2, but at lower levels. The amount of CO_2 produced when a fuel is burned is a function of the carbon content of the fuel. The heat content, or the amount of energy produced when a fuel is burned, is mainly determined by the carbon and hydrogen content of the fuel. Heat is produced when carbon and hydrogen combine with oxygen during combustion to produce CO_2 and H_2O. Natural gas is primarily methane (CH_4), which has a higher energy content relative to other fuels, and thus, it has a relatively lower CO_2-to-energy content.

The relative amounts of CO_2 emitted per unit of energy released is shown in Table 1. Note that the basis of comparison is the amount of CO_2 produced by the combustion of natural gas.

Table 1 – Relative CO_2 Emissions of Various Hydrocarbon Fuels

Type of Fuel	Relative CO_2 Emission
Natural Gas	1.00
Anthracite Coal	1.95
Sub-Bituminous Coal	1.83
Diesel Fuel	1.38
Gasoline	1.35
Propane	1.19

The table data shows that for a given heat energy release, anthracite coal produces 1.95 times the amount of CO_2 as natural gas and 1.07 times the CO_2 as diesel fuel.

Sulfur Oxides (SO_X)

During the combustion of a fuel that contains sulfur (such as coal or fuel oil), the sulfur in the fuel is oxidized into sulfur dioxide (SO_2) and sulfur trioxide (SO_3) gases. Because sulfur can burn to either dioxide or trioxide, these compounds are collectively called **SO_X**, where the "X" can be a "2" or a "3."

Pulp mills, mining, and smelting operations can discharge great quantities of SO_X. Sulfur oxides also enter the atmosphere from natural sources, such as hot springs and volcanic eruption.

While not as toxic as carbon monoxide, these sulfur oxides contribute to acid rain, which is hazardous to all forms of life and corrosive to building structures. In the presence of moisture, they form a weak sulfurous or sulfuric acid which irritates skin, corrodes most metals, and disfigures the exterior appearance of most painted surfaces.

Acid rain is responsible for the acidification of lakes and destruction of forests. As part of industrial smog, acids cause itchy skin, watering eyes, coughing and fatigue. Although the main concern for SO_X in the air is the development of acid rain, it has also been identified as a greenhouse gas.

Allowable emission levels for SO_X vary from jurisdiction to jurisdiction.

Nitrogen Oxides (NO_X)

Fossil fuel combustion also produces nitrogen oxides. NO_X may be any one of, or a combination of, the following compounds:

- Nitrogen monoxide (NO)
- Nitrogen dioxide (NO_2)
- Nitrous oxide (N_2O)

In many cases, more than one of these gases is given off by a single source.

Nitrogen monoxide and nitrogen dioxide are the major NO_X gases formed during the combustion of fuels in boilers and internal combustion engines. The total NO_X formed during combustion increases with temperature and with excess O_2. Usually, more than 90% of the NO_X formed in the combustion zone is NO. Besides the combustion process, nitrous oxide (N_2O) also comes from the agricultural use of synthetic fertilizers.

NO_X compounds have many serious environmental effects. NO and NO_2 have been shown to react with sunlight in a complicated fashion to form a photochemical smog. In the presence of volatile organic compounds, they may form lethal, toxic cyanides. When NO_2 combines with water in the atmosphere, nitric acid (HNO_3) is formed, which accounts for roughly 30% of acid rain. NO is a powerful greenhouse gas.

The presence of NO_X compounds in industrial emissions is now closely regulated.

Methane (CH_4)

Methane (CH_4) is emitted by natural sources such as wetlands, as well as human activities such as leakage from natural gas and petroleum processing systems and the raising of livestock. Natural processes in the soil and chemical reactions in the atmosphere help remove CH_4 from the atmosphere.

CH_4 has 25 times the ability of CO_2 at trapping radiation. Therefore, CH_4 is a more significant greenhouse gas than CO_2, despite the fact that it has a shorter atmospheric lifetime.

Ozone (O_3)

Ozone (O_3) is a compound that contains three oxygen atoms. Ozone is formed in the stratosphere, in a region called the ozone layer, by the action of high intensity ultraviolet radiation on O_2. In this part of the atmosphere, ozone is produced by the catalytic decomposition of O_2 with shortwave UV light. Once produced, ozone can absorb longwave UV light and revert back to O_2. Thus, O_2 and O_3 maintain an equilibrium in the stratosphere.

Stratospheric ozone is critically important since it shields the Earth's surface from hazardous ultraviolet radiation. Only a small percentage of the resulting ozone works down to the lower atmosphere and ground level.

Ozone is also produced in the lower atmosphere by electrical arcs such as brushes in electric motors, arc welding, and lightning. The action of sunlight on a mixture of NO_X and volatile organic compounds (photochemical smog) also produces ozone in this zone.

Chlorofluorocarbons (CFCs)

Compounds which are composed of chlorine, fluorine, and carbon are called **chlorofluorocarbons**. They are man-made substances, commonly used as refrigerants, aerosol propellants, and solvents.

When released into the atmosphere, these gases diffuse to the stratosphere where they are broken down by strong ultraviolet light. This releases chlorine which reacts with and destroys the ozone by converting it back to O_2. The decomposition of the O_3 through the reaction with chlorine prevents the absorption of longwave UV light, which can therefore reach the Earth's surface. CFCs are therefore identified as **ozone depleting substances (ODS)**. They are also greenhouse gases.

Sources of CFCs in the atmosphere are:

a) Mechanical refrigerant leaks
b) Refrigeration system servicing
c) Disposal of equipment that contains refrigerant gas

Fluorinated Gases

Fluorinated gases are entirely man-made; there are no natural sources of these gases. They were developed to replace chlorofluorocarbon and **hydrochlorofluorocarbon (HCFCs)** refrigerants. They include **hydrofluorocarbons (HFCs)**, **perfluorocarbons (PFCs)**, and others. Of the greenhouse gases released by human activity, fluorinated gases are the longest lasting and most powerful.

Sources of fluorinated gases in the atmosphere are the same as those for CFC gases.

Other Commonly Monitored Pollutants

While the above pollutants are the most common, several other gaseous pollutants are also commonly monitored such as arsenic, chlorine, and mercury. Monitoring of these pollutants may be due to either regulatory or plant efficiency requirements.

Objective 2

Identify the common greenhouse and acid rain causing gases and describe their effects.

Greenhouse Effect

The Earth has existed for a considerable time in an equilibrium state, where the amount of energy received from the sun is balanced with an equal amount of energy radiated from the Earth back into space. X-rays and high energy ultraviolet light encounter upper atmospheric components such as oxygen and ozone. Here, they are absorbed or reflected back into space. Slightly lower energy radiation (such as visible light and infrared radiation) passes through the atmosphere to ground level. At ground level, it is largely absorbed and eventually radiated back towards space at an even lower energy level. In this way, energy equilibrium is maintained.

Greenhouse gases allow high energy radiation to pass through, but restrict the transmission of the lower energy radiation that would normally move towards space. Without greenhouse gases in the atmosphere, the Earth's average temperature would be about 40 degrees Celsius colder than it is today, and the planet could not support life. Therefore, greenhouse gases are not only beneficial but necessary for life on Earth.

A visual representation of the Greenhouse Effect is shown in Figure 2. The sunlight that initially gets through the atmosphere is mostly low energy (visible and infrared) with the UV mostly being trapped. Some energy, which would have radiated back out through the atmosphere, is trapped by greenhouse gases and converted to heat. This causes a temperature rise in the atmosphere and on the Earth's surface.

The stable concentration of greenhouse gases, under natural conditions, accounts for the stability of the Earth's overall average temperature over many centuries. However, atmospheric greenhouse gas concentrations have increased since the Industrial Revolution of the 1800s due to human activity. With an increase in greenhouse gas concentration, more outgoing radiation is trapped by the atmosphere. This causes an increase in the Earth's average temperatures.

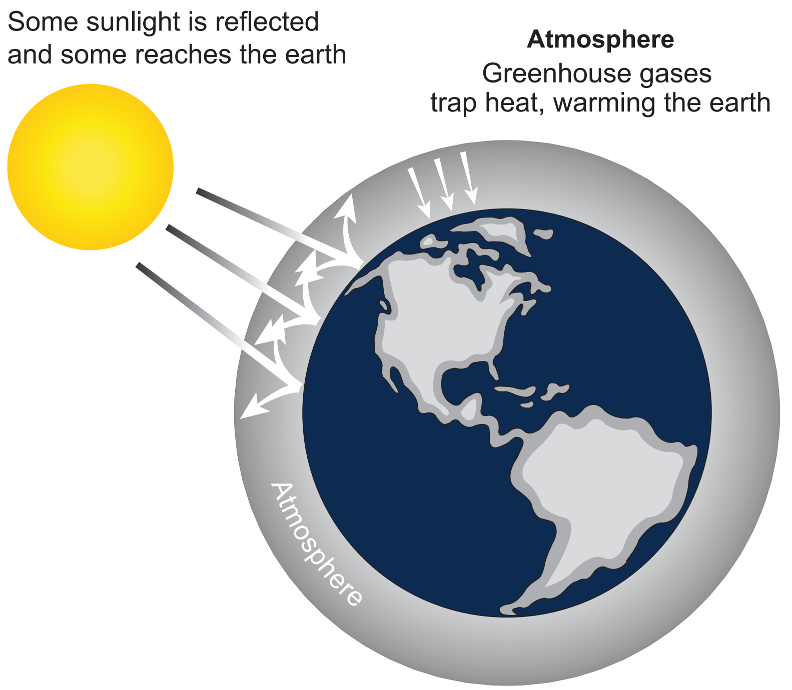
The most common greenhouse gases include:

- Carbon Dioxide
- Methane
- Nitrous Oxide
- Chlorofluorocarbons
- Fluorinated Gases
- Water Vapour
- Ozone

Carbon dioxide, methane, and water vapour exist naturally. They have always been atmospheric components necessary for human life.

Methane has always existed in the atmosphere from natural sources; however, industrial activity has greatly contributed to methane concentrations in the atmosphere. Nitrous oxide normally exists in small amounts in the atmosphere. Like methane, the greatest contributor to atmospheric nitrous oxide has been human activity. Chlorofluorocarbons and fluorinated gases exist entirely due to human activity.

Figure 2 – Greenhouse Effect



Effects of the Various Greenhouse Gases

Not all GHGs are created equal. Some have a higher potential to affect the Earth. In order to compare the effects of various GHGs, the **Global Warming Potential (GWP)** scale was created. Carbon Dioxide was made the standard against which all other greenhouse gases would be compared. As such, CO_2 has a GWP of 1.

Methane has a GWP of 25. This means that methane is 25 times as potent a greenhouse gas as carbon dioxide. Nitrous Oxide has a GWP of 298. CFCs and fluorinated gases are called high GWP gases, since their GWP is well into the thousands.

Table 2 lists some of the greenhouse gases recognized by Environment Canada, and compares their global warming potentials.

Table 2 – GWP of Various Greenhouse Gases

Greenhouse Gas	Formula	GWP
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298
Sulfur hexafluoride	SF_6	22 800
Nitrogen trifluoride	NF_3	17 200
HFC-134a	CH_2FCF_3	1 430
Perfluoromethane	CF_4	7 390
Perfluoroethane	C_2F_6	12 200

Carbon Dioxide (CO_2)

Carbon dioxide is an important greenhouse gas. It accounts for about 65% of global greenhouse gas emissions. CO_2 emissions and other GHGs are rising.

CO_2 does not remain in the atmosphere. About one-half of the CO_2 emitted is used by plants or absorbed by the oceans. The CO_2 absorbed by the oceans is eventually transferred by an extremely slow process to ocean sediments. The rest stays in the atmosphere.

Methane (CH_4)

Methane (CH_4) is believed to be responsible for about 16% of global greenhouse gas emissions. The carbon in methane makes it a heat-trapping gas, like carbon dioxide, but it is about thirty times more active than CO_2. However, while the greenhouse effect of methane is much higher than that of CO_2, methane has an atmospheric life time of about 12 years. This is much shorter than carbon dioxide's. Some scientists believe that methane prevents the atmosphere from eliminating CFCs.

Nitrous Oxide (N_2O)

Nitrous oxide ("laughing gas") is very stable. It lasts an estimated 150 years or longer in the atmosphere. It contributes to the greenhouse effect, and accounts for about 6% of the problem. When it rises to the stratosphere, it is also responsible for destroying ozone.

Chlorofluorocarbons (CFCs)

Chlorofluorocarbons are a group of common refrigerants, solvents, and aerosol propellants that were widely used in industry years ago. They are very stable man-made compounds that destroy ozone after they reach the stratosphere. Ozone shields the planet from harmful UV radiation that can cause cancer. In the lower atmosphere, CFCs absorb infrared rays about 10 000 times more effectively than carbon dioxide, making them powerful greenhouse gases.

The release of CFCs and other ozone depleting substances has decreased since the mid-1990's. Multi-national agreements have restricted and ultimately eliminated their use.

Fluorinated Gases

Fluorinated gases have a very high global warming potential. However, they do not damage the ozone layer, which is why they were proposed as viable replacements for CFCs.

Emissions of fluorinated gases has risen in the United States by 77% and in Europe by 60% between 1990 and 2014. New strategies and policies are being developed to deal with rising fluorinated gas emissions. In 2010, fluorinated gas emissions made up 2% of global GHG emissions.

Water Vapour

Water vapour is the most important and most potent of all greenhouse gases. It absorbs far more radiant energy, from a broader wave spectrum, than CO_2. The ability for air to retain water vapour is dependent on the temperature of the air. As a given sample of air increases in temperature, its relative humidity decreases. This allows (but does not mandate) an increase in absolute humidity.

The traditional method by which water vapour enters the atmosphere is by:

a) Evaporation from bodies of water
b) Transpiration from plants
c) Naturally-occurring combustion due to forest and brush fires
d) Respiration from animals

Since the industrial revolution, greater quantities of water vapour have entered the air from industrial activity. This includes combustion of hydrocarbon fuels and evaporative cooling processes. In addition, water vapour carries latent heat to the atmosphere, which adds to the atmospheric energy content.

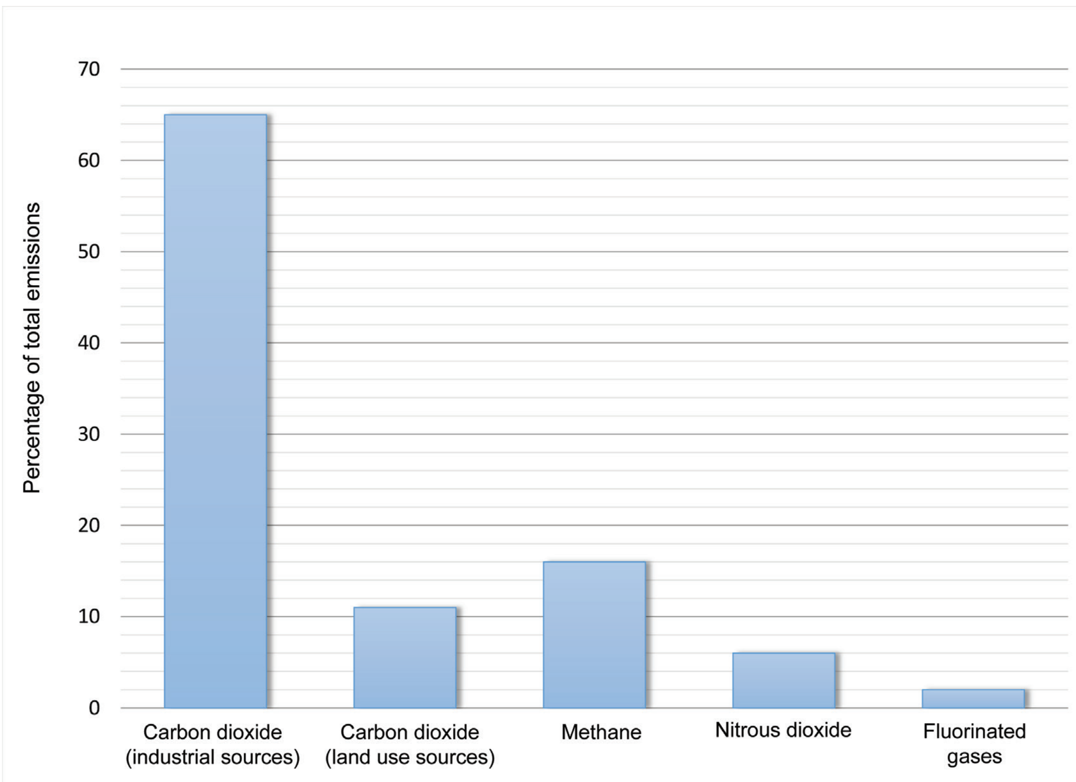
Traditionally, greenhouse gas models have not accounted for the effect of water vapour as a greenhouse gas. As well, the scientific community has been reluctant to assign a GWP value to water vapour. This is because the overall effects of atmospheric water vapour on climate change have been difficult to model. In part, this is due to wide variations in atmospheric water vapour content based on latitude, proximity to land masses, and proximity to bodies of water.

Ozone

In the stratosphere, ozone is very beneficial because it absorbs cancer-causing ultraviolet radiation. However, in the troposphere, ozone is a greenhouse gas. Like water vapour, quantifying the greenhouse gas potency of ozone is difficult. This is because ozone is not present in uniform concentrations across the globe.

Figure 3 shows the United States EPA 2014 estimate for relative amounts of greenhouse gas emissions. In their analysis, they differentiate between industrial and land-use CO_2 emissions.

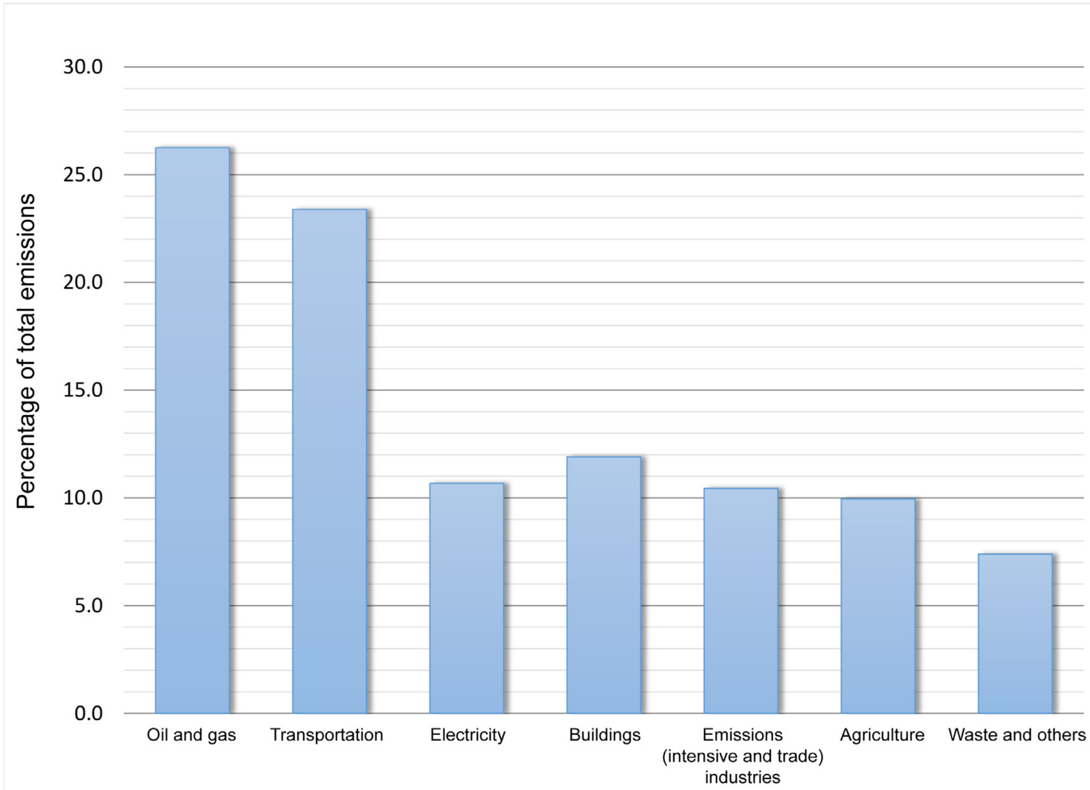
Figure 3 – Global Greenhouse Gas Emissions as a Percentage of the Total - 2014



(Data Courtesy of U.S. EPA)

Figure 4 shows the distribution of greenhouse gas emissions by economic sector in Canada during 2014. The Oil and Gas and Transportation sectors collectively produce around 50% of CO_2 emissions.

Figure 4 – Greenhouse Gas Emissions by Sector - 2014



(Data Courtesy of Environment Canada)

Acid Rain

Acid rain is formed when NO_X and SO_X in the atmosphere undergo complex reactions with water vapour and sunlight. The products that result from these reactions include a number of sulfur and nitrogen aqueous compounds, including sulfuric, sulfurous, nitric, and nitrous acids. These precipitate with rain, snow, hail, sleet, and fog.

The contaminants which form acid rain can be carried in the atmosphere over great distances from their source. Until technology was applied to clean the flue gases, the nickel smelters around Sudbury, Ontario carried NO_X and SO_X emissions as far as Quebec, and acidified the lakes and rivers. Smog from California deposits pollution in the snows of Colorado. The snows melt and the acidic runoff leaches hazardous minerals from the mountains. Some of the meltwater returns in the rivers as a water source for California.

Effects of Acid Rain on Lakes and Rivers

The normal or healthy pH level in lakes is about 5.5 or higher. As the acid levels increase in a lake, the pH decreases. The first to be affected is microscopic life, and this affects the entire food chain. Greater acidity can interfere with the reproductive cycle of aquatic animals.

Metals leached from the soil by the acidic liquids reach higher concentrations than normal. This can restrict the ability of some aquatic animals to breathe properly. For example, fish gills can become deformed and the fish can suffocate.

In a landscape affected by acid rain, the first snowmelt of spring releases a surge of acidic runoff that can lower the natural pH of a still body of water such as a lake. This periodic acidification may only be temporary. Even so, many eggs and hatchlings may not survive. Over time, continuous exposure to acid rain can result in the entire ecosystem within the lake being negatively impacted. Lakes which are affected by acid rain to such an extent that they cannot support most aquatic life are termed "dead lakes."

The degree of negative effects due to acid rain can vary significantly. Some forests, streams, and lakes that experience acid rain do not suffer many negative effects because the alkaline soil in those areas neutralize the acidity in the rainwater. This "buffering" capacity depends on the thickness and composition of the soil and the type of rock underneath it.

Effects of Acid Rain on Plant Life

Forests are being killed by acid rain. Some problems are directly created by acid deposits on leaves; however, the greater problem appears to be the effects of acid deposits on the soil. Nutrients normally dissolved and used by tree roots have either been leached away or lost, or toxic quantities of other materials have been taken into solution by acidic groundwater. These materials interfere with a plant's ability to acquire proper nourishment. The result is that plants weaken and die. These effects impact all plant life, not just the forests.

Effects of Acid Rain on Human Health

Direct contact with acid rain will not cause injury to humans. However, being exposed to the particulates that cause acid rain can present a health hazard. Particulates which trap SO_X and NO_X can be inhaled by humans. This can cause health problems such as emphysema and bronchitis. These are serious conditions. Many people are hospitalized every year and some of them die. Reducing the amount of these toxic particulates reduces the harm to humans and improves the quality of life for those with breathing ailments.

Effects of Acid Rain on Buildings, Structures, and Vehicles

Structures with exposed metals are also susceptible to the corrosive action of acid rain. Acid rain effects buildings and other structures, leading to increased maintenance costs. This is especially true in buildings made of limestone or marble which contain calcium carbonate or calcium-based compounds which are quite reactive with water in highly acidic conditions. Structures with exposed metals, such as copper, zinc, nickel and certain types of steel are also susceptible to the corrosive action of acid rain. To reduce damage to building structures and vehicles, acid-resistant paints are often used.

Objective 3

Describe the common methods for monitoring and reducing gaseous pollutants.

Pollution Monitoring

Thousands of chemical compounds are produced as byproducts of industrial processes and released into the atmosphere. Although many are also produced and released by ongoing natural processes, all emissions can be classified as contaminants or pollutants.

Government regulations cover hundreds of emissions in various jurisdictions. However, only a few are so important and so widespread that they are regulated. The most significant Energy Plant emissions are part of a group called **Criteria Area Contaminants (CAC)**. Environment Canada publishes an ongoing list of CACs on its website. Current CACs include:

- Sulfur Oxides
- Volatile Organic Compounds
- Carbon Monoxide
- Ground-level Ozone
- Nitrogen Oxides
- Particulate Matter
- Ammonia

Although many jurisdictions want to manage the output of CO_2 from industrial sources and do require its measurement, as of 2017 it was not included on the CAC list. Carbon Dioxide monitoring is almost universally used as a measure to ensure complete combustion and therefore maximum energy transfer from the fuel to the process.

Ambient air quality standards (at a specific distance from the source of the pollutant) are set and acceptable exposure limits are identified for each CAC. Exceeding the acceptable limit may cause excessive damage to the environment and increased health risks.

Whether through general regulations or site-specific permitting, each energy plant has:

a) Clearly defined limits for the maximum emissions (Source Emissions) that are allowed from its stacks for each of the CACs produced in its process.

b) Requirements for the continuous monitoring of some of these emissions.

c) Requirements for reporting on the results to a government agency.

For emissions that are monitored, limits may vary between jurisdictions and from plant to plant.

As the government and public demand stricter measures on pollution, the challenge of environmental control will continue to grow. Many pollutants cannot be totally eliminated; only their concentration can be controlled. To effectively fight environmental pollution, plant outputs are regulated and must be continually monitored to ensure compliance. This monitoring also serves as an indicator of how well the existing equipment is functioning.

Gaseous Emission Monitoring

For the energy plant, the boiler stack is usually the main source of atmospheric pollution. Ventilation and exhaust stacks also contribute. Whatever the case, a clear picture of what is being emitted from the stacks is of vital importance for effective pollution control.

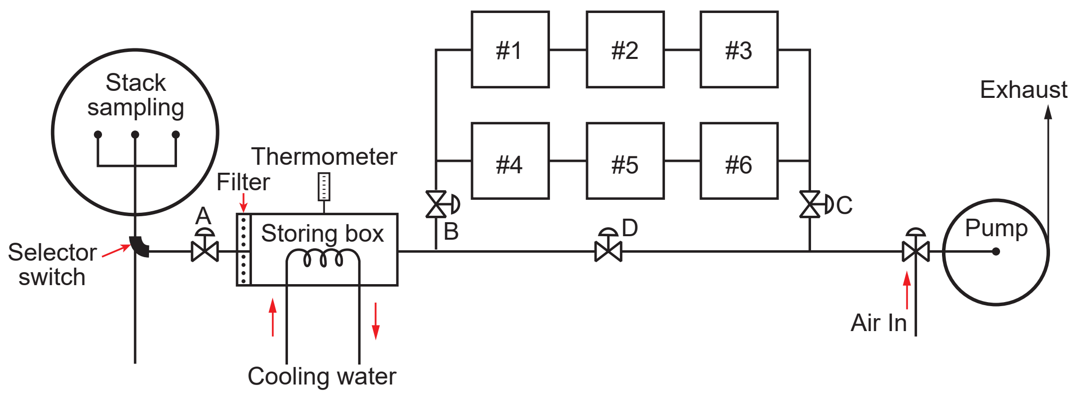
Routine emission monitoring usually involves both **Source Emission Monitoring** (at the facility) and **Ambient Emission Monitoring** (at a predetermined location away from the facility or a designated air monitoring location). Source emission monitoring often involves both in-stack emissions and fugitive emissions (leaks from within the facility). It is usually the responsibility of the Power Engineer to ensure all required emission monitoring is performed according to regulatory or site-specific requirements.

Continuous Emission Monitoring Systems (CEMS) involve the installation of equipment to sample, analyze, and report data at predetermined times for a stack or duct. Regulatory agencies may require the inclusion of a CEMS to ensure compliance with emission standards. The following example is one which may be seen for a boiler stack.

By using a selector switch (a three-way valve), the sampling train shown in Figure 5 may draw flue gas from the stack, or ambient air from a remote location. The pump operates continuously to fill the storing box with the gas being tested. The sample then moves through the sampling train.

Through the manipulation of valves, flue gas is "pulled" from the stack and directed to various analyzers.

Figure 5 – Automatic Sampling and Analyzing Train



Each analyzer contains a reagent or sensor designed to absorb or react with a distinct pollutant. This determines how much of a particular gas is present. Results from the analyzers are sent to recorders and indicators in the control room. Alarms may be installed and set to go off if a preset allowable limit of any gas is exceeded.

Continuous monitoring of the plant emissions is vital for the following reasons:

a) It ensures that emissions are kept at an acceptable level.

b) The results can be used to see how well equipment is functioning.

c) It provides records of plant emissions.

Other methods of monitoring involve stations located around the facility that monitor secondary stacks and fugitive emissions. In some cases, stations are also installed outside the facility compound to measure ambient emissions. These can be portable stations where a plant technician performs site-specific monitoring. They could also be stations used by government officials to determine the accuracy of plant reporting, or to investigate public concerns.

Fixed monitoring sites may be specified in the jurisdictional environmental legislation. These sites would be chosen specific to the location of the facility, the geographic landscape, and the location of other emission emitters in the same area.

Measuring Pollutants

There are different methods of testing stack emissions, both manually and using CEMS. Some methods are better suited to certain emissions.

Here is a brief description of three techniques used to detect four major pollutants: NO_X, CO_2, CO, and SO_2.

Chemiluminescence

Chemiluminescence refers to the emission of light as a result of a chemical reaction. For example, when NO oxidizes in the presence of ozone, a certain amount of light is produced in direct proportion to the amount of NO that is oxidized. This light can be measured and a reading produced. This is the predominant technique used for NO_x measurement.

Non-Dispersive Infrared Detection (NDIR)

Non-Dispersive Infrared Detection (NDIR) is used to detect both carbon dioxide and carbon monoxide in the emissions stream, using different wavelengths. The basis of this technique is the absorption of IR light by CO_2 and CO. In this type of detector, infrared light, at different wavelengths, is passed through two tubes. One tube (the reference tube) contains a non-IR absorbing gas such as nitrogen. The other tube contains the sample gas. CO_2 or CO in the sample absorbs IR radiation. The energy that passes through the reference tube is compared to the energy that passes through the sample tube by a detector that measures the difference in IR absorption. The results of the measurement indicate the CO_2 or CO concentration.

Pulsed Fluorescence Testing

When sulfur dioxide is exposed to ultraviolet light it becomes “excited” at one wavelength. It will then decay to a different (lower) energy state. In doing so, it will emit a UV light at a different wavelength. This light is then converted into an electrical signal, which is representative of the level of SO_2.

There are standards to be met when testing emissions for official purposes. The Environmental Protection Agency of the United States as well as the American Society for Testing and Materials have developed standards that lay out precisely how these tests are to be carried out. Both standards may be referred to in regulations.

Regulations also mandate:

a) Minimum CEMS availability requirements.
b) How long CEMS data must be retained.
c) Annual evaluations to ensure the quality of procedures.

Reducing Levels Of Pollutants

Before researchers understood the long term damaging effects of low levels of pollutants, they believed “The solution to pollution is dilution”. To reduce pollution in the immediate area, much higher “super” stacks were built. As a result, the local pollution was reduced because emissions were discharged higher into the atmosphere. This “solution” only spread the pollution over a greater area; it did not reduce the negative environmental impacts.

Today, the emphasis is on reducing or eliminating emissions in a variety of ways.

Current Methods of Pollution Removal or Reduction

Carbon Monoxide

Carbon monoxide is produced when a fuel is burned with insufficient oxygen.

In a furnace, different conditions can create a shortage of oxygen. The most obvious is that there is not enough air being supplied to the furnace. Another reason is insufficient turbulence. The air and the fuel do not mix well enough for the carbon from the fuel to react completely with the oxygen in the air. Localized shortages of oxygen result in the production of carbon monoxide. Also, overloading of the boiler can cause quick combustion. This deprives the fuel of the time needed to be completely burned in the hot enclosure of the furnace.

Power Engineers can control all three causes of incomplete combustion mentioned above. Most plants are equipped with automatic flue gas analyzers, which continuously monitor the composition of the flue gas leaving the furnace. Even where there are no flue gas analyzers, a Power Engineer should know by experience:

a) How to determine proper combustion from the appearance of the flame.

b) The temperature of the gas at various points in its path.

c) The appearance of the stack emissions.

Carbon Dioxide (CO_2)

Power Engineers must have an understanding of carbon dioxide and it's uses and restrictions. When a fossil fuel is burned, CO_2 is released as part of the basic combustion process. Due to state and federal regulations, it is important to monitor and try to reduce these emission levels. If too much CO_2 is produced, plants can be penalized or fined.

Maximizing combustion efficiency is one way that Power Engineer's can minimize CO_2 production. This ensures that only the required amount of fuel is burned, which results in less CO_2 released.

There are several different ways to improve efficiency. Ensure that:

a) Burners are in good condition (i.e. make sure that burner nozzles are kept clean and burners are tuned).

b) Controls are operating correctly.

c) Stack emission monitoring systems are maintained.

Methods of removing carbon dioxide from flue gas have been developed, but are not currently in widespread use. The most widely tested process, **Carbon Dioxide Capture and Storage (CCS)**, is a method used to remove, transport, and store CO_2 from large stationary emitters such as power plants and natural gas processing plants. CCS has worked on a small scale, and is now being implemented on a larger scale. The process involves a number of steps, which include:

1. Removing CO_2 from the flue gas by contacting it with a solution of amines.
2. Separating the CO_2 from the amine solution by heating.
3. Compressing the separated CO_2 into a liquid.
4. Using the liquid CO_2 to enhance other industrial processes.

Reforestation ties up carbon in the form of plant material as the trees grow thus removing CO_2 from the atmosphere. It is estimated that 10 000 000 acres of new forest would use up all the CO_2 that would be emitted by power plants in the next 10 years.

Other ideas are being researched, such as putting urea into the ocean so more CO_2 will be absorbed into the water. However, altering the ocean's chemistry might not be a viable solution, especially if it has a negative effect on the ecosystem.

Until such processes are proved to be viable, Power Engineers can do their part by being mindful and efficient equipment operators.

Sulfur Dioxide (SO_2)

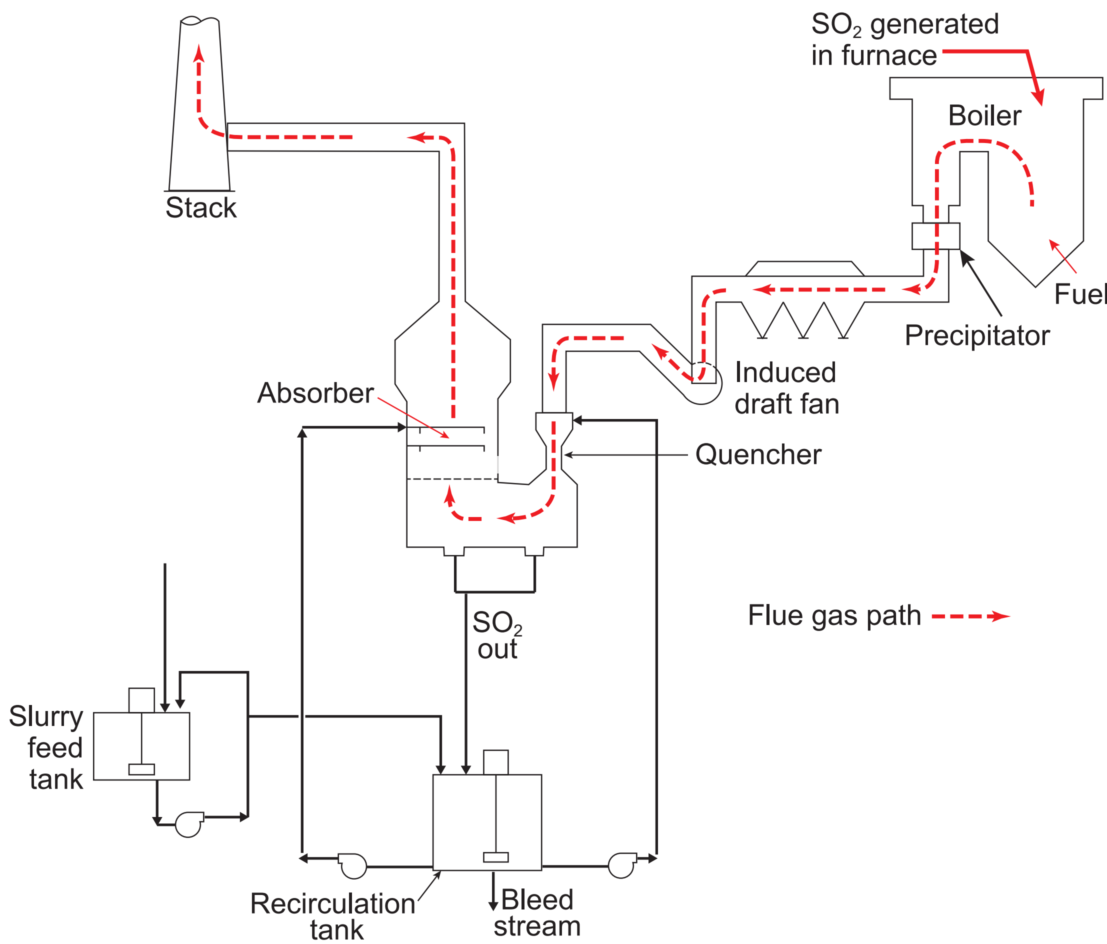
Many facilities have met environmental regulations by using naturally occurring low sulfur coal. Others have installed **Flue Gas Desulfurization (FGD)** systems. The FGD systems are categorized as:

- **Non-Regenerable**, where the medium used to absorb the SO_2 is disposed of as waste.
- **Regenerable**, where the medium is recycled.

The advantage of regenerable systems is that the sulfur is recovered and can be sold. However, these systems are more expensive than non-regenerable systems (which are currently more widely available).

Most of the processes involve wet scrubbing of the combustion flue gas using lime or limestone, alkaline fly ash or sodium carbonate and dilute sulfuric acid. A typical limestone system is shown in Figure 6. Efficiency for these systems can be as high as 90 to 95% with combustion gases containing up to 5000 ppm SO_2.

Figure 6 – FGD System using Wet Scrubbing of Flue Gases with Limestone Slurry



Nitrogen Oxide (NO_X)

Nitrogen oxides (NO_X) are formed from both fuel-bound nitrogen (**fuel NO_X**) and the nitrogen contained in the combustion air introduced into the furnace (**thermal NO_X**). Fuel NO_X is dependent on the:

a) Percent of nitrogen in the fuel

b) Reactivity of nitrogen compounds contained in the fuel

c) Oxygen availability in the combustion zone

The use of fuel that contains less (or zero) nitrogen is the most effective means of reducing fuel NO_X.

It is difficult to control thermal NO_X production in power plants. This is because favourable conditions for NO_X production are created by the combustion practices developed to increase power plant operating efficiency and control other air pollutants. Boilers are designed to have high furnace temperatures and use excess air to ensure complete combustion. This design controls the amount of the undesirable by-products such as smoke and carbon monoxide. Unfortunately, the high temperatures and increased oxygen encourage the formation of high levels of NO_X.

There are two practical means of controlling emissions of nitrogen oxides from power plants. Control may be accomplished either by minimizing their formation in the first place, which is mostly dependent on high temperature and the availability of oxygen; or removing them from the flue gas after they have been produced but before they enter the atmosphere.

Removing NO_X from Flue Gas

NO_X can be removed from the flue gas stream by using technologies such as **Selective Catalytic Reduction** or **Selective Non-Catalytic Reduction**. These methods remove NO_X by causing a reaction between it and ammonia, which produces nitrogen and water. Depending on the method used, a catalyst may or may not be involved in the reaction. NO_X reductions of up to 80% or more are possible.

Controlling NO_X Before it is Produced

The conversion of nitrogen in the air to NO_X is highly dependent on temperature. The formation of NO_X proceeds rapidly at combustion zone temperatures in excess of 1650°C. By maintaining the combustion temperature below 1650°C, the NO_X emission can be reduced.

Besides using low nitrogen fuels, the following are methods that can be used to reduce the formation of NO_X:

a) Two stage combustion
b) Low excess air operation
c) Gas recirculation
d) Specially designed **Low NO_X Burners**

These methods either restrict the conditions under which the nitrogen and oxygen react to reduce available oxygen, or reduce peak flame temperatures to reduce the NO_X produced. This may be done by one of the following.

a) Introducing fuel rich atmospheres
b) Fuel lean atmospheres
c) Longer combustion times
d) Dilution of combustion air with exhaust gases

Depending on the method used, NO_X can be reduced by 30 – 80%.

Chlorofluorocarbons (CFCs) and Fluorinated Gases

Currently, there are no proven methods for removing CFCs or fluorinated gases from the environment.

The use of CFCs was discontinued by the **Group of Seven (G7) countries** after signing the **Montreal Protocol** in 1987. As a result, the release of CFCs has decreased. However, it has been estimated that it will take up to 1500 years for the compounds that are already in the atmosphere to decompose.

There is a movement to regulate the use of fluorinated gases, as well.

Proper maintenance, repair, and storage of machinery which use CFC and fluorinated gases will reduce the amount released to the atmosphere.

Possible replacements for these gases include hydrofluoro-olefins (HFO) and hydrocarbon (HC) refrigerants. These gases have a lower impact on the environment than the refrigerants they would replace.

Natural refrigerants, such as R-744 (CO_2) and R-717 (ammonia) are replacing CFCs and fluorinated gases. CO_2 is sourced from the atmosphere and is not ozone depleting. If accidentally released, it merely returns to its source. When contained in a refrigeration system, it does not contribute to global warming. In this regard, CO_2 is considered a "green" refrigerant, with neutral environmental effect.

Ammonia, though toxic and explosive, is a highly energy efficient refrigerant. If leaked to the environment, it is rapidly absorbed by water and enters the soil, where it provides essential nitrogen for plant growth.

Reducing Pollution - Changing The Energy Source

An important solution to reducing pollutants is to select energy sources that do not pollute. Ideally, these alternate sources are renewable and do not produce other economic or environmental problems. Some solutions offer energy generation that does not release compounds into the environment. Other solutions address natural sources of harmful emissions, and harness these natural sources for power production. An example is to use biomass as a fuel source (explained further below).

There are six commonly used renewable or non-polluting energy sources:

1. Biomass
2. Hydro-Electric
3. Geothermal
4. Wind
5. Solar
6. Hydrogen

Of the above, biomass and hydropower are traditional energy sources. A short overview (with the exception of hydro-electric power) follows.

Biomass

Biomass is a variety of plant-based organic material or municipal waste material. It has no commercial purpose other than to be burned as fuel. Much biomass is sourced from:

- Forest residue
- Wood chips and bark
- **Municipal solid waste**
- **Bagasse**

Biomass is either burned directly as a fuel, or it can be converted into biofuel, such as biodiesel and bioethanol.

Sugar cane grows rapidly. Therefore, when bagasse (waste sugar cane product) is used for power generation, the CO_2 emissions can be quickly recaptured by planting more sugar cane. This reduces the overall environmental impact. Forests, on the other hand, grow slowly. Therefore, new forest growth is not as effective for rapid CO_2 remediation.

Geothermal Energy

The technologies used to produce energy from geothermal sources are determined by the temperature of the liquid in the underground source rock. The most common geothermal power plants use reservoirs of water temperatures greater than 182°C. In this type of plant, hot water flows up through wells in the ground, under its own pressure. As it flows upward, the pressure decreases and some of the hot water boils into steam. The steam is then separated from the water and used to power a turbo-generator. Any leftover water and condensed steam are injected back into the reservoir, which makes this a renewable resource.

Wind Energy

Wind energy is generated when turbines, exposed to an appropriate speed and duration of wind, turn in the moving air and power electric generators. Generation of power from wind is increasing in popularity. Wind power has the advantage of being renewable but has the disadvantage of being intermittent. Because of this, wind generators rely on energy storage systems so that power is available even when there is insufficient wind.

Solar Energy

Solar energy is a nonpolluting source of energy. The energy is free, but harnessing it is expensive. In 1989, the New York Times reported that "the conversion of solar energy to electrical power could become comparable in efficiency to conventional power generation." Tremendous gains in the development of solar cells have taken place in the last few years and, if fossil fuel prices dictate, more research will take place.

Solar energy sources generally utilize one of two types of solar technology:

a) Solar Photovoltaic (PV) is the direct conversion of solar energy into electricity.

b) Solar Thermal processes involve mirrors that focus and concentrate solar energy on a target point which is connected to a heat transfer medium, normally a liquid salt due to the temperatures achieved. The high temperature liquid salt is then circulated through a heat exchanger to produce high pressure steam to drive a turbo generator.

Hydrogen as a Fuel

Using hydrogen as a fuel is not a new idea. However, the methods used to produce, storage, and handle it must be refined before it receives wide acceptance. Hydrogen is an ideal fuel since the only product of combustion is water vapour.

A kilogram of hydrogen delivers about 4.25 times more energy than a kilogram of carbon when burned completely. Fuel cells use hydrogen to produce electricity to drive cars and buses, and for portable power systems. But, fuel cell use is not yet widespread.

Hydrogen is often stored in cryogenic containers to keep the storage pressures from being excessively high. Even a small hydrogen leak poses an explosion hazard due to the wide range in its explosive limits. Hydrogen rich fuels, such as methane and propane, contribute less CO_2 pollution to the air than regular gasoline or diesel fuels. A greater usage of these fuels would reduce equipment costs, but the higher demand would likely result in price increases.

Objective 4

Describe the effects of noise pollution and methods of identifying, measuring, and controlling it.

Noise Pollution

Noise pollution can be defined as "Environmental noise that is annoying, distracting, or physically harmful."

The effects of industrial noise on workers and the surrounding community have been the subject of much research. Chronic exposure to elevated noise levels has been shown to have adverse health effects. Living close to a high noise source area such as an airport can cause hypertension, stress, sleep problems, and psychological problems. These in turn can cause obesity, heart disease, diabetes, anxiety, depression, and headaches.

The effects of noise on the communities near the source are mostly sleep interference and annoyance, depending on the frequency, intensity, and duration of the sound. For example, high frequency tones are perceived as louder than lower frequency tones at the same volume. Intermittent or impulse noises are often more annoying than a constant noise.

Public concern over noise is increasing. This concern has led to stricter limits on noise production. Application for new, permanent facilities or for modifications to existing facilities requires a noise impact statement, if there is an expectation of continuous noise generation. Facilities such as pumping stations, gas processing plants, and gas pipeline compressors are examples of installations that may require noise impact statements.

A noise impact statement should specify the design sound level at the nearest or most impacted permanently or seasonally occupied dwelling. Noise impact statements must consider possible noise impacts before a facility is constructed or in operation. Designers should discuss noise matters with residents during the design and construction phases of a facility. Otherwise, the cost to retrofit a facility already in operation may be significantly more than if noise mitigation was part of the original design.

While residents near plants prefer no increases in sound levels, sometimes it is not possible to achieve. However, if proper sound control measures are incorporated into facility design, increases in sound levels can be kept to acceptable minimums. Sound levels are generally considered to be acceptable when overall quality of life or indoor sound levels for residents are not adversely affected.

Even for facilities with no dwellings within 3 km, uncontrolled sound generation will not be allowed. Reasonable measures should be taken to reduce sound generation even though no sound level criteria are specified.

Sources of Noise

There are numerous sources of noise in a plant. These sources include:

a) Machinery
   - Furnaces
   - Fans
   - Compressors

b) Structural vibrations transferred from moving parts

c) Construction activities

Even leaving compressor room doors open can contribute to unwanted noise.

Furnaces, fans, reciprocating compressors and coal pulverizers generally produce low frequency noise. Gas or steam passing through vents and valves produce high frequency noise.

Noise impact from heavy truck traffic around operating facilities is not always specifically mentioned; however, its impact is not excluded from noise regulations. It is expected that every reasonable measure will be taken by industry to eliminate or reduce the impact of heavy traffic in any given area.

Sound and Sound Measurement

Sound travels as waves through the air, in the same way that waves travel through water. The waves are formed by vibrating bodies or air turbulence, which causes a variation in air pressure. This variation in pressure is actually a transfer of energy, passed through the air via molecular interaction. Because it is a form of energy, sound can be expressed as having specific power and intensity levels.

Sound waves have varying frequencies and wavelengths. As well, sound waves can be reflected, deflected, and absorbed. Absorption of sound occurs when sound waves strike a non-rigid barrier. The energy of the wave moves the fibres on the barrier's surface. Internal friction in the barrier opposes this movement and the energy of the air is converted to heat energy within the barrier.

Reflection and deflection of waves occur when the sound strikes a rigid barrier. Very little of the energy of the wave is absorbed by the barrier; only the direction of the wave is changed.

Variations in sound are caused by the different pressures and frequencies of the sound waves. A human ear is usually capable of hearing sounds which represent pressures from 0.00002 Pa to 200 Pa. Because of this large range, the concept of a **decibel** was created to convert sound pressure levels into a more meaningful scale.

Levels of sound are measured by a sound level meter in Pascals, but are represented on the meter's display in decibels. The decibel scale is not linear. Doubling a decibel reading does not double the sound intensity. The decibel scale is a logarithmic scale so that a decibel reading of 20 dB is 10 times more intense than 10 dB. Thirty dB is 10 times more intense than 20 dB, and so on. As the decibel reading increases by ten, sound intensity increases by a multiple of 10.

Table 3 shows the relationship between the decibel scale and everyday sounds. Table 4 shows the kind of physical damage that can be caused by excessive exposure to sound pressure.

Table 3 – Decibel Scale

Decibels	Examples	Times more intense than 10 dB	Times louder than 10 dB
10 dB	Barely audible (pin drop)	1	1
20 dB	Whisper, rustling leaves	10	2
30 dB	Quiet rural area	100	4
40 dB	Quiet conversation	1 000	8
50 dB	Louder conversation	10 000	16
60 dB	Quiet traffic noise	100 000	32
70 dB	Vacuum cleaner	1 000 000	64
80 dB	Loud highway noise at close range	10 000 000	128
90 dB	Lawn mower	100 000 000	256
100 dB	Jackhammer (pneumatic drill) at close range	1 000 000 000	512
110 dB	Jet engine at about 100m. Human pain threshold.	10 000 000 000	1024

Table 4 – Auditory Damage Caused by Sound Pressure

Decibels	Examples
85 dB	Hearing damage in about 8 hours
100 dB	Hearing damage in about 15 minutes
120 dB	Physical pain, hearing damage in a short period of time
160 dB	Eardrum bursts instantly

Noise Pollution Monitoring and Control

Rules, regulations, and guidelines for noise pollution and noise remediation are generally managed by local jurisdictions (provincial, territorial, or municipal). Each jurisdiction is responsible for emissions within their jurisdiction. Currently, there is no consensus between jurisdictions on how to define and control noise. Most jurisdictions have an application process in place that requires all new facilities being built to conduct an environmental impact assessment which includes predicted noise levels. If the application shows the noise levels are reasonable, it can be approved. However, effort must be shown that noise emissions will be the lowest level achievable based on land control use and zoning.

The noise generated from the facility is considered the point source; however, the sound field it will impact is complex. The amount and level of noise transmitted to the general public, and the distance it travels, are impacted by the topography, humidity, temperature, and wind.

Each facility receives permits to build and operate. In that permit are specified levels of noise emissions that cannot be exceeded. Some legislation will look at noise emissions as an environmental release with potential consequences of fines or by allowing those who are impacted by the emissions to seek compensation for any loss the noise may have caused.

Sound decibel levels do not distinguish between sound frequencies. Sound meters contain weighting networks which consider frequency and adjust the readout of the meter to correspond to how loud a person would perceive the sound to be.

There are 4 weighting “scales” currently used: A, C, D, and Z. “A” is most representative of human hearing. When noise is expressed in decibels, there may be an extra letter after the dB, such as dBA. This letter, A, C, D, or Z indicates the weighting scale used to measure the noise.

Sound meters are also rated by accuracy on a scale of 0 - 3. Type 0 meters are the most accurate. Type 3 are the least accurate. Figure 8 shows a typical hand-held sound level meter.

Noise laws or regulations specify which type of sound meters and which weighting scale must be used to investigate noise levels, and to ensure regulatory compliance.

Figure 7 – Sound Level Meter

Efforts to control noise are aimed at lowering the sound intensity at a given location. The minimum noticeable noise reduction is approximately ten percent on the decibel scale which means a reduction in noise of 5 to 10-fold is necessary to be worthwhile and noticeable.

There are three ways to reduce noise at a given location.

1. Reduce the sound at the source.
2. Modify the sound wave path.
3. Protect hearing with a barrier device, such as ear plugs or ear muffs.

Noises are often controlled by a combination of these methods.

Reducing the sound at the source can be achieved by:

a) Installing vibration isolation mounts and damping equipment for machinery.
b) Decreasing speed of operation.
c) Decreasing blade tip velocities in fans.

To be cost effective, most of these modifications must be included at the design phase.

After the design stage, modification of the sound path to the receiver is often used. Enclosures are a form of sound path modification. They are designed using special materials which reflect sound back to the source, and in some cases, absorb it as well.

All materials have some sound absorbing properties. The energy of a sound wave striking a material surface is either reflected, absorbed, or transmitted. The relative amounts will depend on the sound absorbing quality of the material. Soundproof materials absorb sound waves by trapping them in the material. As a result, very few sound waves are reflected back or transmitted through the materials.

The best materials for sound absorption are usually porous and easy to find. Lead, loose sand, brick, and almost all heat insulators (fiberglass, mineral wool, polyurethane, and cork) are good sound absorbers.

Figure 8 illustrates how sound wave paths are changed by a reflective barrier and an absorbent barrier.

Figure 8 – Sound Reflections and Absorbers

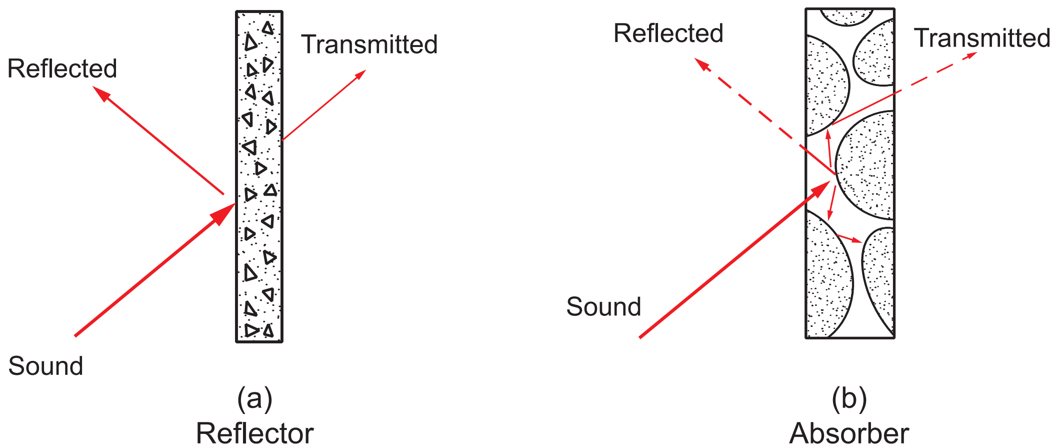
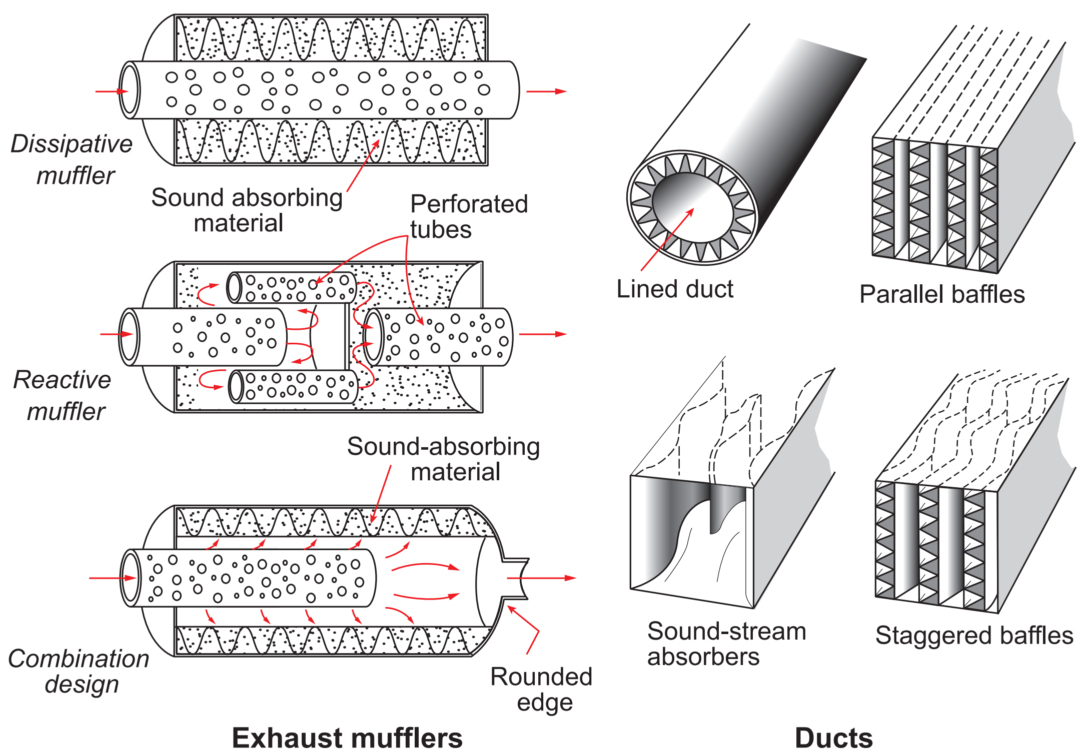


Figure 9 shows two types of noise enclosures that absorb and reflect sound: mufflers and lined ducts. Inlet silencers on forced draft fans are also a form of enclosure.

Figure 9 – Sound Path Modifiers



Sometimes, it is necessary to enclose an entire piece of equipment. If such an enclosure is necessary, it must be completely free of leaks. A hole as small as 1/1000 of the total wall area of the enclosure would leak enough sound to make the enclosure non-effective.

For high frequency noises, the best results are obtained using a double structure with a sound absorbing material between the two structures.

Another form of sound path modification is by creating a buffer zone around the source. By doubling the receiver's distance from the source, the sound pressure can be halved.

Chapter Summary

Activities carried out at facilities where Power Engineers work can generate emissions that can pollute the environment, and cause annoyance and stress to the general public. Emissions caused by combustion of hydrocarbon fuels contribute to the greenhouse effect and acid rain. There are processes in place to reduce the generation of these emissions at the source or to strip toxic gases before they reach the atmosphere. More research and development will improve these systems. However, facilities that burn coal as fuel and generate significant amounts of SO_X and NO_X are being pressured to shut down or convert to a cleaner burning fuel such as natural gas. This can be a very costly conversion and not realistic for some plants.

Reducing the production of pollutants in a process is a better option than trying to remediate the problem afterwards.

Through careful, diligent, and mindful operation of a plant, Power Engineers can do their part to reduce the effect of gaseous and noise pollution on the environment.

CHAPTER 3

Liquid and Solid Emissions

Learning Outcome

When you complete this chapter you should be able to:

Explain how liquid and solid emissions affect plant operation.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Describe the sources and effects of solid pollutants from energy plants.*
2. *Describe the theory of operation of separators/collectors and monitoring of flue gas particulates.*
3. *Describe the disposal methods of solid waste from energy plants.*
4. *List sources and effects of liquid and thermal pollution.*
5. *Describe the preventive measures that can be taken to prevent liquid and thermal pollution.*
6. *Describe methods of liquid waste disposal.*

Chapter Introduction

Many, if not most, industrial processes produce solid or liquid wastes. Some of the categories used to describe industrial waste include:

- Organic and non-organic
- Solid, semi-solid, and liquid
- Hazardous and non-hazardous

Power Engineers use significant amounts of water to generate steam and operate related processes. To protect equipment, chemicals are added to the water to prevent corrosion and scale deposition. Water is also used for cooling systems. Chemicals are added to prevent the growth of bacteria and algae. Wastewater treatment processes produce contaminated organic sludge that needs further treatment. All chemical liquids and chemically treated water must be disposed of according to local regulatory requirements.

Many mines and other industrial processes produce residual waste solids called slags. For example, steel manufacturing produces blast furnace slag. The power industry, by burning solid fuels such as coal and wood waste, produces fly ash, bottom ash, and slag.

Solid waste can contain hazardous components, depending on the source materials. For example, fly ash can contain arsenic, cobalt, and vanadium. Liquid wastes often contain hazardous solids either in solution or suspension. These liquids require cleaning, through filtration or deposition, before they can be reused or released into the environment. The recovered hazardous solids must be disposed of safely.

Power Engineers must be familiar with the waste materials produced by the processes they are responsible for, so that they can be safely handled and disposed. This chapter will examine the effects of liquid and solid waste on the environment and the different options for disposal.

Objective 1

Describe the sources and effects of solid pollutants from energy plants.

Sources of Solid Pollutants

One of the main sources of solid pollutants from energy plants is derived from the fuel that is burned. Coal, wood-based fuel (**hog fuel**), **biomass**, and **municipal solid waste** are solid fuels. When they burn, they produce ash as a residual product. Ash is the non-combustible component of a fuel. When ash is so light that it travels with flue gas, it is called **fly ash**. Larger ash particles that cannot be carried in a flue gas stream, fall and become **bottom ash**. In a solid fuel furnace, ash can be heated to the point where it melts and becomes **slag**.

Fly ash that enters the atmosphere is often referred to as **particulate**. Particulates are typically described as solid or liquid matter small enough to be suspended in the atmosphere.

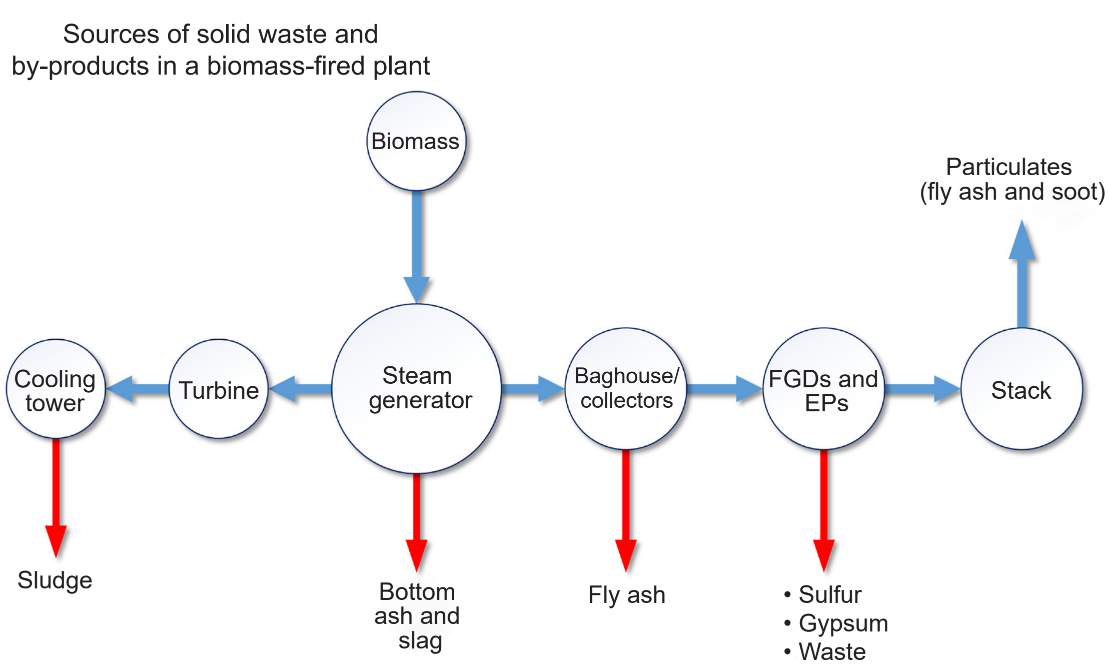
The type of fuel determines both the type of ash and the quantity of ash produced. Analysis of different coals can show ash content of up to 20 percent by mass. Some will end up as bottom ash and slag; the rest is fly ash. In comparison, the ash from wood-based fuels consists of only 0.5 to 2 percent of the total dry mass.

Some **flue gas desulfurization (FGD)** processes result in byproducts that have economic value such as sulfur, sulfuric acid, or gypsum. However, the more common type of flue gas desulfurization process results in no usable product. This sludge must be disposed of properly.

Soot is another particulate. It may form when combustion is incomplete. Soot is different from ash because it contains a significant percentage of carbon residue.

The figure below shows where in the process these solid pollutants are produced in a biomass plant.

Figure 1 – Sources of Solid Waste in a Biomass Plant



Adverse Effects of Solid Pollutants

Particulates form a special type of hazard to humans. They are easily inhaled and can become lodged in the lungs. The smaller the particulate matter, the more damage they can cause. Larger particles can be filtered out in the nose and throat. However, the smallest particles can find their way to the deepest parts of the lungs. From there, these nanoparticles can pass from the lungs to other organs in the body. Adverse health effects associated with particulates include asthma, lung cancer, and cardiovascular diseases.

Particulate matter can also affect the environment. It can reduce visibility, change the pH of lakes and streams, increase the effects of acid rain, and damage forests and crops.

Solid fuels can also contain trace elements such as uranium, mercury, arsenic, and heavy metals. These elements do not burn off. Instead, they are left behind with the ash. The amount of these elements leads to debate on whether or not coal ash should be considered a hazardous waste.

Objective 2

Describe the theory of operation of separators/collectors and monitoring of flue gas particulates.

As was mentioned earlier, fly ash varies greatly in size. There are several methods of removing it from flue gas, including:

a) Mechanical separation using inertia and centrifugal force to cause the fly ash to drop out of suspension into a hopper or collector,

b) The use of fabric filters to trap the particles, and

c) The use of **electrostatic precipitators** that use electrical charges to pull particles out of a gas stream.

These methods are briefly discussed here. The Furnace/Boiler Draft section covers the full details of their construction and operation.

Mechanical Collectors

Mechanical collectors use different methods to remove particulates from the flue gas stream.

a) Collectors may be designed to cause abrupt changes in direction. Since particulate particles are more massive than flue gas, the particles cannot change direction easily, so they fall from the gas path.

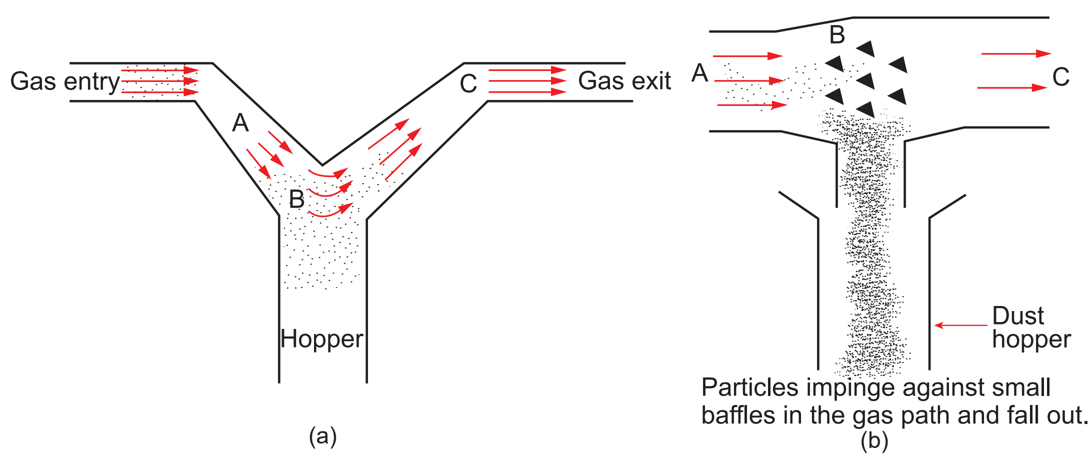
b) Collectors may be designed to slow down the ash by putting barriers in the flue gas path. This causes the ash to impinge upon the barriers and drop out by gravity.

c) Collectors may be designed to cause flue gas to take a circular path so that centrifugal force flings the small particles out of the flue gas.

The collection efficiency is best with the larger, heavier particles. Particles removed from the flue gas stream fall by gravity into hoppers for disposal.

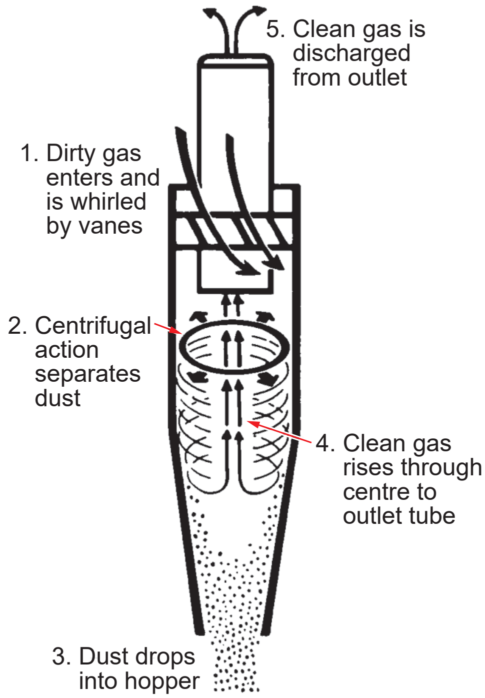
Figure 2 shows the first two methods.

Figure 2 – Particle Removal by Change in Direction (a) and Impingement (b)



Collectors that use centrifugal force are often called "cyclone" separators (Figure 3). This collector uses centrifugal force as well as an abrupt change in direction to cause the particles to fall out.

Figure 3 – Cyclone Separator



(Courtesy of Western Precipitation Corp.)

The efficiency of these types of collectors is dependent on the size of the particles in the flue gas path. Mechanical collectors are unable to remove particles smaller than about 10 **microns**. They cannot, on their own, meet the stringent regulations and emission limits of modern plants. They can however be used to "pre-clean" the flue gas of the larger particles before passing the flue gas through more efficient types of collectors.

Fabric Filters

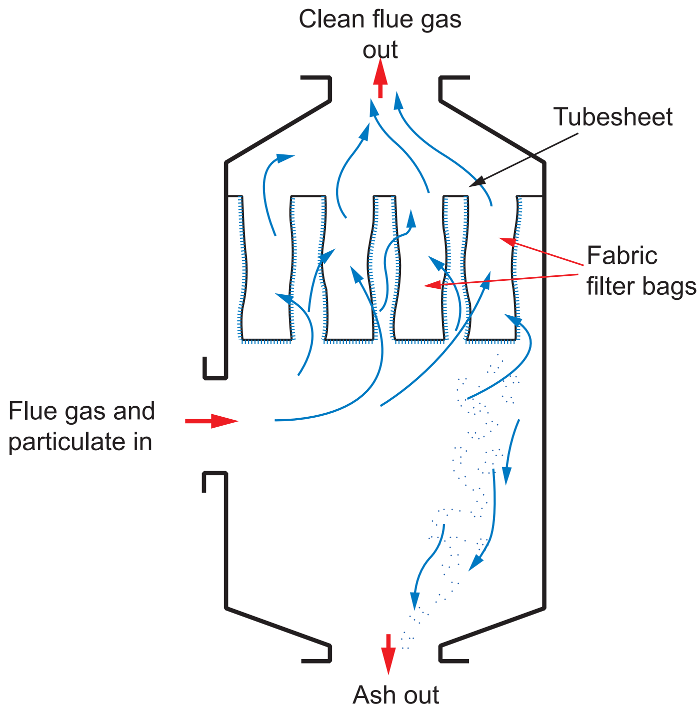
Fabric filters trap dust on fine cloth filters or bags, usually tubular in shape. Figure 4 provides an overview of their typical operation. Several bags are usually enclosed in a large chamber, which is called a **baghouse**. As the flue gas flows through the bags, fine fly ash particles adhere to the fabric surface. The fabric filter obtains its maximum dust-removal efficiency during this period of ash buildup. After a fixed operating period, the bags are cleaned by one of the following methods.

1. Mechanical shaker
2. Rapper system
3. Using reverse pulses of compressed air. This common method shakes the bags and breaks off the dust cake that adhere to the bags.

In all three methods, gravity causes the fly ash to fall into hoppers. The ash is then collected for disposal.

Immediately after cleaning, the filtering efficiency is reduced until the buildup of collected ash takes place again. The fabric filter can be applied in any process area where dry collection is desired and where the temperature and humidity of the gas will not damage the cloth. For particulate matter, efficiencies above 99% can be achieved with fabric filters.

Figure 4 – Baghouse Operation

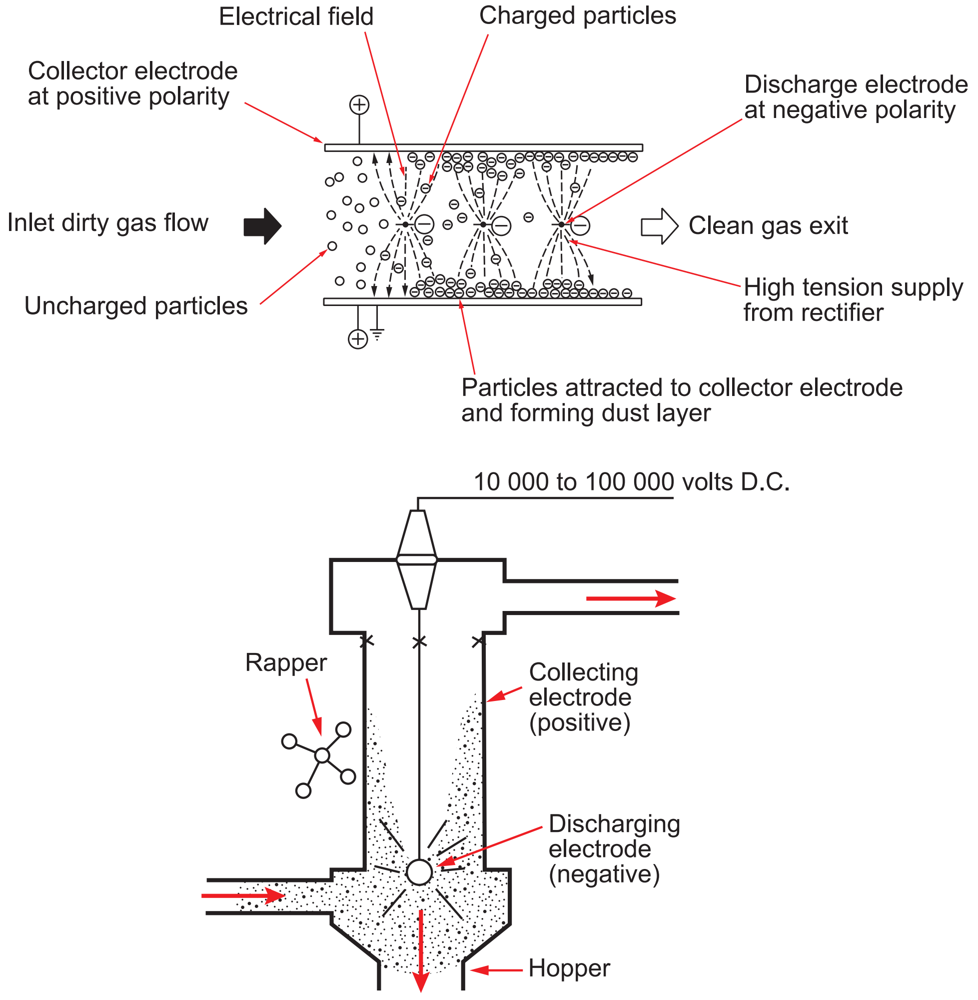


Electrostatic Precipitators

Electrostatic precipitators create an electric charge on the particles to be collected and then gather the charged particles by electrostatic forces onto collecting electrodes. This supplied voltage is between 10 000 and 100 000 volts DC.

Periodically, the collecting electrodes are cleaned by rapping or vibrating. The dust falls into hoppers. An overview of this process is shown in Figure 5.

Figure 5 – Electrostatic Precipitator Operation



Electrostatic collector puts charge on small particles; draws them from gas.

Of all the processes in place, the electrostatic precipitator is the most efficient at removing particulate from flue gases. Depending on the flow velocity and the particulate size, it can remove 99.9% of the particulate.

Objective 3

Describe the disposal methods of solid waste from energy plants.

Solid Waste Disposal

Ash, in its various forms, is either waste or a re-usable, marketable product. The ultimate use of ash depends on its composition. This includes:

a) Trace element concentrations of copper, lead, cadmium, arsenic, mercury, or others.

b) Organic compounds such as dioxins, furans, and polycyclic aromatic hydrocarbons (PAHs).

Waste ash may be disposed of in a dry state in landfills, or as a wet slurry in surface impoundments. A surface impoundment is simply a pond or lagoon built to store waste materials. Both landfills and surface impoundments must be built according to environmental regulations. They must be constructed in a manner to prevent contaminants from **leaching** into the groundwater. This is usually achieved by lining the impoundment with a low-permeability material such as heavy plastic or clay.

Ash has many uses as a marketable product. Re-using ash is preferable to landfill disposal or containment methods. Below are some uses for fly ash.

a) As an additive to Portland cement in the concrete industry

b) As structural fill in road construction

c) As soil amendment and fertilizer in agriculture

d) Stucco

Bottom ash particles are larger in size than fly ash. Bottom ash can be used as filler material in embankments, aggregate for road bases, and for traction control in snowy or icy environments. Coal-derived slag can be used as blasting grit for surface preparation and as a filler in asphalt.

Flue gas desulfurization processes that remove sulfur compounds from flue gas also create marketable byproducts. Like ash, these byproducts may be sold or treated as waste. This is dependent on the process that produced the byproducts, the market value, and end user product specifications. The saleable products of the regenerable FGD process include elemental sulfur, sulfuric acid, and gypsum. Unfortunately, regenerable FGD is more costly to install and is therefore less common. For this reason, most FGD byproducts are diverted to waste disposal.

FGD byproducts can be disposed either wet or dry. Again, surface impoundments or landfills are used. Dry landfill disposal is generally preferred because of its smaller volume and more options for reclamation.

Objective 4

List sources and effects of liquid and thermal pollution.

Liquid Pollution

The most abundant liquid on Earth is water. While nearly three quarters of the Earth's surface is covered with water, only a small amount (about 0.01%) is fresh surface water (lakes and streams). Water found in soil and rock formations is known as **groundwater**. Water consumption demands are met by using surface water and groundwater drawn from wells or springs.

Plants and industrial operations use a tremendous amount of water. Water discharged from these plants is known as **effluent**.

Water alone is not usually considered to be a contaminant. However, many of the thousands of materials suspended or dissolved in it are contaminants. When water is used for any purpose, it is usually of much lower quality when it is disposed. Potentially hazardous materials get into water either by direct dumping, or by various processes where water carries, cleans, or unintentionally dissolves a contaminant. When undesirable material is dissolved or suspended in water, the solution or mixture has the potential to be a liquid pollutant.

In some cases, and only if properly controlled, there are hazardous materials that can be released without creating a problem. Challenges arise when materials are released in an uncontrolled manner, such as a spill or a leak.

In an energy plant, there are many places where liquid wastes could originate such as:

- Cooling tower blowdown
- Boiler blowdown
- Waste from boiler waterside or fireside cleaning
- Ash handling slurries
- Water treatment equipment
- Plant floor drains
- Flue gas scrubbers
- Oil storage locations

If these liquids are not handled properly, liquid pollution could result.

Materials become pollutants when they begin to have adverse effects on other occupants of the ecosystem. The effects of pollutants vary considerably depending on:

- The type and quantity of the pollutant.
- The susceptibility of the local environment to the pollutant.
- Other conditions that may accentuate or lessen the effects of the pollutant.

When hazardous liquid spills occur, they could cause:

- Fires or explosions.
- Exposure of humans, animals, and plants to toxic fumes, vapours, or clouds.
- Hazardous byproducts formed by reactions in the environment.

Evidence of water pollution may show up as an unexpected increase or decrease in the population of one or more species. As well, sickness, deformity, and abnormal behaviour can occur in an otherwise normal population. Thousands of dead fish found along the banks of a river are an indicator of a hazardous spill.

Solid pollutants may be picked up or dissolved by runoff due to **precipitation**, and then become liquid pollutants. Industrial dusts may become liquid pollutants in this way.

Like gaseous and solid emissions, the allowable types and concentrations of liquid pollutant emissions from energy plants are usually regulated with a license or permit system. Permits will also reference allowed disposal processes and other permits that may be required. Power Engineers must ensure that the plants they operate meet these requirements.

Thermal Pollution in Liquid Reservoirs

One of the main factors to consider when choosing the location of a new power plant is the availability of a cooling water supply of sufficient quantity and quality. A condensing steam turbine requires large amounts of cooling water for use in the condenser. The water picks up considerable heat as it travels through the condenser and other related equipment. Then, it may discharge to its source at a higher temperature. This process causes **thermal pollution**.

Other contributors to warm water discharge are industries with high cooling loads, including:

- Steel mills
- Pulp mills
- Chemical processing plants
- Cold storage facilities
- Air conditioning cooling systems

As water gets warmer, its ability to dissolve oxygen decreases (this is the “de-aeration principle”). The reduced percentage of dissolved oxygen can have lethal effects on many kinds of water life. These effects have been proven both by experiment and actual observation. While in tropical regions, aquatic life may survive in water as warm as 35°C, North American aquatic life cannot adapt to such a warm environment. Even in moderate quantities, power plant effluent may asphyxiate fish passing through it, especially in narrow streams.

Elevated temperatures are common in areas below sewer discharge points. Some sections of rivers and lakes now remain free of ice year-round. This interrupts the normal migration patterns of waterfowl, partly because of accessibility to open water.

Thermal stratification can occur in lakes where wind and currents are not sufficient to cause mixing of incoming warm water. Stratification may trap other pollutants in layers at varying depths in a lake. These thermally separated layers are called **thermoclines**. In lakes, thermoclines can have layers with insufficient oxygen.

The release of thermal effluent into natural waters is regulated both at the federal, provincial and territorial levels. Regulations usually focus on limiting thermal releases, in order to not exceed the permitted **maximum weekly average temperature (MWAT)**. To ensure that energy plants have some flexibility in their effluent streams, artificially created lakes provide initial cooling to the released water. These lakes are generally located between the plant and the ultimate point of discharge.

Objective 5

Describe the preventive measures that can be taken to prevent liquid and thermal pollution.

Preventive Measures – Liquid Pollution

Liquid wastes are not pollutants, unless they escape containment, enter the environment, and cause adverse effects.

Proper treatment before the liquid waste enters the environment can prevent pollution.

Occasionally, effluent can be cleaned up to the point that part of it can be reused rather than dumped. This process also reduces the amount of fresh source water required. Some plants, notably in the pulp and paper and oil sand industries, are now being designed so that most or all of their wastewater can be reused, producing "near zero effluent."

The following principles and devices can be used to reduce the effects of liquid pollution:

- pH control
- settling ponds
- vacuum filters
- grease traps

pH Control

Effluents dumped into an existing stream should have a similar pH value to the receiving water. A deviation from this existing pH can damage life in the stream. Industries generating strongly alkaline or acidic effluents must neutralize the effluent before it is released. Even within cities or municipalities with common sewer collection systems, companies are required to maintain their wastewater discharge between given pH values.

Sewer line sampling monitors can detect sources of pH deviation. Fines are levied against the offenders. Companies that produce high or low pH waste streams monitor and neutralize their effluent before it enters the sewer system or waterway.

One common method of control uses a dilution tank or pond. If monitors detect a surge of acid, a chemical pump adds enough alkaline material to bring the effluent back to the desired pH. If the system shows an alkaline deviation, an acid pump is used to bring the pH under control. When the flow is neutralized, it can be discharged.

Settling Ponds

Some industries discharge particulate laden water from the process. In years past, it was common practice to dump the discharge into the nearest body of water and forget about it. The downstream effects did not concern management. However, through responsible management, regulatory requirements, and environmental awareness, this practice has rapidly changed. One method that improves this problem is the use of **settling ponds** or tanks.

Effluent is allowed to flow slowly through a settling pond, where particulate matter settles to the bottom. The clean effluent is then dumped into the body of water. Very fine particles or those in colloidal solution are too small to settle out in a settling pond. Industries that generate large quantities of colloidal material must use coagulants to help cluster these small particles together so that they will settle. This process is also used in some water supplies to cause accelerated settling of fine material.

Occasionally, effluent can be cleaned up to the point that part of it is cycled back to the water intake rather than being dumped. This process also reduces the amount of water required from the source. Some plants, notably in the pulp and paper industry, are now being designed so that most or all of their wastewater can be reused, thus attaining "zero effluent" targets. Oil sands mining operations in northern Alberta continually recycle over 80-95 percent of the water they use. A positive side effect is that some of the settled material formerly lost with effluent flow can be retained. This material may be returned to the process, where it is used rather than lost. This could create increased profits because of improved efficiency.

Vacuum Filters

Another method to capture particles is the vacuum filter. Water flows inward through a fine mesh filter, formed into the shape of a horizontal cylinder. The cylinder is partially submerged in an effluent tank. The cylinder slowly rotates, and material gathers on the outside of the filter. A vacuum is maintained inside the cylinder and causes dewatering of the filtered particles as they rotate above the water line. The material that is on the filter is scraped or blown off by an air jet and collected. The cleaned filter then rotates down into the effluent tank again, to filter more water. The filtered water on the inside of the cylinder is either pumped away for recycling or dumped if no further treatment is required.

Grease Traps

Some plant effluent may contain materials that float on the surface of the water, such as oils and greases. When the density of the materials is much lower than that of water, the material floats readily and can be separated by a simple skimming process, which may be accomplished using **grease traps**.

In a grease trap, water carrying oil or grease enters the chamber where a calm area allows separation to occur by gravity. The grease floats on the top and clean water is conducted away through the bottom outlet pipe. The grease or oil is then removed as it accumulates on top of the water. Large units may have several chambers in series to assure better capture. A surface skimming mechanism may also be used for continuous oil extraction. When the density difference between the water and the material is minimal, or when the material is emulsified with the water, a long calm period may not be enough to cause separation. In some cases, additives may be used to help break the emulsion so that separation can occur by gravity.

Another method is to use centrifugal separation. A centrifuge spins material at high speed, multiplying gravitational force hundreds or even thousands of times. This process is similar to the way that cream is separated from milk in a separator.

Other Methods

When liquids spill, they can travel great distances. This adds to the cost of control, clean up, and disposal. The use of evaporators or crystallizers can eliminate the liquid component of the waste. These devices leave behind a solid material that is easier to handle and cheaper to dispose.

The keys to limiting the effects of an uncontrolled release of liquid are to contain or immobilize the material and neutralize or lower its hazard potential.

Effective isolation may require a specific process to be housed in its own room or building with a dedicated water supply, ventilation, and effluent treatment. Containment dikes or catch basins are used to collect any excursions from the process area until neutralized.

Increased training and vigilance on the part of operators is a most effective method of pollution control.

Earthen or concrete berms are often used to contain releases from large vessels. Berms must be adequate in height so that bermed-in areas are capable of holding 110 percent of the vessel volume, according to Environment and Climate Change Canada and the **United States Environmental Protection Agency (USEPA)**. This volume requirement may increase, depending on local precipitation patterns and frequency of containment inspections. The 110 percent standard may not be sufficient for larger storm events. It is the responsibility of the owner or operator to determine if additional containment capacity is needed to contain rain.

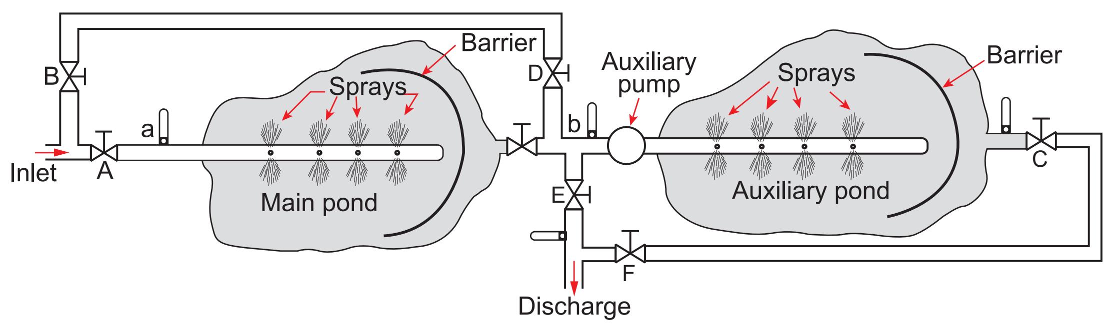
Preventive Measures – Thermal Pollution

Cooling Ponds

Cooling ponds are effective at preventing thermal pollution. If cooling water can be supplied in unlimited quantities, and there is sufficient flat space around the power plant, a cooling pond system might be the answer.

The arrangement shown in Figure 6 uses two ponds in series, although only one might be used at a time. When both ponds are used in series, then valves A, C, F, and G are open, while B, D, and E are closed. High temperature water enters through A and its temperature is recorded with a thermometer at location "a". The water is then sprayed into the main pond where it is discharged in a fine spray above the surface.

Figure 6 – Cooling Pond System



The droplets that are exposed to the atmospheric air not only cool down, but also have a chance to enrich themselves with oxygen. A barrier, as shown, maximizes the time the water spends in the main pond. The water exits through valve C and its temperature is recorded at location "b." The water then enters the suction of the auxiliary pump. The spraying process is repeated in the auxiliary pond and the temperature is recorded at location "c." Finally, the cooled water is discharged into the river or lake.

Cooling Towers

When a plant site cannot accommodate the installation of cooling ponds, **cooling towers** may be used instead. These towers allow most of the cooling water required by the plant to be recycled. Although the towers can cut down on thermal pollution, there are other considerations. If nearby industrial flue gas emissions contain SO_X, the water vapour discharging from cooling towers can contribute to localized acid rain. This causes damage to aquatic and plant life, and may also damage metal structures.

Another concern is the discharge of chemically treated water into the environment. The various chemicals used to keep the cooling tower water from developing bacteria and mold, or to prevent wood decay and metal damage, can have adverse effects on downstream aquatic organisms. The plant must treat this effluent before it can be discharged.

Objective 6

Describe methods of liquid waste disposal.

Liquid Waste Disposal

Environment and Climate Change Canada defines "disposal" and "treatment" as follows:

> ***Disposal:*** *The final disposal to landfill, land application or underground injection, either on the facility site or at a location off the facility site; transfer to a location off the facility site for storage or treatment prior to final disposal; or movement into an area where tailings or waste rock are discarded or stored, and further managed to reduce or prevent releases to air, water or land, either on the facility site or at a location off the facility site. The disposal of a substance is different from a direct release to air, water or land.*
>
> ***Treatment:*** *Subjecting a substance to physical, chemical, biological or thermal processes at a location off the facility site prior to final disposal.*

Several methods of disposal have been used through the years. Landfill was a quick and easy way to hide thousands of drums of hazardous material. The risk was not well assessed, as numerous old landfill sites are now leaking dangerous materials into waterways. Encasement and burial at sea has been used, but this merely moves the hazard to another location.

Deep well injection has been used to dispose of hazardous liquids into subsurface rock formations thousands of feet below the Earth's surface. This practice is a vast improvement over landfills, but again the hazard is only moved to another location.

The USEPA has restrictions regarding the land disposal of hazardous wastes (including Industrial and Municipal Waste Disposal Wells). The restrictions prohibit hazardous waste disposal unless the "waste has been treated to become non-hazardous or the disposer can demonstrate that the waste will remain where it has been placed for as long as it remains hazardous, which has been defined as *10,000* years by regulation."

Diluting liquid waste in order to stay within regulatory limits is not permitted.

There are other technologies and strategies that treat liquid waste to make disposal more effective. These treatment methods include:

- Physical treatment
- Chemical treatment
- Biological treatment
- Thermal treatment

Physical Treatment

Non-hazardous liquid waste can often be treated by dewatering and sedimentation, using settling ponds. Water can be removed from solid components by centrifuges, filtration, or other similar processes. Centrifuges work on the same principle as cyclone separators, but can be more complex in operation. Centrifuges are used in industries such as wastewater treatment, oil and gas, and sewage treatment.

Chemical Treatment

In a chemical treatment, chemicals can be added to liquid waste to neutralize highly basic or acidic liquids. Chemicals that cause precipitation, **coagulation**, and **flocculation** of matter are commonly used in wastewater and water treatment plants. There are also many types of **oxidation processes**. These processes can change organic and inorganic compounds into less hazardous forms.

Biological Treatment

Industrial effluent and wastewater that have significant organic components may be treated by **anaerobic digestion**, which is a biological treatment. This reduces the amount of organic matter and the amount of waste.

Thermal Treatment

The only certain way to destroy many organic materials is through complete combustion. This is accomplished in high temperature incinerators, which is a form of **thermal treatment**.

Environment and Climate Change Canada states: *"incineration is a type of thermal treatment that is recognized as an effective and environmentally sound disposal method for a wider range of wastes"*.

Incinerators can destroy liquid waste; however, they might produce gaseous emissions that require further treatment. Even with incineration, close control and vigilance is necessary to assure complete destruction of the waste.

Handling Liquid Waste

Transportation of hazardous liquids for disposal must be done carefully, in compliance with regulations, and with attention to the possible consequences.

Crude oil, gasoline, liquefied petroleum gas, solvents, fuel oils, lubricating oils, heat transfer oils, and hundreds of liquid products present unique hazards if spills or leaks occur. Spills in lakes, streams, oceans, or environmentally fragile areas cause environmental damage, even if relatively small amounts are involved.

Each liquid must be handled according to information on current material safety data sheets. Neutralizing cleanup and disposal procedures should be followed. Appropriate clothing, tools and containers must be employed and personnel working on the cleanup must be thoroughly decontaminated and monitored for effects—even after the cleanup is complete.

Safety Check

Power Engineers must be very familiar with the chemical compositions of the wastes being disposed. Before handling a waste material, review its Material Safety Data Sheet. Wear all required PPE. Be familiar with the company's Emergency Response Plan in case of a waste product environmental release.

Chapter Summary

Operation of industrial plants provides opportunity for solid and liquid waste to harm the environment. Knowing from where these emissions and effluents originate is the first step in controlling them.

An understanding of how waste treatment and handling systems are designed to work, and to what waste product they are best applied, is essential. With this knowledge, Power Engineers can operate these systems properly and according to regulatory requirements.

Careful selection, operation, and monitoring of emission and effluent control systems can minimize the impact of plant operation on the environment.

Unit Summary

Many human activities have the potential to create significant and lasting damage to the environment. Energy plant emissions have produced acid rain, ozone depletion, global warming and pollution. Though things have improved greatly over the past few decades, the potential for harm remains.

Power Engineers develop and rely on broad perspectives. Power Engineers cannot effectively operate facilities if they know only one of the many interdependent processes they are responsible for. They need to know how all facility components and processes work together.

Similarly, Power Engineers need to know how the Earth's systems work together to support life. They also need to know what pollutants their facilities produce, the effects these pollutants have on the environment, and how to reduce emissions produced from the facility. With this information, the right attitude, and by diligently following responsible operating procedures, Power Engineers can reduce their facility's negative environmental impact.

In the future, it is entirely possible that there will be new energy sources that do not have a negative impact the environment. Until then, Power Engineers have an obligation to ensure that facilities cause the least possible impact on the Earth and its ecosystem.

A self-assessment tool is available on MyPower LMS. Login using the unique user ID and password found on the inside front cover of Unit 1.

Notes

UNIT A-5

Knowledge Exercises and Unit Glossary

Knowledge Exercises – Chapter 1

Name: ______________________________ Date: ________________________________

Instructor: ___________________________ Course: ______________________________

Objective 1

1. Name the four Biogeochemical Cycles that operate within the environment. Describe each one.

Objective 2

2. Explain the role of producers, consumers, and decomposers.

3. Describe how the sun's energy drives the water cycle.

Chapter 1 (Cont.)

Objective 3

4. How does surface disturbance affect the environment?

Objective 4

5. How can the operator identify potential environmental impacts?

Objective 5

6. What are the three types of actions a Power Engineer can take to resolve a problem?

Objective 6

7. Explain why reclamation and remediation may not ever return the land to exactly the way it was before the facility was built.

8. Name three things an operator can do to reduce the amount of potential contamination at a facility, and to reduce the costs of reclamation when shutting down.

Knowledge Exercises – Chapter 2

Name: ______________________ Date: ______________________

Instructor: ______________________ Course: ______________________

Objective 1

1. Discuss the harmful effects of the following pollutants:

   a) Carbon monoxide

   b) Carbon dioxide

   c) Sulfur dioxide

2. Where do chlorofluorocarbons and fluorinated gases originate from? What are they used for and how do they enter the atmosphere? Why are they believed to contribute to global warming?

Chapter 2 (Cont.)

Objective 2

3. Explain the greenhouse effect.

4. Explain how acid rain is formed. What fuels contribute to it?

Objective 3

5. Why is it difficult to remove carbon dioxide from the atmosphere?

Chapter 2 (Cont.)

6. Briefly describe the testing methods used to detect NO_X, CO_2, and SO_2.

Objective 4

7. Discuss the problems associated with chronic noise exposure.

8. Describe how a sound enclosure for equipment, such as a diesel engine, works.

Knowledge Exercises – Chapter 3

Name: ______________________________ Date: ________________________________

Instructor: ___________________________ Course: ______________________________

Objective 1

1. What three ash products result from the burning of coal?

   a.

   b.

   c.

Objective 2

2. Explain why a bag filter works better when it has some dust build up.

3. Which type of particulate collector has the highest efficiency? Explain the operating theory behind this collector.

Objective 3

4. What methods are available for solid waste disposal?

Objective 4

5. Name a potential problem associated with a power plant's cooling water discharges.

Chapter 3 (Cont.)

6. What are the effects of low oxygen content in the water where it discharges from a plant?

Objective 5

7. What factors impact the effects of released pollutants?

8. What can be done to promote settling of very fine particles in a settling pond?

Objective 6

9. How is waste treatment different from waste disposal?

Unit A-5 Glossary

Term	Definition
Ambient emission monitoring	The collection and measurement of ambient air pollutants, to evaluate the status of the atmosphere as compared to clean air standards and historical information.
Anaerobic digestion	A processes whereby microorganisms breakdown biodegradable material in an atmosphere without oxygen.
Aquifer	A body of permeable rock that can contain or transmit groundwater.
Bagasse	Pulpy, fibrous waste product that remains after sugarcane is crushed to extract its juice.
Baghouse	An air pollution abatement device used to trap particulates by filtering gas streams through large fabric bags. The bags are usually made of glass fibers.
Biogeochemical	The term "biogeochemical" combines the terms biological, geological, and chemical. It recognizes that all three segments of the environment are involved in the cycling of molecules and compounds essential to life.
Biogeochemical cycle	The term Biogeochemical Cycle describes the circular pathway that materials and substances take as they move through the environment.
Biomass	A fuel made of organic material, usually plant based.
Bottom ash	The ash formed from the combustion of solid fuel that is too heavy to be entrained with the flow of flue gas.
CAC	See *criteria area contaminants* (CAC).
Carbon dioxide capture and storage (CCS)	A technology to remove and sequester up to 90% of the carbon dioxide emissions made by burning fossil fuels in electricity generation and industrial processes, thus reducing greenhouse gas emissions.
Carnivore	An animal that feeds exclusively on the animal tissue of herbivores and smaller carnivores. Carnivores include animals such as birds of prey and wild cats.
Cathodic corrosion prevention system	A means of preventing metallic corrosion using the principles of electrochemistry and direct current electricity.
CCS	See *carbon dioxide capture and storage* (CCS).
CEMS	See *continuous emissions monitoring system* (CEMS).
Chapman cycle	The ozone–oxygen cycle by which ozone is continually regenerated in Earth's stratosphere.
Chemiluminescence	The emission of light (without the development of heat) during a chemical reaction.
Chlorofluorocarbon	A volatile organic compound that contains only carbon, chlorine, and fluorine. CFCs are derived from methane, ethane, and propane, and have been used as refrigerants or aerosol propellants.
Closed hydrocarbon drain	A fully enclosed piping system for gathering and retaining waste hydrocarbon streams for ultimate disposal or reintroduction to regular process streams.
Coagulation	The use of chemicals that cause suspended matter to join together into larger particles. This makes it easier to remove the suspended matter from the liquid by settling, skimming, draining, or filtering.
Contaminated sewer	A sewer system designed to handle and collect only contaminated waste for treatment and disposal.

Term	Definition
Continuous emission monitoring system (CEMS)	An instrument that provides uninterrupted measurement of actual emissions (such as carbon dioxide, carbon monoxide, sulfur oxides, and nitrogen oxides) from industrial sources, for the purposes of analysis, monitoring, and reporting.
Cooling pond	An artificial body of water created to lower the temperature of process water so it can be re-used in nearby industrial facilities to cool equipment or processes.
Cooling tower	A device that rejects waste heat from water by evaporating a portion of the water, thus cooling the remainder for reuse as industrial coolant .
Criteria area contaminants (CAC)	A set of air pollutants that cause smog, acid rain, and other health hazards.
Decibel	A unit used to measure the intensity of a sound by comparing it with a standard reference point on a logarithmic scale.
Decomposer	An organism that breaks down other dead or decaying organisms. Decomposers are primarily fungi.
Dilbit	Bitumen diluted with naphtha to reduce its viscosity.
Diluent	A thinning agent. In the oil and gas industry, a diluent is added to bitumen to make it easier to transport.
Effluent	The waste product streams discharging from a process, that often require further treatment.
Electrostatic precipitator	An air pollution control device that imparts an electrical charge to particles in a gas stream causing them to collect on an electrode.
Exosphere	The outermost region of the Earth's atmosphere.
FGD	See *flue gas desulfurization* (FGD).
Flocculation	The gathering together of small particles to form larger particles.
Flue gas desulfurization (FGD)	A method of controlling sulfur dioxide emissions by removing the sulfur compounds from the flue gas after combustion.
Fly ash	A product of the combustion of coal. Fly ash is comprised of very fine particles, which are carried out of the furnace with the flue gases. Fly ash ranges in size from about 1 micron to 300 microns.
Fuel NO_X	Nitrogen oxides created by the chemical reaction of oxygen with fuel-based nitrogen.
GHG	See *greenhouse gas* (GHG).
Global warming potential (GWP)	GWP is a relative measure of the amount of heat trapped by the mass of a particular atmospheric greenhouse gas to the amount of heat trapped by the same mass of carbon dioxide.
Grease trap	A plumbing device designed to intercept most greases and oils before they enter a wastewater disposal system.
Greenhouse gas (GHG)	A gas, such as water vapour or carbon dioxide that contributes to global warming by absorbing infrared radiation.
Groundwater	All sub-surface waters, i.e., wells and springs.
Group of seven (G7) countries	An international organization that facilitates economic cooperation among the world's largest industrial nations, including Canada, France, Germany, Great Britain, Italy, Japan, and the United States.
GWP	See *global warming potential* (GWP).
HCFC	See *hydrochlorofluorocarbon* (HCFC).

Term	Definition
Herbivore	An animal that feeds exclusively on plant tissue. Herbivores include animals such as cattle and deer.
HFC	See *hydrofluorocarbon* (HFC).
Hog fuel	A fuel made of coarse wood chips and tree bark.
Hydrochlorofluorocarbon (HCFC)	A class of relatively inert volatile organic compounds that contain carbon, hydrogen, chlorine, and fluorine; manufactured to replace chlorofluorocarbons and reduce ozone layer destruction.
Hydrofluorocarbon (HFC)	A class of synthetically produced volatile organic compounds composed of hydrogen, fluorine, and carbon; developed to replace hydrofluorocarbons and chlorofluorocarbon refrigerants.
Leaching	To drain nutrients, minerals or other soluble substances away from soil, ash, or similar material by the action of percolating liquid, especially rainwater.
Low NO_X burner	A burner with specific design features so that it produces less thermal NO_X.
Maximum weekly average temperature (MWAT)	The largest mathematical mean of multiple, equally spaced, daily temperatures over a seven-day consecutive period, with a minimum of three data points spaced equally throughout the day.
Mesosphere	The region of the earth's atmosphere above the stratosphere and below the thermosphere, between about 50 and 80 km in altitude.
Micron	A unit of measure equal to 0.001 mm or 1 millionth of a meter.
Montreal protocol	An international treaty designed to protect the ozone layer by phasing out the production of numerous substances deemed responsible for ozone depletion.
Municipal solid waste	Untreated solid waste material as collected from household and commercial establishments. It is highly variable in appearance, density, and heat content.
MWAT	See *maximum weekly average temperature* (MWAT).
NDIR	See *non-dispersive infrared detection* (NDIR).
Nitrogen oxide	Oxides of nitrogen, including NO, N_2O and NO_2.
Non-dispersive infrared detection (NDIR)	The most common method used to measure carbon dioxide and carbon monoxide emissions from industrial process effluents including flue gas. An infrared lamp directs waves of light through a tube filled with sample gas toward a detector that measures the amount of infrared light absorbed by the sample.
NO_X	Oxides of nitrogen, including NO, N_2O and NO_2.
ODS (book)	See *ozone depleting substance* (ODS).
Omnivore	An animal that is capable of obtaining nutrients by consuming either plant or animal tissue.
Oxidation	A chemical reaction whereby the atoms of a substance lose electrons.
Ozone depleting substance (ODS)	Stable volatile substance that contains chlorine, fluorine, bromine, carbon, and hydrogen, and reduce stratospheric ozone concentration.
Ozone layer	A layer of the Earth's stratosphere that absorbs most of the sun's ultraviolet radiation through the continuous production of ozone. It contains high concentrations of ozone in relation to other parts of the atmosphere.
Particulate	Fine liquid or solid particles such as dust, smoke, mist, fumes, or smog found in the air.

Term	Definition
Perfluorocarbon (PFC)	A group of powerful greenhouse gases composed of carbon and fluorine that were introduced as alternatives to ozone depleting substances.
PFC	See *perfluorocarbon* (PFC).
Precipitation	Solid that separates from a solution because of some chemical or physical change.
Selective catalytic reduction	A post-combustion exhaust gas treatment that is capable of reducing up to 95% of NO_X emissions from a wide variety of boilers and internal combustion engines. This is accomplished by directing urea or ammonia into the exhaust gas stream in the presence of a platinum catalyst.
Selective non-catalytic reduction	A method of reducing NO_X emissions from industrial and utility boilers by directing urea or ammonia into the furnace without the need for an expensive catalyst.
Settling pond	A holding area for wastewater, where heavier particles sink to the bottom and can be siphoned off.
Slag	A glass-like by-product left over from high-temperature processes such as metal production.
Source emission monitoring	The collection and measurement of air pollutants directly at the emissions source, to determine regulatory compliance with clean air standards.
SO_X	Oxides of sulfur, resulting from combustion (typically SO_2 and SO_3).
Stratosphere	The layer of the earth's atmosphere above the troposphere, extending to about 50 km above the earth's surface.
Symbiosis	The interaction of two species that live together in more or less direct contact. Sometimes this interaction is to mutual benefit (Mutualism). Sometimes one organism benefits at the expense of the other (Parasitism).
Thermal NO_X	Nitrogen oxides created by high temperature chemical reaction of oxygen with combustion air-sourced nitrogen.
Thermal pollution	An adverse rise in the temperature of bodies of water, or the atmosphere, caused by heated industrial effluent streams.
Thermal treatment	The treatment of municipal, commercial, and industrial waste by combustion, gasification, pyrolysis or plasma systems.
Thermocline	A layer in a large body of water which changes temperature more rapidly than the layers above or below.
Thermosphere	The layer of the Earth's atmosphere between the mesosphere and the exosphere. The thermosphere is characterized throughout by an increase in temperature with increasing altitude.
Troposphere	The lowest atmospheric layer. It extends from the Earth's surface up to the base of the stratosphere. The troposphere contains approximately 80% of atmospheric matter, and is where all of Earth's weather occurs.
Ultraviolet (UV) light	Electromagnetic radiation that has wavelengths between that of violet light and x-rays.
United States environmental protection agency (USEPA)	An agency of the United States Federal Government, created to protect human health and the natural environment by writing and enforcing regulations.
USEPA	See *United States environmental protection agency* (USEPA).
VOC	See *volatile organic compounds* (VOC).
Volatile organic compounds (VOC)	Organic chemicals (typically hydrocarbons) with a high vapor pressure (low saturation temperature) at room temperature. This causes molecules to readily evaporate from the liquid state, or sublimate from the solid state, and enter the surrounding air, a trait known as volatility.

Additional Workspace

Additional Workspace