Mineral Resources & Waste Disposal

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Summary

But there must be the look ahead, there must be a realization of the fact that to waste, to destroy, our natural resources, to skin and exhaust the land instead of using it so as to increase its usefulness, will result in undermining in the days of our children the very prosperity which we ought by right to hand down to them amplified and developed.

Theodore Roosevelt

It is easy for Americans to criticize Brazil's record on the environment, since they already live in a rich, industrialized country. But the U.S. achieved this status largely by doing just what Brazil is condemned for: ruthlessly exploiting natural resources - including cutting down most of its native forests. Even more galling, the U.S. continues to be a major degrader of the planet.

Haroldo Mattos De Lemos
Introduction

- Renewable resources are replenished on short-term time scales measured in days to years.
- Non-renewable or finite resources are replenished on time scales measured in millions of years and are essentially lost following consumption.
- Mineral resources include non-food, non-fuel resources such as metals and natural aggregates.
- Reserves are resources that can be economically extracted using existing technology.
- The volume of reserves is much less than the volume of resources.
- Mineral reserves will continue to increase because of the discovery of new mineral sources, increasing prices, and technological improvements in mining operations.

Life on Earth requires the use of resources. The term resources covers everything we use, including such basic assets as air, soil, timber, and water; fuel resources like coal, oil, and gas; and mineral resources, such as sand and gravel. These natural resources may be renewable or non-renewable. Renewable resources are replenished constantly (wind, soil), on short-term time scales measured in months (crops), or over longer intervals of several years (timber). Non-renewable resources are either lost following consumption (fossil fuels) or may be recycled to be used in other products (metals). In 1900, renewable resources (agriculture, food, forest materials) accounted for 41% of the consumption of U.S. raw materials. Today they represent just 8% of total materials consumed (by weight). The use of all types of mineral resources has increased dramatically since 1900, with the greatest increase coming in the most basic resources (Fig. 1).

Figure 1. Selected raw materials consumed in the U.S., 1900 to 1995. For this graph, construction materials have been separated from the remainder of the industrial minerals to illustrate the upsurge in construction following the end of World War II.
We are all familiar with the most common mineral resources but there are a host of others that play vital roles in our society yet remain virtually unknown. The metal palladium is an example of such an unknown mineral resource, despite the fact that it plays an important role in automotive catalytic converters in improving U.S. air quality.

In this chapter we use the term mineral resources to include non-food, non-fuel resources such as metals (e.g., aluminum, palladium) and industrial minerals (e.g., gypsum, phosphate). Mineral resources become concentrated in Earth's crust as a result of specific geologic processes associated with the formation of rocks. Exploration for minerals requires that geologists recognize the telltale evidence that signals the presence of useful mineral deposits. (See the geology of mineral resources section in the chapter, Rocks and Minerals, for more on the geologic characteristic of some of the more common mineral deposits.)

Mineral resources are distributed unevenly within the shallow crust. Reserves represent the volume of mineral resources that can be economically extracted from Earth's crust using current mining technology. The volume of reserves will always be less than the volume of resources (Fig. 2). Many metallic ores formed as a result of igneous or metamorphic processes associated with plate tectonics. Consequently, metallic deposits are often concentrated near current or former plate boundaries. The next section of this chapter discusses the national and international distribution of mineral resources. Nations that are fortunate to have such deposits may earn substantial revenues from exports but such revenues are often affected by cultural forces over which they may have little control.

Reserves continue to increase despite growing demand because of:

1. New sources of minerals that continue to be discovered as geologic understanding of resource concentration improves.

2. Price increases that make previously sparsely distributed ores relatively economical to produce.

3. Technological improvements in mining processes that have resulted in more efficient mining operations. World reserves of gold increased by approximately a third in the
last 30 years, primarily as a result of improved extraction techniques.

Future concerns over resources are less likely to focus on access to suitable reserves and are more likely to be concerned with the interaction between mineral extraction, refining, and the degradation of the environment.

The development of mineral resources depends on more than just the presence of a mineral deposit. Determining if a mining operation will be economically viable depends upon geologic factors (the quality and quantity of the ore body), mining costs, and the market price of the commodity being mined.

The recent history of palladium illustrates some of the cultural forces that may impact the development of specific resources. The U.S. imports over 150,000 kg of palladium annually, more than the total worldwide production. Imports can exceed production only because some nations are selling from stockpiles of the metal. Russia supplied over half of U.S. palladium imports in recent years. The price of palladium on the world market recently soared to over $700/ounce, more than double the average price of the metal in 1998, mainly because of uncertainty about future Russian supplies. This price is likely to decrease as the only U.S. supplier, the Stillwater Mining Company, expands current production to meet higher demand.

Figure 3. Materials flow history for U.S. non-fuel mineral resources. Annual value of resources at different states are indicated in green ($ billions).
Careful stewardship will ensure that renewable resources such as soil and water remain unharmed by use, although some will inevitably be lost to development. In contrast, many energy and mineral resources are finite and will be either consumed or recycled. The consumption of these resources generates waste during extraction, refining, manufacturing, and marketing. Both the volume of waste and concerns about waste disposal increase with a society's affluence and population density. A systems approach to mineral resources examines materials flow (Fig. 3), the fate of a resource from its original source in a mine to its ultimate destination in the waste stream.

Many mineral resources that would have ended up in a dump just a few decades ago are now recycled. Recycling reduces the need to mine the original resources, thus extending the life of the resource base, and provides additional benefits such as energy savings, and pollution reduction.

Think about it . . .
1. Identify three examples each of renewable and non-renewable resources that you use daily.
2. Choose a mineral resource and create a materials flow diagram that illustrates the life cycle of the commodity from extraction to waste disposal/recycling. Use information sources such as the USGS Minerals Information site at http://minerals.usgs.gov/minerals/

The Distribution of Mineral Resources

- Most metallic ores are located adjacent to present or former plate boundaries.
- Mineral resources are more common in large countries than smaller nations although some small countries may have high-grade deposits of individual resources.
- Mineral supply relies on governments remaining on good terms, at least for the trading of mutually beneficial resources.
- The U.S. must import 100% of all the arsenic, bauxite, graphite, and manganese it consumes but has plentiful
supplies of commodities like phosphate rock, asbestos, iron ore, and salt.

- Industrial minerals are the most valuable resource mined in 42 states.

Introduction

Mineral resources (especially metallic minerals) are associated with specific types of geologic settings. Most metallic ores form directly or indirectly as a result of igneous activity that is associated with convergent and divergent plate boundaries. Submarine divergent boundaries are effectively inaccessible for mineral extraction so most mineral exploration is focused on current or ancient convergent boundaries or, less commonly, continental rift zones, the earliest stage in the formation of a divergent boundary. As the geologic processes associated with mineralization are associated with convergent boundaries, it should come as no surprise that many mines are located at high elevations in mountainous terrain formed as a result of plate convergence (Fig. 4).

We are familiar with the distribution of recently active convergent plate boundaries but we must also recognize that there are numerous ancient zones of plate convergence that are no longer located close to a present-day boundary. For example, mines in the Appalachian Mountains contain mineral deposits formed when Africa and North America collided approximately 300 million years ago. Nations such as South Africa earn substantial revenues from the export of mineral resources located in ancient igneous rocks formed over a billion years ago. South Africa has the world's greatest reserves of gold (50 mines) and is a leading producer of diamonds (60 mines) and platinum-group metals. Mining alone generates 8% of South Africa's gross domestic product (GDP).

Figure 4. Mineralization zones associated with geologically recent convergent plate boundaries are shown in orange. Older convergent (or divergent) boundaries will also host mineral deposits.
Global Distribution of Mineral Resources

We will focus on metallic mineral resources in this section because they are less common than basic industrial minerals and are more significant in this era of rapidly improving technological manufacturing. The availability of mineral resources is often directly correlated to land area: **large countries generally have more minerals** than small countries. Large nations such as China, Russia, Canada, Brazil, and the U.S. are among the world leaders in the production of a wide variety of mineral resources. Smaller nations may benefit from localized deposits of individual minerals. For example, **Morocco** in northeast Africa is the world’s foremost exporter of phosphate rock used in fertilizers while **Guinea** in South America is a principal source of bauxite used in the manufacture of aluminum.

For many governments the issue is not one of mineral distribution but of **mineral supply**. In such cases it is relatively unimportant where the mineral is located as long as it can be imported inexpensively. Prices increase and problems arise...
when the required mineral is unavailable. However, many governments have proven extremely flexible in their import policies when the situation required it. Today the U.S. imports 100% of its manganese, 94% of its platinum, and 79% of its chromium (Fig. 5). The major source for each of these imports is South Africa. However, U.S. relations with South Africa have not always been as cordial as they are today. The U.S. imposed trade sanctions against the former apartheid government of South Africa in the late 1980s but was careful to exempt the above mentioned minerals (and several others). As one author has written, we “adopted a very strong policy against importing anything we didn't need from South Africa” (Wheeler, G., 1999, Journal of Geoscience Education).

U.S. Distribution of Mineral Resources

Crushed stone represents the most valuable non-fuel mineral produced in the U.S. (~$9 billion annually) and 22% of total non-fuel mineral production ($40 billion). The total annual value of U.S. industrial minerals represents 72% of the value of all minerals mined in the U.S. Industrial minerals are mined in every state for use in the construction industry and represent the most valuable commodity in all but seven states (Fig. 6). Consequently, it should be little surprise that construction materials (crushed stone, sand, and gravel) dominate mineral production in the more densely populated eastern and westernmost states. The top-10 states in the value of mineral production are distributed throughout the nation (Fig. 7).

Figure 6. Principal minerals produced per state. Zinc is the most valuable commodity in Alaska, crushed stone in Hawaii.
Demand for mineral resources has increased more slowly over the last few decades.

The U.S. is the largest consumer of metals in the world.

Mineral reserves continue to increase because of better geologic knowledge, rising prices, and improved technology.

Past mining practices eroded the landscape and caused pollution.

Modern mining regulations protect the land, wildlife, and people.

Gold production has recently increased substantially because of the development of the cyanide heap leaching mining method.

Figure 7. Top-10 states in order of the value of non-fuel mineral production, 1998. These states account for more than half (52%) of the value of U.S. mineral production. Metals were the dominant resources in Nevada (gold, silver, copper), Arizona (copper), Minnesota (iron ore) and Utah (copper).

Think about it . . .
You are a purchasing agent for a major manufacturing company that must import raw materials from abroad. There are three potential sources of materials, each in a different nation. What factors will you consider in making your decision about where to obtain the materials?
Introduction
Concerns about the availability of mineral resources have often influenced U.S. political policies. The 1872 mining law made public lands available cheaply to be used for mining in an effort to encourage western expansion. President Theodore Roosevelt convened a Conference on Conservation at the White House in 1908 amid anxiety about the future supply of our national resources. Forty-four years later the Paley Commission reported to President Truman that population growth would assuredly endanger the finite supply of U.S. resources. These and other initiatives consistently underestimated the availability of mineral resources and or failed to foresee the development of new technologies that would make resource extraction easier (and less expensive) as well as provide a range of alternative resources. The national demand for resources increased during economic good times after World War II. Recently the demand for most resources has continued to increase, but at a slower rate as a result of positive economic and industrial changes, active metal recycling programs, and the introduction of alternative materials (e.g., plastics, ceramics).

The U.S. is the world's leading consumer of raw materials, accounting for approximately one-third of all materials consumed worldwide.

Mining Processes
The days of the miner with little more than a pan and a pick axe are over. Early mining methods involved physically separating metallic ores from the rock or allowing natural processes (e.g., weathering, erosion) to do it for you. Today's mining operations process hundreds of tons of ore at a time and require extensive physical facilities, a large capital investment, and compliance with numerous environmental regulations.

The production of gold and other metals has increased dramatically in recent decades because of modern mining methods. Gold can be extracted from even low-grade ores that would previously have been considered uneconomical using a technique known as cyanide heap leaching. As a result of this technique, an ore might now be considered economic if it contains as little as ~0.06 ounces of gold per ton. During cyanide heap leaching, the ore is mined and crushed into smaller pieces. This creates more surface area for the cyanide
solution to work on. A cyanide solution is then poured over a pile of the crushed ore. As the solution migrates through the rocks it dissolves out the gold. The solution is collected by a drainage system installed at the base of the pile. The gold is separated from the solution.

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<thead>
<tr>
<th>Mining Processes: Copper Mining</th>
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<tr>
<td><strong>Exploration</strong></td>
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<td><strong>Site development</strong></td>
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<td><strong>Ore extracted</strong></td>
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<td><strong>Ores crushed</strong></td>
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<td><strong>Metals concentrated</strong></td>
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<td><strong>Metals more concentrated</strong></td>
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<td><strong>Metals refined</strong></td>
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Although this new mining technique has dramatically enhanced gold production, it has also resulted in environmental problems in the U.S. and abroad. Cyanide solution polluted the Essequibo River in Guyana along South America's Atlantic Coast in 1995, and a recent (January 30, 2000) leak from the Romanian Baia Mare gold mine killed fish as it polluted
stretches of several rivers (including the Danube) in Romania, Hungary, and Yugoslavia.

Mining and the Environment

Future concerns over resources are less likely to focus on access to suitable reserves of key minerals and are more likely to be concerned with the interaction between mineral extraction, production, and the environment. The environmental impact of mining is dependent upon the type of mined minerals or metals, the environment surrounding the mine, the mining techniques employed, and the methods used to minimize the impact of mining on the environment. Modern mines in the U.S. are regulated to:

- Protect the landscape: Some types of surface mines have to return the land surface to its original shape after mining. Road building and construction inevitably alter natural landscape during the mining process.
- Protect wildlife: Native vegetation has to be reintroduced after mining; companies must not harm surrounding ecosystems. Aquatic ecosystems can be harmed by polluted runoff or groundwater flow that is contaminated by metals, even in low concentrations.
- Protect people: Regulations seek to prevent pollution of air, water, or soil as a result of mining.

Several sites on western public lands such as Death Valley (California), Northern Cascades (Washington), and Grand Staircase (Utah) are examples of places where the value of the aesthetic or recreational resources have been ranked ahead of mineral resources. Each of these sites has been created or expanded over the last few decades despite evidence of potential mineral resources within their boundaries.

Past mining practices have altered the landscape and polluted water systems. During the gold rush days in California, placer deposits with ~1 ounce of gold per ton of gravel were blasted out of river banks by hydraulic mining using high-pressure hoses. The gravel was washed through a series of devices designed to separate out the gold. The remaining gravel and sediment was flushed into river channels. Such mining techniques washed away stream banks and clogged streams with sediment that caused downstream flooding. The eroded landscape that resulted from such mining techniques is still visible today, over a century later.
Water reacts with metallic ores to form an acid-rich runoff termed **acid mine drainage**. Acid mine drainage forms naturally in places where metal-rich rocks are exposed at the surface and can be exaggerated by the effects of mining which exposes large volumes of waste rock to the effects of weathering. The acidity of mine waters can be reduced artificially by adding crushed lime or naturally if the waters flow through carbonate rocks (e.g., limestone). Abandoned mines throughout the West are potential sources of pollution. In addition, drainage within mines can pollute groundwater systems. **Pit lakes**, formed when a former open pit mine site fills with water, can discharge acid mine waters to local aquifers. A flight of snow geese died when they landed on an acidic lake in an abandoned mine in Butte, Montana, in 1995. **Groundwater withdrawals** to prevent flooding of an active mine can lower water levels in aquifers or change the direction of groundwater flow. Water pumped out of the mine into local streams can cause higher-than-normal flows, altering local ecosystems.

Air pollution may result from **smelter emissions** generated during the refining of metallic ores. Sulfur dioxide, a common product of smelters, may combine with water to form sulfuric acid and has killed vegetation downwind from mining facilities in several western mine sites (e.g., Anaconda, Montana).

*Case History: Summitville, Colorado*

There are an estimated half million abandoned hard rock (metal) mines in U.S., and several of these sites have succeeded in making it onto the infamous Superfund National...
Priorities List (see next section) of the nation's most contaminated sites. The Summitville Mine (Fig. 8), located high up (3,500 meters [11,500 feet]) in the Colorado Rockies, was added to the National Priorities List in 1994 but unlike many other contaminated sites, the pollution was not the result of century-old mining techniques but was a much more recent phenomenon.

Summitville is a gold mine that attempted to extract gold from the native ore using cyanide heap leaching. The high altitude of the mine ensures that the site is snow covered for much of the year and that meltwaters are continually passing through the site. The cyanide solution began to leak from the site soon after the mine became operational. Six years later the company declared bankruptcy and walked away from the mine. The pollution of the site itself and several miles of adjoining streams became the problem of the state of Colorado and the EPA. Estimates suggest that the site cleanup will eventually cost $130 million.

Think about it . . .
Use the Venn diagram found at the end of the chapter to compare and contrast the similarities and differences between any two metal mining operations described in the Current Projects section of the Mining Technology site.

Waste Disposal

- Waste can be divided into three basic categories: municipal, hazardous, and radioactive.
- Municipal waste may be disposed of by combustion, burial in a landfill, or recovery (recycling, composting).
- Potential landfill sites are relatively plentiful, unfortunately, they may not be located where a significant volume of waste is generated.
- Landfills produce methane gas and leachates that must be monitored to ensure they can't escape to cause explosions or pollution.
The safest landfill sites are constructed on impermeable materials and contain inert materials (e.g., construction wastes).

Hazardous wastes are flammable, corrosive, reactive and toxic and are disposed of in deep injection wells or secure landfills.

Our existence on the planet requires that we use resources. Careful stewardship will ensure that renewable resources such as soil and water remain unharmed by use, although some are inevitably lost to development. In contrast, many energy and mineral resources are finite and must eventually be consumed. The consumption of these resources generates waste during extraction, refining, manufacturing, and marketing.

We can divide waste into one of three general categories: (1) municipal waste; (2) hazardous (toxic) waste; and, (3) radioactive (nuclear) waste. Nuclear waste is discussed in the chapter, Energy and Air Pollution, and will not be considered further here.

Municipal Waste

Municipal solid waste represents the garbage picked up weekly at curbs across the U.S. Its principal constituents (after recycling) are paper, plastics, and food waste. The U.S. generates 220 million tons of waste each year but this figure is reduced to 156 million tons after recovery by recycling or composting (Fig. 9). Waste production has steadily climbed but both the volume of waste left after recovery and the amount of waste per person after recovery have declined in recent years. Residents of affluent nations typically produce more waste than...
inhabitants of developing nations. For example the citizens of Washington, D.C., generate approximately four times as much municipal waste per person as their peers in the large cities of São Paulo, Brazil, or Bangkok, Thailand.

Municipal waste in the U.S. undergoes one of three possible fates; it may be burned (combustion), buried (landfill), or recovered to be used again (Fig. 10). Changes in U.S. waste management strategies over the last 40 years have resulted in greater emphasis being placed on recovery methods and proportionally less waste being assigned to landfills. Modern efforts to limit waste generation often revolve around the mantra of the three Rs, reduce, reuse, and recycle (we revisit this topic in the next section). Recovery accounted for just 6% of all U.S. municipal waste disposal in 1960 but approximately 30% today.

Combustion (Incineration)
Seventeen percent of U.S. waste is reduced in volume by burning at high temperatures (900-1,000°C) in incinerators (Fig. 11). Waste-to-energy facilities may use the heat produced to generate electricity. Combustion can reduce the volume of waste by up to 90% at the landfill (ashes). Unfortunately, combustion may generate emissions that run afoul of federal clean air standards and require expensive antipollution technology. The more than 100 incinerators in the U.S. burn over 100,000 tons of waste per day. These facilities are overseen by the EPA's Office of Air and Radiation to guard against the potential for air pollution.

Combustion is most extensively used as a disposal technique in the northeast with several states accounting for more than 20% of their waste disposal by incineration (Fig. 11).
Landfills

Waste is buried, isolating it from people and the rest of the physical environment. Thirty years ago this would have meant taking garbage to the dump, today the disposal facilities are specifically engineered sanitary landfills.

Landfills account for over half of all U.S. municipal waste disposal (53%) but this proportion has steadily declined over the last several decades. There are approximately 2,300 landfills in the U.S., down from over 8,000 in the late 1980s, however, the volume of landfill space has remained essentially constant because modern landfills are much larger than their predecessors. Landfills are most common in the largest states.
Alaska, California, and Texas have 30% of U.S. landfills (Fig. 12).

Two cities, New York and Los Angeles, account for nearly a tenth of all U.S. garbage. Both cities are running out of room in their current landfills and must consider alternative disposal strategies in densely populated regions with high land prices (Fig. 12). New York's last major landfill, Fresh Kills, will close during 2001. Efforts to reduce the volume of waste going to landfills (Fig. 13) have included the implementation of aggressive recycling programs or negative economic incentives (e.g., charging extra fees for multiple trash containers). New York began to ship its waste to a landfill in Waverly, Virginia, in the late 1990s to take advantage of lower disposal (tipping) fees in more rural locations.

![Figure 13. State landfill disposal rates are greatest in western states where population density is least. Map from EPA Municipal Solid Waste site.](image)

Municipal solid wastes that are not recycled are typically disposed off in **sanitary landfills** that are constructed under strict guidelines that seek to prevent the escape of pollutants. The goal of a sanitary landfill is to compress waste to its smallest volume and confine it in a restricted area, away from potential interference (Fig. 14). The principal environmental problems associated with landfills are the escape of explosive gases and polluted liquids. In an effort to prevent these problems, landfills are enclosed by layers of impermeable materials such as plastic and clay with the goals of preventing water from entering the landfill, and stopping waterborne pollutants from leaking from the site. **Leachate** is the term used to describe water polluted with chemicals and/or bacteria from a landfill. Leachate may contaminate local water supplies.
if it finds a passage to escape from the landfill. **Methane gas** forms naturally in landfills as a result of the decomposition of organic waste (e.g., food and yard wastes). The uncontrolled escape of this explosive gas represents a hazard, whereas the controlled escape of the gas creates a resource that can be used as a heating fuel.

Locating a landfill requires consideration of the site's underlying **geology** and the **type of waste**. The principal geologic characteristics are concerned with water. Permeability – the ability of water to flow through the rock or sediment underlying the site – controls how readily leachate that escapes from the site may contaminate groundwater. In addition the relative locations of the **water table** (top of the groundwater source) and the landfill site will influence the potential risk of pollution. The potentially safest landfill sites are on low-permeability materials far from the water table. Unfortunately, sometimes we have little choice were we must site landfills and some are inevitably in non-ideal locations. The type of waste placed in the landfill can be controlled if there is a risk of contamination of the surrounding environment. Hazardous, soluble wastes (Fig. 15) are best placed in secure landfills whereas, non-hazardous, non-soluble items may be discarded in almost all landfills. Landfills are divided into three types based upon geology and character of waste:

- **Class 1** – site on low permeability rocks, may accept all types of wastes.
- **Class 2** – site on rock/sediment above water table, no hazardous waste accepted.
• Class 3 – site directly connected to groundwater supply, accepts inert materials only that are non-hazardous and non-soluble, e.g., concrete, clays.

Hazardous Wastes

Hazardous wastes include materials that are:

• **Flammable** - ignite readily, e.g., petroleum products, solvents
• **Corrosive** - acids (ph<2) or bases (ph>12), e.g., household cleaners.
• **Reactive** - may explode in contact with water, other materials.
• **Toxic** - to people or organisms, e.g., pesticides, PCBs, mercury.

Modern disposal methods for hazardous wastes involve placing them in a **secure landfill** (Fig. 16) or isolating them in rock layers using deep well injection. Secure landfills are similar to sanitary landfills in that they seek to isolate the waste but take some additional steps to ensure leachates don't escape the site. Leachate retrieval and treatment facilities are routinely...
included in secure landfill and groundwater wells around the landfill site are used to monitor any potential contamination from leaks.

**Deep well injection** (Fig. 17) accounts for more than half of all chemical hazardous wastes disposed of annually in the U.S. The waste is pumped into rock layers that are geologically separated from groundwater sources. Disposal layers are separated from aquifers by aquicludes - impermeable layers of rock or sediment.

However, even under the best circumstances there is much about the subsurface geology that is unknown. Hazardous chemical wastes might contaminate groundwater supplies by leaking from surface storage sites, leaking from corroded or cracked well casings in the injection wells, or by traveling through fractures from the disposal layer to the groundwater supply.

The Safe Drinking Water Act created the Underground Injection Control (UIC) Program to regulate injection wells. The EPA defines five classes of wells according to the type of waste they inject and where the waste is injected.

**Superfund**

Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in 1980 to clean up the nation's most heavily polluted sites. Superfund was created as part of CERCLA to pay for the cleanup sites where the original polluter could not be determined or was unavailable to cover the expense of cleaning the site. Superfund’s implementation has generated a three-cornered conflict between the Environmental Protection Agency (EPA, administers Superfund), businesses, and environmentalists. The EPA has received criticism from both business advocates, who believe cleanup costs are too high and standards too stringent, and citizen groups that believe that the pace of cleanup should be accelerated and that high standards should be maintained.

There are thousands of hazardous waste sites in the U.S. and Superfund can only deal with the worst cases (Fig. 18), which it places on the National Priority List (NPL). Nearly 2,000 sites have made it on to the NPL since the program was implemented and over 670 have been cleaned up. The EPA
identifies priority sites for cleanup using a hazard ranking system that evaluates the:

- Potential for leakage from the site, now and in the future.
- Toxicity and volume of waste.
- Proximity to people and habitats.

Cleanup of polluted sites involves several steps that occur over several years. Sites must first be evaluated and a remediation program designed and implemented (Fig. 19). Sites are continually added and removed from the NPL. Most Superfund sites are in northeastern states; in order of number of sites the top five are (1) New Jersey, (2) Pennsylvania, (3) California, (4) New York, (5) Michigan. Superfund sites have a variety of origins. The 10 worst sites include landfills, military bases, nuclear reservations, mine sites, and industrial facilities. As of September 2001, there were 1228 sites on the NPL at various stages of remediation.

Figure 18. Distribution of Superfund sites in lower 48 states.

Figure 19. Status of 1,405 NPL sites at the end of the 1997 fiscal year. Construction had begun or was completed at nearly 70% of sites.
Recycling

- Community recycling programs typically feature glass, paper, metal cans, and some plastics.
- The three Rs are: reduce, reuse, and recycle.
- Recycling reduces waste, reduces pollution, saves energy, protects lands, saves resources, and can be good for business.

Recycling Programs

Recycling programs have long been the public's most popular environmental activity but are not without effort. Recycling requires source separation, the sorting of recycled materials by type. Most community recycling programs collect glass (unbroken), paper (including newspapers, magazines, cardboard, office papers), metal cans (aluminum, steel), and some plastics (Fig. 20). Plastics are labeled with a "chasing arrow" symbol with a number.

Figure 20. The bulk (by weight) of recycled materials in the U.S. are paper and paperboard.

Plastics with a 1 (polyethylene) or 2 (high-density polyethylene) can be recycled. These plastics are used to make plastic bottles, detergent and oil containers, trash cans, drainage pipes, plastic lumber, and many other products. Milk jugs can be recycled but their caps cannot. Caps and lids of many plastic containers are made of denser plastics than the
container itself. Even a small amount of a different plastic can ruin the melt of recycled plastics.

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<th>Plastics Number</th>
<th>Plastic Type Used for…</th>
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<tbody>
<tr>
<td>1</td>
<td>PETE, polyethylene Soda bottles</td>
</tr>
<tr>
<td>2</td>
<td>HDPE, high-density polyethylene Milk and detergent containers</td>
</tr>
<tr>
<td>3</td>
<td>V, vinyl or polyvinyl chloride Food wrap, vegetable oil bottles</td>
</tr>
<tr>
<td>4</td>
<td>LDPE, low-density polyethylene Grocery bags, newspaper wrappers</td>
</tr>
<tr>
<td>5</td>
<td>PP, polypropylene Drug prescription bottles, bottle caps</td>
</tr>
<tr>
<td>6</td>
<td>PS, polystyrene Foam cups, meat packing, shipping</td>
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A variety of specialized recycling programs focus on specific items. For example, over 90% of lead-acid automotive batteries are recycled in the U.S. For recycling programs to be successful they must go hand-in-hand with waste reduction and reuse of recycled materials. These are the three Rs:

- **Reduce**: Buy products with less packaging, buy in bulk, stop junk mail.
- **Reuse**: Buy items that can be reused, use non-disposable items (e.g., cloth towels instead of paper), use rechargeable batteries.
- **Recycle**: Recycle items made of plastics, paper, glass, metals.

The average U.S. recycling rate for solid waste is 30%. Several states have recycling rates of over 40% (e.g., Minnesota's recycling rate is nearly 50%) and some, typically those with large land areas and low population density (e.g., Montana, Wyoming) have rates below 10% (Fig. 21). For recycling to be effective there must be a market for recycled materials. Although the market for recycled goods has started to gain momentum, it was initially outpaced by the collections of curbside recycling programs.

**Benefits of Recycling**

**Recycling reduces waste**: Recycling reduces the volume of waste going to landfills, the principal method of waste disposal in the U.S. About 10 years ago there was widespread concern that the nation was running out of landfill space as older, less secure landfills closed down. As the public increased recycling efforts the volume of waste was reduced below expectations and the landfill "crisis" evaporated. Large cities may face problems as current landfills reach capacity but most
communities should have little difficulty finding additional landfill space.

**Recycling reduces pollution:** The manufacture of materials from ore often generates pollution of the air (smoke stack emissions) and/or water:

- Aluminum recycling (Fig. 22) reduces air pollution by 95% compared to making metal from ore.
- Glass recycling (Fig. 22) reduces air pollution by ~20% and water pollution by 50%.

Cadmium in nickel-cadmium rechargeable batteries can cause blood and reproductive damage to humans. Cadmium from the batteries may contaminate local water supplies if dumped in a conventional landfill. Used motor oils are a form of hazardous waste but can be recycled at many fast-lube or oil change centers.
Recycling saves resources: A principal reason to recycle waste is to reduce the need to mine, quarry, or log the original resources, thus extending the life of the resource base.

- One ton of paper made from recycled wastepaper saves 17 trees and 7,000 gallons of water.
- 43% of U.S. copper, 55% of lead, 32% aluminum, and 19% of zinc come from recycled metals.

Recycling protects land: Some resources such as sand, used to make glass, are in no danger of being exhausted, but by reusing the previously manufactured product we eliminate the need to alter the landscape by mining or quarrying. Furthermore, the reduction in waste results in less land being converted to landfills.

Recycling saves energy: The recycling of metals such as aluminum produces dramatic energy savings and reduces pollution associated with smelting. The amount of energy needed to produce aluminum from recycled materials is only 5% of that required to refine the metal from bauxite (aluminum ore). By saving energy, recycling also reduces pollution, saves (energy) resources, and reduces costs. Some examples of energy savings:

- Glass saves 30% of the energy needed to make glass from sand.
- Paper saves 60% of energy needed to make paper from wood.
- Steel cans saves 74% of energy needed to make cans from iron ore.

Recycling is good for business: Paper recycling is more common in nations with limited forest resources. Many countries on the eastern Pacific Rim import wastepaper, mainly from the U.S. and Germany, which account for two-thirds of the world's wastepaper exports. Large amounts of wastepaper are used in paper production in relatively tree-less nations; for example, wastepaper is the source for almost all of the paper and paperboard produced in Taiwan. The recycled content of paper reflects the total amount of wastepaper contained, most of which represents scraps generated during the paper production process itself. Post-consumer recycled materials are those made from used paper that has been returned by consumers participating in recycling programs.
Summary

1. What is the difference between renewable and non-renewable resources?
Renewable resources are on short-term time scales measured in months or years. Non-renewable resources are either lost following consumption or may be recycled to be used in other products. Industrial minerals (sand and gravel, crushed stone, gypsum) are relatively abundant and typically are not recycled. Many metals are costly to extract and are recycled to save money and prolong the life of the resource base.

2. What is the difference between resources and reserves?
Mineral resources represent any concentration of minerals within Earth's crust. Most resources are too sparsely distributed to be developed. Reserves are mineral resources that are sufficiently concentrated to be economically extracted from the crust using current mining technology. Resources are much more abundant than reserves.

3. Global populations have doubled over the last 40 years so why haven't the amount of reserves declined because of increased demand?
Three factors have resulted in the increase of mineral reserves over the last few decades. New sources of minerals continue to be discovered as geologists better understand the geologic conditions behind the concentration of minerals and metals. If the price of resources increases, it becomes more economically attractive to mine previously uneconomic ores. Improvements in mining technology have made it easier (and cheaper) to produce many metals (e.g., gold).

4. What are the most valuable mineral resources in the U.S.?
Annual production of crushed stone, cement, and sand and gravel ($5.1-8.6 billion) are all worth more than the annual
value of precious metals such as gold ($4 billion). Copper and gold are the most valuable metallic resources.

5. How do modern mining methods differ from those of the past?
Modern mining methods place greater emphasis on the use of chemical solutions to extract metals from lower-grade ores. For example, cyanide heap leaching can extract gold from low-grade ores that would not have been mined 20 years ago.

6. Can mining cause harm to the environment?
Yes, mining can result in environmental degradation to land, water, air, and wildlife resources. Development of a mine alters the character of the land itself and diminishes the aesthetic and recreational resources of a region. Acid mine drainage, acidic waters generated when metals are leached out of ores or waste rock, may contaminate groundwater or streams. Emissions from smelters can result in air pollution, generating large volumes of sulfur dioxide. Aquatic wildlife may be harmed by polluted runoff to streams and habitat may be destroyed at the mining site itself.

7. What are the principal components of municipal solid waste?
The U.S. produces 220 million tons of waste per year and approximately 30% of that waste is recycled. Two-thirds of the remainder is composed of paper and paperboard (31%), food wastes, yard waste, and plastics.

8. What happens to municipal solid waste?
Most municipal waste is deposited in landfills (53%) but the proportion that is recycled (30%) has increased steadily over the past few decades. The remainder of the waste is disposed of by combustion, burning at high temperatures.

9. What are the advantages and disadvantages of combustion?
Combustion reduces the volume of waste going to landfills and can generate energy for electricity, but the emissions from burning waste may contribute to air pollution.

10. What are the characteristics of a sanitary landfill?
Sanitary landfills are waste disposal facilities where waste is isolated from the surrounding environment. The waste is protected from the infiltration of water by a clay cap and polluted fluids are retained in the landfills by underlying clay and plastic liners. Organic waste decomposes in landfills to
form explosive methane gas that may be extracted for use in energy production.

11. How are landfills classified?
Landfills are classified on the basis of the surrounding physical environment and the type of waste they contain. Class 1 landfills are the most secure because they are constructed on low permeability rocks and accept all types of waste. Class 3 landfills are directly exposed to groundwater and can only accept inert (non-reactive) materials.

12. What are hazardous wastes and how are they disposed of?
Hazardous wastes are corrosive, toxic, flammable, and reactive. They must be disposed of in secure landfills that have a range of measures to protect the surrounding environment. Liquid chemical wastes are disposed of by deep well injection to deep, permeable layers that are separated from overlying aquifers by intervening impermeable layers.

13. What is Superfund?
Superfund is a federal fund for the disposal of hazardous wastes. The National Priorities List includes the most heavily contaminated hazardous waste sites in the nation. Over 670 sites have already been cleaned up and an additional 1200 sites are currently in various stages of clean up.

14. What municipal waste materials are typically recycled?
Municipal waste recycling involves paper, metals (aluminum, steel), compost (yard waste), glass, and plastics. Only two (of seven) types of plastics are recycled.

15. What are the three Rs?
Reduce (use less packaging), reuse (don't use disposable items), and recycle (recycle items made of paper, glass, metals, etc).

16. What are the benefits of recycling?
Recycling has several benefits beyond simply reducing the volume of waste going to landfills. Recycling saves original resources, reduces air pollution associated with the production of resources, protects the land because it results in less mining, and saves energy as less energy is used to recycle materials than to process them from ores.
Venn Diagram: Mining Operations

Use the Venn diagram, below, to compare and contrast the similarities and differences between any two metal mining operations described in the Current Projects section of the Mining Technology site at http://www.mining-technology.com/projects/index.html.

Site 1: ____________________  Site 2: ____________________