1 # Geologic Resources: Nonrenewable Mineral and Energy Resources

Chapter 15

2 ## Nature and Formation of Mineral Resources

- **Mineral resource: concentration of naturally occurring material in or on the earth's crust that can be extracted at an affordable cost; nonrenewable resource**
- **Mineral resources**
- **Metallic: Fe, Cu, Al**
- **Non-metallic: salt, clay, sand, phosphates, soil**
- **Energy resources: coal, oil, natural gas, & U**
- **Magma**
- **Hydrothermal**
- **Weathering**

3 ## Categories of Nonrenewable Mineral Resources

- Identified resources: deposits of a nonrenewable mineral resource with a known location, quantity, and quality based on geological evidence and measurements
- Undiscovered resources: potential supplies of a nonrenewable mineral resource assumed to exist but having unknown specific information
- Reserves: identified resources mineral con be extracted
- Other resouces: identified and undiscovered not classified as reserves

4 General Classification of Mineral Resources

5 ## Ore formation

- Magma: wells up into earth's crust at divergent and convergent plate boundaries
- Hydrothermal process: sea floor spreading allows magma to upwell; seawater dissolves metals from rock or magma; as solutions cool, their dissolved minerals cool and form deposits
- Hydrothermal also includes hydrothermal vents and manganese nodules on the Pacific Ocean floor; may have formed from hot solutions rising from volcanic activity
- Weathering: sedimentary sorting and precipitation-placer deposits also evaporite mineral deposits
- Weathering by water-residual deposits of metal ores in soil

6 ## Hydrothermal Vents

7 ## Finding Nonrenewable Mineral Resources

- Satellite imagery
- Aerial sensors (magnetometers)
- Gravity differences
- Core sampling
- Sensors to detect electrical resistance or radiation
- Seismic surveys
- Chemical analysis of water and plants (to detect leaching ores)

8 ## Removing Nonrenewable Mineral Resources

- Surface mining
- Overburden (material lying over deposit)
- Spoil (waste)
- Open-pit

- Dredging
- Strip mining (spoil banks)
- Mountaintop removal (spoil allowed by Bush to be dumped in valleys and streams)
- 2 Subsurface mining
- Room and pillar
- longwall

9 Surface Mining Control and Reclamation Act of 1977

- Surface mined land not restored in many countries
- Requires mining companies to restore most surface mined land so it can be used for the same purpose as it was before it was mined
- Levied a tax on mining companies to restore land that was disturbed by surface mining before the law was passed

10 Subsurface Mining

- Disturbs less land than surface mining
- Usually produces less waste material
- Not as effective
- Expensive and dangerous
- Collapse of roofs and walls, explosions of dust and natural gas, lung diseases
- Mine shafts and tunnels
- Room and pillars: pillars of ore are left holding up roof
- Longwall: shear off ore, move roof supports and allow roof to collapse (subsidence of layers on top)

11 Open Pit Mine

12 Dredging

13 **Area Strip Mining**

14 Brisbee Strip Mine, AZ

15 **Contour Strip Mining**

16 **Australian Underground Coal Mine**

17 **Room-and-pillar**

18 **Longwall Mining of Coal**

19 Environmental Impacts of Using Mineral Resources

- Scarring and disruption of the land surface
- Collapse or subsidence of land above (unsettle houses, break sewer, gas, and water lines)
- Wind/water erosion of toxin laced mining wastes
- ACID mine drainage-sulfuric acid produced by aerobic bacteria feeding on iron sulfide
- Emission of toxic chemicals into the atmosphere
- Exposure of wildlife to toxic mining wastes stored in holding ponds and leakage of toxic wastes

20 AMD: Acid Mine Drainage

- Acid mine drainage, sometimes referred to as AMD, results when the mineral pyrite (FeS_2) is exposed to air and water, resulting in the formation of sulfuric acid and iron hydroxide
- For chemists, the equation for AMD formation is:
- $FeS_2 + 3.75\ O_2 + 3.5\ H_2O \Leftrightarrow Fe(OH)_3 + 2\ H_2SO_4$
- acidity and iron, can devastate water resources by lowering the pH and
- coating stream bottoms with iron hydroxide, forming an orange color

21 Environmental Effects of Extracting Mineral Resources

22 Pollution and degradation due to mining

23 Environmental Effects of Processing Mineral Resources

- Ore mineral
- Gangue-waste material mixed in ores
- Tailings-removing the gangue from ores produces piles of waste
- Smelting-used to separate the metal from the other elements in the ores (emit tons of air and water pollution)
- Mining uses a lot energy, produces a lot of wastes, and the products after used become wastes

24 Life Cycle of Mineral Resource

25 Carrying Capacity for Geologic Resources

- Exhaustion of the resource or
- Environmental damage caused by extraction, processing, and conversion to products
- Mining industry uses 5-10% of global energy use
- Major contributor to air and water pollution (greenhouse gases)

26 Grade

- grade: percentage of metal content of an ore
- More accessible and higher grade ores extracted first
- Extracting less accessible and lower grade will lead to greater environmental impacts
- Takes about 75,000 tons to extract about 4.5 lbs gold
- Cyanide heap leaching

27 **KLOOF GOLD MINE, SOUTH AFRICA**

28 Gold found in Sedimentary Rocks

29 Ore at West Wits Fields

30 Kloopf Production

- Production for the past three financial years:

31 Economic Depletion of a nonrenewable resource

- Costs more to find, extract, transport,and process the remaining deposit than it is worth
- then,: recycle, reuse, waste less, use less, find a substitute, or do without

32 Supplies of Mineral Resources

- Economic depletion
- Depletion time (time it takes to use 80%)
- Reserve to production ratio (# yrs use up reserve at current use rate)
- Foreign sources
- Economics
- Environmental resources
- Mining the ocean
- Finding substitutes

33 Depletion Curves of mineral resources

34 Free Market vs Government/Industry

- Free market price goes up then: exploration, better mining technology, lower grades become profitable, research for substitutes, & conservation
- If govt. and industry control supply, demand, and price then a competitive market doesn’t exist
- Our govt subsidizes exploration and depletion
- Incentives for wise dev and use or cheap prices?

35 General Mining Law of 1872

- Designed to encourage mineral exploration and develop west
- Person can assume legal ownership of land on all U.S. public land except parks and wilderness by patenting it
- To get patent: declare there are minerals, spend $500 improve land, file claim, pay annual fee of $ 100/20 acres, pay $2.5-$5/acre for land
- Purchased land may be used, leased, or sold for any purpose
- Purchaser may be domestic or foreign interest

36 Provisions of Mining Law 1872

- Hardrock mining companies pay no royalties (oil and gas pay 12.5% and coal pays 8-12.5%)
- No provisions for any environmental clean up

37 Mining Companies vs Environmentalists

1

- Cost +$100 million to develop
- Provide jobs
- Supply resources for industry
- Stimulate national and local economies
- Reduce trade deficits

- Same American consumers money
- 1 in 10,000 new sites will become producing mine
- 2 Permanently banning sale of land; give 20 yr lease
- Require mining companies to pay 8-12% royalty
- Mining companies legally and financially responsible for clean up
- Actual cost of mining small part of product

38 Developing Public Lands or Extracting Minerals from Lower Grade Ores?

- Public lands are mostly in Alaska & the West
- There are mineral deposits on that land
- Environmentalists & others suggest mining for lower grade ores since extraction and mining technology is greatly improved
- 1900 Cu ore 5% by mass; now 0.5% and costs less due to better technology

39 Uranite

- Coarse botryoidal uraninite
- carbonate gangue shows bireflectance (top left)
- Uranium is a very dense, radioactive metallic element, naturally occurring in most rocks, soil, in the ocean. It is not rare, and in fact occurs more commonly than gold, silver or mercury.

40 **Magnetite, iron, haematite and limonite. Scotland**

- A magnetic separate in which angular magnetite (brown grey), a coarse-grained crystal of haematite (blue-grey, centre top left) and limonite (blue-grey, low reflectance, centre bottom left) are natural phases.

41 Copper Ore

42 **Zircon, native gold, copper and iron. Gold concentrate. Brazil**

- Zircon (grey) is accompanied by irregular-shaped high fineness gold (~960) (yellow, high reflectance) grains. Copper metal (pink, high reflectance, centre) and iron (white, high reflectance, top left).

43 Bauxite: Aluminum Ore

- Found in deeply weather volcanic rocks, usually basalt, form bauxite deposits
- This one is from Australia.

44 Iron Ore

- It almost always consists of iron oxides, the primary forms of which are magnetite (Fe_3O_4) and hematite (Fe_2O_3).

45 Tilden Iron Ore Mine in Michigan

46 Tilden Mine

47 Anthracite Coal – Llewellyn, PA

- **200 feet below the surface the Salem Coal Vein runs 70 feet high and 200 feet wide for about 10 miles.**

48 Anthracite Coal in PA

- 7 billion extractable tons of coal in Eastern Pennsylvania

49 Coal in Pennsylvania

- Power Operating mine site, Centre Co.

50 Coal Mining

- Long shear wall cut

51 Extraction of Lower Grade Ores

- Better earth removing equipment
- Better techniques for removing impurities
- Limited by quantities of freshwater to mine and process minerals (esp in arid areas)
- Cost prohibitive
- Environmental impact

52 Mining the Ocean

- Sources include seawater, sediments, hydrothermal vents, and Mn nodules
- Seawater too diffuse for most: currently extract Mg, Br, and NaCl
- Sand, gravel, phosphates, S, Sn, Cu, Fe, W, Ag, Ti, Pt, and diamonds in sea floor deposits on continental shelf
- Deep ocean floor: Au, Ag, Zn, Cu are found as sulfide deposits at hydrothermal vents and Mn nodules-too expensive to mine

53 Microbe Mining

- Environmentally safer: reduce air and water pollution
- Wells drilled into ores to fracture deposit
- Inoculated with natural or genetically engineered bacteria to extract desired metal
- Well flooded w water and pumped to surface
- Metal removed
- 30% of Cu mined with microbes
- Drawback is it is slow-decades not months

54 Microbe Mining

- *Science* 264 (1994), 778-9. proving cheaper and enabling the extraction of metals from low grade ores. It has been used for copper, and is also being used for gold and phosphate.
- *GEN* (1 Nov 1993), 1, 21. A bacterial system to remove heavy metals including radioactive compounds from water is being promoted by a British company; The Citrobacter species have been

tested on uranium, and act by a combination of bio-accumulation (metals accumulate inside cells, which are resistant to their toxic effects) and biosorption (metals stick to cell surfaces).

55 Substitutes

- Ceramics and plastics can be used in place of metals
- Cost less to produce (less energy), don't require painting, can be molded, don't oxidize
- No substitutes for He, phosphorus for phosphate fertilizers, Mn for steel production, and Cu for wiring
- Substitutes not viable if require more energy to produce or if they are inferior to the materials they replace

56 Types of Energy the World Uses

- Solar: directly heats the earth & all buildings
- Solar indirect: wind, flowing water, biomass
- Commercial energy: coal, oil, natural gas, nuclear

57 Important Nonrenewable Energy Sources

58

59

60 Current Use of Commercial Energy

- Use of coal is declining because it is the most polluting of the fossil fuels
- Use of oil continues to increase by 1%/yr
- Natural gas in increasing by 2% /yr
- Production of electricity by nuclear power will be phased out due to reductions of government subsidies
- Developing countries are still burning wood

61 Commercial Energy use for World

62 Commercial Energy Use of US

63 Commercial Energy Use in US

64 Evaluating Energy Resources

- Renewable energy
- Nonrenewable energy
- Future availability
- Net energy yield
- Cost
- Environmental effects

65 Net Energy

- Each time high quality energy is used, even to make more high quality energy, some of the energy will be degraded

- Net energy is the total amount of energy available from an energy resource after subtracting the energy used to find, extract, process, & transport the energy to the users
- It can be expressed as a ratio of total energy available from the resource and the amount energy used to make it available

66 **Estimated Net Energy Ratios for Space Heating**

67 Net Energy for High Temperature Industrial Heat

68 Net Energy for Transportation

69 Refining Crude Oil

- Petroleum (crude oil)
- Primary Recovery
- Secondary Recovery
- Tertiary Recovery
- Petrochemicals
- Refining

70 North American Energy Resources

71 Oil Shale and Tar Sands

- Oil Shale
- Keragen
- Tar Sands
- Bitumen

72 Inflation Adjusted Price of Oil

73 Production Curve World

74 Petroleum Production in US

75 **CO_2 emissions per unit of energy as expressed in % of emissions produced by coal**

76

77

78 **Using Heavy Oils from Oil Shale and Tar Sand as Energy Resources**

1

- **Advantages**
- **Moderate existing supplies**
- **Large potential supplies**

2

- **Disadvantages**

- **High costs**
- **Low net energy yield**
- **Large amount of water needed to process**
- **Severe land disruption from surface mining**
- **Water pollution from mining residues**
- **Air pollution when burned**
- **CO_2 emissions when burned**

79

80

81 Natural Gas

- **50-90% methane**
- **Conventional gas**
- **Unconventional gas**
- **Methane hydrate**
- **Liquefied Petroleum Gas (LLPG)**
- **Liquefied Natural Gas (LNG)**
- **Approximately 200 year supply**

82 Composition of Natural Gas

- 50-90% by volume of methane
- Smaller amounts of heavier gaseous hydrocarbons such as ethane, propane, and butane
- Small amounts of hydrogen sulfide

83 Where is natural gas found?

- Conventional natural gas found above oil deposits
- Unconventional natural gas found by itself
- Methane hydrate is a gas trapped in ice crystals deep beneath the arctic permafrost and beneath deep ocean sediments
- most is in Russia and Kazakhstan (42%)

84 Liquefied petroleum gas (LPG)

- Propane and butane gases are liquefied and removed as LPG
- Stored in pressurized tanks for use in rural areas not served by natural gas pipelines

85 Liquefied Natural Gas (LNG)

- LPG is dried to remove water vapor and methane is removed and hydrogen sulfide removed
- LNG is then pumped into pressurized pipelines for distribution
- Kept refrigerated at -184C (-300F)

86 Coal

- **Stages of coal formation**
- **Primarily strip-mined**
- **Used mostly for generating electricity**
- **Enough coal for about 1000 years**
- **Highest environmental impact**
- **Coal gasification and liquefaction**

87 Coal Formation

88 Coal Supplies

- Coal provides ~21% of world's commercial energy
- It is used to generate electricity and make steel
- ~66% of coal is in US (much anthracite PA)
- Coal is most abundant fossil fuel
- Identified sources at current rates about 200 years and unidentified at current rates about 1000 years; when consumption rates go up, estimated coal sources will last about 200 years

89 **Coal Mining and Consumption has Greatest Environmental Impacts of all Fossil Fuels**

- Land disturbance
- Air pollution
- CO_2 emissions
- Release of particles of Hg
- Release of radioactive particles
- Water pollution
- Health and property damage

90 Burning Coal More Efficiently

- Fluidized bed combustion
- Coal gasification:converts coal into synthetic natural gas (SNG)

91 **Natural Gas as Energy Resource**

- **Advantages**
- **Ample supplies (125 years)**
- **High net energy yield**
- **Low cost (w subsidies)**
- **Lower CO2 emissions**
- **Moderate env impact**
- **Easily transported by pipeline**
- **Low land use**
- **Good fuel for fuel cells and gas turbines**
- **Disadvantages**
- **Nonrenewable resource**

- **Releases CO_2 when burned**
- **Methane can leak from pipelines**
- **Difficult to transfer from country to country**
- **Shipped across ocean as highly explosive LNG**
- **Sometimes burned off and wasted at wells due to low price**
- **Requires pipelines**

92 Burning Coal More Cleanly

- Fluidized Bed combustion

93 Fluidized Bed Combustion

- Sorbent, limestone or dolomite, captures sulfur released by coal combustion
- Jets of air suspend the mixture of sorbent and burning coal during combustion
- The red hot particles flow like a fluid
- Elevated pressure and temperatures produce a high pressure gas stream that can drive a turbine
- Steam generated can drive a steam turbine
- http://www.netl.doe.gov/publications/factsheets/program/prog031.pdf

94 Coal Gasification

95 Coal Gasification

- Coal/water slurry and oxygen are reacted at high temperature and pressure to produce syngas (SNG)
- Ash flows out of the bottom into a water filled sump where it becomes solid slag
- The syngas moves from the gasifier to a radiant syngas cooler which generates high pressure steam
- Then the syngas is scrubbed of particles and sulfur
- The gas can then be used to power a gas turbine
- http://www.lanl.gov/projects/cctc/factsheets/tampa/tampaedemo.html

96 **Using Coal as Energy Source**

1
- **Advantages**
- **Ample supplies (225-900 yrs)**
- **High net energy yield**
- **Low cost with huge subsidies**

2
- **Disadvantages**
- **Very high environmental impact**
- **Severe land disturbance, air pollution, and water pollution**
- **High land use including mining**
- **Severe threat to human health**
- **High CO_2 emissions when burned**
- **Releases radioactive particles and Hg into air**

97 **Syngas as Energy Source**

1
- **Advantages**
- **Large potential**
- **Supply**
- **Vehicle fuel**
- **Moderate cost (w lg govt subsidies)**
- **Lower air pollution when burned than coal**

2
- **Disadvantages**
- **Low to moderate net energy yield**
- **Higher cost than coal**
- **High environmental impact**

- **Increased surface mining of coal**
- **High water use**
- **Higher CO_2**
- **emissions than coal**

98 Source of Energy in Nuclear Fission Reactor

- Neutrons split the nuclei of atoms like U 235 and Pt 239
- The chain reaction that results continues to split atoms
- Energy is release as high temperature heat
- Rate of fission is controlled by rods made of graphite
- Heat that is generated is used to produce high pressure steam which spins turbines to generate electricity

99 Main Components of Light water Reactor (LWR)

- **Core: 35,000-70,000 long thin fuel rods which are packed w fuel pellets**
- **Fuel pellets made of uranium oxide are 1/3 size of cigarette & has the energy of 0.9 metric ton of coal**
- **Control rods are moved in and out of the reactor core to absorb neutrons regulating the rate of fission**
- **Moderator slows down the neutrons emitted so chain reaction can be kept going**
- **Coolant which circulates through core to remove heat and produce steam for generating electricity**

100 Composition of
components

- Uranium oxide is only 3% fissionable U 235; remainder is nonfissionable U 238
- In nature, 0.7% is fissionable and must be concentrated, enriched, for use
- The moderator may be liquid water (75% of all reactors), graphite (20% of all reactors), or heavy water, deuterium (5% of all reactors)

101 Nuclear Energy

102 **Nuclear Fission Reactor Schematic**

103 The Nuclear Fuel Cycle

104 Low Level Radioactive wastes

- Give off small amounts of ionizing radiation
- Must be stored safely for 100-500 years before it decays to safe levels
- Put in steel drums and dumped in ocean
- Put in steel drums and shipped to regional landfills run by federal and state govt

105 High Level Radioactive Waste

- Give off large amounts of ionizing radiation
- Must be stored safely for 10,000 years and 240,000 years if Pt 239 not removed
- Spent fuel rods stored in water or in dry storage casks at plant sites
- Asstmt of wastes from plants that produce plutonium and tritium for nuclear weapons

106 WHERE?

- Bury it deep underground
- Shoot it into space or into the sun (expensive and accident in launch disastrous)
- Bury it under ice sheet or ice cap
- Dump into descending subduction zones in deep ocean
- Bury it in thick deposits of mud on deep ocean floor
- Change it into harmless, or less harmful, isotopes
- Biggest problem: is the area stable?

107 Dealing with Nuclear Waste

- Low level waste
- High level waste
- Underground burial
- Disposal in space
- Burial in ice sheets
- Dumping in subduction zones
- Burial in ocean mud
- Conversion into harmless materials

108 **What covers waste**

109 **Waste container**

110 Chernobyl

111 What happens to decommissioned nuclear plants?

- Operational about 15-40 years then it is too contaminated with radioactive materials and parts have worn out
- It is dismantled and the large volume of radioactive materials are stored in high level nuclear waste storage facilities (which do not currently exist!)
- A physical barrier may be erected and guarded for 30-100 years until it is dismantled
- The plant may be entombed
- May cost $300-500 million to decommission

112 Deep Underground storage

113

114

115

116 Nuclear Reactors and Nuclear Weapons

- Technology for reactors given or sold to other countries and is sufficient to use for development of nuclear weapons too
- Bomb grade Pt 239 needs to be kept secure
- Dirty bombs can be conventional bombs w added radioactive materials eg irridium 192, cobalt 60, cesium 137, americium 241
- Sources for the radioactive materials include hospitals, university research labs, industries, and smoke detectors

117 Dirty Bombs

- Render large areas unsuitable for habitation
- Kill in the immediate area and later from cancers
- Cause terror and panic
- There is an average of 100 thefts a year of radioactive materials

118 Nuclear Power replace Oil?

- Oil produces only about 2-3% of electricity in the US
- Major use of oil is for transportation, so nuclear power is unlikely to replace oil

119 No new nuclear power plants?

- Multibillion dollar construction cost overruns
- Stricter government safety regulations
- Higher operating costs and more malfunctions than expected
- Poor management
- Public concerns about safety
- Investor concerns about the economic feasibility of nuclear power

120 **Nuclear Power to Produce Electricity**

1 - **Advantages**
- Large fuel supply
- Low env impact
- Emits 1/6 CO_2 as coal
- Moderate land disruption & water pollution
- Moderate land use
- Low risk of accidents w multiple safety systems

2 - **Disadvantages**
- High cost (even w subsidies)
- Low net energy yield
- High env impact if accidents
- Catastrophic accidents have happened Chernobyl
- No solution for long term storage of wastes
- Spreads knowledge & technology for building nuclear weapons

121 Nuclear Power Risks

- US Nuclear Regulatory Commission (NRC) estimates 15-45% change of a complete core meltdown at a US reactor during the next 20 years

- Other problem areas include:
- Chance of failure of containment shell in case of meltdown
- Boric acid, produced as byproduct, could corrode steel cover for the fuel rods resulting in lack of coolant
- terrorist targets

122 Comparison of Risks in Coal & Nuclear Power

1 • Coal
- Ample supply
- High net energy yield
- Very high air pollution
- High CO_2 emissions
- 65K to 200K deaths/year in US
- High land disruption
- High land use
- Low cost w huge subsidies

2 • Nuclear Power
- Ample supply of uranium
- Low net energy yield
- Low air pollution
- Low CO_2 emissions
- About 6K deaths / year in US
  much lower land disruption
- Moderate land use
- High cost (w huge subsidies)

123 Nuclear Alternatives

- Breeder nuclear fission reactors convert U 238 to P239
- Nuclear fusion
- New reactor designs
- Advanced light-water reactors built in safety
- Pebble bed modular

Reactor (PBMR) 10K uranium oxide particles are encapsulated that are meltdown proof

124 Future of Nuclear Power

- Still receives 58% of federal energy research funding
- Some believe better to develop other means of generating energy-too dangerous and can't compete in deregulated energy market
- Some say continue to look for cheaper and safer ways to generate nuclear energy
- If alternatives fail to produce viable alternative, will still have nuclear power available