Nonrenewable vs. renewable energy sources
• Nonrenewable resources
  – available in finite, limited quantities
  – depleted by use
    • natural processes do not replenish within reasonable period of time
      – on human time scale

Nonrenewable vs. renewable energy sources
• Nonrenewable resources
  – include
    • minerals
- copper, tin, aluminum, radioactive ores
  - fossil fuels
    - coal
    - oil
    - natural gas

6 Nonrenewable vs. renewable energy sources
   - Renewable resources
     - available in potentially unlimited quantities
     - term is not used exclusively to describe energy resources
     - replaced by natural processes fairly rapidly
       - on a scale of days to decades
     - can be used forever
       - as long as they are not overexploited in short term
       - must be used in sustainable manner
         - gives them time to replace or replenish themselves

7 Nonrenewable vs. renewable energy sources
   - Renewable resources
     - include
       - non-energy
         - trees
         - fishes
         - fertile agricultural soil, fresh water
       - energy
         - solar
         - wind
         - geothermal
         - hydroelectric

8 Nonrenewable energy: resources vs. reserves
   - Nonrenewable resources
     - must differentiate between deposits that can be extracted and those that cannot
       - resource
       - reserve

9 Nonrenewable energy: resources vs. reserves
   - Nonrenewable resources
     - resource
       - naturally occurring substance
       - of potential use to humans
       - can potentially be extracted using current technology
     - reserve
       - known deposits that can be extracted profitably with existing technology
         - under certain economic conditions
10 Nonrenewable energy: resources vs. reserves

- Nonrenewable resources
  - resource
    - total amount changes only by amount that is used each year
  - reserve
    - an economic concept
    - amount changes as
      - technology advances
      - as new deposits are discovered
      - as economic conditions vary
    - reserves are smaller than resources

12 OUTLINE

- Renewable vs. Non-Renewable Energy
- Fossil fuels - general
  - formation
  - resources vs. reserves
- Coal
  - formation
  - types
  - reserves
  - extraction
  - use patterns
  - use issues

13 Fossil fuels

- general
  - definition
  - formation
- specific types
  - formation
  - resources and reserves
  - use patterns
  - use issues

14 Fossil fuels

- General definition
  - partially decayed remains of plants, animals and microorganisms that lived millions of years ago

15 Fossil fuels

- General formation
~300 million years ago
  • much of earth’s climate was mild and warm
    – plants grew year round in vast swamps
  • as swamp plants and aquatic microorganisms died
    – fell into or sunk in water
      » decomposed very little due to lack of oxygen
    – covered by layers of sediment

16 Fossil fuels
  • General formation
    – over great periods of time
      • heat and pressure that accompanied burial of organic material by sediments
    – converted non-decomposed organic material into carbon-rich materials we now call fossil fuels

17 OUTLINE
  ♦ Renewable vs. Non-Renewable Energy
  ♦ Fossil fuels - general
    ♦ formation
    ♦ resources vs. reserves
  ♦ Coal
    ♦ formation
    ♦ types
    ♦ reserves
    ♦ extraction
    ♦ use patterns
    ♦ use issues

18 Fossil fuels
  ♦ Types
    – coal
    – oil
    – natural gas

19 Fossil fuels
  ♦ Coal
    ♦ formation
    ♦ types
    ♦ reserves
    ♦ extraction
    ♦ use patterns
    ♦ use issues
Fossil fuels
• Coal
  + formation
  + types
  + reserves
  + extraction
  + use patterns
  + use issues

Coal
  – formation
    • ~300 million years ago
    – tropical freshwater swamps covered many regions of earth
    • conditions in swamps favored extremely rapid plant growth
    – resulting in accumulations of dead plant material under water
      » decay was inhibited due to low oxygen concentrations

Coal
  – formation
    • partially decayed accumulated plant material was covered by sediments
      – especially when geologic changes in earth caused some swamps to be submerged by seas
      – over vast periods of time, heat and pressure that accompanied burial
        » converted non-decomposed plant material into carbon-rich rock called coal

Coal
  – types
    • occurs in different types, or grades, dependent on
      – varying amounts of heat and pressure to which it was exposed during formation
Fossil fuels
- Coal
  - types
    - exposed during formation to
      - higher heat and pressure
        » drier (lower water content)
        » more compact (harder)
        » higher heating value (=higher energy content)
      - lower heat and pressure
        » wetter (higher water content)
        » less compact (softer)
        » lower heating value (=lower energy content)

Fossil fuels
- Coal
  - types
    - three most common grades
      - lignite
      - bituminous
      - anthracite

Fossil fuels
- Coal
  - lignite
    - characteristics
      » moist, water content of ~45%
      » soft, woody texture
      » produces little heat compared to other types
      » heat value of 7000 BTU/pound
      » dark brown in color
      » contains ~20 noncombustible compounds
      » contains ~35% carbon

Fossil fuels
- Coal
  - types
    - lignite
      - uses
        » often used to fuel electric power plants
      - deposits
        » sizable deposits found in western US
        » largest US producer is North Dakota
        » cost to mine (1997) $10.91/2000 pounds

Fossil fuels
- Coal
  - types
    - bituminous
      - characteristics
– moderately dry, water content of 5-15%
– moderately hard
  » although it's also called a soft coal
– produces nearly twice the amount of heat as lignite
  » heat value of 12,000 BTU/pound
– dull to bright black with dull bands
– contains ~20-30 noncombustible compounds
– contains ~55-75% carbon

30 Fossil fuels

• Coal
  – types
    – bituminous
      • uses
        – extensively by electric power plants
        » produces a lot of heat
      • deposits
        – found in US in Appalachian region, near Great Lakes, in Mississippi Valley, in central Texas
        – cost to mine (1997) $24.64/2000 pounds

31 Fossil fuels

• Coal
  – types
    – anthracite
      • highest grade of coal
      • characteristics
        – very dry, water content of 4%
        – very compact
        » called hard coal
        – produces twice the heat of lignite
        » heat value of 14,000 BTU/pound
        – dark, brilliant black in color
        – contains ~1 noncombustible compound
        – contains ~95% carbon

32 Fossil fuels

• Coal
  – types
    – anthracite
      • uses
        – electric power generation and other industrial uses such as production of steel
      • deposits
        – in US, most is located east of Mississippi River, particularly in PA
Fossil Fuels
- Coal
  - formation
  - types
  - reserves
  - extraction
  - use patterns
  - use issues

Fossil Fuels
- Coal
  - deposits and reserves
    - coal is most abundant fossil fuel in world
    - found mostly in Northern Hemisphere
    - found in seams or veins
      - underground layers that vary in thickness from 2.5cm to >30m in thickness
    - easily located
      - geologists believe most (if not all) major deposits have been located

Fossil Fuels
- Coal
  - deposits and reserves
  - known, proven world reserves
    - location
      - ~66% located in US, Russia, China, India
        » with US accounting for 24% of those
    - could last
      - ~200 years at present rate of consumption
      - ~65 years if rate of consumption increases by 2% per year

Figure 10.4: Distribution of coal deposits, Raven & Berg

Fossil Fuels
- Coal
  - deposits and reserves
  - known US reserves
    - location
      » throughout US
      » more in eastern 1/2 of continental US
    - could last US
      » ~300 years at present rate of consumption
Fossil Fuels

- Coal
  - deposits and reserves
    - unknown, unproven world reserves
      - additional coal reserves that are currently too expensive to develop
        » for example, deposits at depths >5000 feet would cost more to extract than would be offset by current price of coal

Fossil Fuels

- Coal
  - deposits and reserves
    - unknown, unproven world reserves
      - location
        » ~85% are located in US
      - could last
        » ~1000 years at present rate of consumption
        » ~149 years if rate of consumption increases by 2% per year

Fossil Fuels

- Coal
  - deposits and reserves
    - unknown, unproven US reserves
      - could last US
        » ~400 years at present rate of consumption

Fossil Fuels

- Coal
  - deposits and reserves
    - known AND unknown world reserves
      - could last
        » ~200-1000 years depending on rate of consumption

Fossil Fuels

- Coal
  - formation
  - types
  - reserves
  - extraction
  - use patterns
  - use issues

Fossil Fuels

- Coal extraction
  - two basic types of coal mines
    - surface mines
• subsurface mines

47 Fossil Fuels
  • Coal extraction
    – surface mines
      • also called strip mining
      • used when overburden is 30-100 meters thick
        – overburden = rock/earthen material on top of vein/seam of coal
      • results in best utilization of coal reserves
        – it removes most of coal in a vein
        – can be profitably used in a vein as thin as 1/2 meter

48 Fossil Fuels
  • Coal extraction
    – surface mines
      • have increased globally
        – in US, from 30% of coal extracted in 1970 to 60% of coal extracted currently
      • advantages over subsurface mining
        – less expensive
        – safer for miners
        – allows more complete removal of coal
      • disadvantage over subsurface mining
        – disrupts land more extensively
          » adverse environmental impacts

49 Fossil Fuels

50 Fossil Fuels
  • Coal extraction
    – subsurface mines
      • employed when overburden is thick, >-30-100 meters
      • account for ~40% of current coal extraction
    – advantage over surface mining
      • disrupts land less extensively
      – less potential for adverse environmental impacts
    – disadvantages over surface mining
      • more expensive
      • less safe for miners
      • less complete removal of coal

51 Fossil fuels
  ◀ Coal
    + formation
    + types
    + reserves
    + extraction
    + use patterns
    + use issues
Fossil Fuels

Coal use patterns
- provides
  - ~21% of world’s commercial energy
  - ~22% of US’s commercial energy
- used to
  - generate
    - ~62% of world’s electricity
    - ~53% of US’s electricity
  - make
    - ~75% of world’s steel

Figure 10.9: World commercial energy sources, 1997, Raven & Berg

Coal use patterns
- many analysts project a decline in coal use over next 40-50 years because of
  - its high CO₂ emissions
  - harmful human health effects
  - availability of less environmentally harmful ways to produce electricity

Fossil fuels
- Coal
  + formation
  + types
  + reserves
  + extraction
  + use patterns
  + use issues

Coal use issues
- coal contains
  - small amounts of sulfur
– which is released into atmosphere as $\text{SO}_2$ when coal is burned
  » $\text{SO}_2$ is a greenhouse gas
• trace amount of mercury and radioactive materials
– which are released into atmosphere when coal is burned

60 Fossil Fuels
• Coal use issues
  – most abundant fossil fuel
  – produces highest environmental impact from
    • land disturbance
    • air pollution
    • greenhouse gas emissions ($\text{SO}_2$, $\text{CO}_2$)
    • release of toxic mercury particles
    • release of thousands of times more radioactive particles into atmosphere per unit energy produced than does a normally operating nuclear power plant
    • water pollution

61 Fossil Fuels
• Coal use issues
  – human health impacts
    • occupational
      – coal mining is one of most dangerous jobs in world
      – during 20th century, ~90,000 American coal miners died in mining accidents
        » though death rates declined in latter part of century
      – between 1870 and 1950, 30,000 miners died in PA alone
        » equivalent of one man per day for 80 years

62 Fossil Fuels
• Coal use issues
  – human health impacts
    • occupational
      – miners have increased risk of black lung disease
        » lungs become coated with inhaled coal dust restricting oxygen exchange, causing ~2000 deaths per year

63 Fossil Fuels
• Coal use issues
  – land disturbance
    • in US, thousands of square kilometers have been disturbed by mining
      – only about 1/2 of that has been reclaimed

64 Fossil Fuels
• Coal use issues
  – land disturbance
    • types
      – open trenches
      – topsoil removal/erosion
      – landslides caused by lack of vegetation
mountaintop removal
land subsidence
trailing dumps

Fossil Fuels

Coal use issues

- land disturbance

- acid mine drainage
  - produced when rainwater seeps through iron sulfide minerals exposed in waste mines
  - carries sulfuric acid to nearby streams and lakes

Coal use issues

- air pollution
  - many elements taken up by ancient plants were concentrated in coal formation process
    - such as uranium, lead, cadmium, mercury, rubidium, thallium, zinc
  - released when coal is burned
    - as gas into atmosphere
    - are concentrated as in fly ash
  - coal is responsible for ~25% of all atmospheric mercury pollution in US

Coal use issues

- air pollution
  - acid deposition
    - both sulfur oxides (SOx) and nitrogen oxides (NOx) form acids when they react with water
    - SOx and NOx emissions react with water in the atmosphere to form
      - an acid which falls from atmosphere to surface, known as acid deposition or acid precipitation

Coal use issues

- greenhouse gases
  - coal contains up to 10% sulfur by weight
  - unless sulfur is removed by washing or flue-gas scrubbing
    - it is released during burning and oxidizes to sulfur dioxide (SO2) or sulfate (SO4)
    - ~18 million metric tons SOx released annually in US (~75% of total US emissions)

Coal use issues

- greenhouse gases
  - high temperatures and rich air mixtures used in coal-fired burners also
    - oxidize nitrogen compounds (mostly from atmosphere) into nitrogen oxides (NOx)
» ~5 metric tons of NOx released annually in US (~30% of total US emissions)

Fossil Fuels
• Coal use issues
  – greenhouse gases
    • combustion of coal produces CO₂
      – ~one trillion metric tons released annually in US (~50% of total US emissions)

Fossil Fuels
• Coal use issues
  – making coal a cleaner fuel
  • desulfurization systems
    – clean power plants’ exhausts
      » chemicals react with pollution and pollution settles out (precipitates)
      » modern “scrubbers” remove ~98% of sulfur
    – expensive, adds to cost of coal energy

Fossil Fuels
• Coal use issues
  – clean coal technologies
    • new methods for burning coal such as fluidized bed combustion
      – mixes crushed coal with particles of limestone in a strong air current during combustion
      – takes place at lower temperatures so there are fewer nitrogen oxides produced
      – sulfur reacts with calcium in limestone and precipitates out

Fossil Fuels
• Coal use issues
  – clean coal technologies
    • new methods for burning coal such as fluidized bed combustion
      – process is more efficient than traditional coal burning
        » produces more heat for a given amount of coal
        » therefore, reduces CO₂ emissions

Figure 10.8: Fluidized-bed combustion of coal, Raven & Berg

Fossil Fuels
• Coal use issues
  – converting coal into gaseous and liquid fuels
    • solid coal can be converted into synfuels
      – synthetic natural gas (SNG)
        » by process of coal gasification
      – liquid fuel such as methanol or synthetic gasoline
        » by process of coal liquefaction
    • most analysts expect synfuels to play only a minor role as an energy resource in the next 30-50 years
76 Figure 10.16: Coal gasification, Raven & Berg

77 The End