Petroleum, gas, coal, uranium, et al. There's only so much...
Renewable and Nonrenewable Resources

- Resources can be divided into renewable and nonrenewable resources.
  - *Renewable resources* can be replenished over relatively short time spans.
    - Plants and animals for food
    - Fiber for clothing
    - Trees for lumber and paper
    - Energy from the Sun, wind, and flowing water
  - *Nonrenewable resources* are deposits that take millions of years to form.
    - Fossil fuels
    - Metals
    - Groundwater
How much do each of us use?

**Metallic Resources**
- 249 kg (553 lbs) Iron
- 35 kg (77 lbs) Aluminum
- 11 kg (25 lbs) Copper
- 6 kg (14 lbs) Lead
- 6 kg (13 lbs) Manganese
- 5 kg (11 lbs) Zinc
- 9 kg (20 lbs) Other metals

**Nonmetallic Resources**
- 5713 kg (12695 lbs) Stone
- 4025 kg (8945 lbs) Sand and gravel
- 360 kg (790 lbs) Cement
- 137 kg (304 lbs) Clays
- 178 kg (395 lbs) Salt
- 162 kg (361 lbs) Phosphate rock
- 302 kg (672 lbs) Other nonmetals

**Energy Resources**
- 3500 kg (7700 lbs) Petroleum
- 3700 kg (8140 lbs) Coal
- 3850 kg (8470 lbs) Natural gas
Copper mine, Morenci, Arizona
Coal, petroleum, and natural gas are the primary fossil fuels in society.

- 81 percent of energy consumed in the U.S. comes from fossil fuels.
- *Fossil fuels* use energy from the Sun stored by plants and animals millions of years ago.
- Reserves are declining and future energy needs will have to be met with alternative energy sources.
U.S. Energy Consumption, 2014

Sources of Energy:
- Petroleum: 34.8 quadrillion Btu (35%)
- Natural gas: 27.5 quadrillion Btu (28%)
- Coal: 17.9 quadrillion Btu (18%)
- Renewable energy: 9.6 quadrillion Btu (10%)
- Nuclear electric power: 8.3 quadrillion Btu (8%)

Users of Energy:
- Transportation: 27 (27%)
- Industrial: 21.4 (25%)
- Residential and commercial: 11.3 (12%)
- Electric power: 38.5 (39%)

Reading this double graph:
The left side indicates what energy sources we use. The right side shows where we use the energy. The lines with numbers that connect the graphs provide more details. Use the top line as an example. It shows that 71% of the petroleum is used by the transportation sector. It also indicates that 92% of the energy used by the transportation sector is petroleum.
Energy Resources – Traditional Fossil Fuels

• Coal
  – Today, accounts for ~18 percent of the nation’s energy needs
    • The major fuel used in power plants to generate electricity.
  – Though the percentage of energy used that is derived from coal is decreasing, the energy demand continues to increase—so this does not mean we are using less coal!
    • Problems with coal use include environmental damage from mining and air pollution from burning it.
Surface Coal Mine
Energy Resources – Traditional Fossil Fuels

• **Oil and Natural Gas**
  – Combined, provide more than 60 percent of the energy consumed in the United States
    • In 2011, natural gas production exceeded coal production for the first time in 30 years
  – Petroleum formation
    • Both oil and natural gas consist of hydrocarbon compounds and are found in similar environments
    • Formation begins with the burial of large quantities of organic material
    • Organic material is transformed to liquid and gaseous hydrocarbons through chemical reactions with increasing burial over millions of years
    • Liquids and gases migrate into permeable beds
Drilling for Oil

Modern offshore oil production platform in the North Sea.

The first successful oil well was completed by Edwin Drake (right) on August 27, 1859, near Titusville, PA. The oil-bearing reservoir rock was encountered at a Depth of 21 meters (69 feet).
• Oil and Natural Gas
  – Traps for oil and gas
    • An *oil trap* is an environment that allows for economically significant amounts of oil and gas to accumulate underground.
      – All traps have two basic conditions.
        » A *reservoir rock*—A porous, permeable unit.
        » A *cap rock*—An impermeable unit.

• Common traps:
  – Anticline.
  – Fault trap.
  – Salt dome.
  – Stratigraphic (pinchout) trap.
Common Oil Traps

A. Anticline

B. Fault trap

C. Salt dome

D. Stratigraphic (pinchout) trap
Seismic Search for Oil and Gas

Explosive charge used to generate artificial seismic waves

The seismic data collected is used to map oil bearing geologic structures

Seismographs

Limestone

Shale acts as a caprock

Porous sandstone (reservoir for oil and gas)

Natural gas

Oil

Salt water

Seismic waves reflect off boundaries between different layers
Oil Sands, Oil Shale, and Gas Hydrates

- Oil Sands
  - Mixtures of clay and sand combined with water and bitumen (a viscous tar)
    - Oil in oil sands is much more viscous and cannot be pumped out
  - Several substantial deposits around the world
    - Largest reserve in Alberta, Canada
  - Obtaining oil from tar sands requires large amounts of energy and has significant environmental drawbacks
Oil Sands
Oil Sands
Oil shale in the United States
Oil shale in the Green River Formation
Energy Resources – Traditional Fossil Fuels

• Hydraulic Fracturing
  – In some regions, significant amounts of natural gas are *trapped in shale* with low permeability.
  – Shale is shattered (“fracking”) to release the gas.
  – Concerns for groundwater contamination and induced seismicity.
    • Still a controversial practice
Hydraulic Fracturing

Large amounts of water are delivered, mixed with sand and chemicals and pumped into the well.

Waste water is stored in an open pit and then taken to a treatment plant.

Natural gas flows into storage tanks.

Stored gas is sent to market via pipelines.

THE PROCESS:

- Hydraulic fracturing involves the injection of water, sand, and chemicals at high pressure into a well.
- The pressurized mixture creates new cracks in the rock layer. The cracks are held open by the sand grains.
- When pressure is released, hydraulic fracturing fluid (waste water) and natural gas flow to the surface.

Well turns horizontal.

Natural gas and waste water flows from fractures into well.
Nuclear Energy

• Nuclear energy is an important part of U.S. energy needs
  – Fuel comes from energy released by nuclear fission (splitting atoms)
    • Resulting controlled chain reaction releases heat used to drive steam turbines
    • U\textsuperscript{235} is the only naturally occurring isotope that is readily fissionable
      – Primarily fuel used in nuclear power plants
      – Rare isotope in Earth’s crust
Nuclear Energy

• Obstacles to Development
  – Plant safety
    • Skyrocketing costs for safety features
      – Plants cannot explode like bombs, however the escape of radioactive debris during a meltdown is a major hazard.
    • Example: Fukushima nuclear power plant, 2011.
Tsunami Destroys Nuclear Power Plant
Alternate energy sources - nuclear

San Onofre Power Plant
Renewable Energy

• Renewable energy sources regenerate and can be *sustained indefinitely*
  – The use of renewable energy is not new
    • 150 years ago, wood supplied most of our energy needs.
    • 13 percent of U.S. electricity is generated from renewable resources.
Renewable Energy

• Solar Energy
  – Direct use of the Sun’s rays to supply energy.
  • Passive solar collectors
    – South-facing windows.
  • Active solar collectors
    – Solar hot water.
    – Trough solar collectors.
    – Photovoltaic (solar) cells convert the Sun’s energy directly to electricity.
    – Stirling dish converts thermal energy to electricity.
Parabolic Troughs
Alternate energy sources - solar

Solar energy “farm” -- Mojave Desert near Victorville
Solar One (near Barstow)
near Sacramento
Renewable Energy

- Wind Energy
  - Converting the kinetic energy of a moving air mass (wind) into other forms of energy to perform work.
  - Increase in the number of wind turbines installed.
    - Wind turbines supply 3 percent of world electricity.
  - Wind speed is crucial in determining suitability of installing a wind-energy facility.
Global Installed Wind Capacity

MW (Megawatt = 1 million watts)

- 2000: 17,400
- 2001: 23,900
- 2002: 31,100
- 2003: 39,431
- 2004: 47,620
- 2005: 59,091
- 2006: 73,949
- 2007: 93,901
- 2008: 120,715
- 2009: 159,079
- 2010: 197,943
- 2011: 238,435
- 2012: 283,132
- 2013: 318,644
- 2014: 369,597
Wind Energy Potential for the United States

Annual Average Wind Speed at 80 meters

Wind Speed
m/s

>10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
<4.0

Map of the United States showing annual average wind speeds at 80 meters.
Still Pumping...
Alternate energy sources - wind

Palm Springs Wind Farm
Renewable Energy

• Hydroelectric Power
  – *Hydroelectric power* is power generated by falling water used to drive turbines to produce electricity.
  – Most energy is produced at large dams.
    • Dams have finite lifetimes.
    • Limited sites to construct dams.
  – Recently a different type of hydro power has come into use: *pumped water-storage system*.
    • Water is pumped to a higher storage reservoir during periods of low demand.
Grand Coulee Dam
Alternate energy sources - hydroelectric

Glen Canyon Dam, Arizona (Colorado River)
Alternate energy sources - hydroelectric

Hoover Dam, Nevada/Arizona border (Colorado River)
Renewable Energy

• Geothermal Energy
  – *Geothermal energy* is power generated by tapping into underground steam and hot water.
    • Used for heating and to generate electricity
  – Three factors determine if a geothermal reservoir has commercial value.
    • A potent source of heat
    • Large and porous reservoirs
    • A cap of low-permeability rocks
Geothermal Development in Iceland

Because the entire country consists of geologically young volcanic rocks, warm water can be encountered in holes drilled almost anywhere.

Iceland straddles the Mid-Atlantic Ridge. This divergent plate boundary is the site of numerous active volcanoes and geothermal systems.

The steam at this power station in southwestern Iceland is used to generate electricity. Hot (83°C) water from the plant is sent via an insulated pipeline to Reykjavik for space heating.
The Geysers
Alternate energy sources - geothermal

Cerro Prieto Geothermal Power Plant, near Mexicali, B.C.
Alternate energy sources - geothermal

SDG&E Geothermal Power Plants, near El Centro
Renewable Energy

- Biomass—Renewable Energy from Plants and Animals
  - *Biomass* is organic material made from plants and animals.
    - Wood
    - Crops
      - Biofuels
    - Manure
    - Garbage
      - Biogas
• **Tidal Power**
  
  – Ocean’s energy potential remains largely untapped
    
    • Tidal power is harnessed by constructing a dam across the mouth of a bay or estuary in a coastal area.
    
    • The narrow opening between the bay and the open ocean magnifies the variations in water level that occur as the tides rise and fall.
Tidal Power

A. Diagram of tidal power generation process:
- High tide
- Bay at high tide
- Dam
- Current
- Power generation
- Impounded water
- Low tide

B. Photograph of a tidal power plant.
Alternate energy sources - tidal

La Rance Barrage, France
Mineral Resources

- *Mineral resources* are the endowment of useful minerals ultimately available commercially.
- Mineral resources include:
  - *Reserves*—already identified deposits from which minerals can be extracted profitably.
    - An *ore* is a useful metallic mineral that can be mined for profit.
- 98 percent of the continental crust is composed of only eight elements
  - A deposit is valuable if the element is concentrated above the level of its average crustal abundance.
  - Known deposits that are not economically or technologically recoverable may become profitable if the demand changes.
Most Abundant Elements in the Continental Crust

- Oxygen (O) 46.6%
- Silicon (Si) 27.7%
- Aluminum (Al) 8.1%
- Iron (Fe) 5.0%
- Potassium (K) 2.6%
- Magnesium (Mg) 2.1%
- Sodium (Na) 3.6%
- Others 1.5%
Bingham Canyon, Utah
(Copper)
<table>
<thead>
<tr>
<th>Metal</th>
<th>Principal Ores</th>
<th>Geological Occurrences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>Bauxite</td>
<td>Residual product of weathering</td>
</tr>
<tr>
<td>Chromium</td>
<td>Chromite</td>
<td>Magmatic segregation</td>
</tr>
<tr>
<td>Copper</td>
<td>Chalcopyrite, Bornite, Chalcocite</td>
<td>Hydrothermal deposits; contact metamorphism; enrichment by weathering processes</td>
</tr>
<tr>
<td>Gold</td>
<td>Native gold</td>
<td>Hydrothermal deposits; placers</td>
</tr>
<tr>
<td>Iron</td>
<td>Hematite, Magnetite, Limonite</td>
<td>Banded sedimentary formations; magmatic segregation</td>
</tr>
<tr>
<td>Lead</td>
<td>Galena</td>
<td>Hydrothermal deposits</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Magnesite, Dolomite</td>
<td>Hydrothermal deposits</td>
</tr>
<tr>
<td>Manganese</td>
<td>Pyrolusite</td>
<td>Residual product of weathering</td>
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<tr>
<td>Mercury</td>
<td>Cinnabar</td>
<td>Hydrothermal deposits</td>
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<tr>
<td>Molybdenum</td>
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<tr>
<td>Nickel</td>
<td>Pentlandite</td>
<td>Magmatic segregation</td>
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<td>Platinum</td>
<td>Native platinum</td>
<td>Magmatic segregation; placers</td>
</tr>
<tr>
<td>Silver</td>
<td>Native silver, Argentite</td>
<td>Hydrothermal deposits; enrichment by weathering processes</td>
</tr>
<tr>
<td>Tin</td>
<td>Cassiterite</td>
<td>Hydrothermal deposits; placers</td>
</tr>
<tr>
<td>Titanium</td>
<td>Ilmenite</td>
<td>Magmatic segregation; placers Rutile</td>
</tr>
<tr>
<td>Tungsten</td>
<td>Wolframite, Scheelite</td>
<td>Pegmatites; contact metamorphic deposits; placers</td>
</tr>
<tr>
<td>Uranium</td>
<td>Uraninite (pitchblende)</td>
<td>Pegmatites; sedimentary deposits</td>
</tr>
<tr>
<td>Zinc</td>
<td>Sphalerite</td>
<td>Hydrothermal deposits</td>
</tr>
</tbody>
</table>
• Magmatic Differentiation
  – Separation of heavy minerals that crystallize early or enrichment of rare elements in the residual melt
  • Especially in the late stages of a melt
  – Sometimes crystals form in a fluid-rich environment
  • As fluids don’t solidify, the crystals grow unusually large
    – *Pegmatites* are rocks with unusually large crystals.
    – Often contain some of the least abundant elements.
    – Some pegmatites include semiprecious gems such as beryl, topaz, and tourmaline.
Pegmatites
Pegmatite in the Black Hills, South Dakota

Casts of spodumene crystals
Pegmatite near Warner Springs
Cryo-Genie Mine

Bi-color tourmaline, aquamarine...
• Hydrothermal Solutions
  – **Hydrothermal (hot water) solutions** are the best known and most important ore deposits.
  – **Vein deposits**
    • Hot, metal-rich fluids migrate through cracks in the rock before eventually depositing the metals.
    • Many of the most productive deposits of gold, silver, and mercury occur as hydrothermal vein deposits.
Pegmatites and Hydrothermal Deposits

- Geyser
- Fault
- Hydrothermal disseminated deposits
- Hydrothermal vein deposits
- Pegmatite deposits
- Magma chamber

High-grade gold ore deposit in a quartz vein
Igneous and Metamorphic Processes

• Hydrothermal Solutions
  – *Disseminated deposits*
    • Instead of being concentrated in narrow veins, disseminated deposits are distributed as small masses throughout the entire rock
      – Example: Copper, Bingham Canyon mine.
  – *Hydrothermal activity at oceanic ridges*
    • Black smokers are a source of metal-rich sulfide deposits.
Native Copper
Keweenaw Peninsula, Michigan
Sulfide Deposits along a mid-ocean ridge
Black smoker, East Pacific Rise
• **Diamonds**
  – Best known as gems but commonly used as abrasives
  – Originate at great depths (200 kilometers!)
  – Carried upward through pipe-shaped conduits that increase in diameter toward the surface
  – Crystals are disseminated in ultramafic rock called *kimberlite*. 
• **Metamorphic Processes**
  – Many important ores are created by *contact metamorphism*.
  – Most common minerals associated with contact metamorphism
    – Sphalerite (zinc).
    – Galena (lead).
    – Chalcopyrite (copper).
    – Magnetite (iron).
    – Bornite (copper).
Talc Exploration
Dillon, Montana, 1979
Mineral Resources Related to Surface Processes

- *Weathering* creates deposits by concentrating metals into economically valuable concentrations (*secondary enrichment*).

- **Bauxite**
  - Principal ore of aluminum.
  - Forms in rainy tropical climates from chemical weathering and the removal of undesirable elements by leaching.
Bauxite
• Other Deposits
  – Weathering processes concentrate metals that are deposited through low-grade primary ore.
    • Examples: copper and silver.
    • Typically occurs in deposits containing pyrite.
      – Pyrite is important because when it chemically weathers, sulfuric acid forms.
      – Enables percolating waters to dissolve the ore metals.
      – Metals gradually migrate downward through the primary ore body until they are precipitated.
Mineral Resources Related to Surface Processes

• Placer Deposits
  – *Placers* are deposits formed when heavy metals are mechanically concentrated by currents.
  – Involve heavy and durable minerals.
  – Examples include:
    • Gold.
    • Diamonds.
    • Tin.
Placers
“sourdough” in 1850
(how old do you think he is???)
Gold Dredge near Nome, Alaska
Gold Dredging in Colorado
Nonmetallic Mineral Resources

• Use of the word “mineral” is very broad
  – Materials not used for fuels or processed for metals are called *nonmetallic mineral resources*.

• Two common groups
  – Building materials.
  – Industrial minerals.
Nonmetallic Mineral Resources

• Building Materials
  – Natural aggregate
    • Crushed stone, sand, and gravel.
  – Gypsum
    • Plaster and wallboard.
  – Clay
    • Tile, bricks, and cement.
Aggregate in action
Nonmetallic Mineral Resources

• Industrial Minerals
  – Fertilizers
    • Nitrate, phosphate, and potassium compounds are important to agriculture.
  – Sulfur
    • Used to produce sulfuric acid.
  – Salt
    • Used to “soften” water, keep streets ice-free, and as a nutrient.
Potash Mine
Phosphate Mining in Florida
End of Chapter