Chapter 15:

Fossil Fuels and the Environment

Eric Kulin/ageFotostock

Oil Boom in North Dakota. Continuous Shale Oil Resources in Bakken Oil Fields

Jeff Wheeler/ZUMA Press/Newscom

A busy North Dakota highway. People are moving to North Dakota to take employment in the oil fields. The Bakken formation in western North Dakota is one of the biggest oil finds in recent history.

Overview

- Fossil Fuels
- Oil
- Natural Gas
- Shale Gas
- The Environmental Effects of Oil and Natural Gas
- Coal

Fossil Fuels

- Fossil fuels are forms of stored solar energy
  - Plants convert solar energy to chemical energy through photosynthesis
  - Oil, natural gas, and coal
    - Formed from incompletely decomposed organic matter converted by chemical reactions
    - Provide 87% of energy consumed worldwide

Oil

- Hypothesized that crude oil and natural gas are derived from organic materials (mostly plants) that were buried with marine or lake sediments in *depositional basins*
- Primarily found along plate boundaries
  - Exceptions to this include Texas, Gulf of Mexico, North Dakota, and the North Sea

Oil

- Conventional and continuous oil and gas resources
  - Resources are the total amount of oil and gas present in the rocks
  - Reserves are that portion of the resource that is identified and is currently available to be legally extracted at a profit
  - Continuous oil resources are regional in extent, occurring in broad geologic basins
    - Bakken formation in North Dakota, for example

Oil

- Source rock
  - Fine grained, organic-rich sediment
  - At least 500 m depth
  - Subjected to increased heat and pressure
    - Initiates the chemical transformation
  - Elevated pressure causes sediment to be compressed
    - Initiates upward migration to lower-pressure reservoir rock

Crude Oil and Natural Gas

- Reservoir rock
  - Coarser grained and relatively porous
  - Ex: sandstone and porous limestone
- Trap
  - Cap rock (often shale) blocks natural upward migration of the oil and gas
  - Often form in anticlines or faults

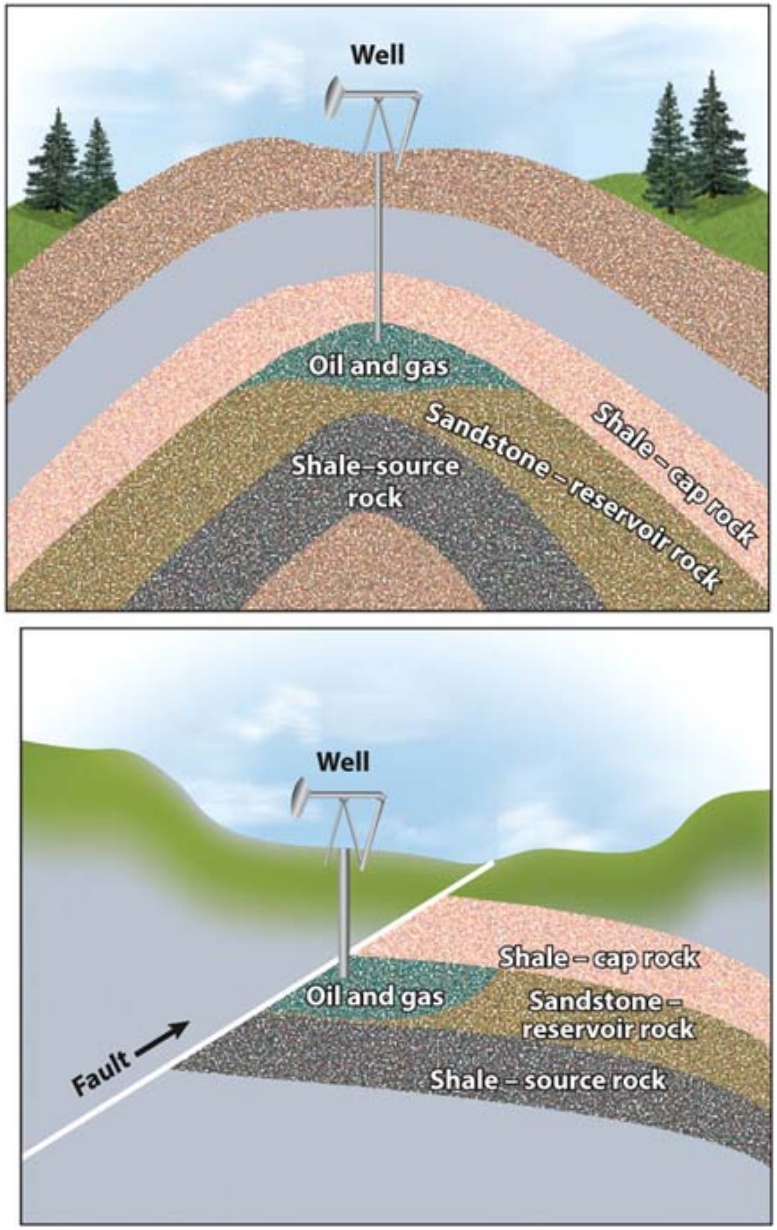


Figure 15.2 Two types of oil and gas traps: (a) anticline and (b) fault.

Sandstone and Limestone

Tar Sands

- Sedimentary rocks or sands impregnated with tar oil, asphalt, or bitumen
  - Recovered by mining sands and washing the oil out with hot water
  - Found in Alberta, Canada
    - Strip mined
  - Waste-disposal similar problem as with shale, but greater volume of waste produced
  - Inherently dirty process
  - Transportation via pipeline

https://www.desmog.ca/2013/09/30/oil-export-tar-sands-bitumen-cannot-be-refined-eastern-canada

Wally Bauman/Alamy

Figure 15.4 Mining tar sands north of Fort McMurray in Alberta, Canada. The large shovel-bucket holds about 100 tons of tar sand. It takes about two tons of tar sand to produce one barrel of oil.

Oil Shale

- Fine grained sedimentary rock containing organic matter (kerogen)
  - When heated to 500º C oil shale yields oil
  - Destructive distillation
  - Oil from shale called synfuel

http://sweetcrudereports.com/2017/10/19/opec-output-cut-threat-shale-supply-grow-81000bpd/

Oil Shale

- Recovery performed on both surface and subsurface
  - Disposal of waste a problem because shale must be retorted (crushed and heated)
  - Volume of waste 20–30% greater than original volume
- Oil shale mining may develop as oil prices rise

Petroleum Production

- Primary production
  - Involves pumping oil from wells
  - Recovers only 25% of petroleum in reservoir
- Enhanced recovery
  - Increases the amount recovered to ~60%
  - Steam, water, or chemicals injected into the reservoir to push oil towards wells

Petroleum Production

- Proven oil reserves
  - Portion of total resource that has been identified and can be extracted at a profit
  - Majority are located in Middle East

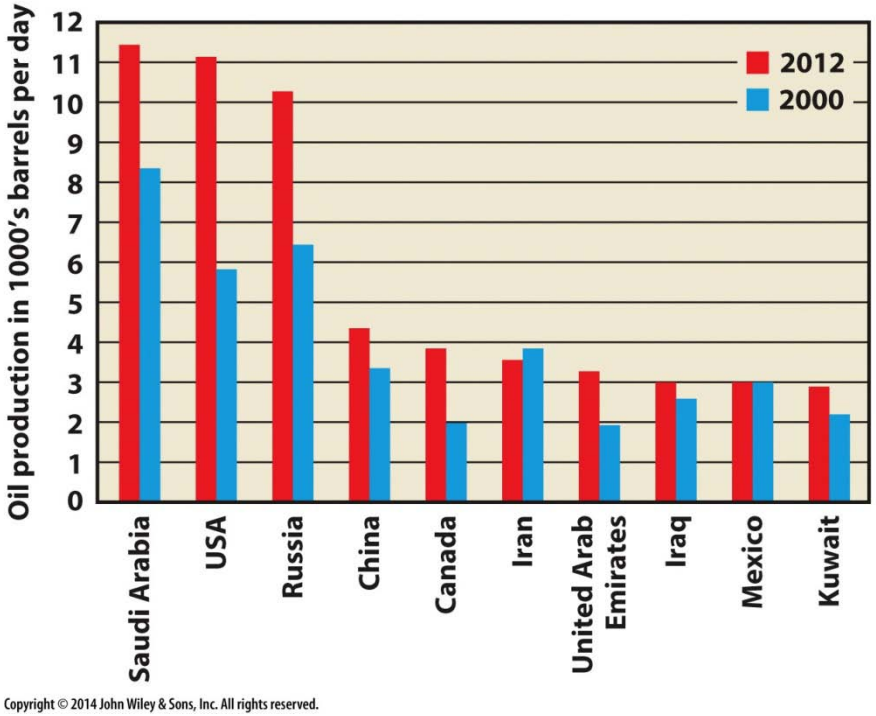


Figure 15.5 The World's top 10 producers of oil in 2000 and 2012. The U.S. is now one of the two top producers.

Oil in the Twenty-First Century

- Before shortages occur, need appropriate action to avoid
  - Military confrontation
  - Food shortages
  - Social disruption
- Need to develop alternative energy sources
  - Solar energy
  - Wind power
  - Nuclear power

Natural Gas

- Mixture of hydrocarbon gases. Most common is methane CH_4. Also includes propane C_3H_8 and butane C_4H_{10}.
- Only begun to utilize this resource
  - Pipelines technology is much better today
- Recoverable gas
  - Worldwide estimates = 100 years
  - New supplies are being found
- Considered a clean fuel
  - Produces fewer pollutants than burning oil or coal
  - Could be a transition fuel to alternative energy
  - Final gas resource : methane hydrate

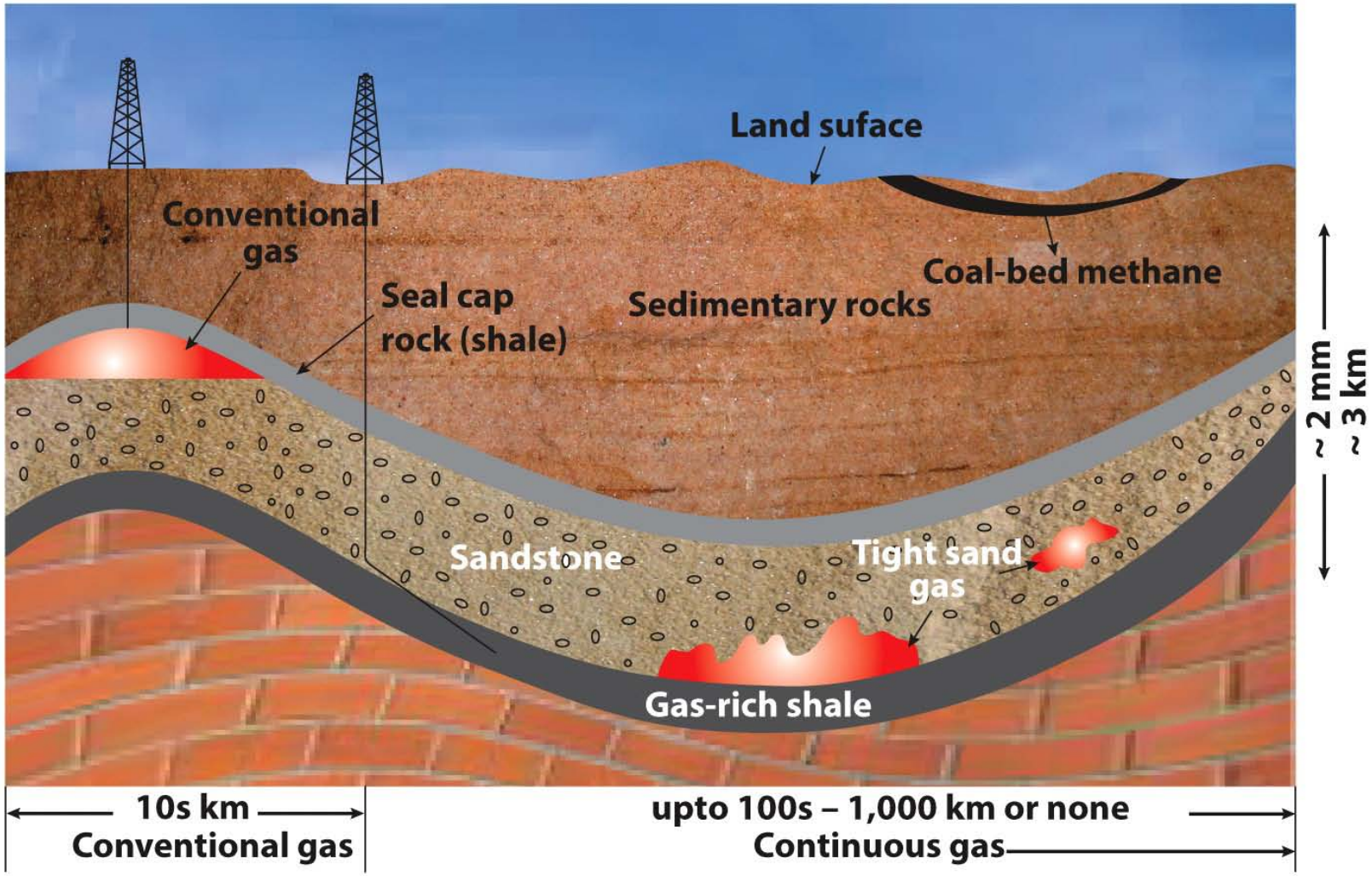


Figure 15.6 Conventional and continuous natural gas deposits (reservoirs).

Shale Gas

- Natural gas within tiny openings of shale rock
  - Shale has a lot of open space between grains
  - Fluids are held tightly
- At present consumption, this resource could supply all U.S. demand for natural gas for about 20 years
- In early stages of evaluating the shale gas resource and reserves; numbers will change as more is known about the geology

Shale Gas—Methane

- Methane is distributed throughout the black shale as a continuous gas resource
- Found in geologic basins in parts of Ohio, New York, Pennsylvania, Virginia, and Kentucky
- Recovery of the methane is costly
  - Requires deep wells at horizontal position
  - Water and other chemicals used to fracture the rocks (hydrologic fracturing, sometimes called fracking) to recover the gas
- Drilling and fracking could result in water pollution

Shale Gas—Tight Gas

- Natural gas produced from continuous deposits (reservoirs) of dense sandstone or limestone
- Originally produced in organic-rich sediments and has migrated to reservoir rock
- Held tightly (hence the name tight gas)
- Many gas recovery wells in tight gas rock reservoirs drilled horizontally and fracked to enhance production
- The tight gas resource in the United States supplies about 25% of all the natural gas produced in the country today

Coal-Bed Methane

- Partial decomposition of plants buried by sediments that slowly convert the organic matter to coal.
- Processes responsible for the formation of coal also release a lot of methane that is stored within the coal
- Estimated amount of coal-bed methane in the United States is more than 20 trillion cu m
- Represents a five-year supply of methane
- Environmental benefits
  - Produces much less carbon dioxide than coal or petroleum when burned
  - Reduces the amount of methane released into the atmosphere

Coal-Bed Methane

- Serious environmental concerns include:
  - Disposal of large volumes of water
  - Migration of methane, which may contaminate groundwater or migrate into residential areas
  - Safe disposal of salty water
  - Water removed from the groundwater aquifers
  - Serious and distressing noise pollution

Methane Hydrates

- Deposited beneath the seafloor at depths >500m
  - White, ice like compound
  - Made up of molecules of methane gas “trapped” in ice (cages of frozen water)
  - Form as a result of microbial decomposition on the sea floor
  - Also found on land in permafrost

Methane Hydrates

- Deep, cold seawater provides high pressure and low temperatures
  - At lower pressure and warmer temperatures, methane gas escapes as bubbles from the ice trap
- Potential energy source but currently no way to mine or transport the gas

Environmental Effects of Oil and Natural Gas

- Recovery, refining, and use of oil and natural gas cause environmental problems
  - Air and water pollution
  - Acid rain
  - Global warming

Recovery

- Environmental impacts of recovery on land
  - Use of land to construct pads for wells, pipelines, and storage tanks and to build a network of roads
  - Pollution of surface waters and groundwater

Drilling for oil in the Sahara Desert of Algeria

Recovery

- Accidental release of air pollutants
  - Hydrocarbons
  - Hydrogen sulfide
- Land subsidence (sinking) as oil and gas are withdrawn
- Loss or disruption of and damage to fragile ecosystems, such as wetlands

Recovery

- Environmental impacts of recovery in ocean
  - Oil seepage into the ocean
  - Release of drilling muds containing heavy metals, such as barium
  - Aesthetic degradation from the presence of offshore oil drilling platforms

Ken Graham/Bruce Coleman, Inc.

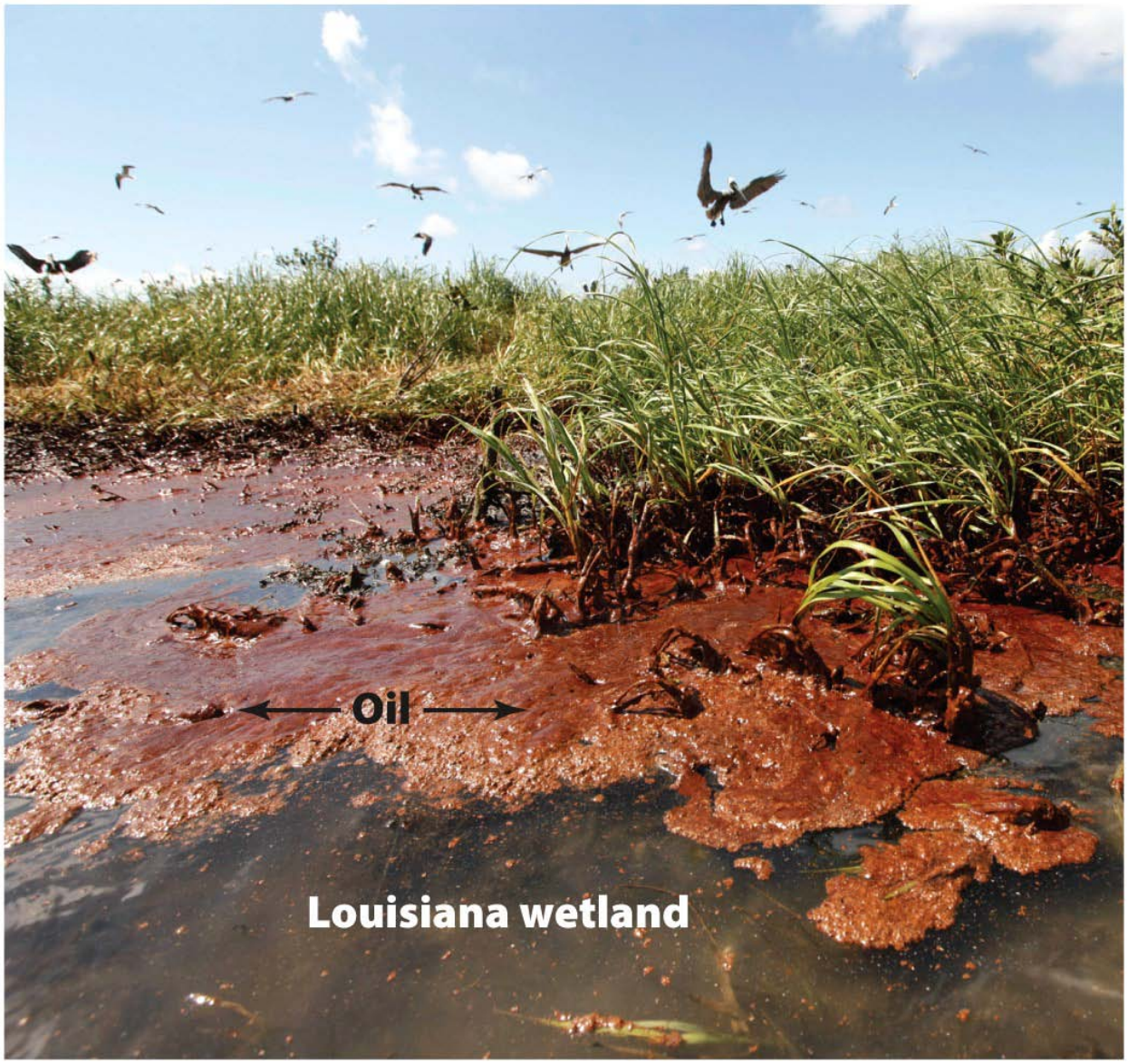
Drilling for oil in the Cook Inlet of southern Alaska.

Refining

- Fractional distillation at refineries
  - Crude oil heated so its components can be separated and collected
- Accidental spills and slow leaks
  - Hydrocarbons, hydrogen sulfide released, polluting soil and ground water
- Variety of chemicals used in the industrial process which have the potential to pollute

Delivery and Use

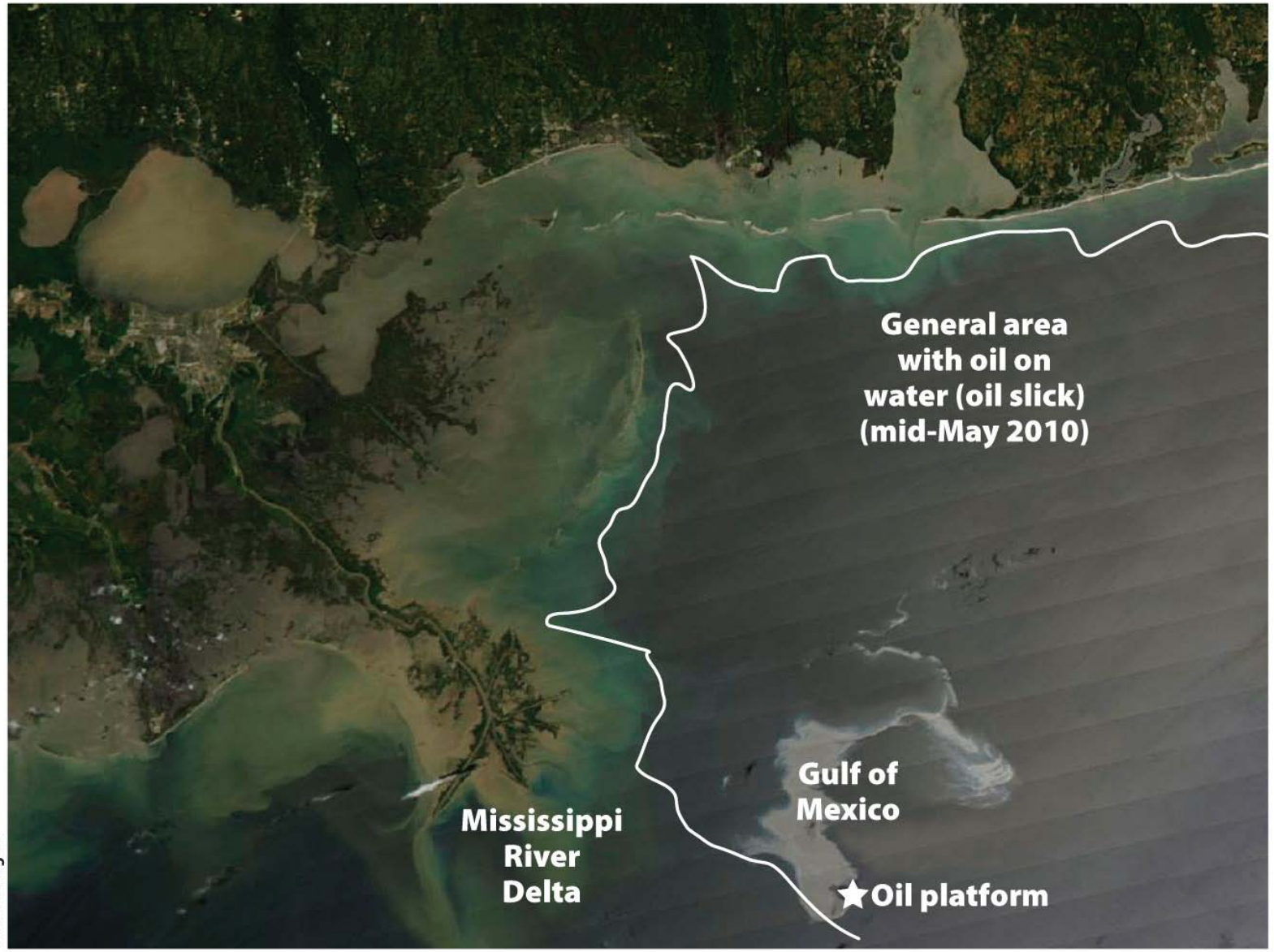
- Transportation of crude oil
  - On land by pipelines
  - Across the ocean in tankers
  - Both have danger of oil spill
- Air pollution from combustion
  - Most serious impact associated with use
  - Contributes to urban smog



Gerald Herbert/©AP/Wide World Photos

Figure 15.12 A Louisiana wetland after the *Deepwater Horizon* oil spill in the Gulf of Mexico.

The Oil Spill in the Gulf of Mexico, 2010



NASA Images

United States Coast Guard

NOAA

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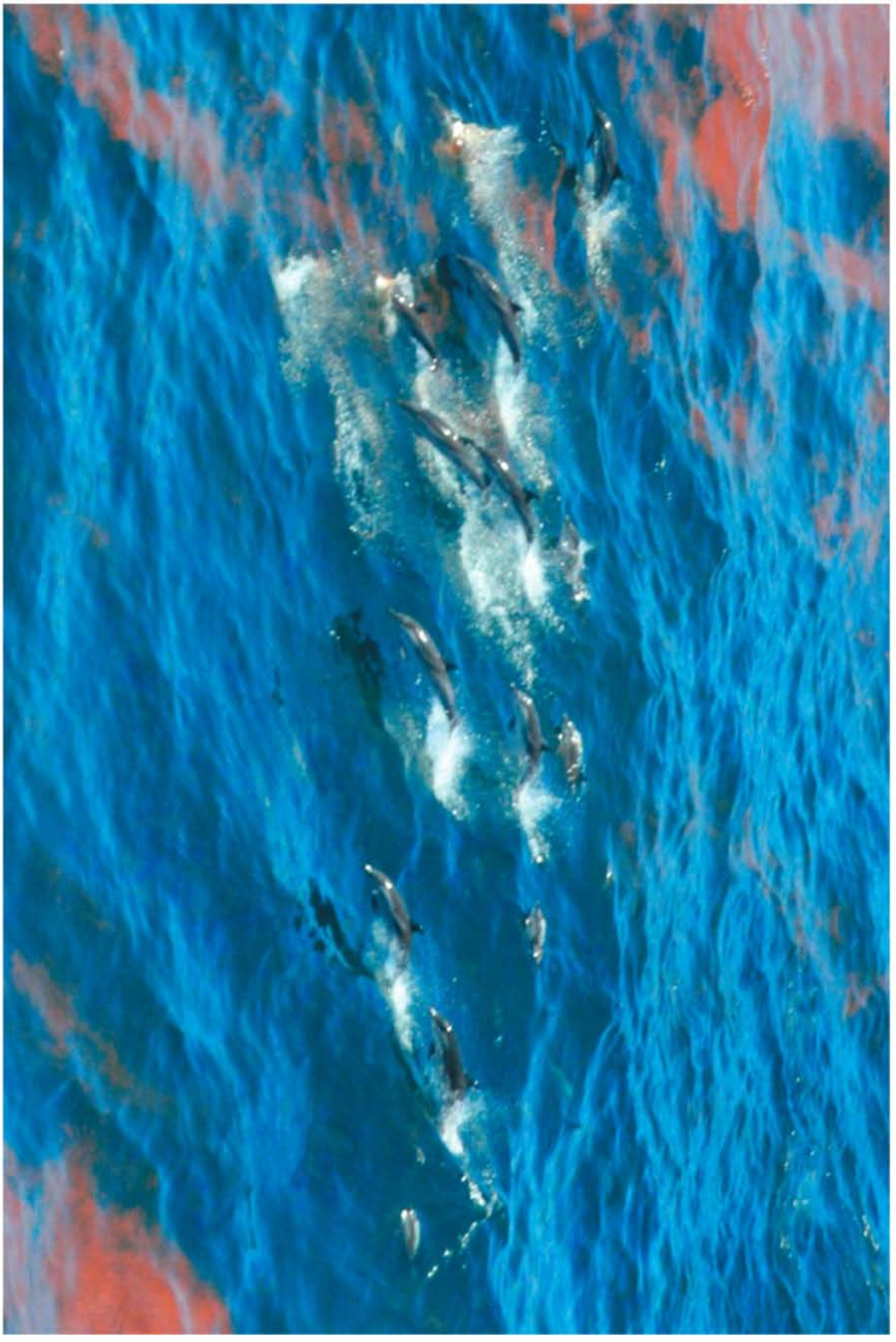
NOAA



NOAA

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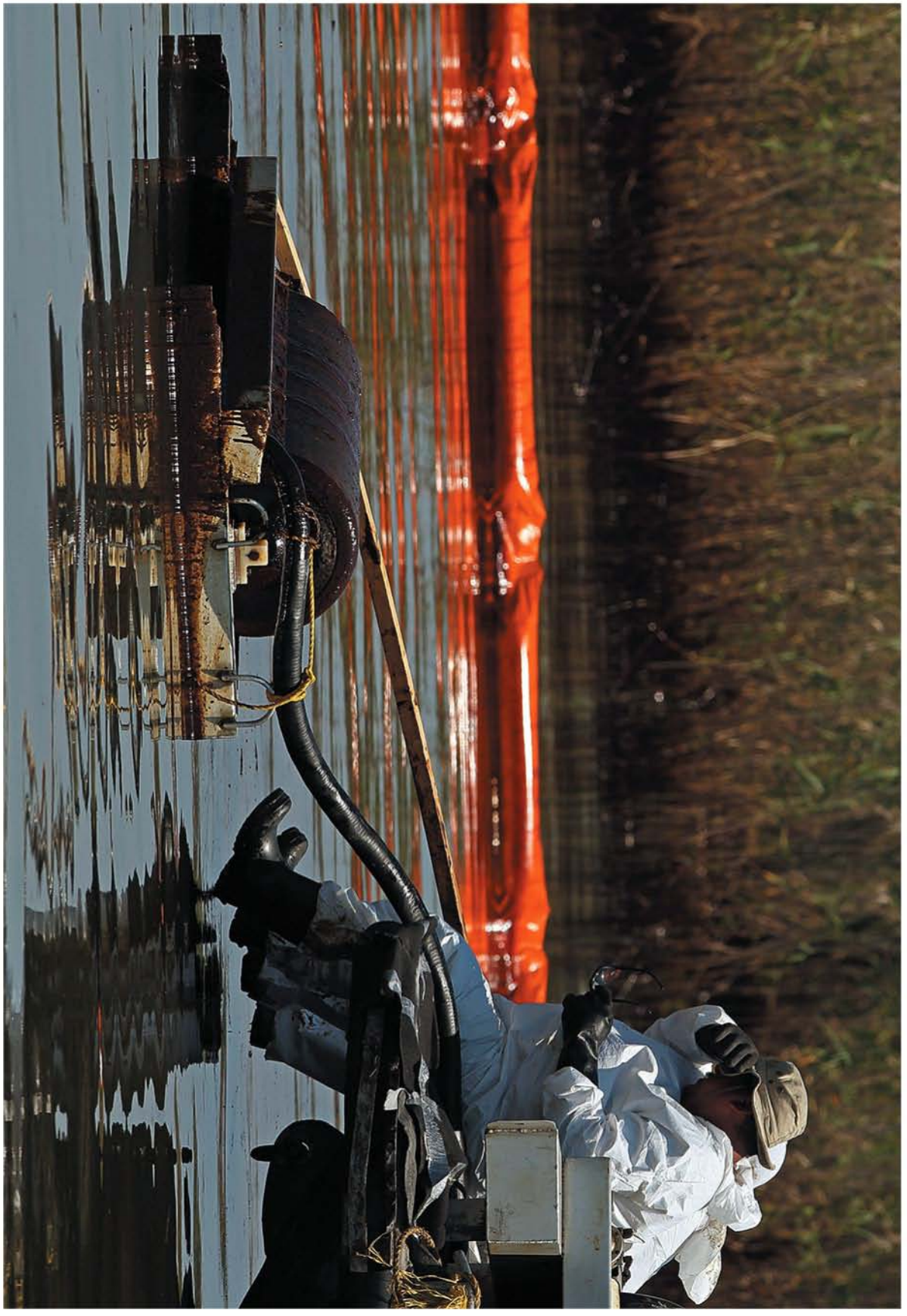

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Coal

- Partially decomposed vegetation in sedimentary environment
  - Slowly transformed in solid, brittle carbonaceous rock if buried in a sedimentary environment
- Most abundant fossil fuel
- At current consumption rate could last 200 years

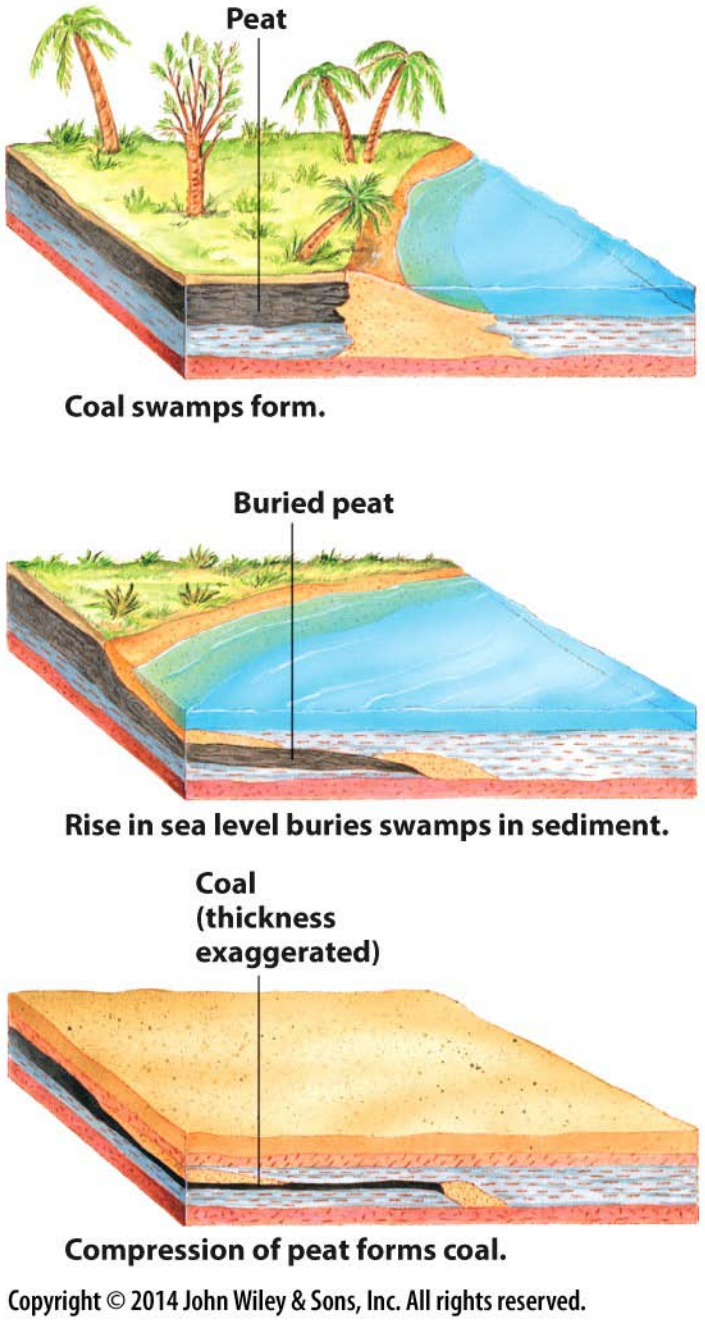

Figure 15.18 Processes by which buried plant debris (peat) is transformed into coal.

Coal

- Classified according to its energy and sulfur content
  - Anthracite, bituminous, subbituminous, lignite
  - Anthracite (high energy) & lignite (low energy)
  - Sulfur content of coal is important because low sulfur coal emits less sulfur dioxide and is therefore more desirable as a fuel in power plants.

Coal Mining and the Environment

- Avoid air pollution
- Reclamation
  - Process of restoring and improving disturbed land, often by reforming the surface and replanting vegetation

Strip Mining

- Surface process
  - Overlying layers of soil and rock are stripped off to reach the coal
  - Impact of large strip mines varies from region to region, depending on topography, climate and reclamation practices.
- Acid mine drainage
  - Side effect of strip mining
  - The drainage of acidic water from mine sites

Strip Mining

- Acid mine drainage
  - Occurs where surface water infiltrates spoil banks
  - Water reacts with sulfide minerals –pyrite (FeS_2) to produce sulfuric acid
  - Acid pollutes streams and groundwater
  - Pollute and damage water, lands and biological resources.

Figure 15.22 Tar Creek near Miami, Oklahoma, runs orange in 2003 due to contamination by heavy metals from acid mine drainage.

Strip Mining

- In arid and semiarid regions the land is more sensitive to mining activities
  - Exploration and road building
  - Soil is thin and water scarce
    - Makes reclamation more difficult
- Reclamation can minimize damage
  - Laws vary by site

IndexStock/SuperStock

Figure 15.21 Strip coal mine in Wyoming. The land in the foreground is being mined, and the green land in the background has been reclaimed after mining.

Mountaintop Removal

- Appalachian Mountains of West Virginia
  - Strip mining levels tops of mountains and fills valleys with mining waste
  - Flood hazard increases
    - Coal waste sludge dams formed by mine waste
    - Toxic waste water is stored
  - Also produces large amounts of coal dust
  - Lung diseases and asthma
  - Mining debris, flat lands.

Mountaintop Removal in West Virginia

Mandel Ngan/Getty Images, Inc.

Figure 15.24 Mountaintop mining in West Virginia has been criticized as damaging to the environment as vegetation is removed, stream channels are filled with rock and sediment, and the land is changed forever.

Strip Mining

- Surface Mining Control and Reclamation Act (SMCRA) of 1977
  - Prohibit mining on prime agricultural land
  - Reclamation includes
    - Disposing of wastes
    - Contouring the land
    - Replanting vegetation

Prof. Ed Keller

Mining an exposed coal bed at the Trapper Mine in Colorado

Prof. Ed Keller

the land during restoration following mining. Topsoil (lower right) is spread prior to planting vegetation.

Underground Mining

- Accounts for 40% of coal mined in the U.S.
- Environmental problems:
  - Acid mine drainage and waste piles pollute streams
  - Cater shaped pits, Land Cave in and collapse, hazardous fumes
  - Black lung disease, disabilities
  - Land subsidence can occur over mines
  - Coal fires in underground mines
    - Naturally caused
    - Deliberately set

Transporting Coal

- Coal must get from mining areas to large population centers
  - Significant environmental issues
- Methods
  - Freight trains
  - Slurring pipelines
    - Require large amounts of water

The Future of Coal

- Comprises 90% of fossil fuel reserves
- Coal power plants emit
  - 70% of sulfur dioxide
  - 30% of nitrogen oxides
  - 35% of carbon dioxide

The Future of Coal

- Clean Air Amendments of 1990 mandate reducing coal emissions
- Options for cleaner coal include:
  - Chemical and/or physical cleaning of coal prior to combustion
  - New boiler designs that permit lower temperature of combustion
  - Injection of material rich in calcium carbonate into the gases following burning
    - Scrubber—removes sulfur dioxides

The Future of Coal

- Options (continued)
  - Conversion of coal at power plants into gas (syngas) before burning
  - Conversion of coal to oil
  - Consumer education about energy conservation and efficiency to reduce the demand for energy
  - Development of zero-emission coal-burning electric power plants

The Future of Coal

- As oil and gas are used up, increased use of coal will have environmental impacts
  - More land strip mined
  - Air pollutants
  - Aesthetic degradation
  - Noise
  - Dust
  - Release of harmful or toxic trace elements into the water, soil, and air

Chapter Summary

- Fossil fuels
  - Forms of stored solar energy
  - Fuels formed from the incomplete biological decomposition of dead and buried organic material
- Fossil fuels are nonrenewable
  - We will eventually have to develop alternative sources to meet our energy demands
  - We must decide when the transition to alternative fuels will occur and what the impacts of the transition will be

Chapter Summary

- Environmental impacts related to oil and natural gas include
  - Those associated with exploration and development
    - Damage to fragile ecosystems
    - Water pollution
    - Air pollution
    - Waste disposal
  - Those associated with refining and processing
    - Pollution of soil, water, and air
  - Those associated with burning oil and gas for energy to power automobiles, produce electricity, run industrial machinery, heat homes, etc.
    - Air pollution

Chapter Summary

- The United States is undergoing a fossil fuel revolution
  - Abundant new supplies of conventional and continuous oil and gas are being developed
- This revolution will have profound economic and environmental consequences

Chapter Summary

- Coal remains an important resource for producing electric power, but
  - The new abundance of cleaner burning natural gas is likely to surpass coal as the fuel of choice in the coming decades
- Coal is an energy source that is particularly damaging to the environment
  - Environmental impacts of mining, processing, transporting, and using coal are many
  - Mining coal can cause fires, subsidence, acid mine drainage, and difficulties related to land reclamation
  - Burning coal can release air pollutants, including sulfur dioxide and carbon dioxide, and it produces a large volume of combustion products and by-products, such as ash, slag, and calcium sulfite

Chapter Summary

- It has been argued that development and maintenance of a quality environment for future generations is unsustainable at current use of fossil fuels
- Achieving sustainability will require wider use of alternative renewable energy sources and less dependence on fossil fuels