Ch. 15 - Nonrenewable Energy Resources

Evaluating Energy Resources

What Types of Energy Do We Use?

99% of energy we use to heat the earth and all our buildings comes directly form the sun.

1% of energy used is commercial energy sold in the marketplace (oil, gas, coal)

How Should We Evaluate Energy Resources?

Types of energy used and how we use them determines our quality of life and our harmful environmental effects.

Dependency on fossil fuels is primary cause of air and water pollution, land disruption, and global warming

Affordable oil - expected to be depleted in 40-80 years

Goals:

> #1 - eliminate unnecessary waste by improving energy efficiency
>
> #2 - (disagreement) - either start relying more on renewable energy sources, or burn more coal and synthetic liquid and gaseous fuels made from coal.

Energy alternatives take 50^{+} years to phase in

Net Energy

def'n: the total useful energy available from the resource over its lifetime minus the amount of energy used (1st law of energy), automatically wasted (2nd law of energy) and unnecessarily wasted in finding, processing, concentrating and transporting it to others.

Oil - Crude Oil and how it is processed

Petroleum (crude oil) is a fossil fuel produced by the decomposition of deeply buried dead organic matter from plants and animals under high temperatures and pressures over millions of years.

- consists mostly of hydrocarbons, with small amount of sulfur, oxygen and nitrogen.

Prime oil recovery - pumping out oil that flows into the bottom of the well by gravity

Secondary oil recovery - water is injected into nearby wells to force oil to the surface.

Primary and secondary oil recovery - only 35% of oil can be recovered.

Enhanced or tertiary oil recovery - recover about 10-25% of remaining heavy oil (inject steam or CO_2 into the well cavity).

Crude oil is transferred to a refinery where it is fractionated by distillation to produce naphtha, diesel oil, home heating oil, fuels (gasoline) and various solid fractions (waxes, asphalt, greases, etc.)

Petrochemicals - refinery products that are use as raw materials in the production of organic chemicals, pesticides, cosmetics, synthetic fibers (nylon, acrylates, etc.), medicines, etc.

World's Oil Supplies

Oil reserves - identified deposits from which oil can be extracted profitably at current prices with current technology.

OPEC controls 67% of world oil supplies

Saudi Arabia - 26%
Iraq - 10%
United States - 2.3%

Reserves are expected to be depleted in 35-80 years - depending on consumption. At the current rate of consumption, reserves will last 44 years. But global oil consumption is expected to increase 25% by 2010.

Pros and Cons of Conventional Oil

Advantages:

Oil is cheap, easily transported (pipelines, trucks, ocean tankers), has a high net energy yield

Low prices encourage waste and discourage improvements in energy efficiency of switching to another source of energy

Disadvantages:

Reserves are running low

Demand may exceed production in 10-20 years

Can cause pollution and environmental degradation throughout its life cycle

Drilling causes land disturbance - accelerating erosion, producing waste material, polluting soil and water when spilled.

Groundwater contamination

Burning produces CO_2, a greenhouse gas, sulfur dioxide and nitrogen oxides

Pros and Cons of Shale Oil

Oil shale - fine grained rock containing a solid, waxy mixture of hydrocarbons called kerogen

Shale oil is extracted from the rock by crushing, heating to vaporize the kerogen, condensing to form heavy, slow flowing dark-brown shale oil. Must be heated to reduce viscosity for pumping. Sulfur, nitrogen and other impurities must be removed.

Global supplies are potentially 200 times larger than estimated supplies of conventional oil

Disadvantages:

Lower net energy yield - take about 1/2 barrel oil to process shale oil

Requires large amounts of water (scarce where shale deposits are located)

Greatly disturbs the land leaving mountains of shale rock (expands when heated)

Can contaminate water supplies with salts, toxic metals and cancer-causing substances

Underground processing of shale oil is too expensive and produces more sulfur dioxide than surface processing.

Pros and Cons of Oil from Tar Sands

Tar Sand - mixture of clay, sand, water and bitumen (gooey black high-sulfur heavy oil)

Removed by surface mining, heated with pressurized steam to soften the bitumen and float it to the top. Bitumen is then purified and chemically upgraded into a synthetic crude oil suitable for refining.

World's largest deposit - Athabasca Tar Sands - northern Alberta, Canada. (33 years supply for Canada alone)

Also found in Venezuela, Colombia and parts of former Soviet Union

Disadvantages:

Net energy yield is low (1/2 half barrel to extract and process)

Requires large quantities of water to process

Upgrading bitumen releases large quantities of air pollutants

Creates huge waste disposal ponds

Natural Gas - What is it?

Mixture of 50-90% methane (CH_4) by volume; contains smaller amounts of ethane, propane, butane and hydrogen sulfide.

Deposits normally occur near hot spots where high temperatures and pressures or catalytically active metals break down long chain hydrocarbons in petroleum to the smaller molecules.

Conventional natural gas - lies above most reservoirs of crude oil

Unconventional deposits - include coal beds, shale rock, deep deposits of tight sands and deep zones that contain natural gas dissolved in hot water.

Gas Hydrates - an ice-like material that occurs in underground deposits (globally)

Liquefied Petroleum Gas (LPG) - propane and butane are liquefied and removed from natural gas fields. Stored in pressurized tanks.

Removal of natural gas from remote locations costs more than it is worth.

Liquefied Natural Gas (LNG) - natural gas is converted at a very low temperature (-184^{o}C)

World's Natural Gas Supplies.

Russia and Kazakhstan - 40%
Iran - 15%
Qatar - 5%
Saudi Arabia - 4%
Algeria - 4%
United States - 3%
Nigeria – 3%
Venezuela - 3%

Most natural gas reserves are located in the same places as crude oil

Pros and Cons of Natural Gas

Advantages:

Cheaper than Oil

Known US reserves 65-80 years

World reserves - >125 years

Easily transported over land (pipeline)

High net energy yield

Produces less air pollution than other fossil fuels

Produces less CO_2 than coal or oil

Extracting natural gas damages the environment much less that either coal or uranium ore

Easier to process than oil

Can be used to transport vehicles

Can be used in highly efficient fuel cells

Disadvantages:

When processed, H_2S and SO_2 are released into the atmosphere

Must be converted to LNG before it can be shipped (expensive and dangerous)

Conversion to LNG reduces net energy yield by one-fourth

Can leak into the atmosphere; methane is a greenhouse gas that is more potent than CO_2.

Coal - What is it?

Coal is a solid, rocklike fossil fuel; formed in several stages as the buried remains of ancient swamp plants that died during the Carboniferous Period (ended 286 million years ago); subjected to intense pressure and heat over millions of years.

Coal is mostly carbon (40-98%); small amount of water, sulfur and other materials

Three types of coal

- lignite (brown coal)
- bituminous coal (soft coal)
- anthracite (hard coal)

Carbon content increases as coal ages; heat content increases with carbon content.

Subsurface Mining - labor intensive; world's most dangerous occupation (accidents and black lung disease)

Surface Mining - three types

- Area strip mining
- contour strip mining
- open-pit mining

How is coal used?

Coal provides 25% of world's commercial energy (22% in US).

Used to make 75% of world's steel

Generates 64% of world's electricity

Remainder of world's electricity is produced by:

- hydroelectric dams - 18%
- nuclear energy - 17%
- other - 1% (solar, wind, etc.)

In US electricity is produced by coal (57%), nuclear energy (19%), natural gas (11%), hydroelectric power (9%), oil (3%) and renewable resources (1%)

Coal-Fired Electric Power Plant

Coal is pulverized to a fine dust and burned at a high temperature in a huge boiler. Purified water in the heat exchanger is converted to high-pressure steam that spins the shaft of the turbine. The shaft turns the rotor of the generator (a large electromagnet) to produce electricity.

Air pollutants are removed using electrostatic precipitators (particulate matter) and scrubbers (gases). Ash is disposed of in landfills. Sulfur dioxide emissions can be reduced by using low-sulfur coal.

World's Coal Supplies

US - 66% of world’s proven reserves

Identified reserves should last 220 years at current usage rates. Unidentified reserves could last about 900 years

Pros and Cons of Solid Coal

World's most abundant and dirtiest fossil fuel

High net energy yield

Disadvantages:

harmful environmental effects

mining is dangerous (accidents and black lung disease)

harms the land and causes water pollution

causes land subsidence

surface mining causes severe land disturbance and soil erosion

surface mined land can be restored - involves burying toxic materials, returning land to its original contour, and planting vegetation (expensive and not often done)

Acids and toxic metals drain from piles of water materials

Coal is expensive to transport

Cannot be used in solid form in cars (must be converted to liquid or gaseous form)

Dirtiest fossil fuel to burn releases CO, CO_2, SO_2, NO, NO_2, particulate matter (fly ash), toxic metals and some radioactive elements.

Burning coal releases thousands of times more radioactive particles into the atmosphere per unit of energy than does a nuclear power plant

Produces more CO_2 per unit of energy than other fossil fuels and accelerates global warming.

A severe threat to human health (respiratory disease)

Fluidized-bed combustion - developed to burn coal more cleanly and efficiently.

Use of low sulfur coal - reduces SO_2 emissions

Pros and Cons of Converting Solid Coal into Gaseous and Liquid Fuels

Coal gasification - synthetic natural gas (SNG)

Produce hydrogen gas

Coal liquefaction - produce a liquid fuel - methanol or synthetic gasoline

Synfuels can be transported by pipeline inexpensively; burned to produce electricity; burned to heat houses and water; used to propel vehicles.

Coal gasification and coal liquefaction - low net energy yield; 30-40% of energy content would be lost in the energy conversion

Synfuels requires huge amount of water, release more CO_2 than coal.

Nuclear Energy

Three reasons why nuclear power plants were developed in the late 1950s:

Atomic Energy Commission promised electricity at a much lower cost than coal

US Gov't paid ~1/4 the cost of building the first reactors

Price Anderson Act protected nuclear industry from liability in case of accidents

Globally, nuclear energy produces only 17% of world's electricity (6% of commercial energy)

Why is nuclear power on the decline?

huge construction overruns

high operating costs

frequent malfunctions

false assurances

cover-ups by government and industry

inflated estimates of electricity use

poor management

Chernobyl

Three Mile Island

public concerns about safety, cost and disposal of radioactive wastes

How a Nuclear Reactor Works

Nuclear fission of Uranium-235 and Plutonium-239 releases energy that is converted into high-temperature heat. This rate of conversion is controlled. The heat generated can produce high-pressure steam that spins turbines that generate electricity.

Light-water reactors (LWR)

Core containing 35,000-40,000 fuel rods containing pellets of uranium oxide fuel. Pellet is 97% uranium-238 (nonfissionable isotope) and 3% uranium-235 (fissionable).

Control rods move in and out of the reactor to regulate the rate of fission

Moderator - slows down the neutrons so the chain reaction can be kept going [liquid water in pressurized water reactors; solid graphite or heavy water (D2O)].

Coolant - water to remove heat from the reactor core and produce steam

1/3 of fuel rod assemblies must be replaced every 3-4 years. They are placed in concrete-lined pools of water (radiation shield and coolant).

Nuclear wastes must be stored for 10,000 years

After 15-40 years of operation, the plant must be decommissioned by

dismantling it

putting up a physical barrier, or

enclosing the entire plant in a tomb (to last several thousand years)

Advantages of Nuclear Power:

Doesn't emit air pollutants (i.e., no CO_2)

Water pollution and land disruption are low

Nuclear Power Plant Safety

Very low risk of exposure to radioactivity

Three Mile Island - March 29, 1979; No. 2 reactor lost coolant water due to a series of mechanical failures and human error. Core was partially uncovered

Nuclear Regulatory Commission estimates there is a 15-45% chance of a complete core meltdown at a US reactor during the next 20 years.

US National Academy of Sciences estimates that US nuclear power plants cause 6000 premature deaths and 3700 serious genetic defects each year.

Low-Level Radioactive Waste

Low-level waste gives off small amounts of ionizing radiation; must be stored for 100-500 years before decaying to levels that don't pose an unacceptable risk to public health and safety

1940-1970: low-level waste was put into drums and dumped into the oceans. This is still done by UK and Pakistan

Since 1970, waste is buried in commercial, government-run landfills.

Above-ground storage is proposed by a number of environmentalists.

1990: the NRC proposed redefining low-level radioactive waste as essentially nonradioactive. That policy was never implemented (as of early 1999).

High-Level Radioactive Waste

Emit large amounts of ionizing radiation for a short time and small amounts for a long time. Must be stored for about 240,000 years if plutonium-239 is not removed by reprocessing.

Spent fuel rods; wastes from plants that produce plutonium and tritium for nuclear weapons.

Possible Methods of Disposal and their Drawbacks

Bury it deep in the ground

Shoot it into space or into the sun

Bury it under the Antarctic ice sheet or the Greenland ice cap

Dump it into descending subduction zones in the deep ocean

Bury it in thick deposits of muck on the deep ocean floor

Change it into harmless (or less harmful) isotopes

Currently high-level waste is stored in the DOE $2 billion Waste Isolation Pilot Plant (WIPP) near Carlsbad, NM. (supposed to be put into operation in 1999)

Worn-Out Nuclear Plants

Walls of the reactor's pressure vessel become brittle and, thus, are more likely to crack.

Corrosion of pipes and valves

Decommissioning a power plant (3 methods have been proposed)

immediate dismantling

mothballing for 30-100 years

entombment (several thousand years)

Each method involves shutting down the plant, removing the spent fuel, draining all liquids, flushing all pipes, sending all radioactive materials to an approved waste storage site yet to be built.

Connection between Nuclear Reactors and the Spread of Nuclear Weapons

Components, materials and information to build and operate reactors can be used to produce fissionable isotopes for use in nuclear weapons.

Can We Afford Nuclear Power?

Main reason utilities, the government and investors are shying away from nuclear power is the extremely high cost of making it a safe technology.

All methods of producing electricity have average costs well below the costs of nuclear power plants.

Breeder Reactors

Convert nonfissionable uranium-238 into fissionable plutonium-239

Safety: liquid sodium coolant could cause a runaway fission chain reaction and a nuclear explosion powerful enough to blast open the containment building.

Breeders produce plutonium fuel too slowly; it would take 100-200 years to produce enough plutonium to fuel a significant number of other breeder reactors.

Nuclear Fusion

D-T nuclear fusion reaction; Deuterium and Tritium fuse at about 100 million degrees Celsius

Uses more energy than it produces