

Supplementary Notes (PJ Shlachtman, Miller book):

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 from 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
- goal – #1 – eliminate unnecessary waste by improving energy efficiency
#2 – (disagreement) – either start relying more on renewable energy sources, or burn more coal and synthetic liq. and gaseous fuels made from coal.
- Energy alternatives take 50+ years to phase in

Net Energy

Definition: 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)

- 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 CO₂ 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 used 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

- 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 CO₂, 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

- 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.
- S, N, and other impurities must be removed.
- Global supplies are potentially 200X 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 (CH₄) 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°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 Oil from 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 CO₂ than coal or oil
- Extracting natural gas damages the environment much less than 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, H₂S and SO₂ 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 CO₂.

Coal

What is it?

Coal

- 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, CO₂, SO₂, NO, NO₂, particulate matter (flyash), 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 CO₂ 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 SO₂ 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 CO₂ than coal.

Nuclear Energy

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

1. Atomic Energy Commission promised electricity at a much lower cost than coal
2. US Gov't paid ~1/4 the cost of building the first reactors
3. 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

1. dismantling it
2. putting up a physical barrier, or
3. enclosing the entire plant in a tomb (to last several thousand years)

Advantages of Nuclear Power:

- Don't emit air pollutants
- 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
- Spent fuel rods; wastes from plants that produce plutonium and tritium for nuclear weapons.
- Possible Methods of Disposal and their Drawbacks
 1. Bury it deep in the ground
 2. Shoot it into space or into the sun
 3. Bury it under the Antarctic ice sheet or the Greenland ice cap
 4. Dump it into descending subduction zones in the deep ocean
 5. Bury it in thick deposits of muck on the deep ocean floor
 6. 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)
 1. immediate dismantling
 2. mothballing for 30-100 years
 3. 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 1-200 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
- Uses more energy than it produces