Alternative Energy
Alternative Energy

Main sources of Energy: Coal, Petroleum and Natural Gas account for 90% of World Energy Production (1993)

Other sources:
- Nuclear (7%), Hydro (2.5%), Geothermal and Wind (0.5%)
- Solar, Tidal, Biomass
Nuclear Energy

- **Fission:** Splitting of large atomic nuclei into smaller ones e.g., splitting of $^{235}$U(92) into Barium (56) and Krypton(36) + 3 neutrons + Energy (2 million electron volts)
- 1 gm of $^{235}$U = 2.7 metric tons of coal = 13.7 barrels of crude oil
- **Fusion:** combining of smaller atoms into a larger atom e.g., H(1) + H(1) = He(2)
- $^{235}$U can be induced to split by firing neutron into the nucleus which in turn produces more neutrons that splits other $^{235}$U nuclei and a chain reaction ensues
- A controlled chain reaction is used to produce continuous moderate release of energy (criticality) which heats water to turn steam turbines
Nuclear Fission and Chain Reaction

Involution Uranium 235

(other particles and energy)
Enrichment of U

- Natural Uranium is 99.3% $^{238}\text{U}$ (stable), 0.7% $^{235}\text{U}$
- Most modern reactors require enriched U with 4% $^{235}\text{U}$
- Beneficiation: Natural ore contains <1% $\text{U}_3\text{O}_8$ which is concentrated to form Yellowcake (70-90% $\text{U}_3\text{O}_8$)
- Enrichment: $\text{U}_3\text{O}_8$ is converted to gaseous UF$_6$ which is passed through thousands of porous membranes to concentrate $^{235}\text{U}$
- Enriched UF$_6$ is converted to $\text{UO}_2$, compacted into small pellets and loaded in 5m long metal tubes to form fuel rods
Nuclear Reactor

- In a nuclear reactor fuel rods are interspersed with moderator (Graphite or Deuterium).
- **Moderators** are rods of light element which slows down neutrons emitted by $^{235}$U atoms.
- Slowing down of neutrons can either a. increase the chances of it’s interaction with another $^{235}$U atoms
- Boron Steel **control rods** are used to absorb slow neutrons to control the reaction rates.
- In a fast breeder reactor the core of highly enriched uranium is encircled by $^{238}$U. Neutrons escaping from the core turns nonfissionable $^{238}$U to fissionable $^{239}$Pu
Conventional Nuclear Fission Reactor. Heat is Generated by Chain Reaction

- Control rods to modify the rate of chain reaction
- Fuel rods
- Reactor core
- Cooling water
- Heat exchanger
- Power-generating loop
- Steam-driven turbine to produce electricity
- Containment building
Nuclear Waste

- Spent fuel rods remain radio active for many thousand years and have to be properly stored: major safety concern
- US repository: Yucca Mountains in Nevada
Geology of Uranium

- 95% of all known deposits are in sedimentary or meta-sedimentary rocks
- U minerals occur in granites and carbonates
- U dissolves in surface water during weathering and is carried by ground water.
- Local reducing condition in aquifers redeposit U from solution
## Economics of U

### Price and Reserve

<table>
<thead>
<tr>
<th>Price</th>
<th>Reserve (million lbs of U$_3$O$_8$)</th>
<th>Resource (including Reserve)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$30/lb</td>
<td>290</td>
<td>3,780</td>
</tr>
<tr>
<td>$50/lb</td>
<td>947</td>
<td>6,487</td>
</tr>
<tr>
<td>$100/lb</td>
<td>1,493</td>
<td>9,823</td>
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</tbody>
</table>

- **Price:** $11/lb in 1993 from $70/lb in 1976
- **US produced 6 million lbs and imported 32 million lbs in 1995; production can at most be increased 4X by 2010, meeting 15% of US energy needs.**
- **Reserve will last several decades only**
Future

- **Natural Uranium**
  - 99.7% $^{238}\text{U}$, 0.7% $^{235}\text{U}$
  - $^{238}\text{U}$ can be converted to $^{239}\text{Pu}$ which is fissile

- **Breeder Reactors**: produces more fissionable fuel than they consume
  - High cost and Late breakeven point

- **US** has 109 Nuclear power plants (out of 437 worldwide) and no breeder reactor

- **Nuclear Energy** produces 22.5% of all electricity in US compared to 76% for France

- Presently in disfavor
Nuclear Reactor Safety

- Runaway chain reaction and core meltdown
  - Three Mile Island (1979): 35-45% meltdown
  - Chernobyl (1986): closed down in the year 2000
  - Risk: 1 in a million per reactor per year
  - No risk of atomic blast

- Loss of containment due to explosion, terrorist activity, earthquake etc
Hazards

- **Handling:**
  - Miners exposed to higher radiation
  - Tailings from processing plants
  - Security during handling in processing plants e.g., theft of Pu

- **Wastes:**
  - Cannot be neutralized by burning or chemically
  - No permanent waste disposal site anywhere
  - Decommissioned reactors: 20 reactors likely to be decommissioned in the US by 2000
    - Cost of decommissioning $100 – 500 million
Age Distribution of Nuclear Reactors Worldwide

![Bar chart showing the distribution of reactor ages worldwide. The x-axis represents reactor age in years (1 to 40), and the y-axis represents the number of reactors. The chart indicates that the highest number of reactors are between 11 and 13 years old.]
Radioactive Waste Disposal

- Isotopes with short half-lives are gone quickly, those with long half-lives will decay too little
- Low level wastes: 90% of all radioactive wastes
  - 20 temporary and 6 commercial disposal sites
  - States to take care of their low level waste
- High level wastes e.g., spent nuclear fuel rods
  - Should be so disposed as to cause less than 1000 death in 10,000 years
High Level Waste Depository

- Rocketing to sun
- Under Antarctica Ice sheet
- Subduction Zone
- Sea bed disposal
- Bedrock caverns
  - Granites, basalt, tuff, shale, salt caverns
  - Salt: High melting point, impermeable in dry condition, self-sealing, cheap resource
- No permanent high level waste repository yet
Requirements for a radio-active waste disposal system

- Design and Fabricate a System that will
  - Last thousands of years longer than recorded human history
  - Be robust enough to isolate highly radioactive material so that it will not threaten human health and environment for more than ten thousand years.
Waste Canisters are Emplaced into Salt Walls
Story of Yucca Mountain Site

- **1982:** Nuclear Waste Policy Act
  - Congress charges DOE with the task
  - Two high level waste depository in the eastern and the western USA
  - Billions collected from tax on utilities
- **1986:** Hanford, WA, Yucca Mtn, NE and Deaf Smith County, TX short listed as western sites
- **1987:** Congress suddenly decides on Nevada (screw Nevada bill)
  - Nevada to receive $20 million/year
- **Feb 15, 2002:** Pres. Bush approved Yucca Mtn as the site for high level nuclear waste repository
Proposed Waste Disposal Site Nevada
Major Faults Near the Yucca Mountain Site
Yucca Mountain Site

- Geologically stable (?)
  - Limited fault displacement
  - No volcanism in 10,000 years
- Tuff host rock, 1000 ft below the surface, 1000 ft above the water table
- Arid climate, no streams, low water table
- Low population density
- Federally owned land, close to Nevada test sites
Fusion

- Abundant fuel source
- Products are nontoxic
- Lack of technology to contain the reactants
  - Laser, magnet (tokomak)
- Cold Fusion???
The Process of Nuclear Fusion

Hydrogen-3 (tritium) nucleus + Hydrogen-2 (deuterium) nucleus → Helium-4 nucleus + (energy released) + (leftover neutron)

Proton: +
Neutron:  

Solar Energy

- Inexhaustible resource
- No hazardous waste, air or water pollution
- No transmission loss
- Solar energy is dispersed and variable
- Major areas of application:
  - Solar Heating
  - Solar Electricity
Solar Heating

- Passive Heating: no mechanical assistance
  - Building design to allow maximum amount of sunlight to stream through in winter months
  - Water in barrels, indoor swimming pools, rocks, bricks and concrete etc absorbs and store heat which is radiated in cooler times (night)
  - Wide eaves during the summer and drapes and shutters during the winter insulates house.
Design Features of Home and Landscaping can Optimize Use of Sun

In summer, leaves and wide eaves together shade windows, reducing incoming sunlight.

Lower-angle winter sun streams through tree branches and under eaves.
Active Solar Heating

- Involves mechanical circulation of solar heated water
- Flat glass faced water filled boxes with dark lining is used to heat water
- Hot water is stored and circulated as needed
- Collectors can be mounted on roofs: no extra land needed
- 40 to 90% of home heating needs can be supplied
- Would require back-up system for cloudy days
- Retrofit of existing homes is expensive
- Can aggravate indoor air pollution
Active Solar Heating System

Sunlight

Water-filled collector

Some hot water can be used as needed.

Pump

Storage tank for heated water
Solar Electricity

- Solar Cells (photovoltaic cells), usually made of silicon, is used to convert sunlight in electricity.
- High cost of production:
  - Lack of technology (only 20% efficiency)
  - Lacks economy of scale
- 100 watt light bulb requires 2 sq meter of cell
- Solar electricity can supply 10 – 15% of US energy needs
Solar cells: Indirect pollution

- Modern cells require Gallium and Arsenic which are highly toxic metals
- A 100 megawatt plant will require:

<table>
<thead>
<tr>
<th>Material</th>
<th>Solar</th>
<th>Nuclear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel (tons)</td>
<td>30 to 40,000</td>
<td>5000</td>
</tr>
<tr>
<td>Concrete</td>
<td>200,000</td>
<td>50,000</td>
</tr>
<tr>
<td>Glass</td>
<td>5000</td>
<td>--</td>
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</tbody>
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Large scale disturbance of land, evaporation, surface run-off patterns etc
Geothermal Energy

- Uses earth’s heat (from shallow level magmas) to heat water
- Most of the productive areas situated near plate boundaries
- Geothermal steam: virtually pollution free
- Geothermal water:
  - Corrosive: Large % of dissolved solids
  - Pollutes surface and ground water
  - Land subsidence risk
Geothermal Energy is Utilized by Tapping Circulating Warmed Ground Water

- Hot water, steam tapped for energy
- Natural recharge by cool water infiltrating from surface through fractures, etc.
- Cold water returned

Diagram showing permeable rocks and impermeable rocks with circulating warmed water and cooling magma.
US scenario

- The Geysers, California is the main US field
  - Operating since 1960
  - 2000 Megawatt (MW) capacity

- Total US production
  - Utilities: 5000 MW
  - Non-utilities ~10 billion watts
  - Less than 1% of total energy consumed

- Other areas in world:
  - Iceland, Llardello (Italy), Wairakei (New Zeland), Japan, Mexico, Philippines etc…
Long-term problems

- Slow heating of fresh water
- Power plant must be cited in the geothermal field requiring long transmission
- Cannot be used, like gas, for transportation
- Rather rare, only in plate boundaries
- Hot-dry Rocks can have potential use
Hydro Power

- Supplies 4% of US energy needs and 10% of US and 6% of world electricity
- Potential hydro energy 3X present value
- Clean, renewable, non polluting source, uses but does not consume water
- Construction of dams causes silting-up of reservoirs, habitat destruction, water loss by evaporation, even earthquakes
- Risk of Dam failure
- Dependent on the vagaries of climate
Wind Power

- Clean, inexhaustible, renewable
- High capital cost
- Dispersed in 3d, intermittent
  - Newer turbines are generating 95% of time
- Windiest places far removed from population centers: high transmission cost
- Require arrays of windmills: 100 sq.miles needed for 1000 MW power
Percentage of Electricity Demand that Could be Supplied by Wind-Power Technology

Wind Resource in the United States
India excels in tapping power
PTI
(Washington, Jun 1)

INDIA HAS been highly successful in harnessing alternative power sources and has emerged as a leader of the windmill revolution, the prestigious US New Earth Policy Institute has said.

India ranks fifth in tapping power from this unconventional source -- 1,167 megawatts, researcher for the American Wind Energy Revolution Sergio Serrichio and the President and founder of the New Earth Policy Institute Dr Lester Brown said.

Germany leads by generating 6,113 megawatts, followed by the US 2,554, Denmark 2,300, Spain 2,235, the Netherlands 449, Italy 427, UK 406, China 265 and Sweden with 231 megawatts.

Asserting the viability of windmills in fulfilling power needs while being ecologically safe, they said just three States of the United States -- North Dakota, Texas and Kansas -- can generate enough electric power to meet the entire power need of the US through this source.

The economics of windmills is more attractive than other modes of production as it costs only three to six cents per kilowatt per hour.

Windmills can be set up on ranches or farms. Though solar power needs further development, it has proved indispensable for space research and for items like calculators while providing power to far-flung areas which have no electricity and are not connected to the grid, Brown said.
US scenario

- Potential: 25-50% of all US electricity
- Production: only 3% of US generating capacity, 1% of actual power generation
- The Great Plains region is the most promising area in the US
Biomass

- Second largest source of renewable energy in US
- Burning of wood, urban refuse, harvest waste etc
- Alcohol produced from grains or non-food part of plants is a renewable source
- Mixed with gasoline (90:10) to make gasohol.
- Part of super unleaded fuel
- US produced 800 million gallons in 1992
- Contributed only 0.12% of all energy consumed
- Clean Air Act (1990) calls for alternative fuel fleet vehicles: brighter prospect for alcohol
- Biogas (rich in methane) can be derived from oxygen free decay of organic waste
Hydrogen Fuel Cell

Hydrogen is the most abundant element in the universe, constituting about 93% of all atoms. It is found in water (H₂O), fossil fuels (basically, compounds of hydrogen and carbon), and all plants and animals.

A fuel cell is a generator that chemically produces electricity from hydrogen and oxygen. It produces direct current like a battery, and continues to produce power as long as fuel is supplied.

There are many types of fuel cells:
- PEM (Proton Exchange Membrane): better suited for small-scale power generation, such as in a vehicle
- Molten carbonate: operate at very high temperatures, and are best suited for large scale operations, such as power plants
- Alkaline (the kind the space program uses).
Hydrogen Fuel Cell

- The red Hs represent hydrogen molecules (H2) from a hydrogen storage tank.
- The orange H+ represents a hydrogen ion after its electron is removed.
- The yellow e- represents an electron moving through a circuit to do work (like lighting a light bulb or powering a car).
- The green Os represent an oxygen molecule (O2) from the air, and
- The blue drops at the end are for pure water--the only byproduct of hydrogen power.
Advantages

- A fuel cell is quiet, efficient and clean.
- Fuel cells usually run on pure hydrogen gas, which can be produced cleanly from solar power, as well as other renewable energy sources.
- Fuel cells running on hydrogen produce no pollution; the only byproduct is pure water.
- Fuel cells are about 50% efficient, while internal combustion engines are only 12%-15% efficient.
- And, since there are no moving parts, fuel cells can be very reliable and make almost no noise.
- Safe and non-toxic
Carbon-adsorption systems:

- refrigerated and pressurized tanks that can store massive amounts of hydrogen.
- over 7 gallons of hydrogen could be stored in a single gram of this new material.
- This allows a range of nearly 5,000 miles from a single tank!
- These tanks would weigh less than 200 pounds, occupy about half the amount of space used by current gasoline tanks, and could be refueled in 4-5 minutes.
- current lead-acid batteries consume over 17 times as much space and 45 times as much weight as gasoline tanks (45 cubic feet of space and 6,750 pounds for a driving range equivalent to 15 gallons of gasoline), have range of only 100 miles and breakdown is frequent.
Present scenario

Some companies that already have hydrogen fueled vehicles on the road are:

(1) Mercedes-Benz, with about 20 cars and vans,

(2) BMW, which is testing liquid hydrogen in two sedans and plans to have a fleet of 100 hydrogen vehicles on the road in the 1990s,

(3) Mazda, which had 3 vehicles as of 1993, and

(4) Ballard Power Systems, which is developing and selling fuel cells and hydrogen-fuel-cell-powered buses (to the city of Chicago, for example)

Various individuals and universities are also researching and developing hydrogen vehicles.
The End