WELL KNOWN ISSUES

- Energy use is increasing
- Raw fuel reserves are limited
- Pressure on standard of living
- Global warming

SOME PROPOSED SOLUTIONS

- Replace coal with renewables (wind, solar)
- Sequester CO2
- Switch to biofuels
- Conservation
- Add heating insulation
- Bring back nuclear

More proposed solutions

- Drive smaller cars
- Expand use of geothermal
- Use oil shale and tar sands for gasoline
- Build smaller houses
- Increase the efficiency of everything
- Cars: hybrids, plug-in hybrids, fully electric

Strategy Assessment

- It's a hodge-podge
- Are all problems being addressed?
- Are alternatives compared by means of a cost-benefit analysis?
- Are we providing sufficient funds for R&D innovations?
- Does the media do a good job informing the public?

Main Course Goals

- Put logic and order into the energy situation
- Develop a comprehensive overview
- Learn how to measure and evaluate options
- Arm you with the knowledge to make sensible decisions

Outline

- Energy uses
- Energy consumption
- Fuel reserves
- The greenhouse effect
- Energy technologies

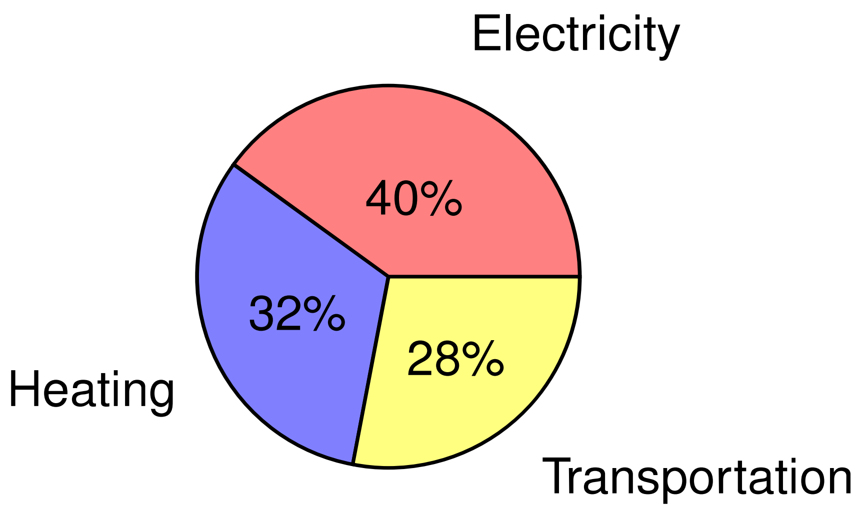
Energy Sources and Uses

- A useful breakdown of energy usage
  - Heating - gas, oil
  - Transportation - oil
  - Electricity - coal, nuclear, gas, hydro
- Heating - anything will do
- Transportation - need mobile fuel
- Electricity - lighting, cooling, industry

US Energy Usage

- Electricity
- Transportation
- Heating

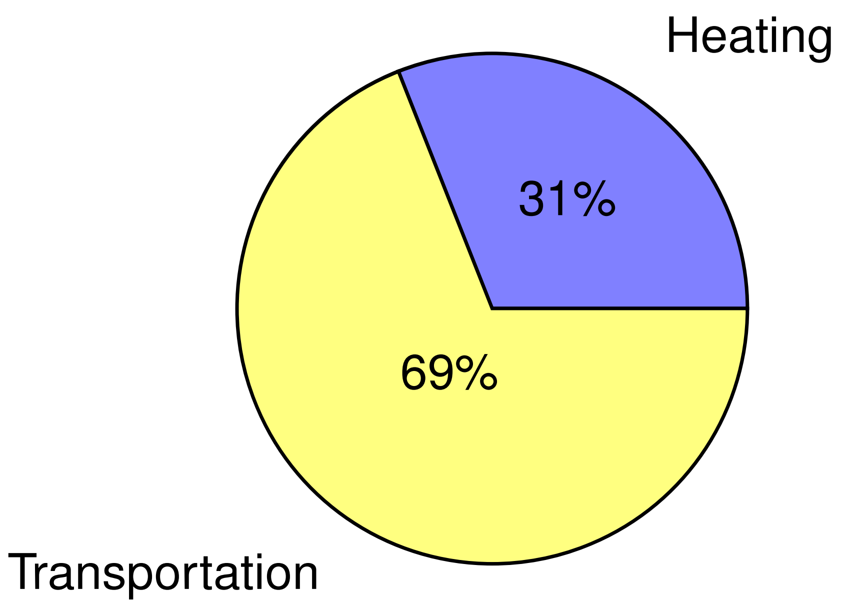
Energy by Application in 2007



(EIA-DoE 2007)

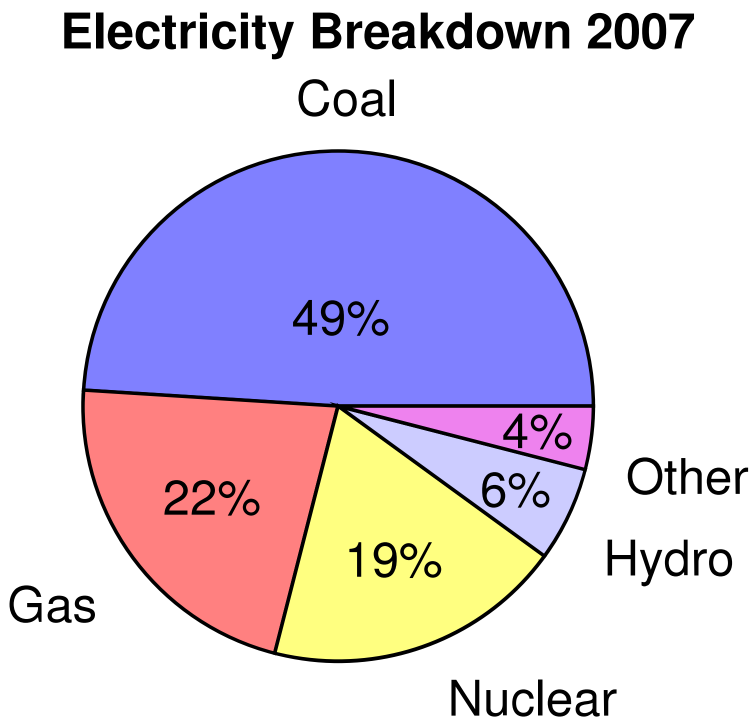
US Oil Usage

- Transportation vs. heating

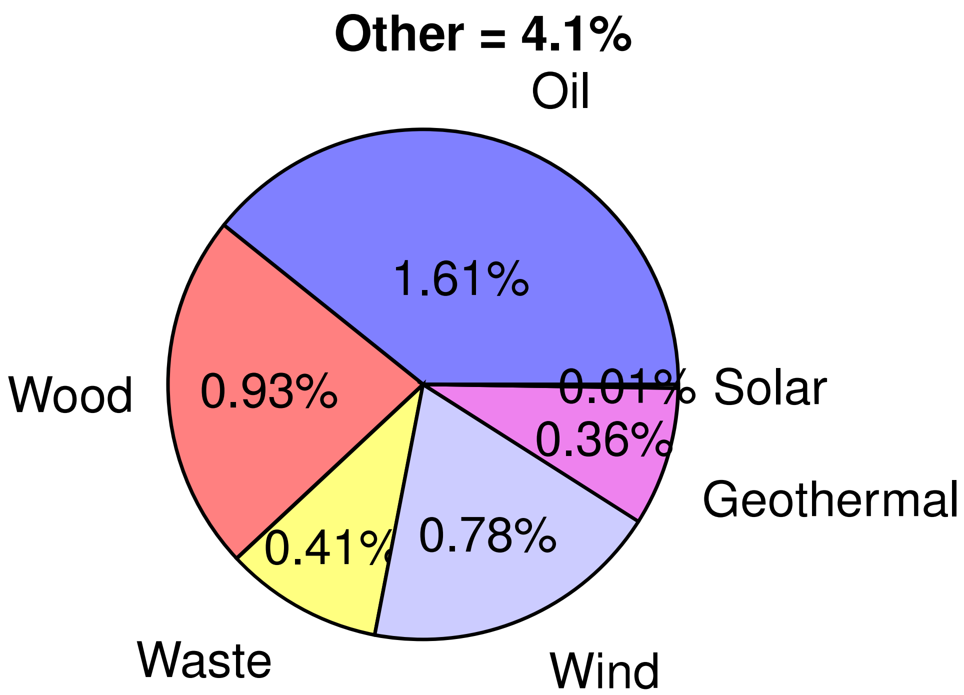


US ELECTRICITY BREAKDOWN

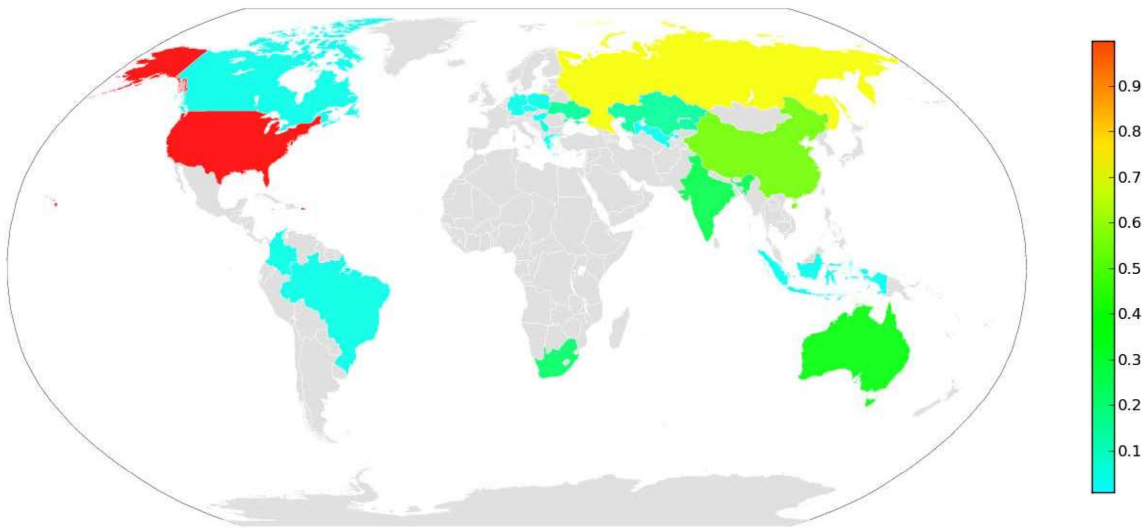
- How do we obtain electricity?



OTHER


Other = 4.1%
Oil
1.61%
Wood
0.93%
0.01% Solar
0.36%
Geothermal
0.41%
0.78%
Waste
Wind

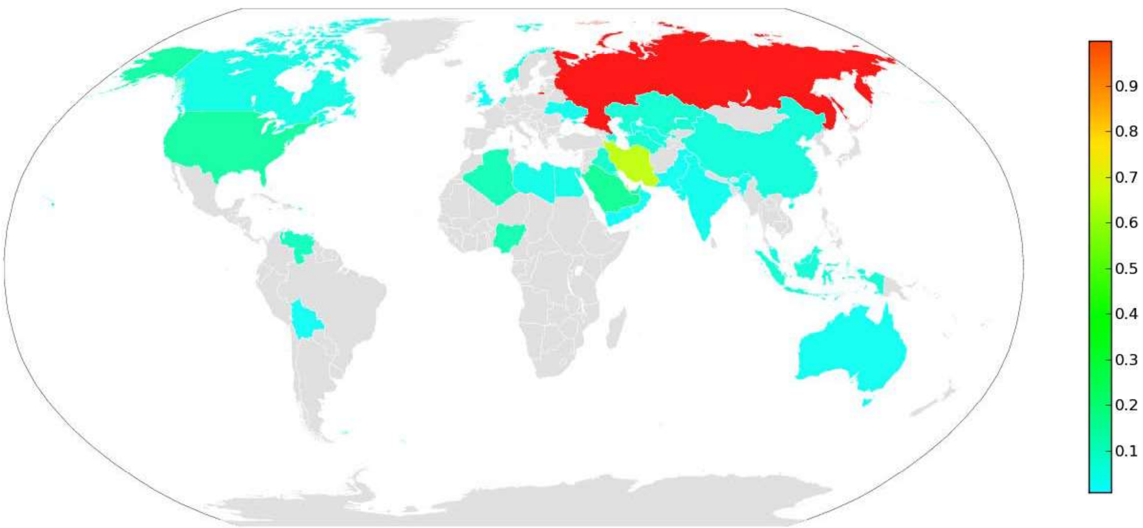
World Coal Reserves = 930423 millon short tons



[data from doe.eia.gov]

- Lots of coal in US, Russia, China, India, Australia
- Data normalized to peak value.

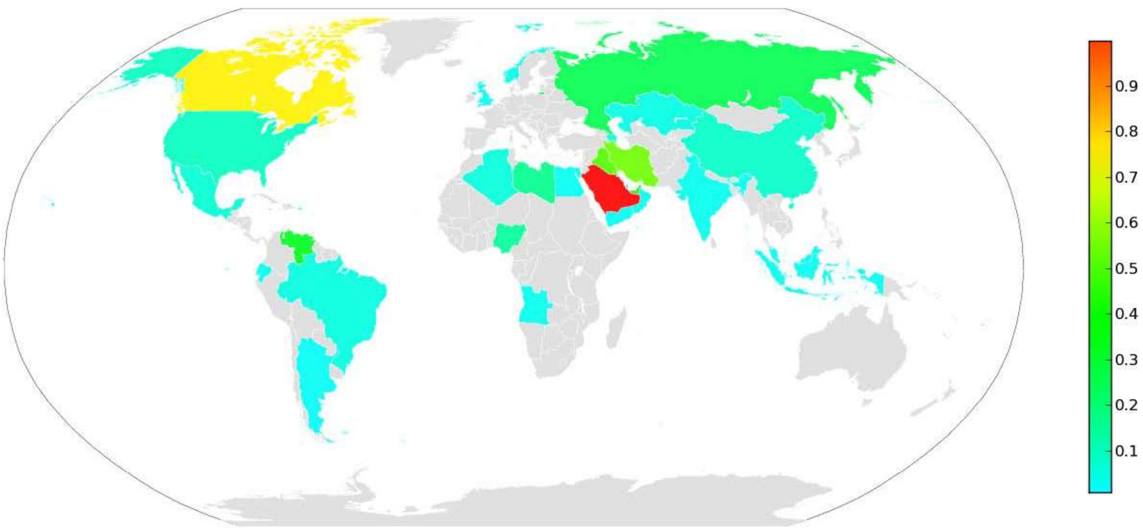
WORLD GAS RESERVES = 6189 MILLION MILLION CUBIC FEET



[data from doe.eia.gov]

- Gas in Russia
- Data normalized to peak value.

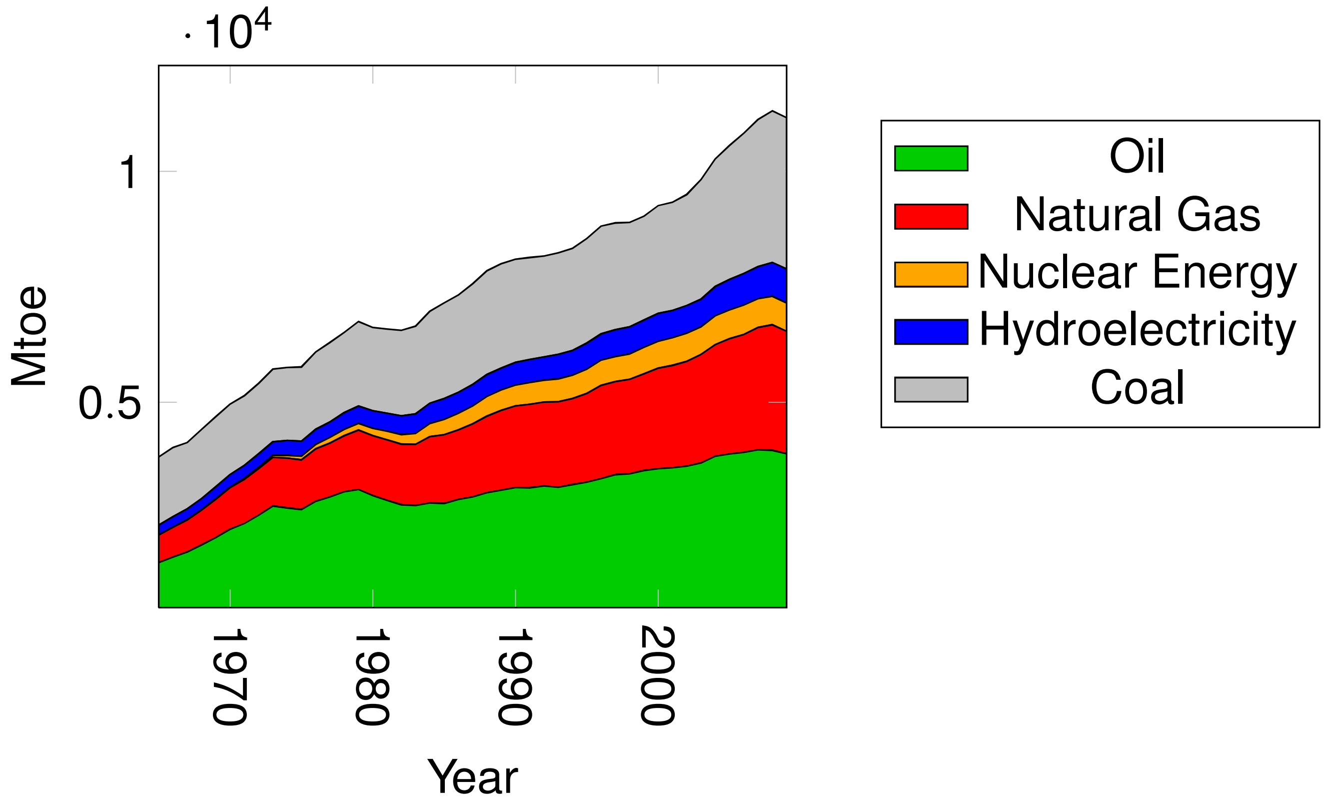
WORLD OIL RESERVES = 1277 THOUSAND MILLION BARRELS



[data from doe.eia.gov]

- Oil in Saudi Arabia.
- Compare barrels, ft^3, tonnes, short tons, Mtoe

World Energy Consumption



- Growth in energy usage related to increase population and standard of living
- Note recent reduction in 2008-2009.

How long will the supplies last?

- Oil and natural gas - 50 years
- Coal - 300 years
- Oil shale and tar sands - 350 years
- Nuclear fission
  - Today's light water reactors - 100 years
  - Future breeders - 10,000 years
- Nuclear fusion
  - DT reaction - 10,000 years
  - DD reaction - ∞
- Renewables - ∞

How about using H instead of nuclear to replace fossil fuels?

- Hydrogen is not a naturally occurring fuel
- There are no hydrogen mines
- It must be manufactured - it's an energy carrier
- Basic problems are tough
  - Takes considerable energy to produce hydrogen.
  - Difficult to transport .
  - Expensive to transport.
  - Energy density is low: vs. for gasoline.

THE MAJOR TECHNOLOGIES OF INTEREST

- Fossil fuels
- Nuclear fission
- Hydroelectric
- Renewables
  - Wind
  - Solar thermal
  - Solar voltaic
  - Biomass
  - Geothermal
  - How do these work?

How does a power plant work?

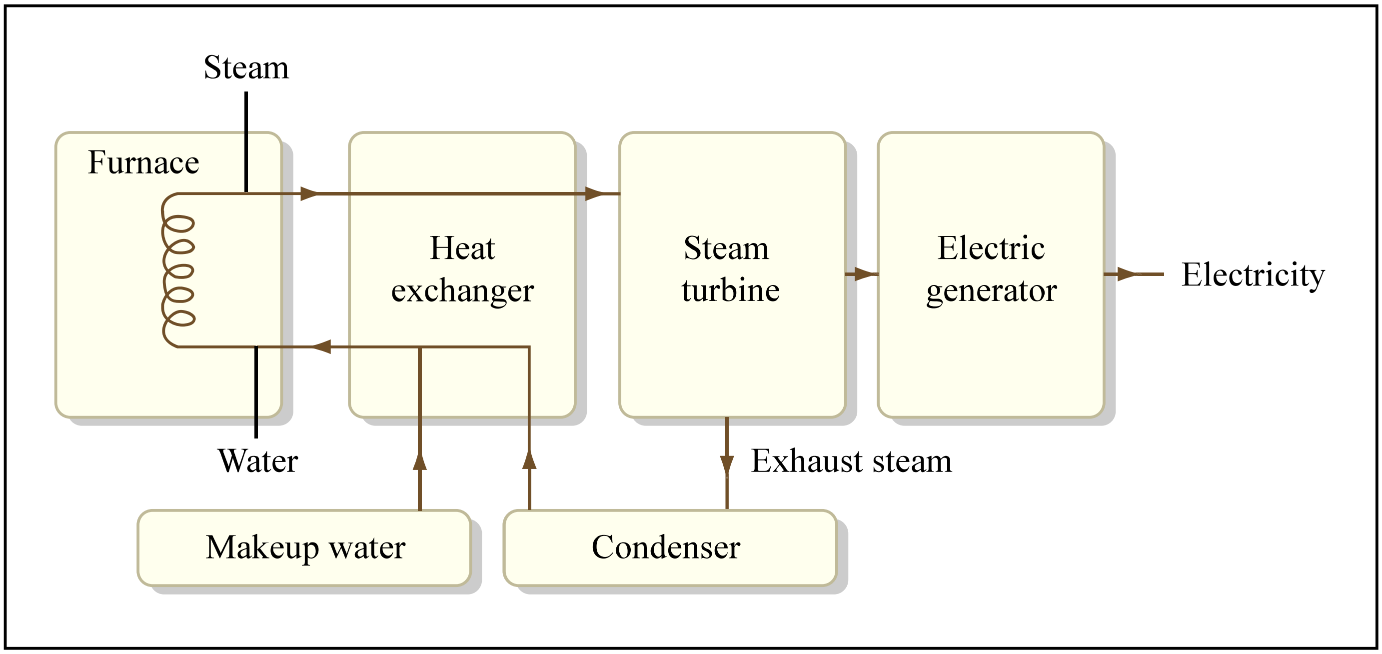


Image by MIT OpenCourseWare.

- Exhaust steam is waste heat into the environment
- Heat engine efficiency is given by furnace inlet temperature and exhaust temperature: $\eta = (1 - T_e/T_i)$

REAL HEAT ENGINES

Coal

Oil(gasoline)

Gas

Nuclear

Images from Israel Electric Company Archive via Pikiwiki, TTTNIS, Sancio83 on Wikimedia Commons, and Andrew J. Ferguson on Flickr.

- Power density ~300 W/m^2. Total footprint may be different.

FOSSIL FUELS

- Put the fuel in a tank and light a match
- All fossil fuels use oxygen to burn
- All fossil fuels produce large amounts of CO2
- All fossil fuels produce some amount of pollution due to impurities
- Basic chemical reactions:
  - Coal $C + O_2 \rightarrow CO_2 + \text{heat}$
  - Gas $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \text{heat}$
  - Gasoline $C_8H_{18} + 12.5O_2 \rightarrow 8CO_2 + 9H_2O + \text{heat}$

The Problems with Fossil Fuels

- We are running out of gas and oil - US oil production peaked in 1970.
- Much of the supply is in unstable parts of the world.
- We have a good amount of coal.
- All fossil fuels produce large amounts of CO_2, which is a greenhouse gas.
- Carbon sequestration is not yet a proven technology.

REVIEW THE GREENHOUSE EFFECT

- How do "greenhouse" gasses cause global warming?
- Radiation from the sun hits the earth
- Most is in the visible frequency range
- Some is reflected, most absorbed.
- Re-radiation rate depends on temperature ($\propto T^4$)
- At equilibrium the earth reaches a high enough temperature so that

Power in = Power out

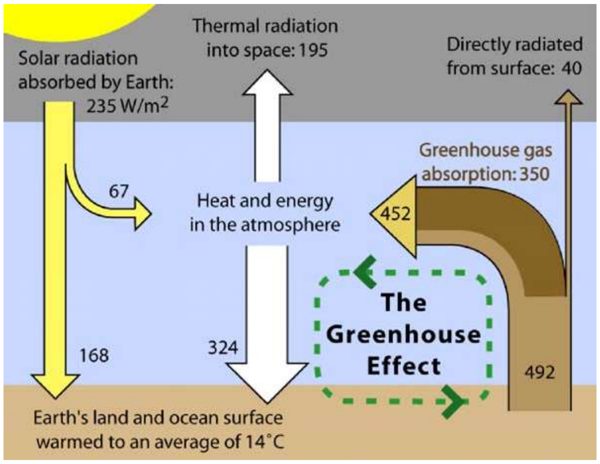


Image created by Robert A. Rohde / Global Warming Art.

POLLUTION

Shangai

Bombay

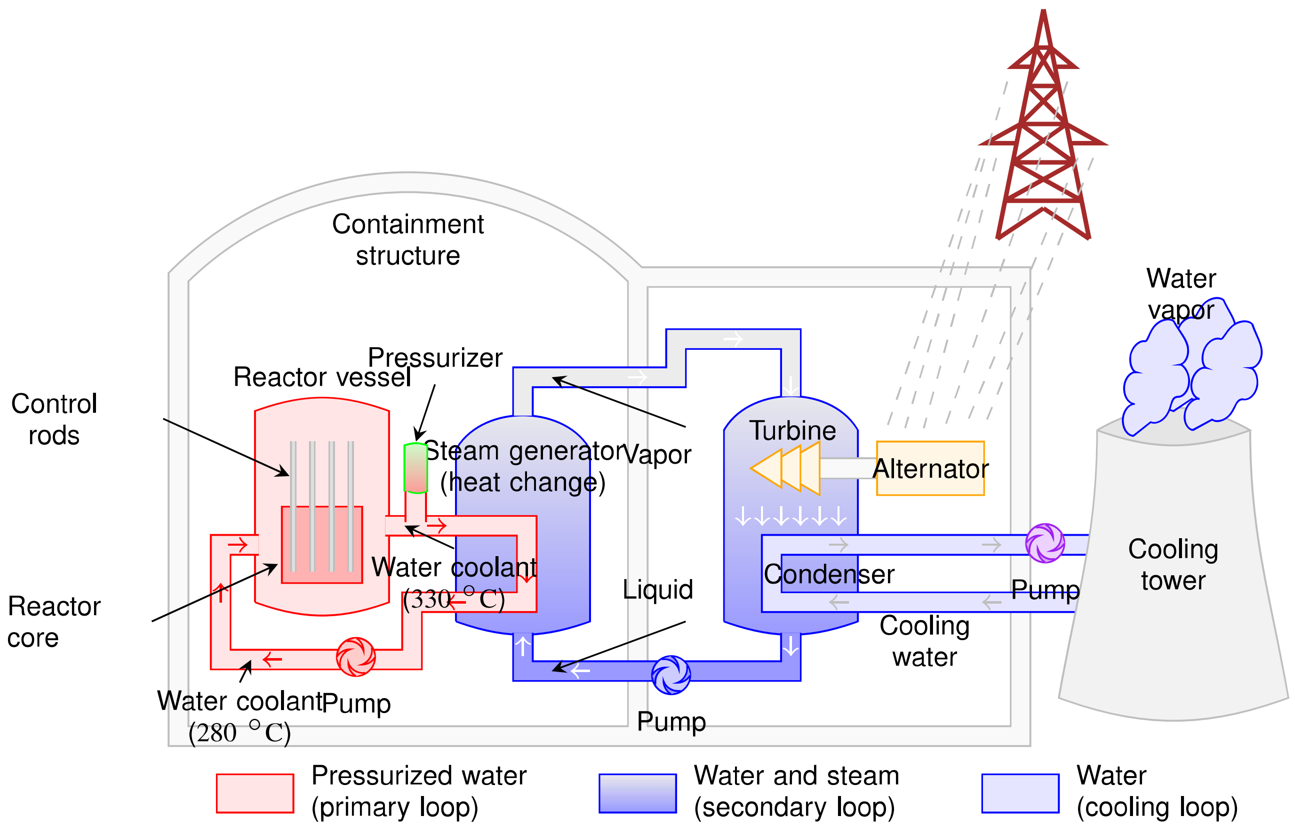
NUCLEAR FUEL

- More difficult than fossil fuel
- Natural uranium

$$99.3\%^{238}U + 0.7\%^{235}U$$

- Only ^{235}U produces energy by fission
- Complicated enrichment needed for 4% ^{235}U
- Place fuel rods in a reactor vessel

Nuclear Fuel



Basic Nuclear Reaction

- After several intermediate steps the key nuclear reaction is

$$\mathrm{n} + {}^{235}\mathrm{U} \rightarrow 2\,\text{fission products} + 2.5\mathrm{n} + 6\beta + 10\gamma + 10\nu + \text{energy}$$

- A large amount of energy is released
- This is converted to heat
- 1 nuclear reaction = 1,000,000 fossil reaction

Hydroelectric

- Put your paddle wheel into flowing water
- Attach the shaft of the wheel to a generator
- Voila - electricity
- Main source of energy is gravity
- Key power relation is given by:

$$\begin{aligned}\text{Power } &= (\text{hydraulic head})(\text{flow rate})(\text{efficiency}) \\ &= \rho g h[\mathrm{J/m^3}] \times Q[\mathrm{m^3/s}] \times \eta[\%]\end{aligned}$$

- Implied power density is low. Hydraulic head is 0.27 kWh/m^3 at 100m.
- Need large reservoirs to store water (power density ~3 W/m^2)

SCHEMATIC DIAGRAM

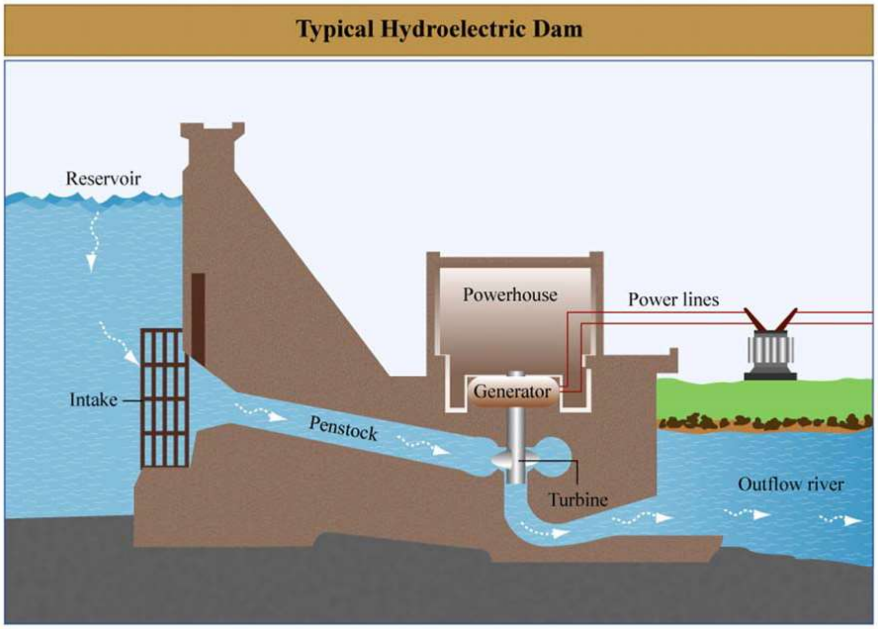


Image by MIT OpenCourseWare. Adapted from Tennessee Valley Authority.

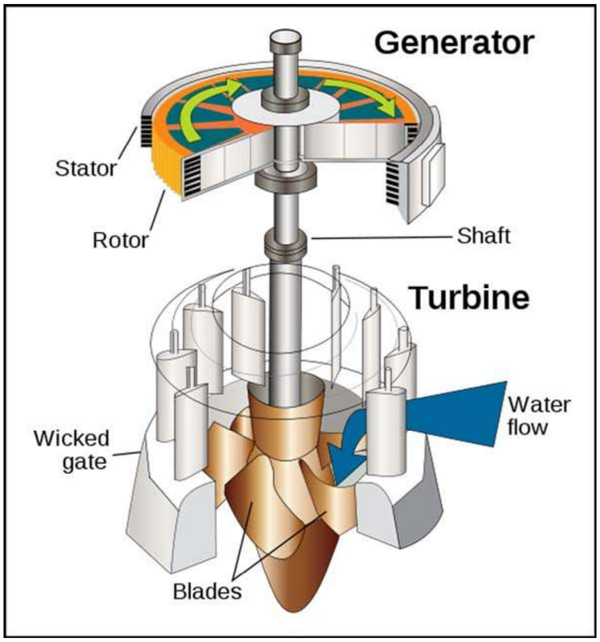


Image by Mikhail Ryazanov on Wikimedia Commons.

HYDROELECTRIC PLANT

Photo by Lynn Betts, USDA Natural Resources Conservation Service.

Wind Power

- Wind turns the windmill blades
- Mechanical motion converted to the shaft of a generator, producing electricity
- Low power density (~2 W/m^2)
- Cape Wind - 25 square miles of water
- Produces 400 MWe peak
- Produces 130 MWe average

Wind Power in Quebec

Photo by André Cotte on Flickr.

SOLAR

- Peak normal solar irradiance is $1kW/m^2$ (at surface, 1.366 kW at top of atmosphere, known as the solar constant)
- The sun's energy can make electricity
- There are two ways:
- Solar thermal
  - Rays are focused
  - Focused rays can heat water
  - Water turns to steam to make electricity
- Solar voltaic
  - The sunlight impinges on a solar voltaic cell
  - The energy is directly converted into DC electricity

Solar Energy

Photos by Sandia National Labs and Rainer Lippert on Wikimedia Commons.

- Like wind, the power density is low
- Peak power produced is about 100 - 200 W/m^2
- Average power is about 30 - 60 W/m^2
- 25 square miles produces about 100 - 200 MW on average

BIOMASS

- Burn wood, plants, etc.
- Burn lot’s of it
- Huge land area required
- Potential for new discoveries

Photo by Dattodesign on Flickr.

GEOTHERMAL

- Dig a hole in the ground
- Keep digging until you reach steam or hot water - steam mixture under pressure
- This hot fluid is forced to the surface
- Use it to make steam
- Use the steam to make electricity
- Pump the water back into the earth

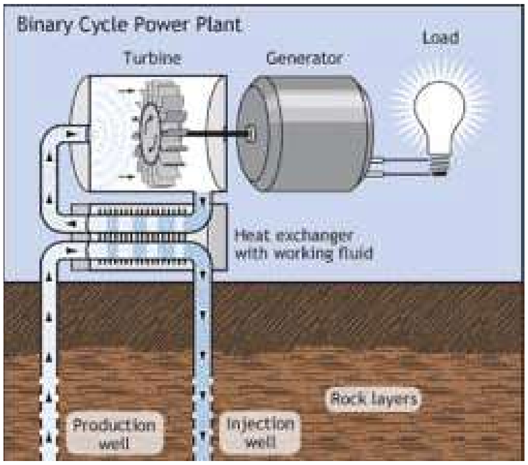


Image from EERE.

Discussion

- Questions?