02-Energy Sources

Text: Chapter 1-Chapter 2

ECEGR 3500

Electrical Energy Systems

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Overview

- Electricity Generation Trends
- Fossil Fuels
- Combustion
- Coal
- Oil
- Natural Gas
- Nuclear
- Hydro
- Wind

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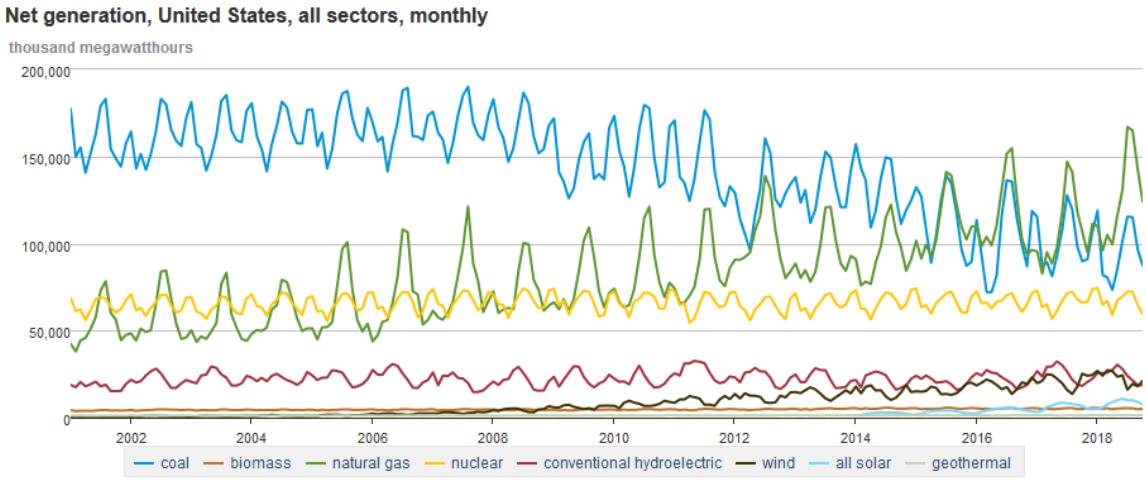
Trends



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Fossil Fuels

- >85% of energy in the U.S. is from fossil fuels
- Fossil Fuels: coal, oil, natural gas (and butane, propane, etc.)

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Fossil Fuels

- Contain hydrocarbons and are found in the Earth's crust
- Formed under very specific conditions
  - temperature
  - pressure
  - oxygen level
  - time
- Hydrocarbons => organic matter

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Fossil Fuels

- Energy in fossil fuels originates from the sun
- Photosynthesis stores energy from the sun in organic matter
  - CO_2 and water form sugar and oxygen using energy from the sun
- $6CO_2 + 6H_2O$ (+ light) $\longrightarrow C_6H_{12}O_6 + 6O_2$

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A Few Notes

- Since CO_2 is absorbed from the atmosphere during photosynthesis, plant matter act as carbon sinks
- Burning fossil fuels releases CO_2 that was previously in the atmosphere (it does not create carbon)
- Oxygen produced by approximately 1 tree offsets the oxygen used by each person

Fossil Fuels

- Fossil fuels can be thought of as stored solar energy
- Mankind's "Energy Trust" or "Energy Inheritance"
  - 30% of electricity comes from coal-fired power plants
  - 33% of electricity comes from natural gas-fired power plants
  - <1% of electricity comes from oil-fired power plants

Fossil Fuel Combustion

- Energy is released by combusting hydrocarbons
  - Pure Carbon: 32.8 MJ/kg
  - Pure Hydrogen: 141.80 MJ/kg
- Reaction for methane

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O + \text{energy}$$

See Higher Heating Value versus Lower Heating Value

Fossil Fuel Combustion

- 1 kg of methane contains approximately 0.750 kg of carbon (why?) and 0.250 kg of hydrogen
- Empirically measured heating value of methane is 55.50 MJ/kg
- This is close to a back-of-the-envelope calculation of
  - 0.75 x (32.8) + 0.25 x (141.80) = 60.05 MJ

energy from Carbon combustion energy from Hydrogen combustion

Exercise

Which do you expect to release more heat, combusting 1 kg of methane (CH_4) or 1 kg of propane (C_3H_8)?

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Exercise

Which do you expect to release more heat, combusting 1 kg of methane (CH_4) or 1 kg of propane (C_3H_8)?

Answer: Methane. There is a higher ratio of hydrogen (which has a greater heating value) to carbon in methane than in propane.

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Energy Content

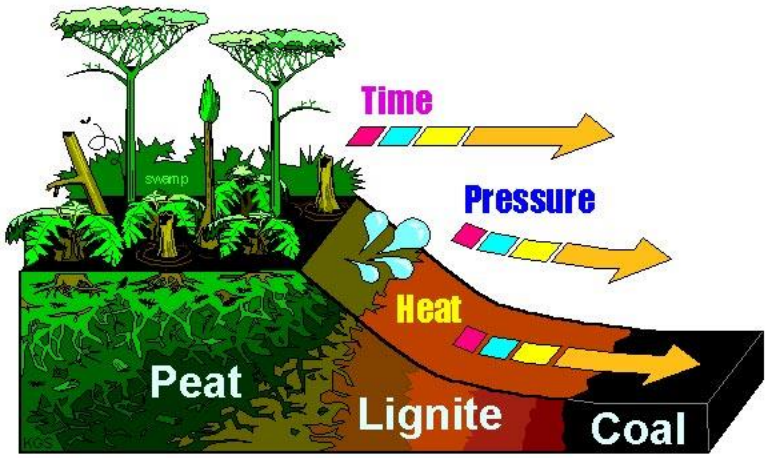
- Specific Energy Density: energy content in 1 kg (MJ/kg)
- Approximate ranges:
  - Coal (Anthracite): ~30 MJ/kg
  - Coal (Lignite): ~<20 MJ/kg
  - Oil (Diesel): ~45 MJ/kg
  - Oil (Gasoline): ~45 MJ/kg
  - Natural Gas: 45-55 MJ/kg
- For comparison:
  - Fats: ~40 MJ/kg

Coal

- Coal formation begins with peat
  - Peat: collection of decayed plants and plants parts (bark, roots), protected from oxidizing and biodegrading by being submerged underwater
- Over time, peat becomes buried with sediment
- Sediment compresses the peat resulting in
  - heating
  - drying (water is compressed out)

Coal

- +1 million years later: complex hydrocarbons break down into simpler ones
  - Hydrocarbons with low carbon/hydrogen ratios (methane) escape to the surface
  - Remaining hydrocarbons are carbon rich
- Types of coal (descending heating value):
  - Anthracite (highest quality, most expensive)
  - Bituminous
  - Subbituminous
  - Lignite (lowest quality)



source: http://www.uky.edu/KGS/coal/coalform.htm

Coal

- Most of the organic matter was deposited during the aptly named Carboniferous Period
  - 354 to 290 million years ago
- Earth was hot, humid and swamp-like

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Coal

- US: approximately 25% of the world's supply of coal
- Coal is found in 26 states
- Demonstrated Reserve Base: 477 billion short tons (2000 lbs) in 2009
  - 2% Anthracite
  - 53% Bituminous
- Consumption is around 0.8 billion short tons per year

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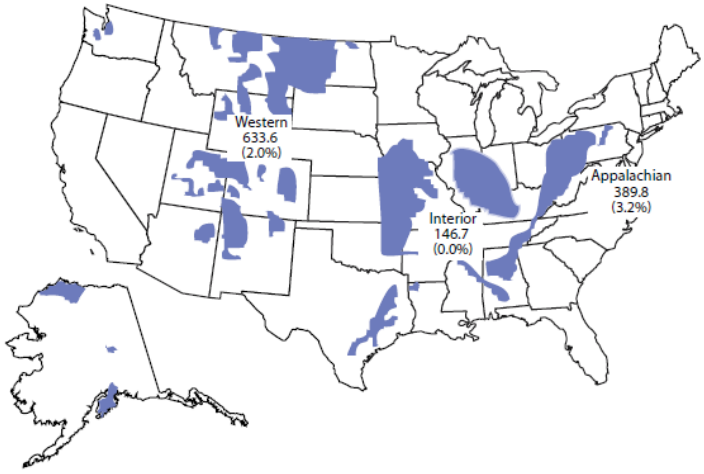
Coal

Coal production in 2008 (change from 2007)



Source: Energy Information Administration, Quarterly Coal Report, October-December 2008, DOE/EIA-0121(2008/Q4) (Washington, DC, April 2009).

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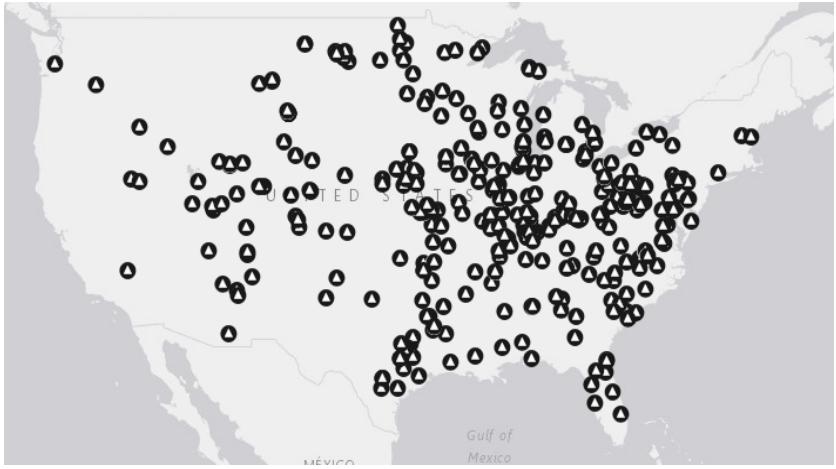
Coal-fired Power Plants in the U.S.

2017



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Oil

- Originated as marine life (algae)
- Dead matter sinks to the oxygen deprived bottom of oceans, seas, rivers, etc.
- Over time it is buried and heats up

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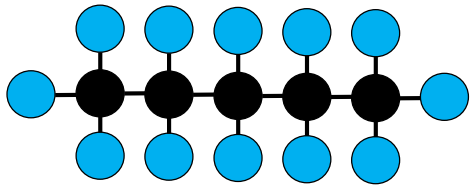
Oil

- Between 7,500 and 15,000 ft (much deeper than for coal) the temperature is sufficient for oil formation
  - 180° F (a hot cup of coffee)
  - Requires 10,000 – 1,000,000 years
- Very specific geological features are needed to prevent the oil from seeping to the surface

Oil

- Remaining Hydrocarbons are of the form:
  - C_nH_{2n+2} where n is the number of carbon atoms
- Gasoline: n is between 5 and 12
- Diesel: n is 16 or more
- Gasoline and Diesel often contain non-hydrocarbons (e.g. sulfur)



Example (pentane):
5 Carbon
12 Hydrogen

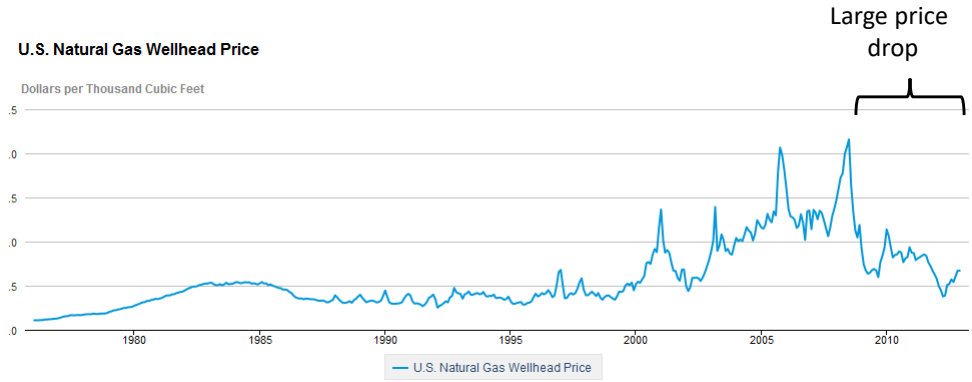
Natural Gas

- Natural gas is primarily methane
  - CH_4
- Produced by the same process of oil but at temperatures that occur at greater than 15,000 ft
- All carbon bonds are broken

Natural Gas (U.S.)

- Approx. 2.47 trillion cubic feet (Tcf) technically recoverable (2014)
  - Consumption of 26.6 Tcf/year (~93 years)
- 2010: 90% of natural gas consumed was produced domestically
- Uses:
  - Heating
  - Electrical generation
  - Plastics
  - Fertilizer

Natural Gas



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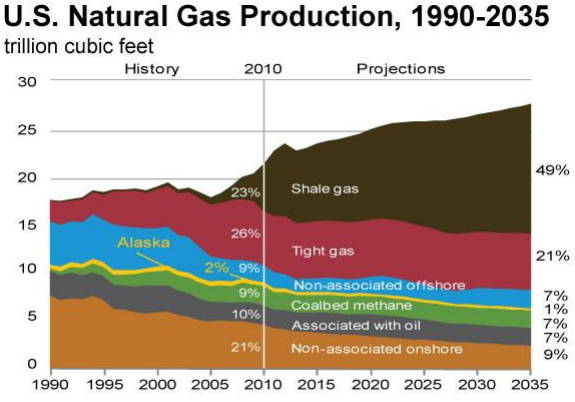
Shale Gas



Source: U.S. Energy Information Administration, AEO2012 Early Release Overview, January 23, 2012.

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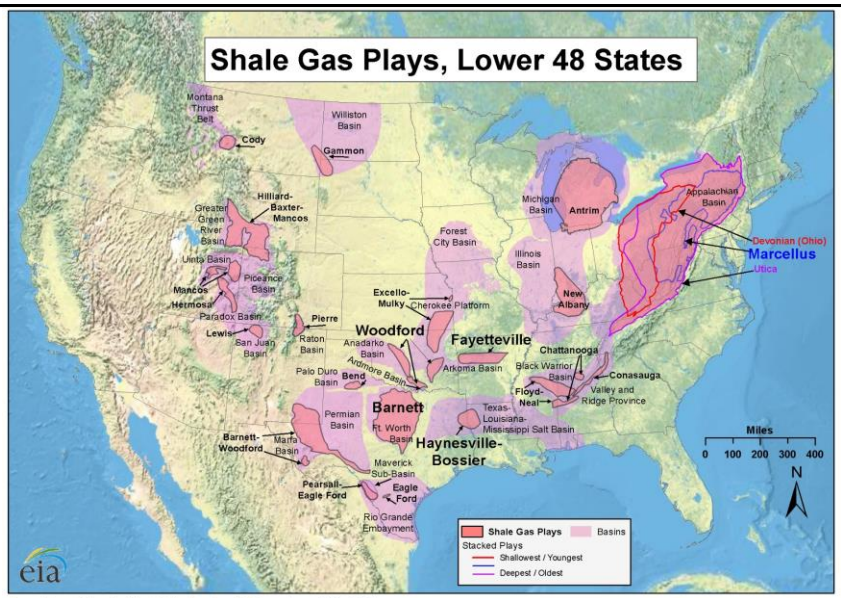

Source: Energy Information Administration based on data from various published studies.
Updated: March 10, 2010

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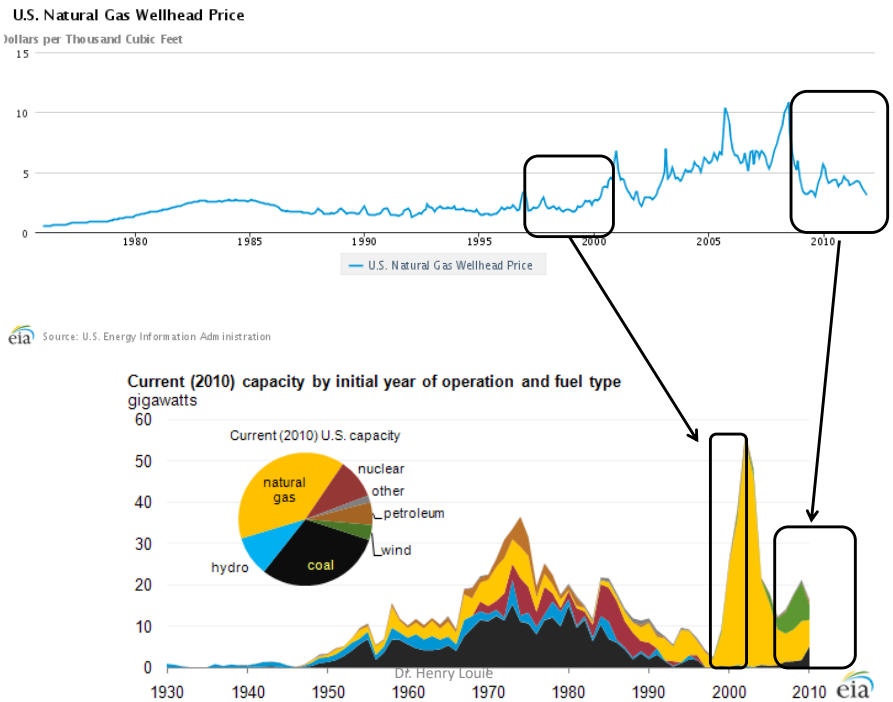

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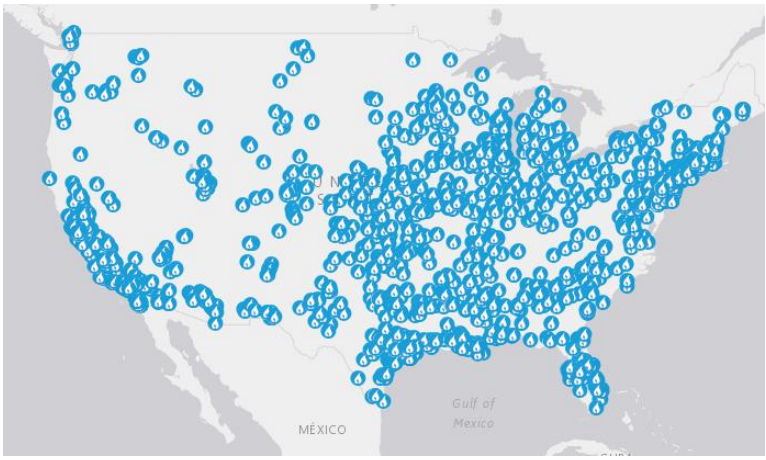
Natural Gas Power Plants in the U.S.



2016

Nuclear Power

- 19% of electricity generated in the U.S. is from nuclear reactions
  - Fission (splitting atoms), not fusion (combining atoms)
- 100 reactors in operation (U.S.)
- After a gap of nearly 20 years, a new nuclear power plant was commissioned in the U.S. (Watts Bar in Tennessee)

Nuclear Power Plants in the U.S.

2016

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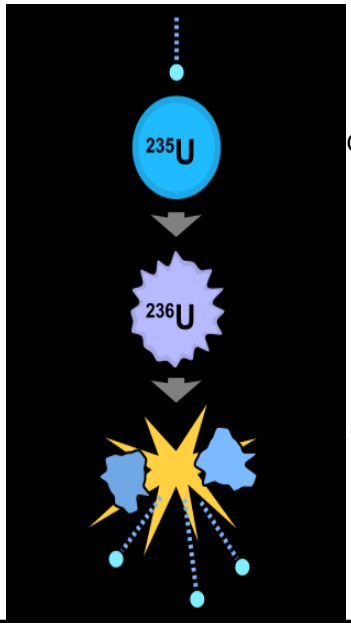
Nuclear Power



Combine slow moving neutron with U^{235}

Quickly decaying (unstable) U^{236} isotope

Various fission products + 2 or 3 neutrons + energy

Examples:
$Ba^{143} + Kr^{90} + 3n$ + energy
$Xe^{134} + Sr^{100} + 2n$ + energy

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Nuclear Power

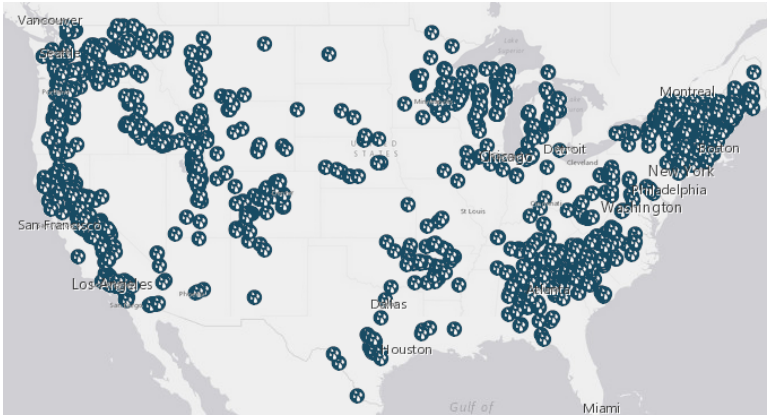
- Nuclear reactions based on: $E = mc^2$
- ~0.1 percent of Uranium nucleus mass converted to energy
- From each fission:
  - Kinetic energy of daughter nuclei (~165 MeV)
  - Kinetic energy of neutrons (~6 MeV)
  - Gamma rays (~7MeV)
  - Rest: (~22 MeV)
- Compare to chemical oxidation: few eV per event

1 MeV (million electron volts) = 1.609 x 10^{-13} joules

Hydro Power

- Hydroelectric generation is the most prolific and mature of the renewable energy sources
  - Nearly 50% of the total energy production from all renewable sources
- It is mainstream enough that in some cases it is not considered a renewable energy
  - Renewable Portfolio Standards often do not count existing freshwater hydropower
- Only incremental increases in hydro power capacity in the U.S.

Hydro Power



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Wind Power

- Rapid increase in capacity since 2000
- Locations must have very strong wind resources
- Variable and intermittent generation source

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Wind Power Plants in the U.S.

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Solar Photovoltaic and Solar Thermal

- Rapid increase since ~2010 due to low costs
- Total energy supply is low (<1%)
- Primarily solar photovoltaic, but also solar thermal

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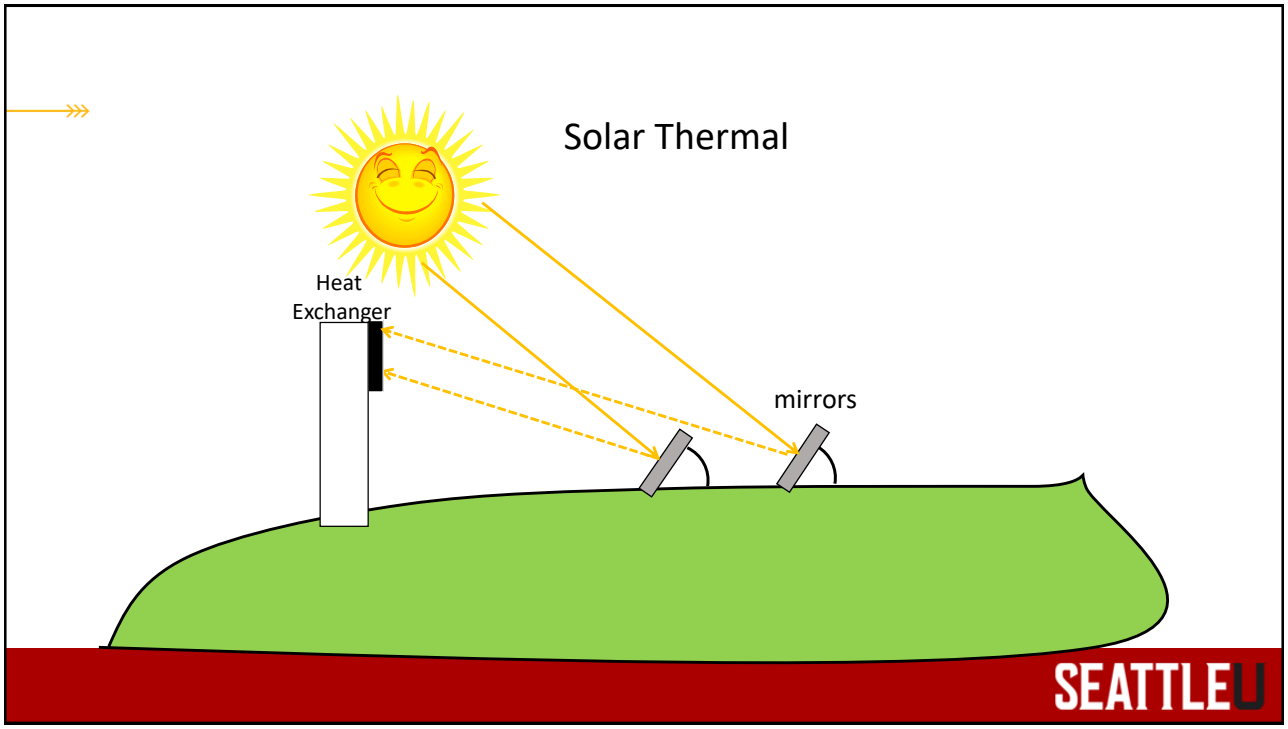

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Solar Power Plants in the U.S.

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Key Points

- Fossil-fuels obtained their energy from the sun over the last +300 million years, and play an important role in our energy mix
- Oil is rarely used for electricity generation (when and why?)
- Natural gas is the most energy dense source of fossil fuels
- Different parts of the country rely on different fuel types to generate electricity