02-Energy Sources

Text: Chapter 3

ECEGR 3500

Electrical Energy Systems

Professor Henry Louie

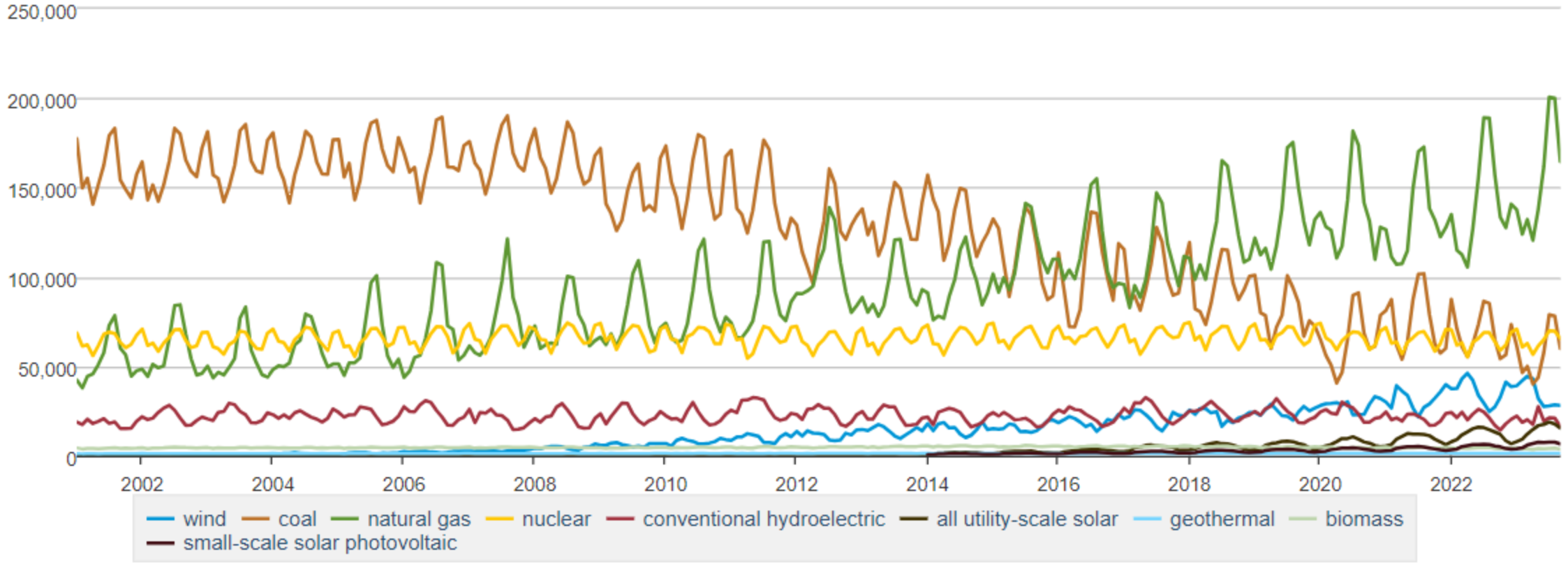
Overview

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

Net generation, United States, all sectors, monthly

DOWNLOAD

thousand megawatthours



Data source: U.S. Energy Information Administration

Fossil Fuels

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

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

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
- $6CO_2 + 6H_2O\ (+\ light) \longrightarrow C_6H_{12}O_6 + 6O_2$

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"
  - 19% of electricity comes from coal-fired power plants
  - 40% 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)?

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.

Energy Content

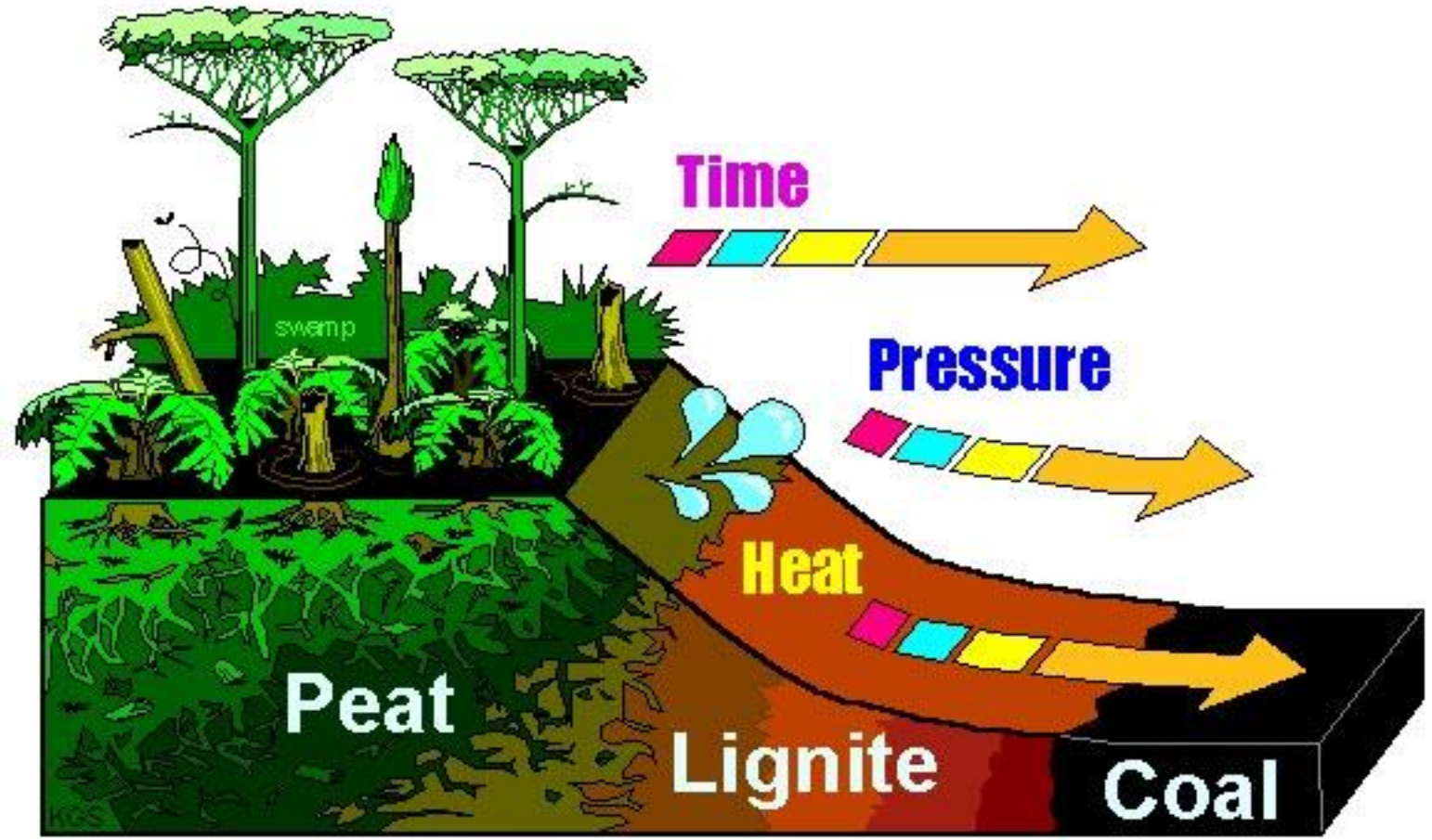
- Specific Energy Density: energy content in 1 kg (MJ/kg)
- Approximate ranges:
  - Coal (Anthracite): ~30 MJ/kg
  - Coal (Lignite): ~<20 MJ/kg
  - Oil (Diesel): ~45 MJ/kg
  - Oil (Gasoline): ~45 MJ/kg
  - Natural Gas: 45-55 MJ/kg
- For comparison:
  - Fats: ~40 MJ/kg

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

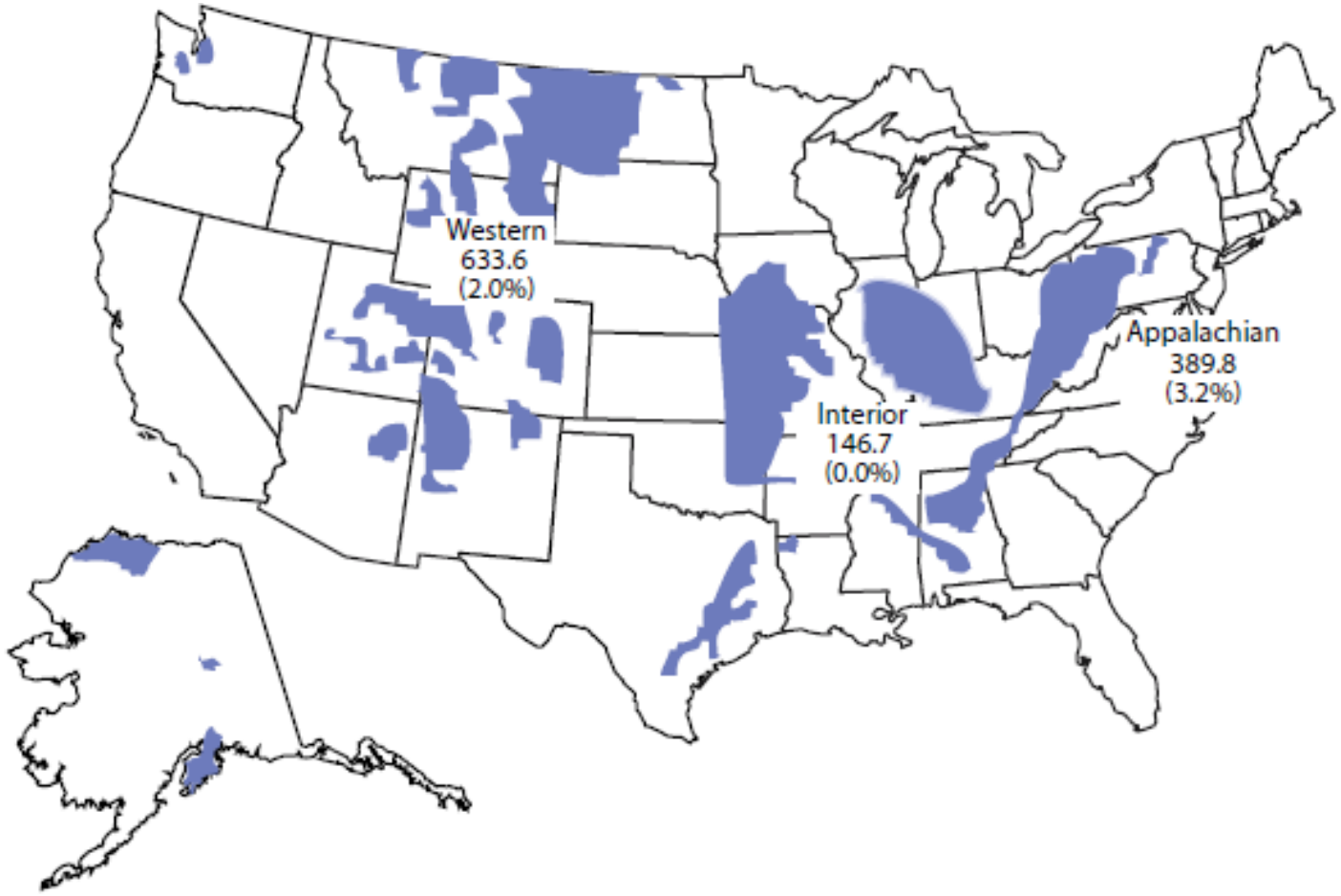
©The Field Museum, GEO85637c.

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

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).

Coal-fired Power Plants in the U.S.

2014

Coal-fired Power Plants in the U.S.

2022

Oil

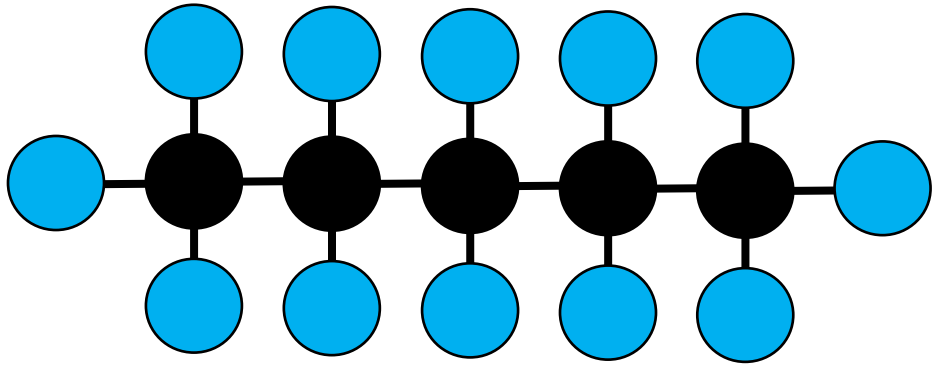
- Originated as marine life (algae)
- Dead matter sinks to the oxygen deprived bottom of oceans, seas, rivers, etc.
- Over time it is buried and heats up

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

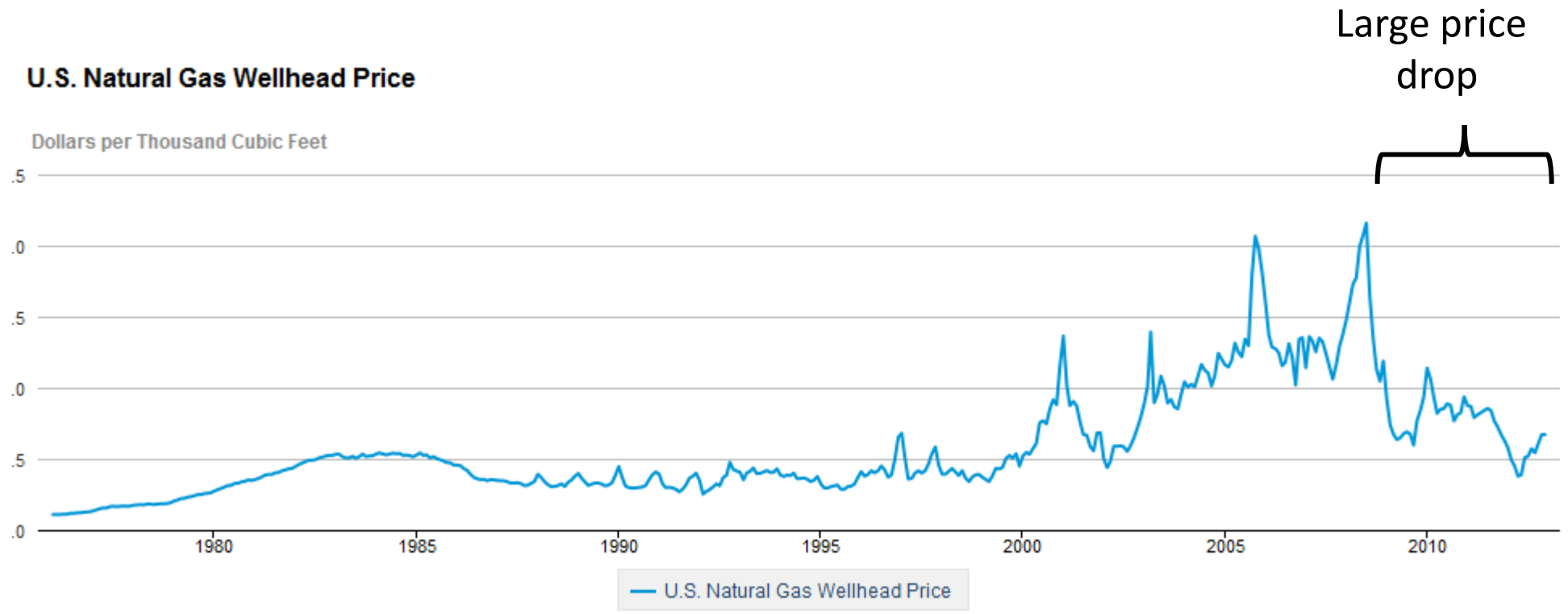
Natural Gas

- 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

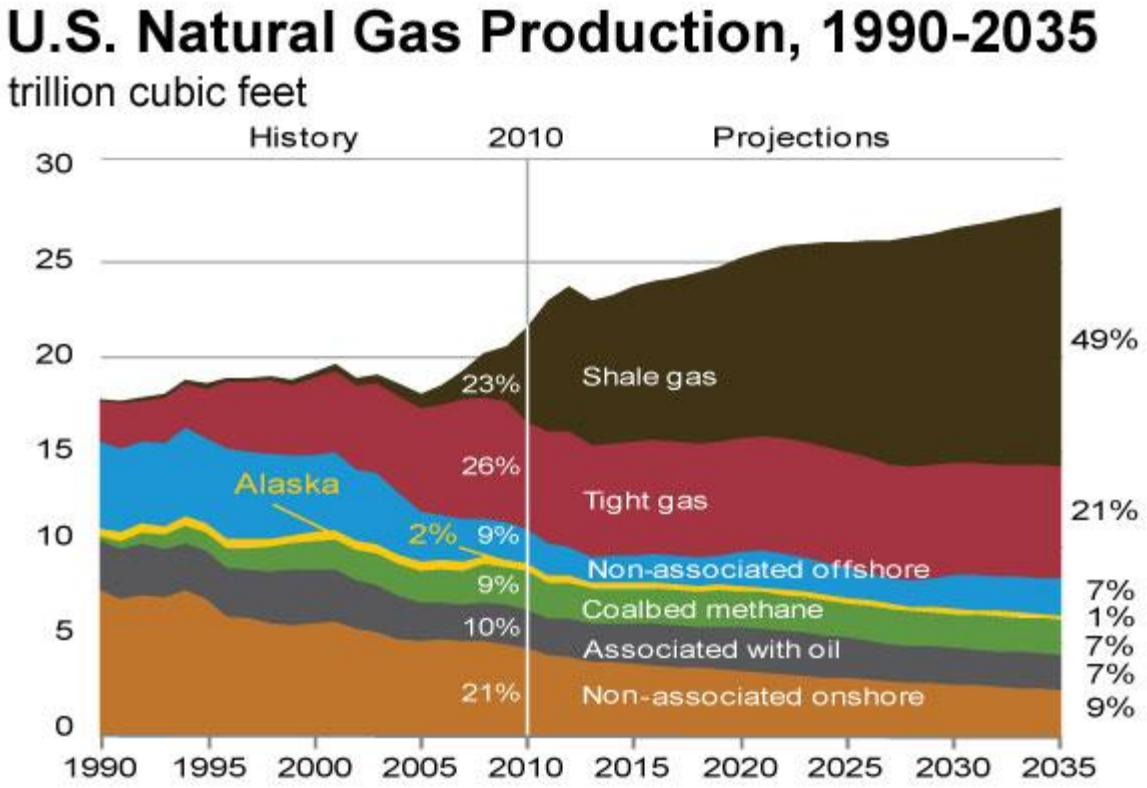
Natural Gas (U.S.)

- 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

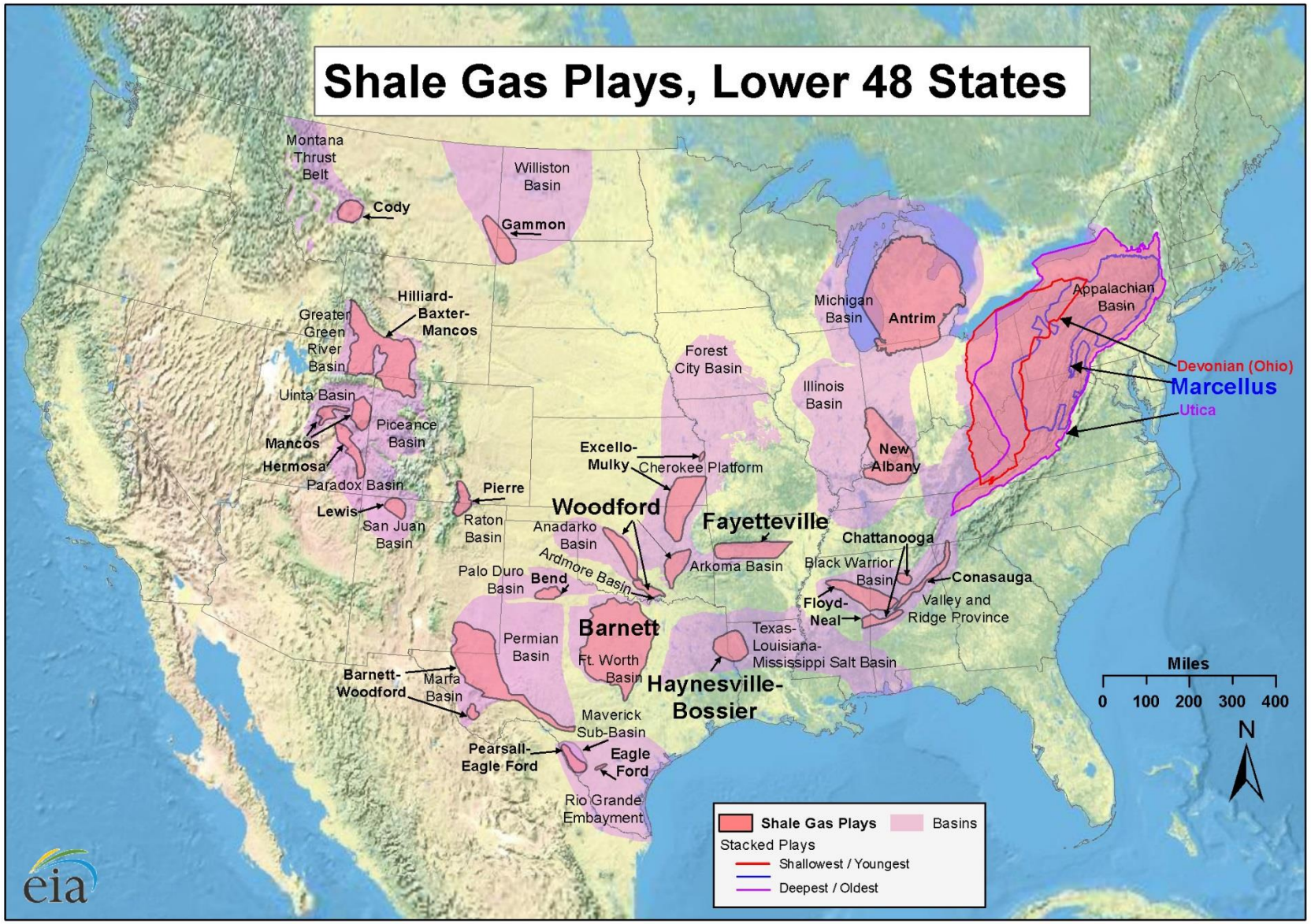
Natural Gas


Large price drop
U.S. Natural Gas Wellhead Price
Dollars per Thousand Cubic Feet
.5
.0
.5
.0
.5
.0
1980
1985
1990
1995
2000
2005
2010
U.S. Natural Gas Wellhead Price

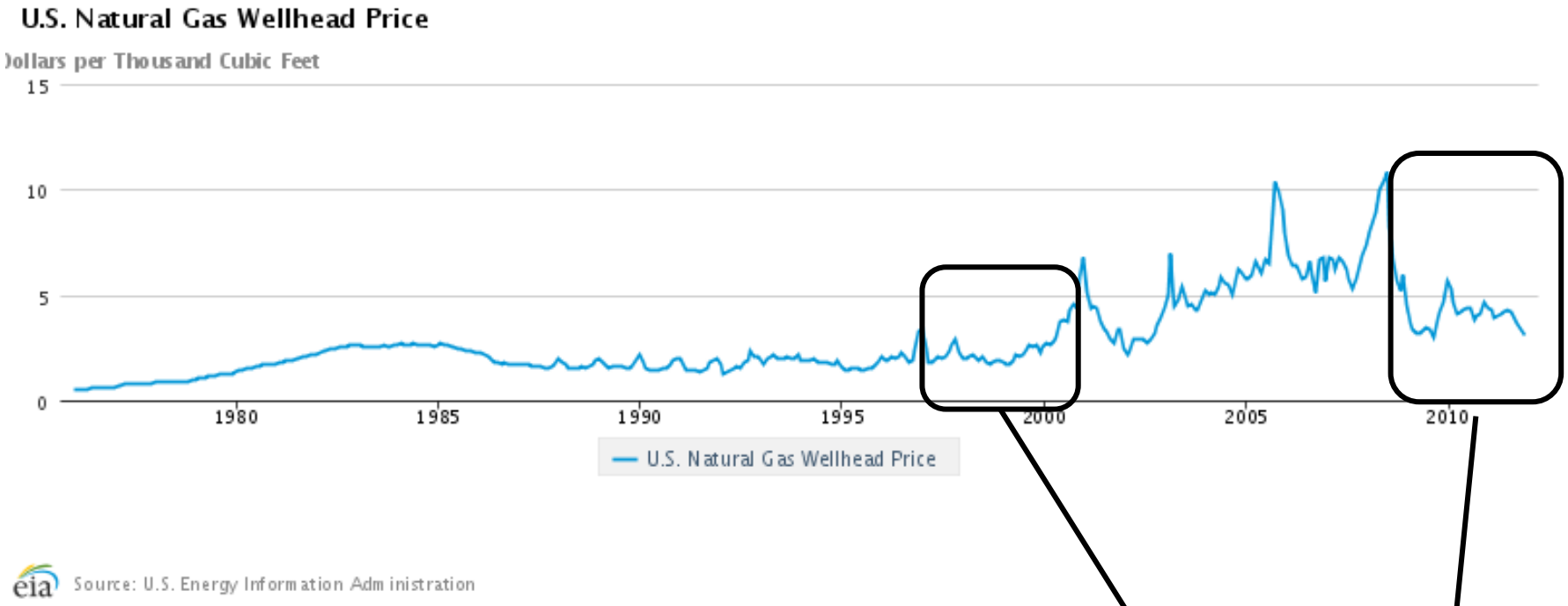
Shale Gas



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



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


U.S. Natural Gas Wellhead Price
Dollars per Thousand Cubic Feet
15
10
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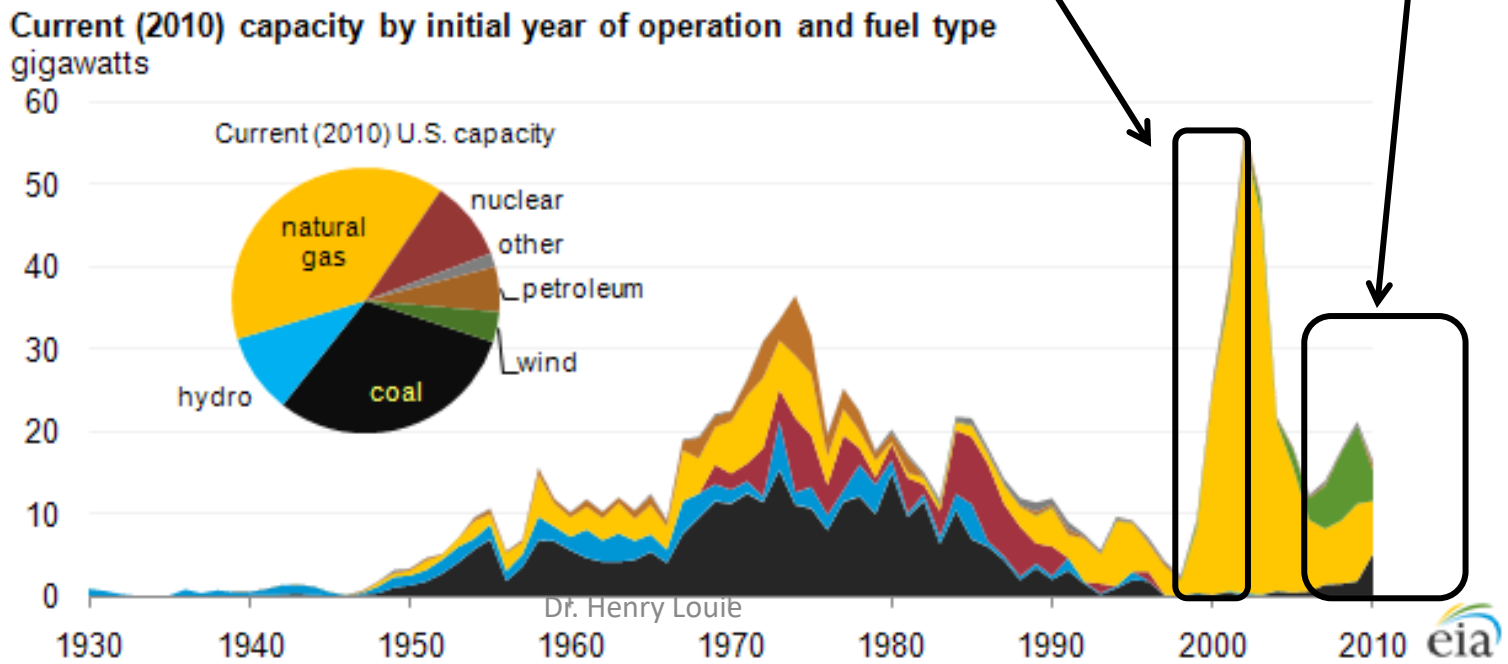
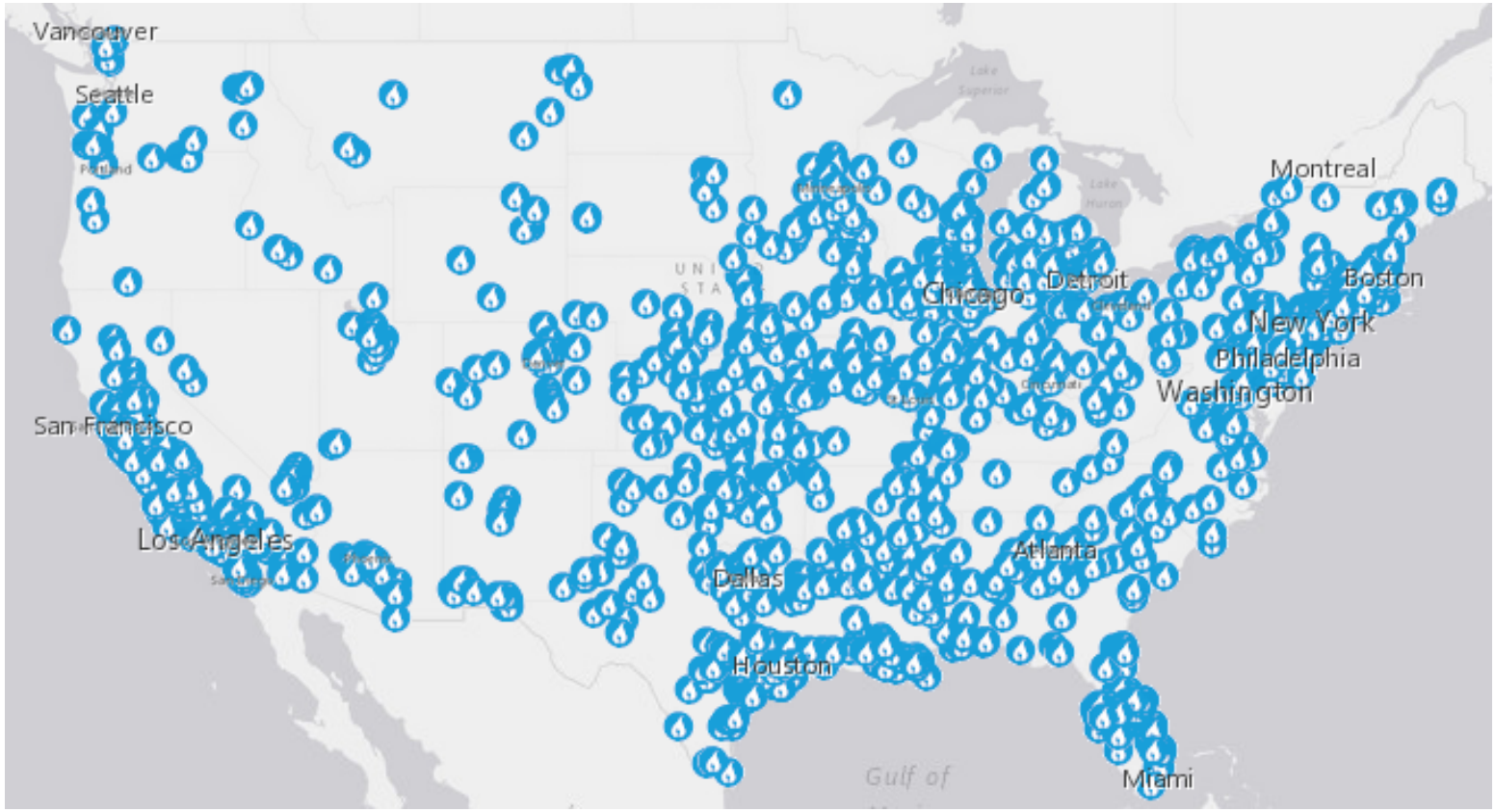
2005
2010
U.S. Natural Gas Wellhead Price
eia
Source: U.S. Energy Information Administration

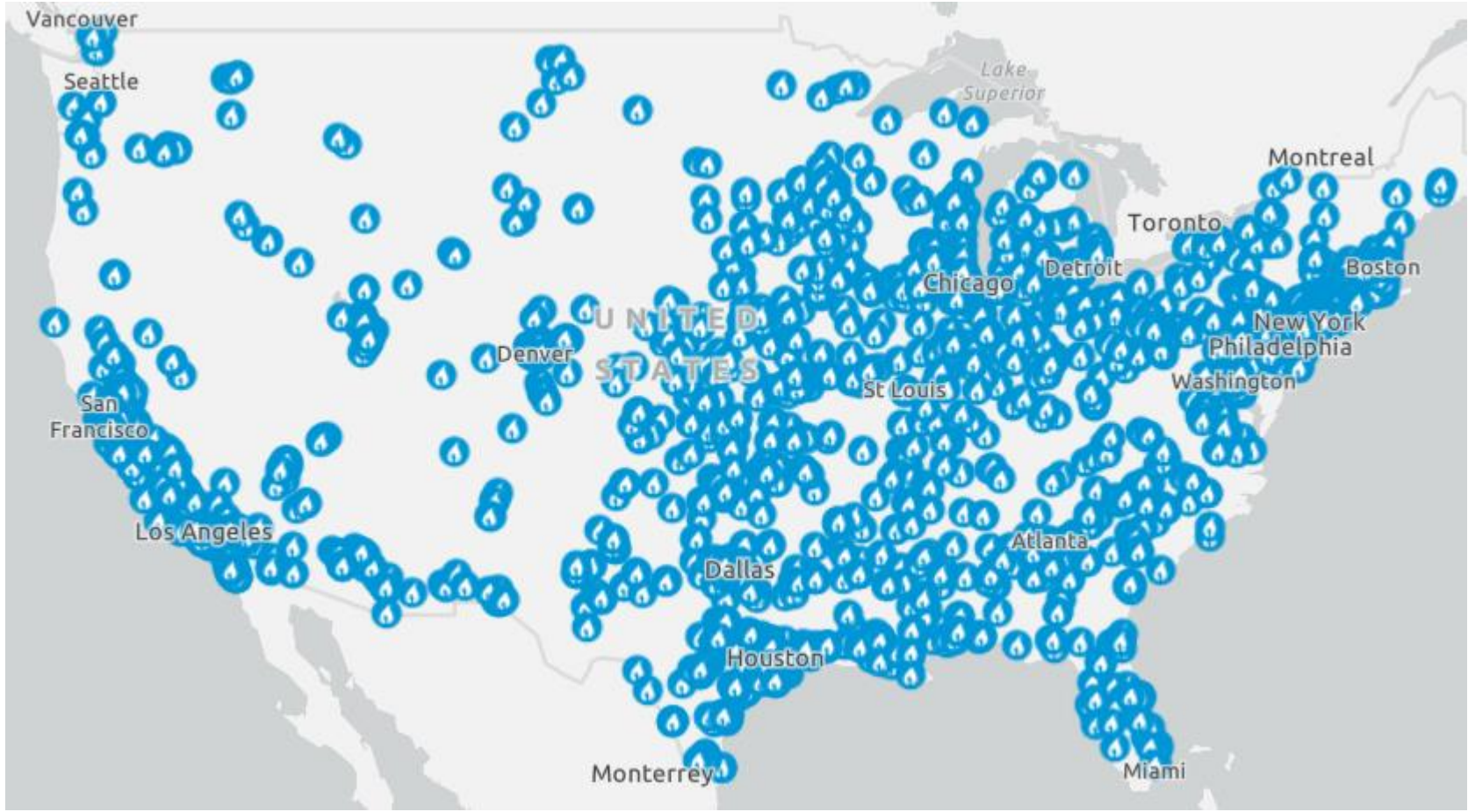

Current (2010) capacity by initial year of operation and fuel type
gigawatts
60
50
40
30
20
10
0
Current (2010) U.S. capacity
natural gas
nuclear
other
petroleum
wind
hydro
coal
1930
1940
1950
1960
1970
1980
1990
2000
2010
eia

Natural Gas Power Plants in the U.S.

2014



Natural Gas Power Plants in the U.S.



2022

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)

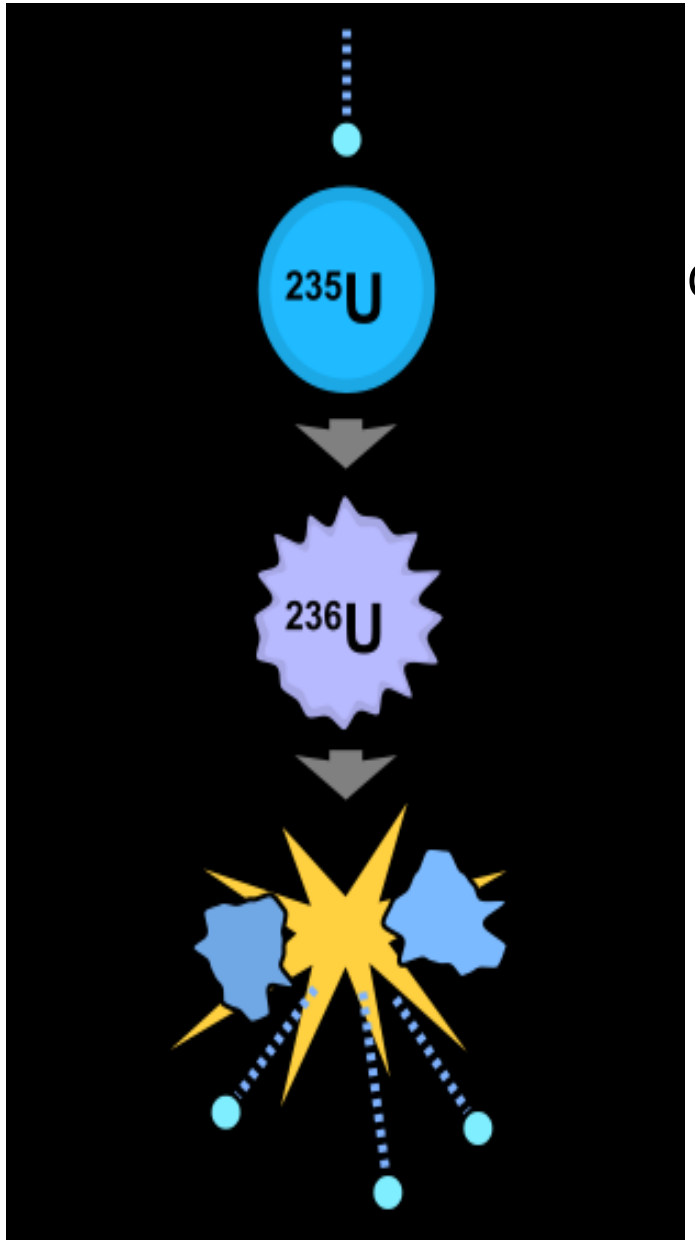
Nuclear Power Plants in the U.S.

2016

Nuclear Power Plants in the U.S.

2022

Nuclear Power



Combine slow moving neutron with U^{235}

Quickly decaying (unstable) U^{236} isotope

Various fission products + 2 or 3 neutrons + energy

Examples:

$Ba^{143} + Kr^{90} + 3n + energy$

$Xe^{134} + Sr^{100} + 2n + energy$

Nuclear Power

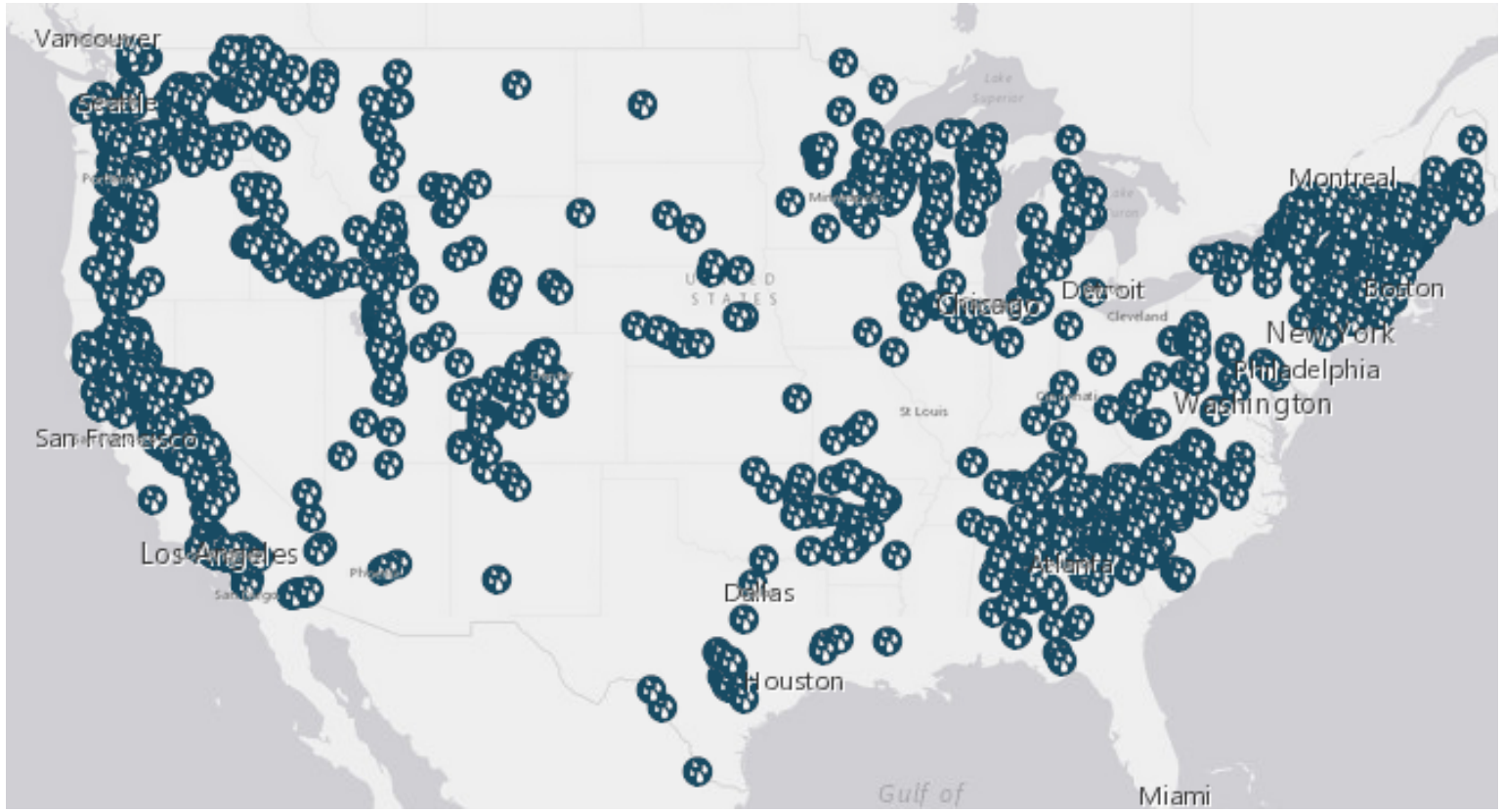
- Nuclear reactions based on: $E = mc^2$
- ~0.1 percent of Uranium nucleus mass converted to energy
- From each fission:
  - Kinetic energy of daughter nuclei (~165 MeV)
  - Kinetic energy of neutrons (~6 MeV)
  - Gamma rays (~7MeV)
  - Rest: (~22 MeV)
- Compare to chemical oxidation: few eV per event

1 MeV (million electron volts) = 1.609×10^{-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.

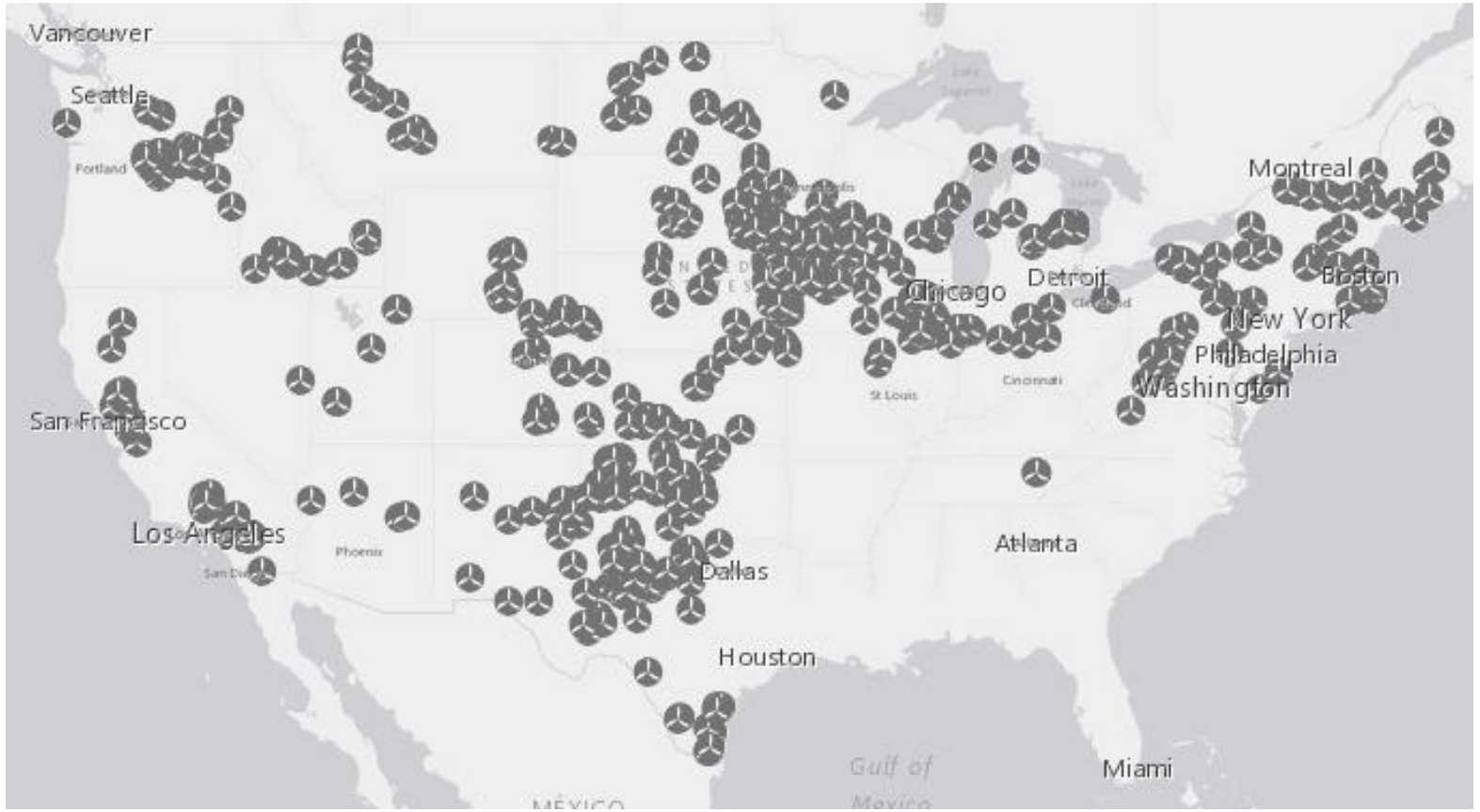
Hydro Power


Vancouver
Seattle
Montreal
Boston
New York
Philadelphia
Washington
San Francisco
Los Angeles
Dallas
Houston
Miami
Gulf of

Wind Power

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

Wind Power



2014

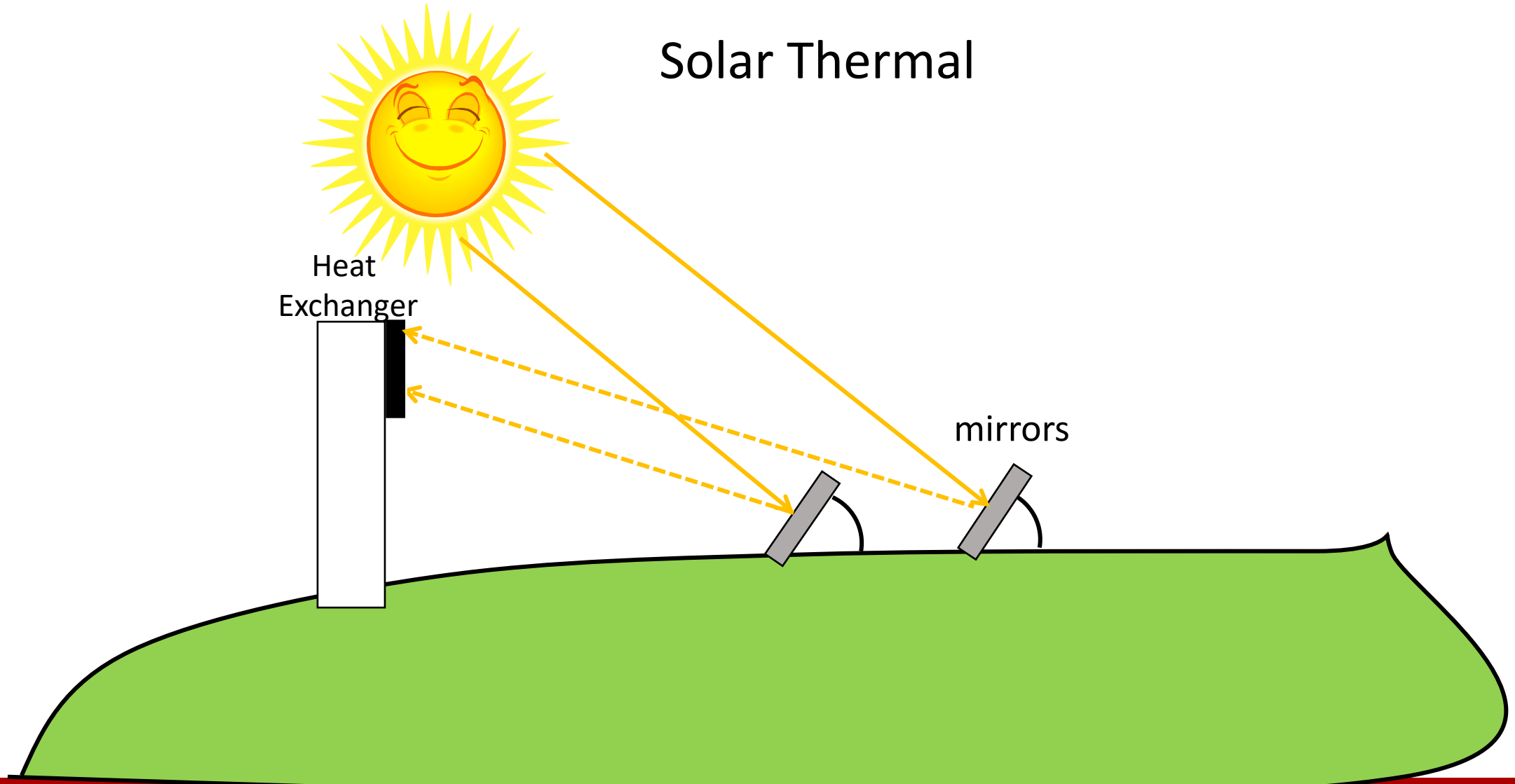
Wind Power Plants in the U.S.

2022

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

Solar Thermal

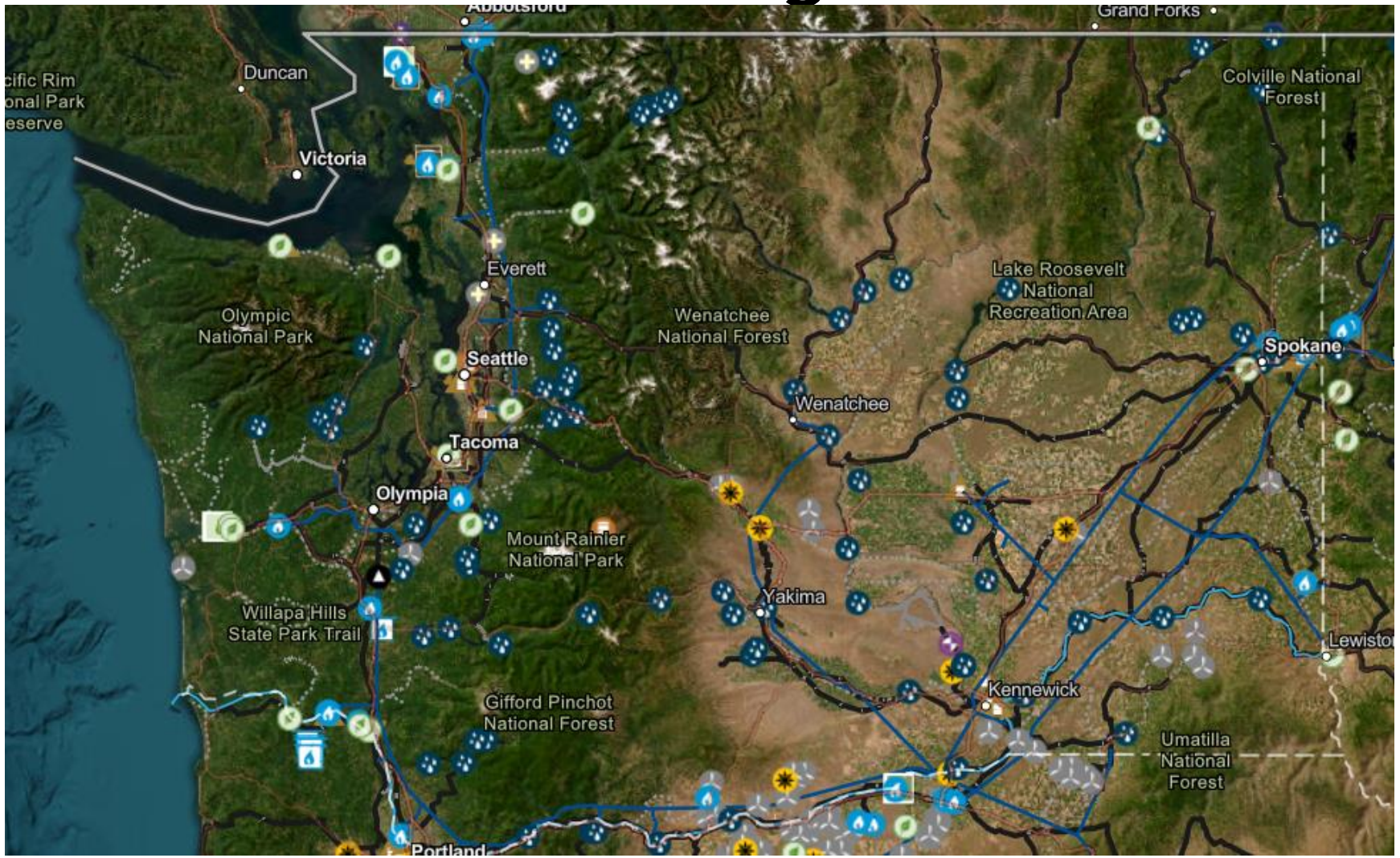


Solar Power Plants in the U.S.

Solar Power Plants in the U.S.

2022

Power Plants in Washington State



Source: EIA

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