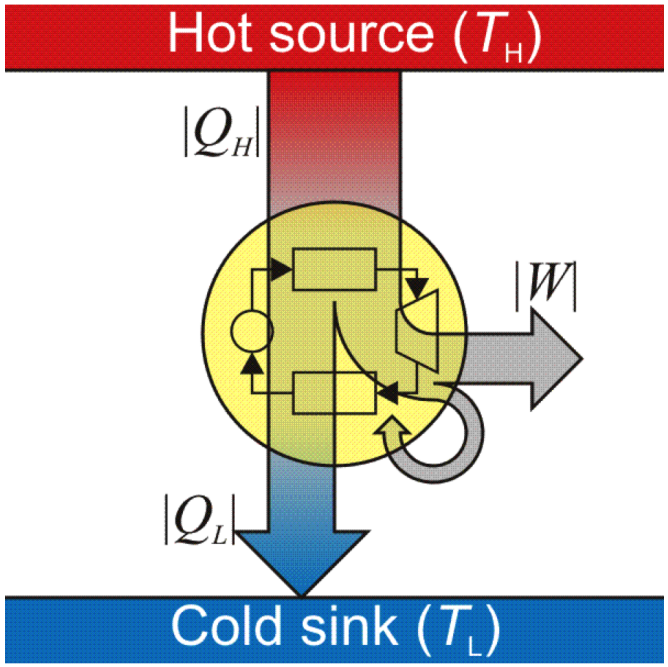
# Energy from Combustion

*Fossil Fuels, Biomass Energy*

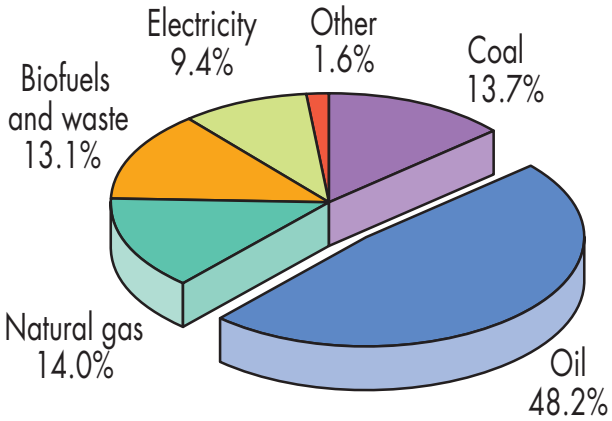


# Outline of Topics

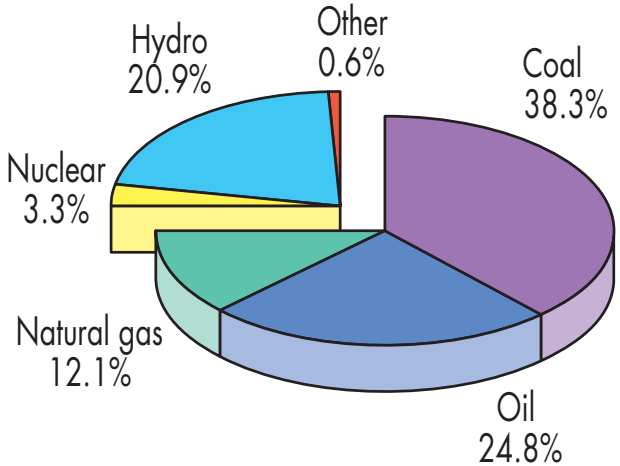
## Lecture Question

What are the major sources of energy used globally? How do they work?

1973

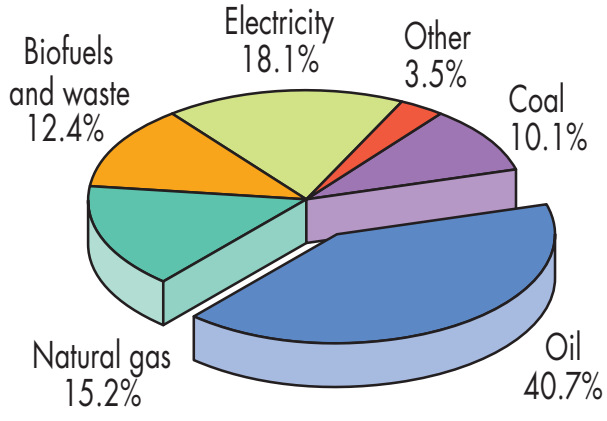



**4 672 Mtoe**

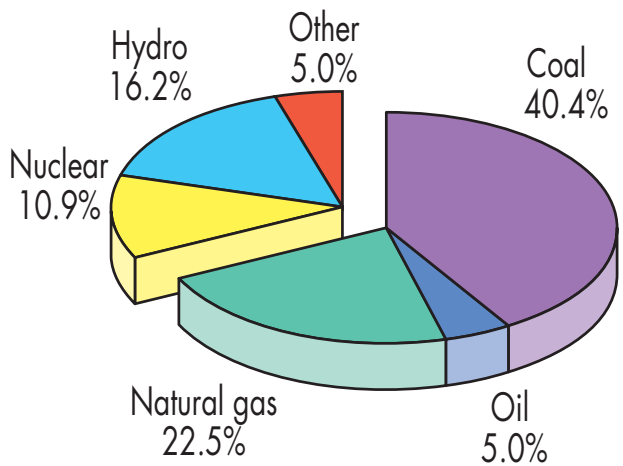



**6 129 TWh**

2012




**8 979 Mtoe**



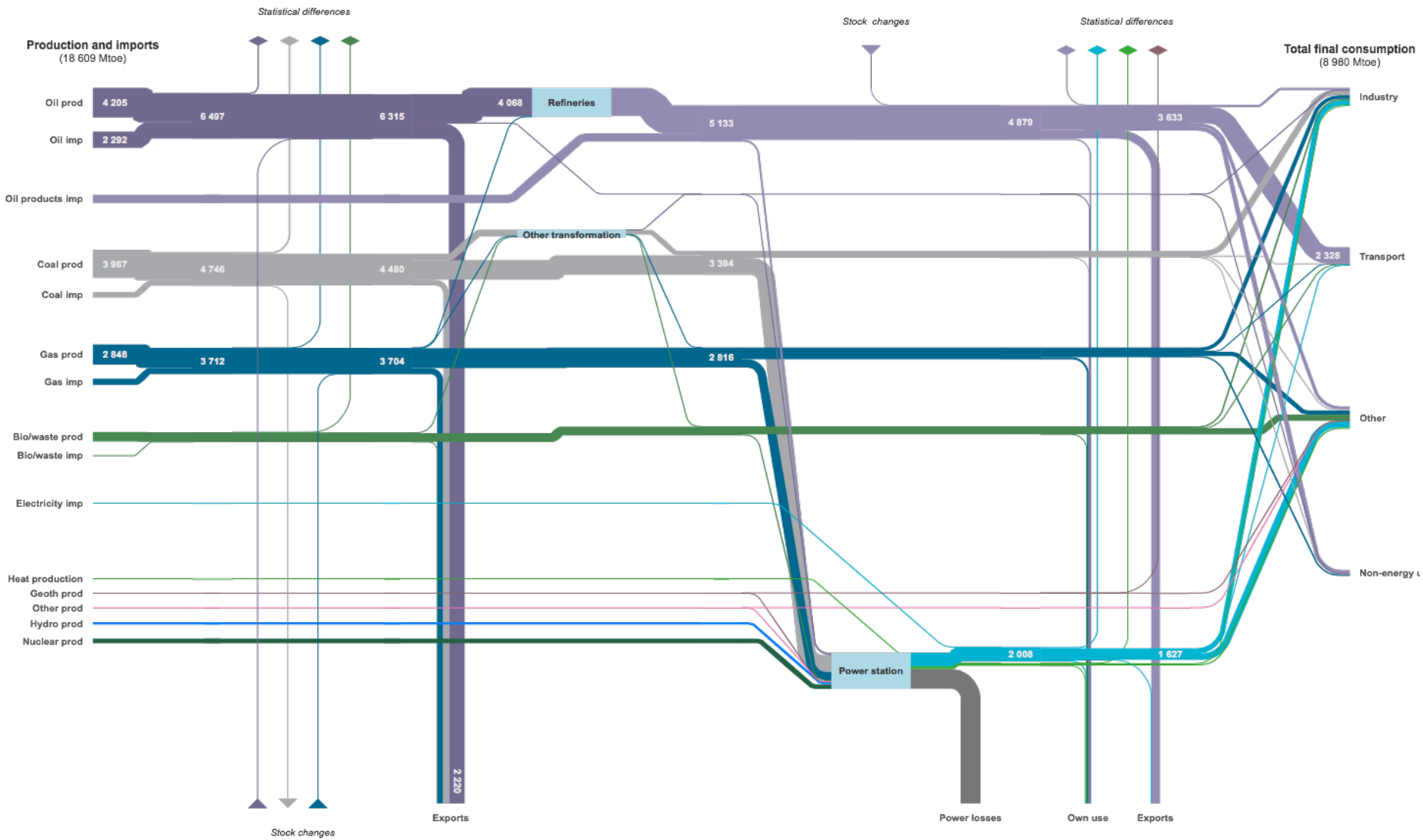

**22 668 TWh**

Figures show *consumptive* use (not generation).

- Top is direct use, bottom is how electricity is generated
- 2012 totals: oil 41.6%, gas 19.3%, coal 17.4%
- 2012: fossil fuels 78.3%
- Note the big drop-off in oil-produced electricity.
- 2012: nuclear 2.0%, hydro 2.9%

# Sankey Diagram for Global Energy Flow

## Can you provide an overview of global energy flow?

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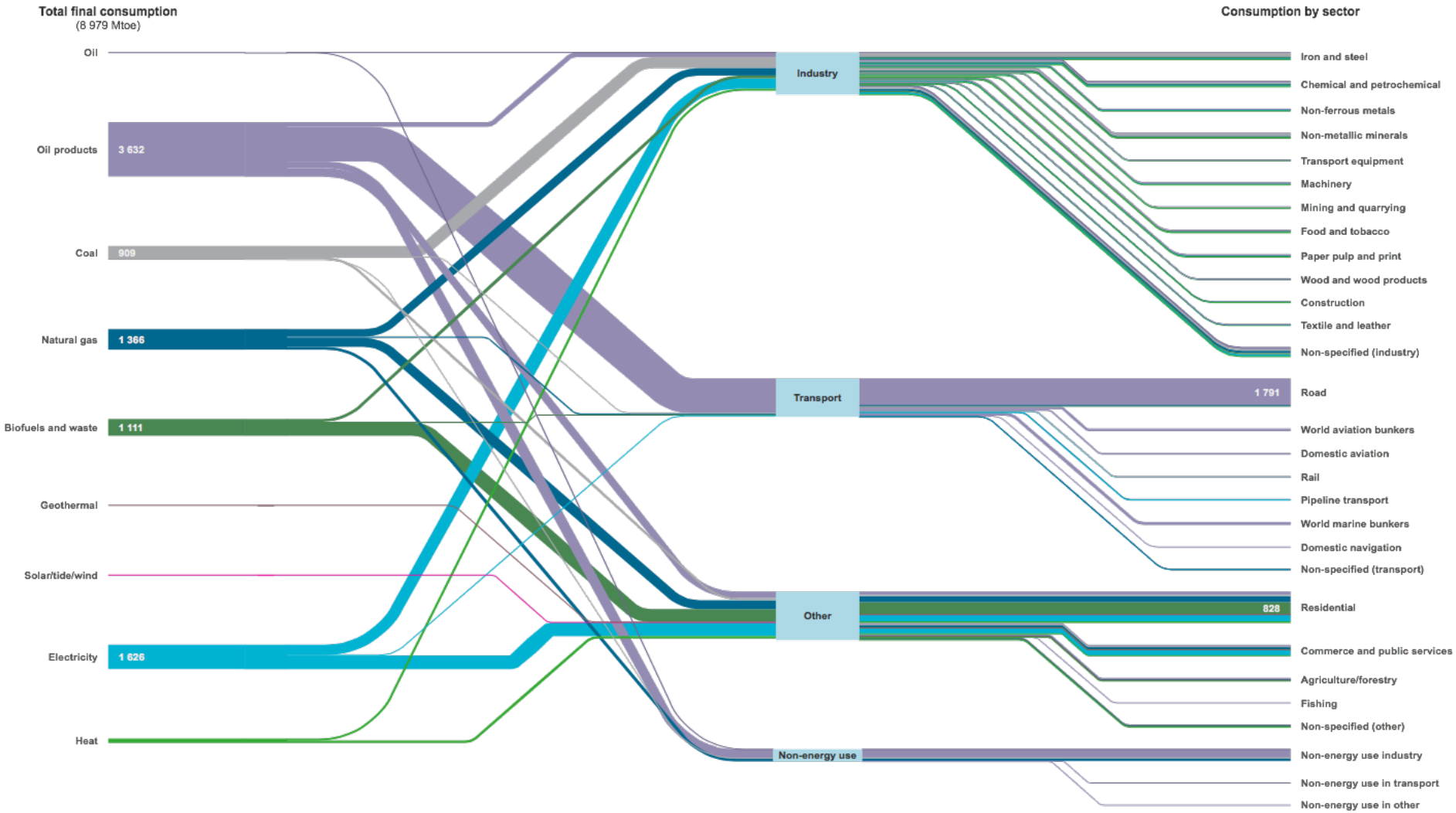
# Consumption by Sector

## What services does this energy provide?

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# Lecture Question: US Energy Mix

## What about energy sources in the US: top five sources?

Energy flow diagram for 2013:

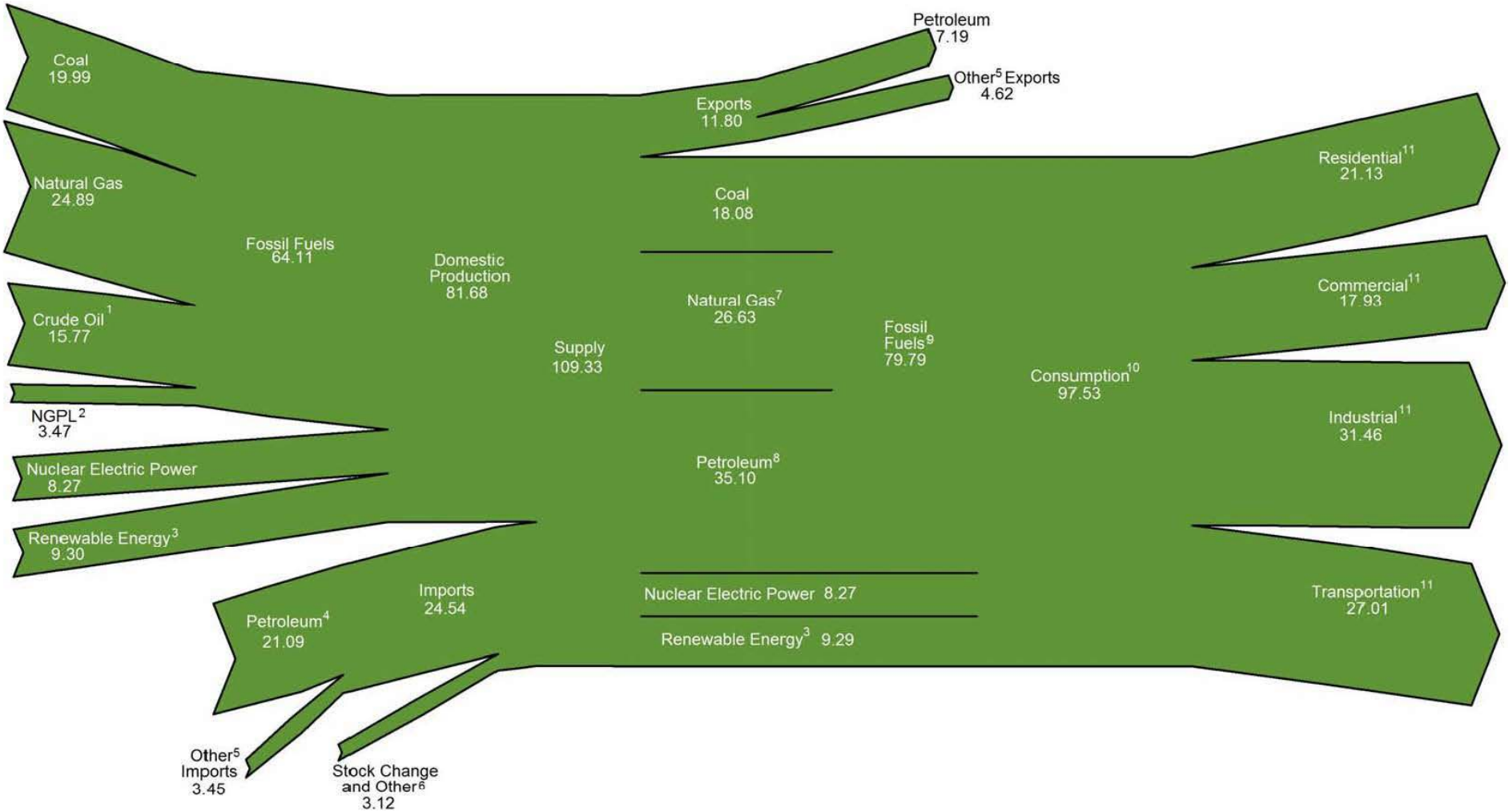
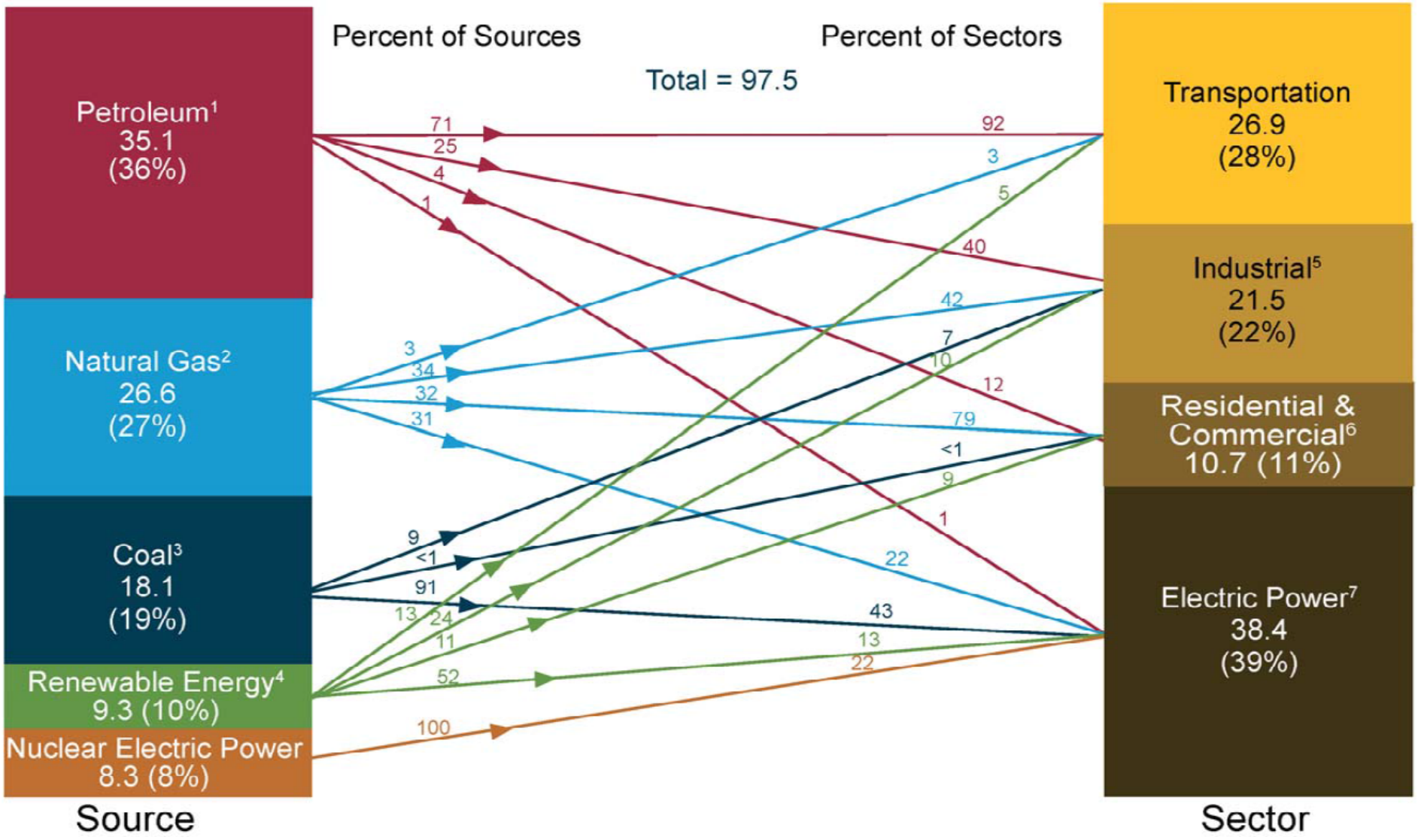



Figure taken from the US Energy Information Administration. Renewable energy includes hydro, biomass, geothermal, solar/PV, and wind. Roughly speaking: fossil fuels provide 80%, nuclear and renewables 10% each.

# US Energy Consumption by Source and Sector

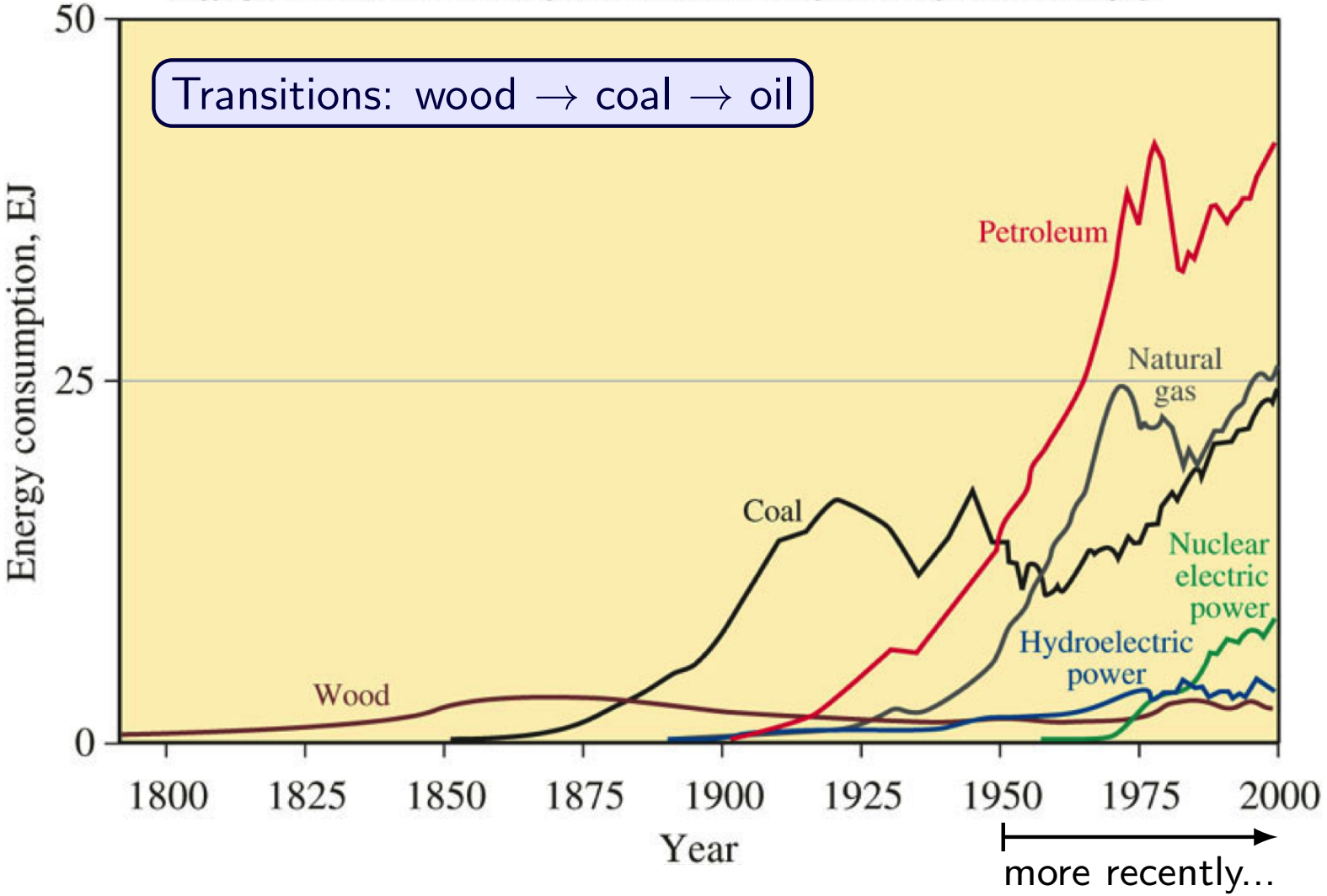
For the US, break down which energy source is used for which purpose.



# US Energy Sources: Historical Trends

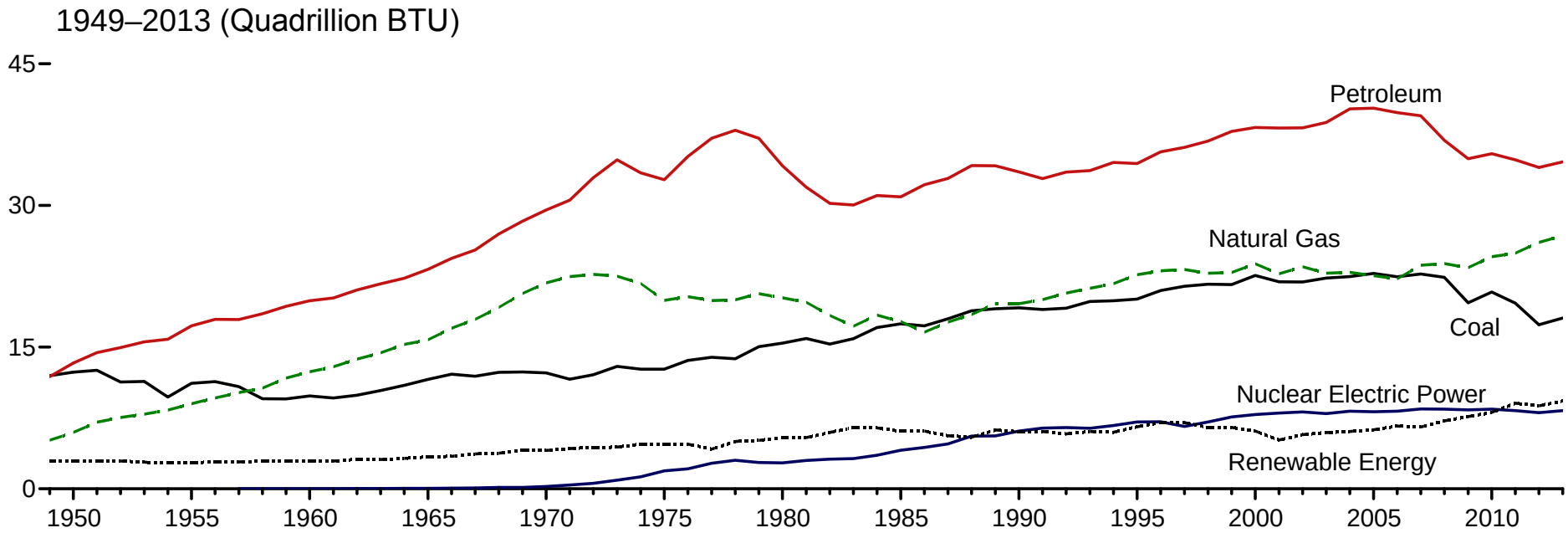
How has US energy source mix evolved over time?





# US Energy Sources: Recent Trends

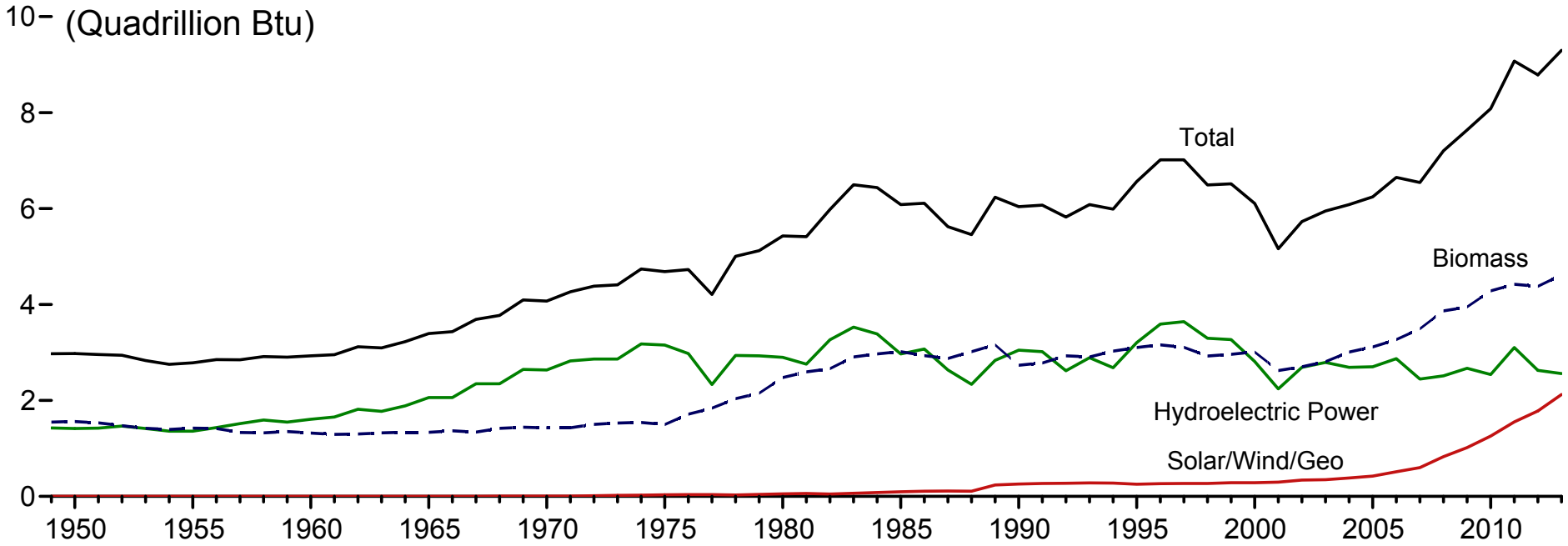
## How has US energy source mix evolved since 1950?




- Oil consumption has been falling for the last 10 y
- Recent surge of natural gas
- Recent drop in coal
- Nuclear is stagnant: no increase over past 10 y
- Renewables growing: 53% increase over past 10 y

## US Renewable Energy Source Mix

Renewables meet about 10% of the energy needs in the US. Can you be more specific?




- Recent increase driven by biomass and solar/PV, wind and geothermal
- Biomass: ethanol, biodiesel, wood, biomass waste
- Other: geothermal (10.4%), solar/PV (14.5%), wind (75.1%)
- Last 10 y: geothermal +24%, solar/PV +390%, wind +1026%

## Energy Source Comparison

What criteria should we use to compare the desirability of energy sources?

- Cost: internal vs external costs
- Type of resource:
  - Nonrenewable
  - Renewable
  - Exhaustible
- Impact on environment/health
- Versatility (variety of potential uses)
- Energy content. How measured?
  - Per unit mass, eg cal/g or MJ/kg
  - Per unit volume, eg cal/gal or J/L
  - Per unit of envmtl/health impact

## Life Cycle Analysis

How can *life cycle analysis* be applied to energy sources?

- What is Life Cycle Analysis (LCA)?
  - A comprehensive approach to assessing/comparing energy sources. A complete 'cradle to grave,' 'well to wheels' type of assessment.
  - Choose one or more criteria to assess (eg, cost, environmental impact, sustainability, net energy yield)
  - Apply these criteria to every stage of the energy production cycle Energy collection $\rightarrow$ end use $\rightarrow$ waste disposal
- Typical stages in LCA
  1. Extraction (eg mining, drilling, harvesting of energy source)
  2. Processing (refining, enrichment, etc)
  3. Transport
  4. Storage
  5. End use (eg, generating electricity)
  6. Waste disposal
- *Infrastructure Requirements*: construction and maintenance of infrastructure needed for the energy/fuel cycle also should be considered in LCA.

## Class Exercise

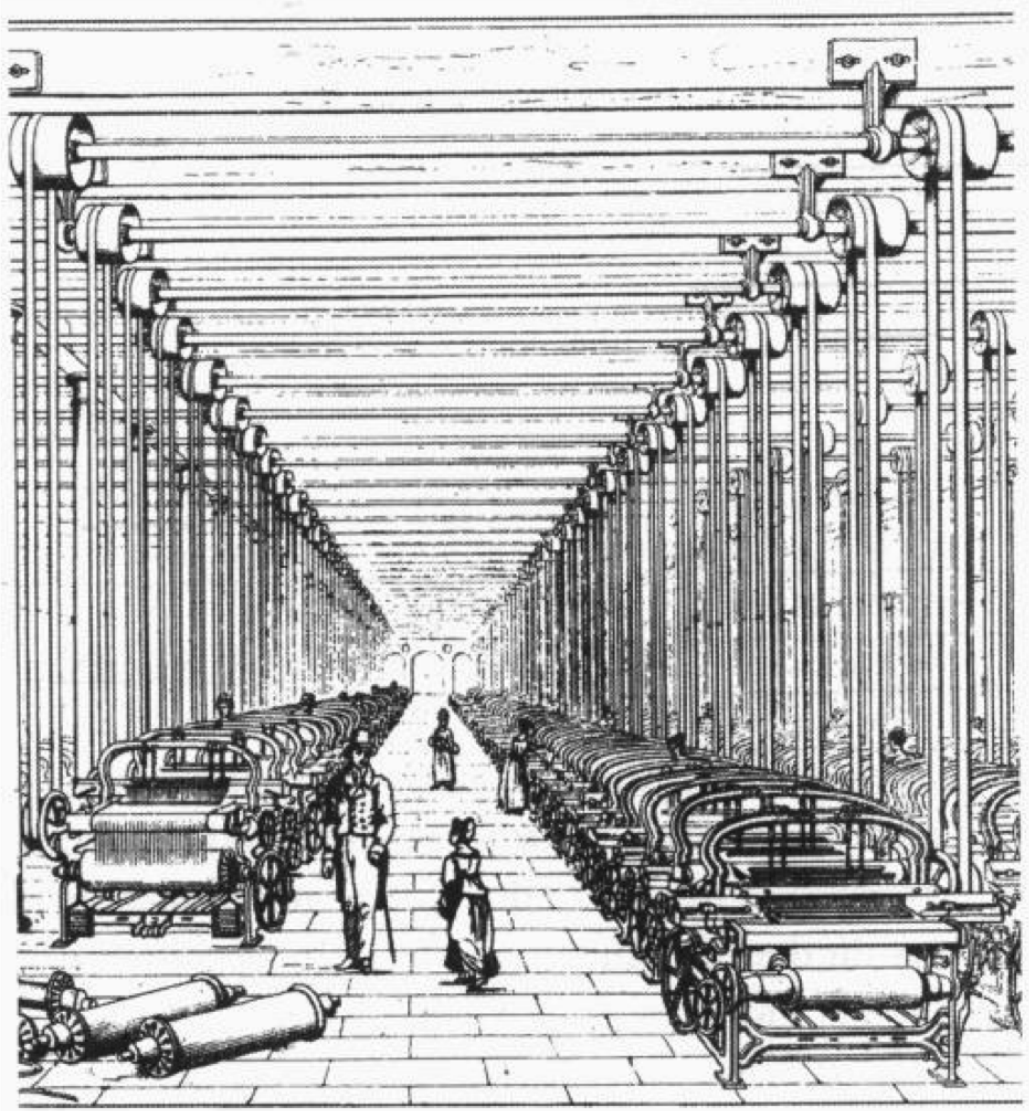
In what ways does our energy usage impact the environment? List as many impacts as you can.

Some possibilities (not exhaustive):

- Recovery and refinement
  - Mining
  - Dam construction
  - Waste generation
- Transport and storage: spills, leaks.
- Energy production
  - Air pollution (many issues from last section on air pollution are related to energy use)
  - Thermal pollution
  - Effects on local hydrology (dams, thermal power plants)
- Waste disposal: spent fuel (esp nuclear)

## Benefits of Electricity

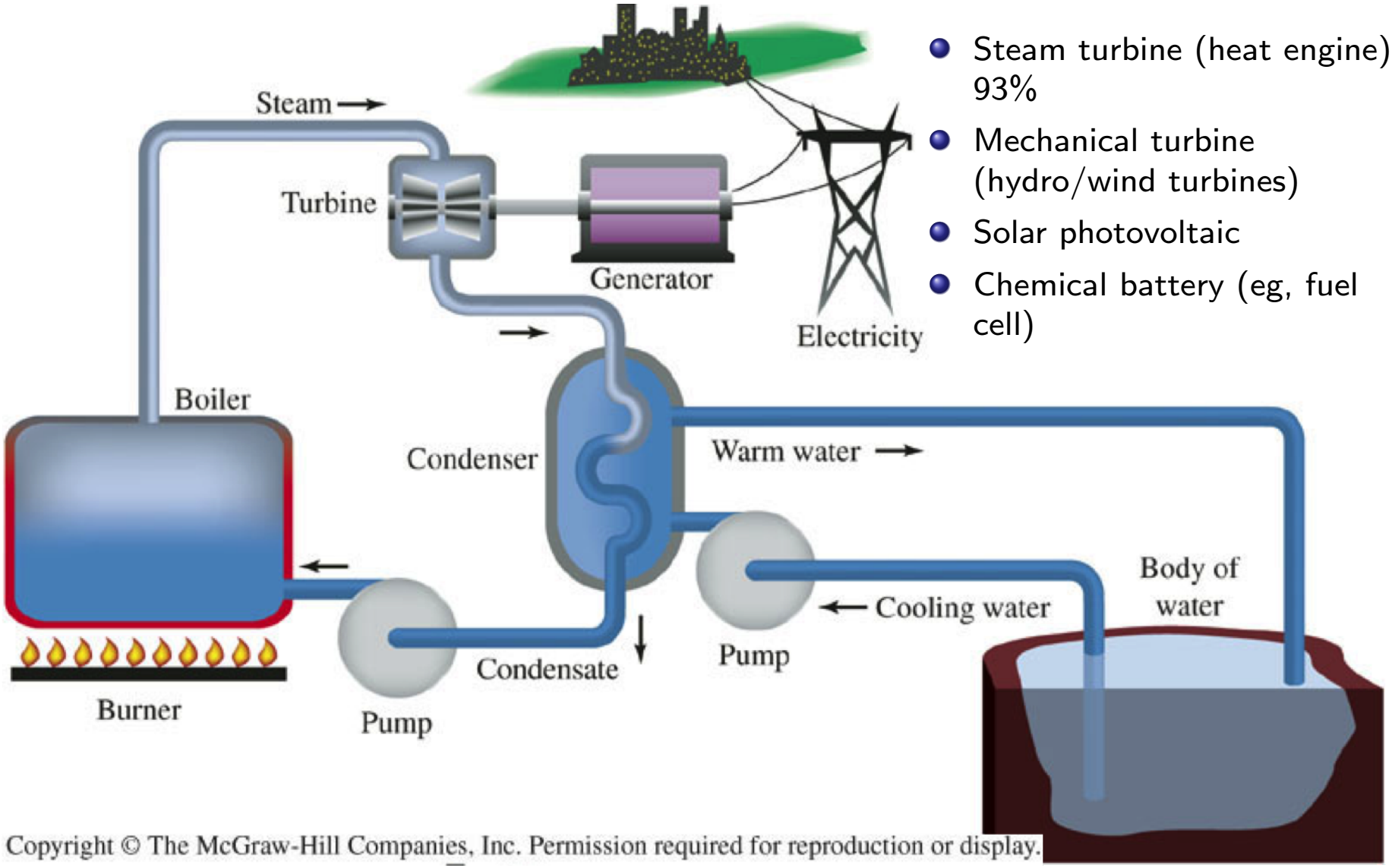
Globally 18% of energy consumption is from electricity; in the US it is 39%. Why is electricity so useful?



- Clean, efficient way to distribute energy (distribution losses 6–8%)
- Electricity can be converted to many other forms of energy (heat, light, mechanical) with high efficiency
- Electric motors replaces steam-mechanical engines
- Problems: inefficiencies in *storage* and *generation*

# Electricity Generation

## How is electricity produced?




- Steam turbine (heat engine): 93%
- Mechanical turbine (hydro/wind turbines)
- Solar photovoltaic
- Chemical battery (eg, fuel cell)

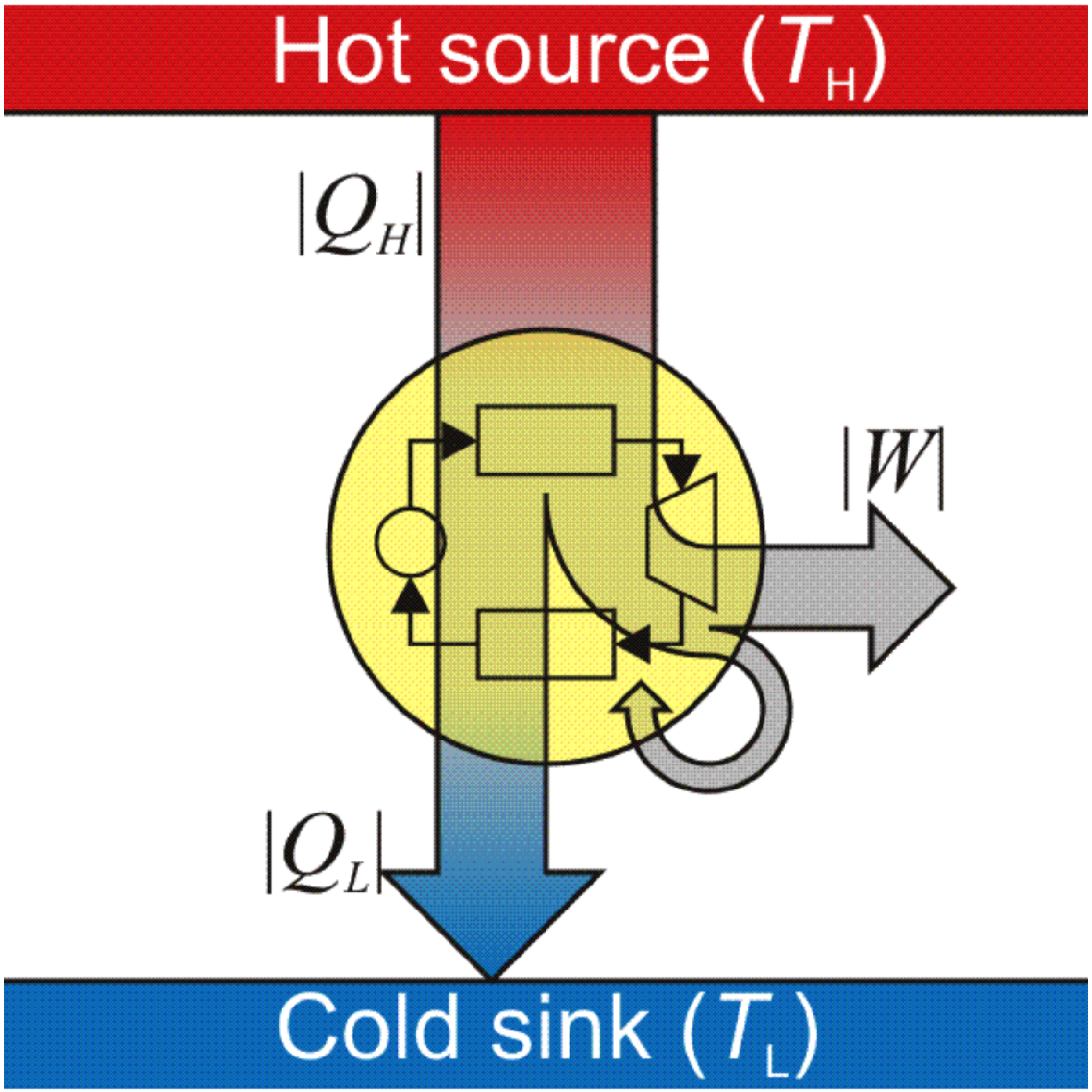
## Heat Engines

### What is a heat engine?

- A heat engine is any device designed to convert thermal energy into mechanical energy/work
- Very versatile, since any energy source can be converted to heat. The thermal energy can originate from a variety of other energy sources (chemical energy, nuclear energy, etc)
- Conversion from heat to work is often due to the thermal expansion of a gas
- Two common examples (give energy transformations)
  - Thermoelectric power plant
    For a coal power plant: chemical energy $\rightarrow$ heat (steam creation/expansion) $\rightarrow$ mechanical energy $\rightarrow$ electrical energy. For a nuclear power plant, the originating energy source would be nuclear energy.
  - Internal combustion engines in motor vehicles
    chemical energy $\rightarrow$ heat (expansion) $\rightarrow$ mechanical energy

## Efficiency of Heat Engines

What is the upper limit of heat engine efficiency?




- How much heat energy ($Q_H$) can be harnessed as usable work (W) from a heat engine, and how much is wasted as residual heat ($Q_L$)
- Answered by the Laws of Thermodynamics: max theoretical efficiency is

$$\frac{T_H - T_L}{T_H}$$

Typically 35–45% (in practice) for conventional power plants.

## Lecture Questions: Laws of Thermodynamics

What are the first two Laws of Thermodynamics, and why do they limit the maximum efficiency of a heat engine?

- First Law of Thermodynamics: Energy can be neither created nor destroyed.
  *'There is no such thing as a free lunch.'*
- Second Law of Thermodynamics: the total entropy (randomness) of the universe can never decrease.
  *'You can't break even.'*
- Energy quality: Heat is a very 'low quality' (high-entropy) form of energy, while mechanical and electrical energy are high quality (low entropy) forms.
- 'Cogeneration' or *combined heat and power* (CHP) generation can be used to increase efficiency to 75–80% (roughly double)

## Energy from Combustion Reactions

What is a combustion reaction? Give an example.

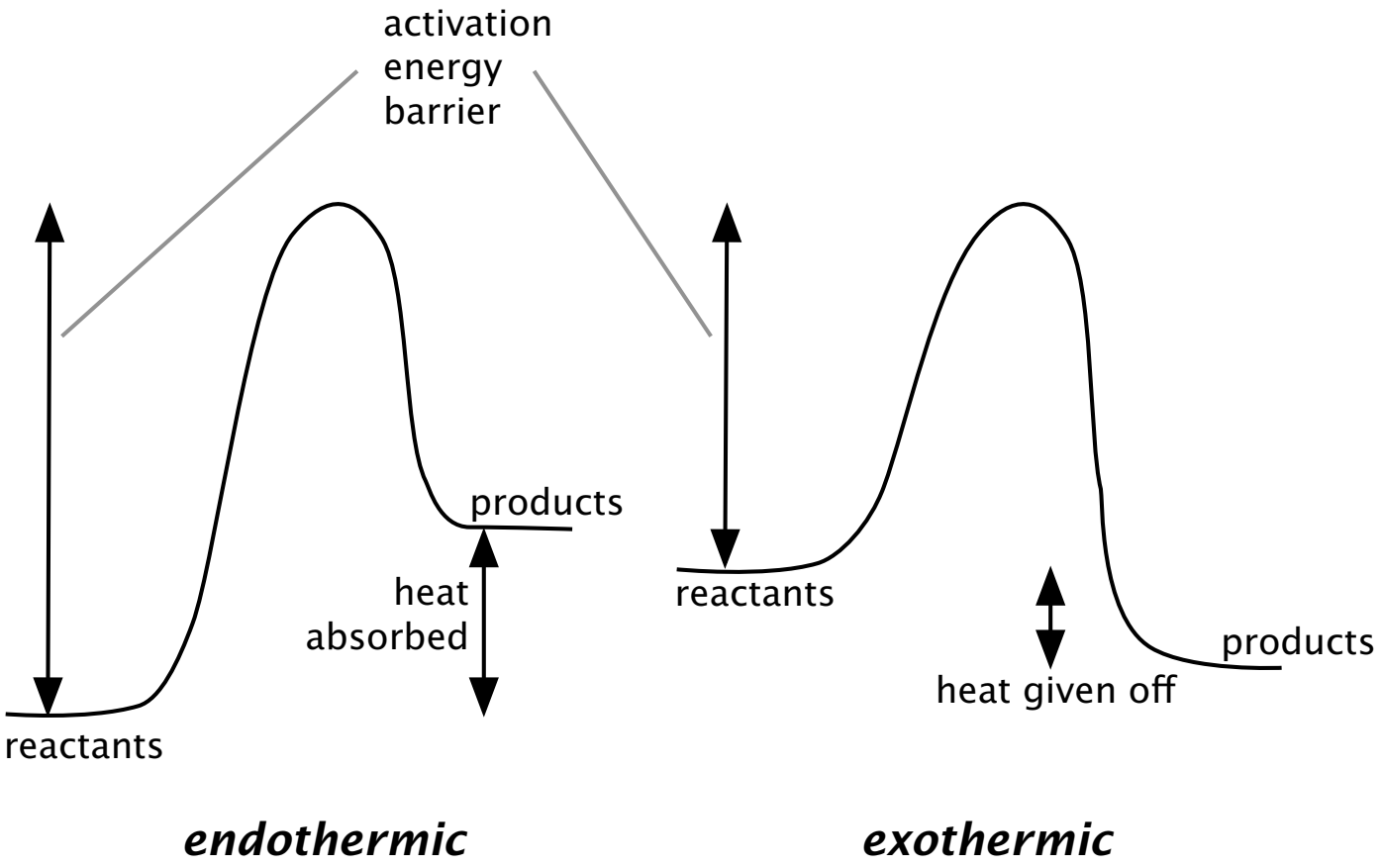
- Consider the combustion of methane, the simplest hydrocarbon. Complete combustion of hydrocarbons and other organic molecules will yield the most oxidized forms of the elements in the compound.

$$CH_4 + 2\,O_2 \longrightarrow CO_2 + 2\,H_2O + 891\,kJ$$

- Note that the energy is a molar quantity: that is how much energy is given off when one mole of $CH_4$ is burned
- Where does the heat come from?

## Lecture Question: Reaction Energetics

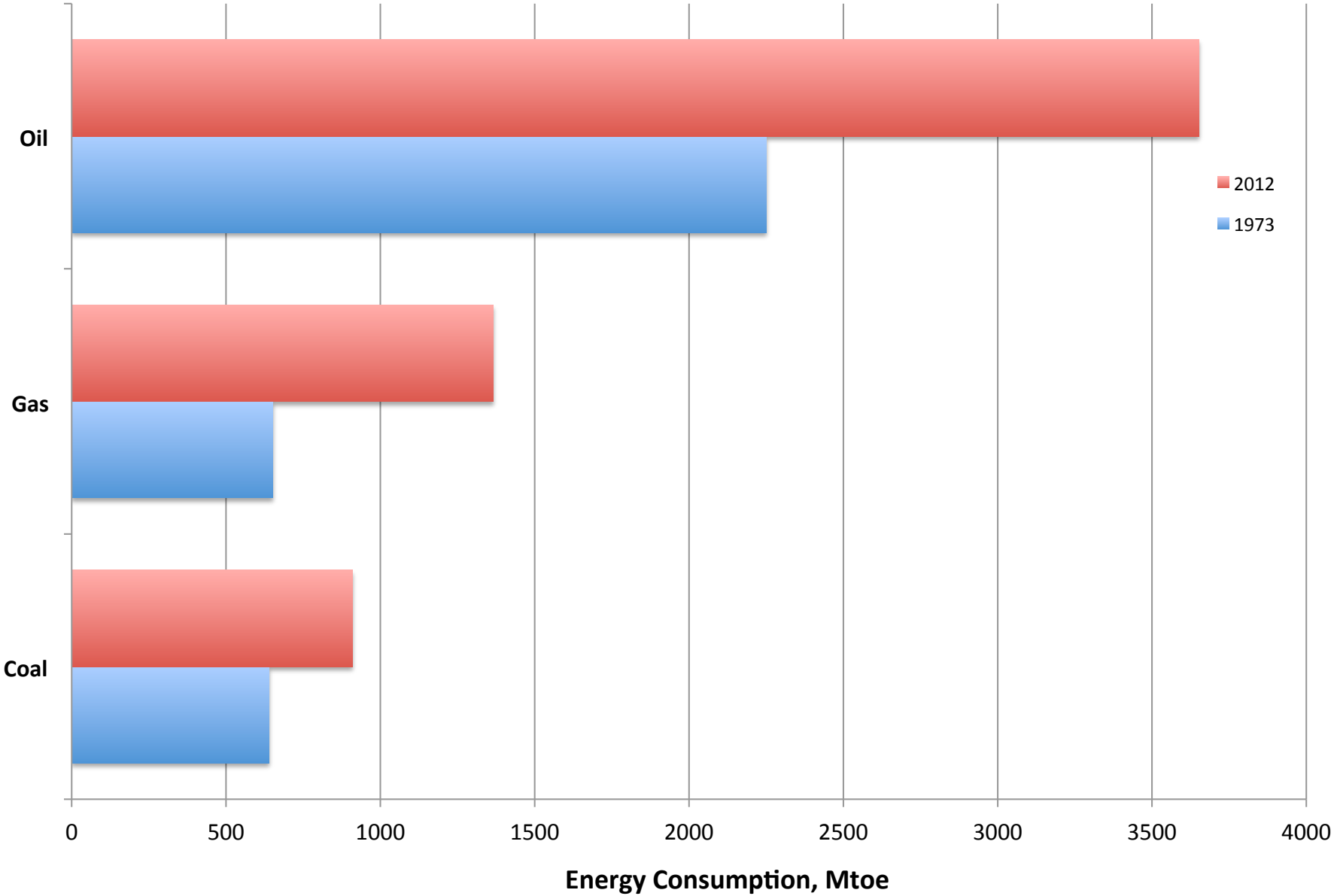
Define *exothermic* and *endothermic* reactions. Why do some reactions produce heat while others consume it?

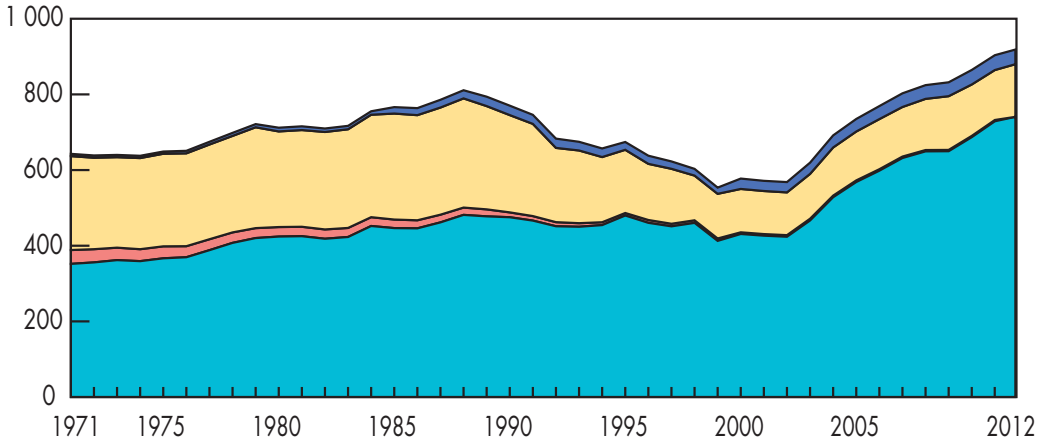



- Breaking bonds *requires* energy
- Forming bonds *produces* energy
- So where is the energy 'held' in a combustible fuel?

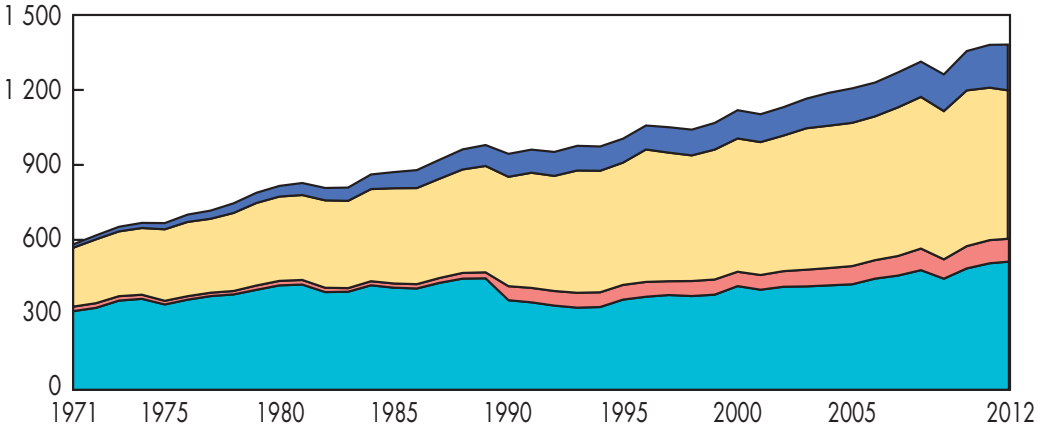
# Overview of Fossil Fuels

What are the three main fossil fuels, and how are they mostly used?

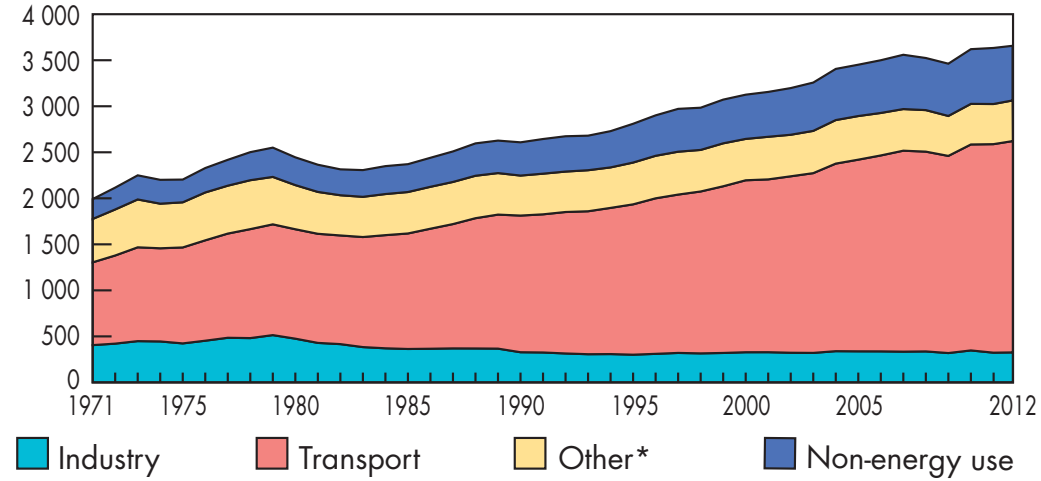





*Coal*: electricity




*Natural gas*: heating, electricity, cooking




*Oil*: transportation, heating

*Other includes agriculture, commercial and public services, and residential energy use.

## Natural Gas

### What is natural gas?

- Gaseous mixture of hydrocarbons
  - Mostly methane, $CH_4$ (60–80%)
  - Others: $C_2$ HCs (5–9%), $C_3$ HCs (3–18%), $C_4$ HCs(2–14%)
- Formed by decomposition of plant and animal remains that had been buried
  - Lack of oxygen, high heat and pressure
  - Methane is produced by anaerobic respiration
  - Plenty produced in sediments and landfills
  - Often accompanies coal and oil deposits

## Coal

### What is coal?

- A solid mixture consisting largely (about 85%) of carbon
  - Representative formula is $C_{135}H_{96}O_9NS$
  - Plenty of other impurities
  - Toxic metals like Pb, Hg, As
  - Radioactive isotopes of various types
- Three broad grades of coal
  - Anthracite (hard coal): highest carbon content and heat value.
  - Bituminous coal (soft coal)
  - Lignite (brown coal): lowest carbon content and heat value.
- Originated as plant matter in hot, muggy regions
  - Most current coal formed 200-350 million years ago
  - Plant matter decays under conditions of low oxygen, high heat and pressure
  - First converted to peat

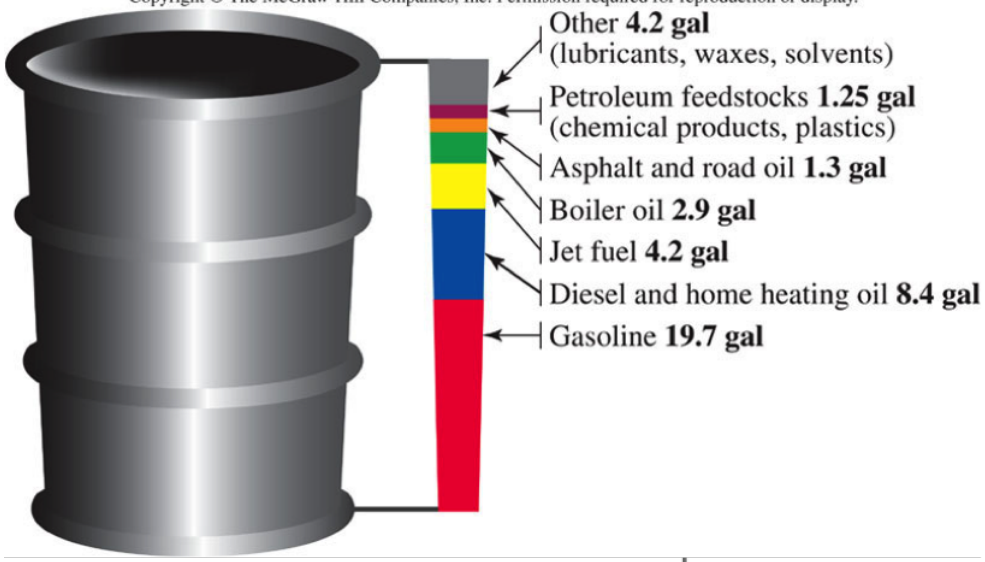
## Petroleum Oil

### What is oil?

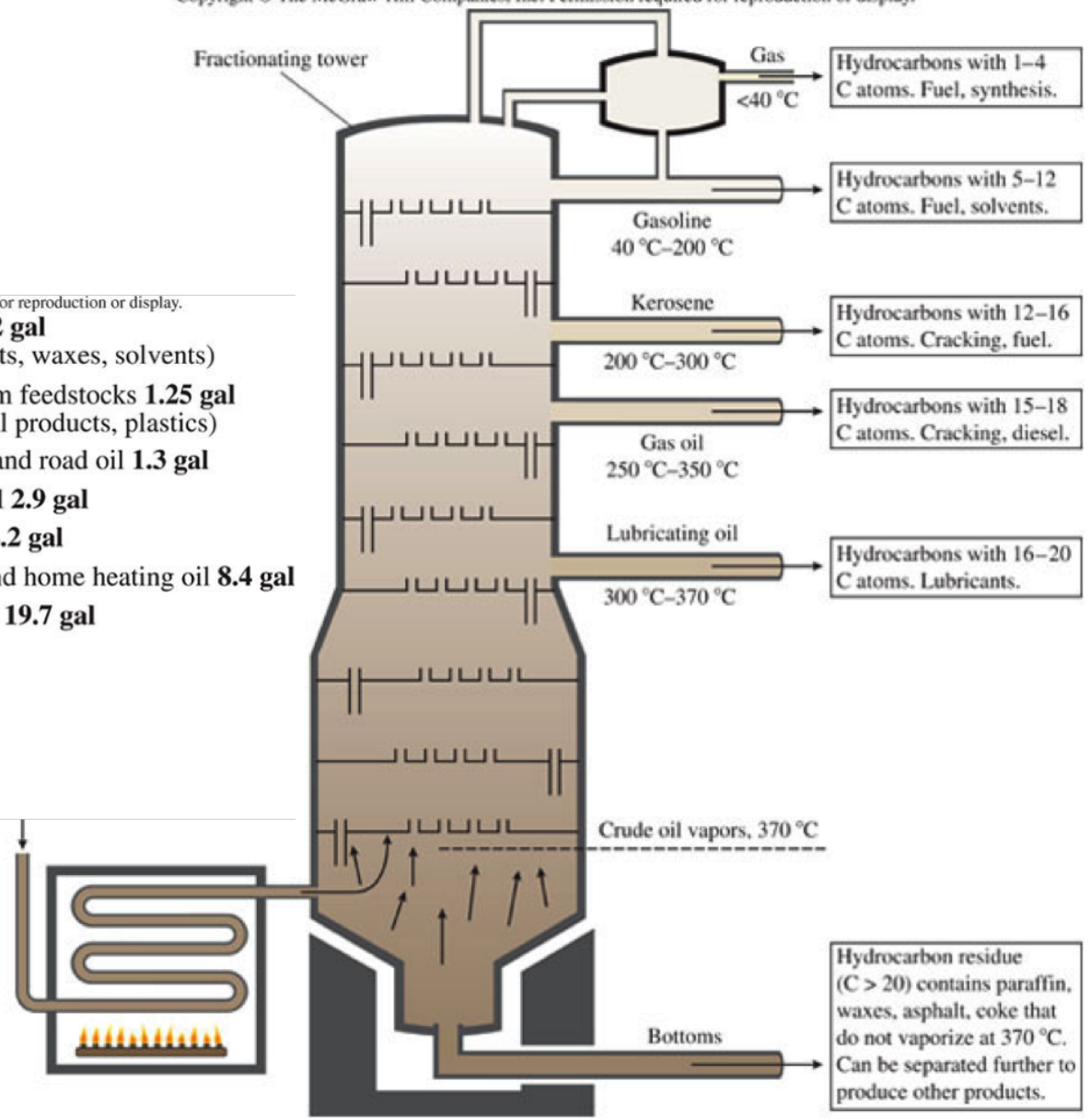
- A very complicated liquid mixture of hydrocarbons
- Liquid HCs start at $C_4$–$C_5$
- Almost always contains dissolved natural gas as well
- Formed by decomposition of biological matter, probably from ocean-dwelling microorganisms

# How is oil refined?







## Oil Distillate Refinement

Do we do anything else with gasoline?

*Conversion* of other oil fractions to gasoline.

- Cracking: Breaking apart larger molecules into smaller ones
- Thermal cracking
- Catalytic cracking

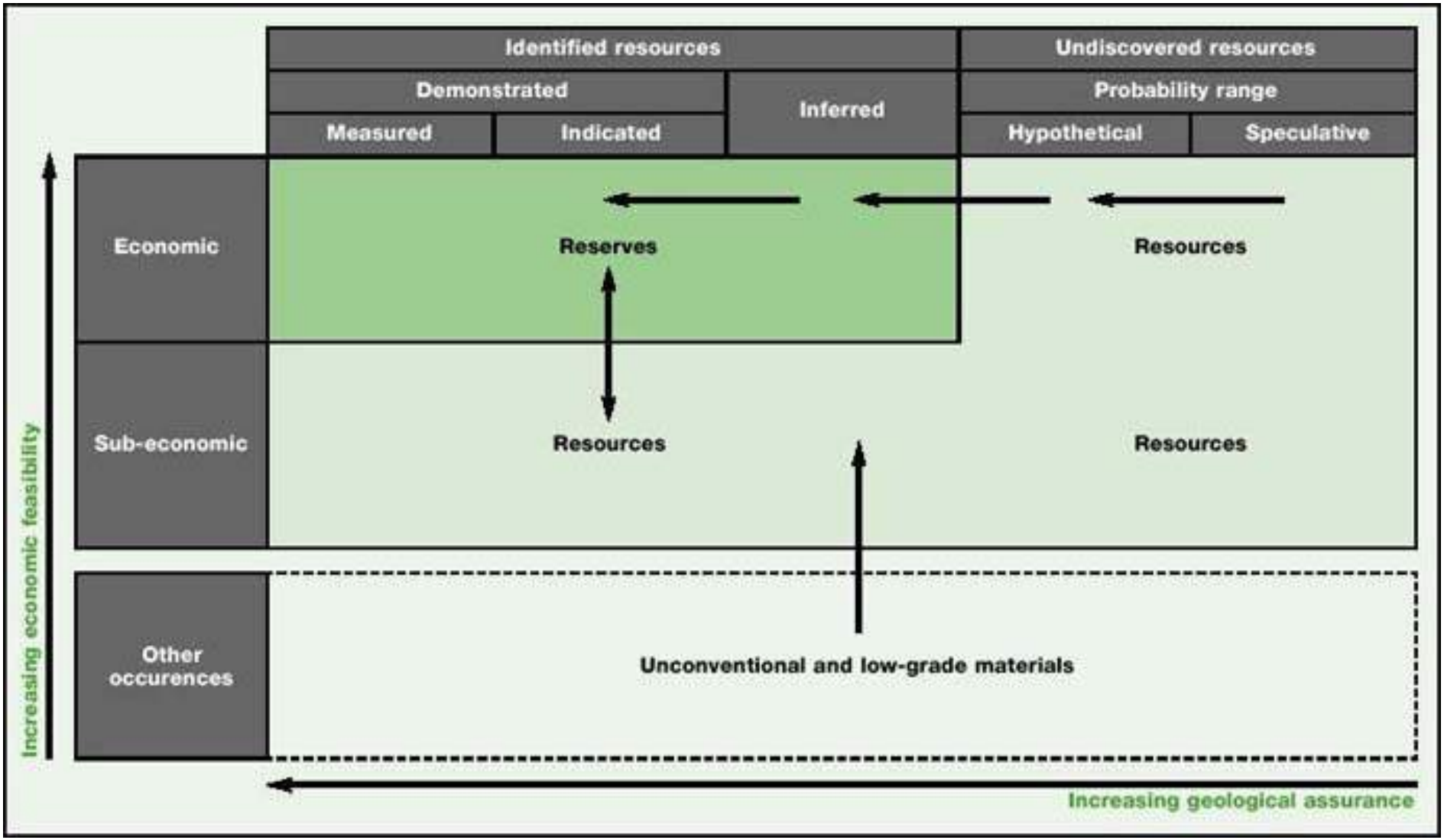
**Gasoline enhancement**

- Purpose: make it burn better or cleaner
  - Examples: antiknock agents tetraethyl lead (TEL), MTBE
- Reformulated Gasoline (RFG)
  - Oxygenated gasolines have fewer volatile hydrocarbons
  - Common additives: MTBE, ethanol, methanol
  - Reduce CO emissions
  - Reduced smog
  - May have reduced impact on groundwater (lower BTEX)

## The Future of Fossil Fuels

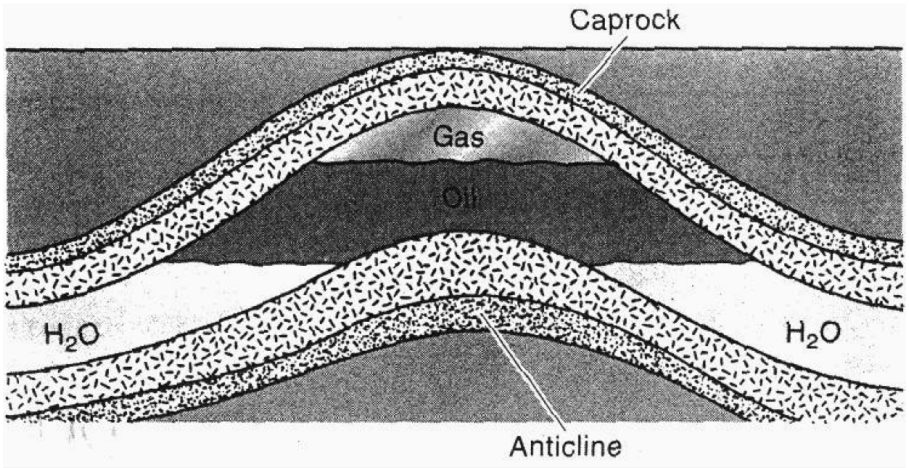
Explain the concept of fossil fuel reserves and available resources.

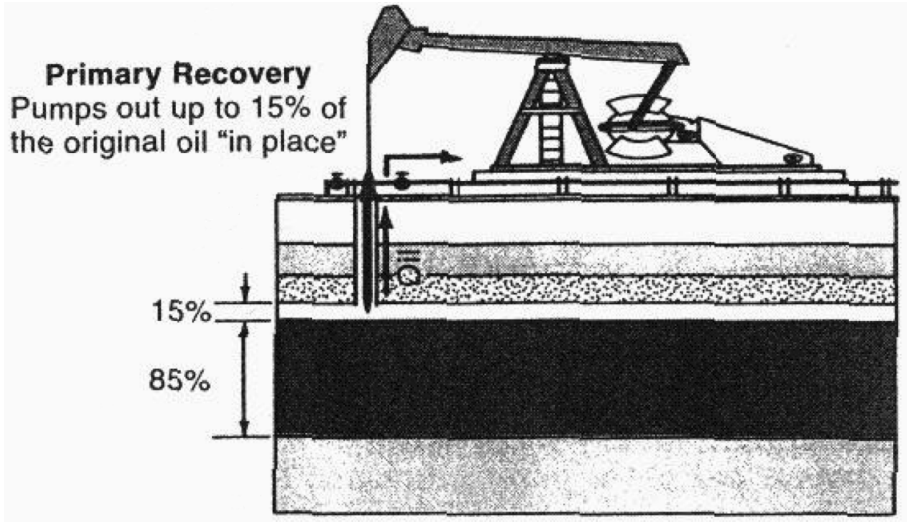
McKelvey resource classification figure:

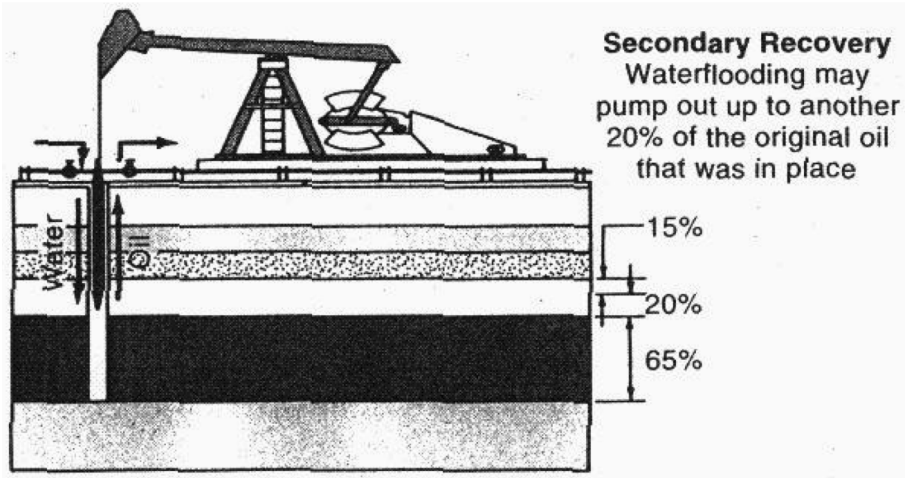


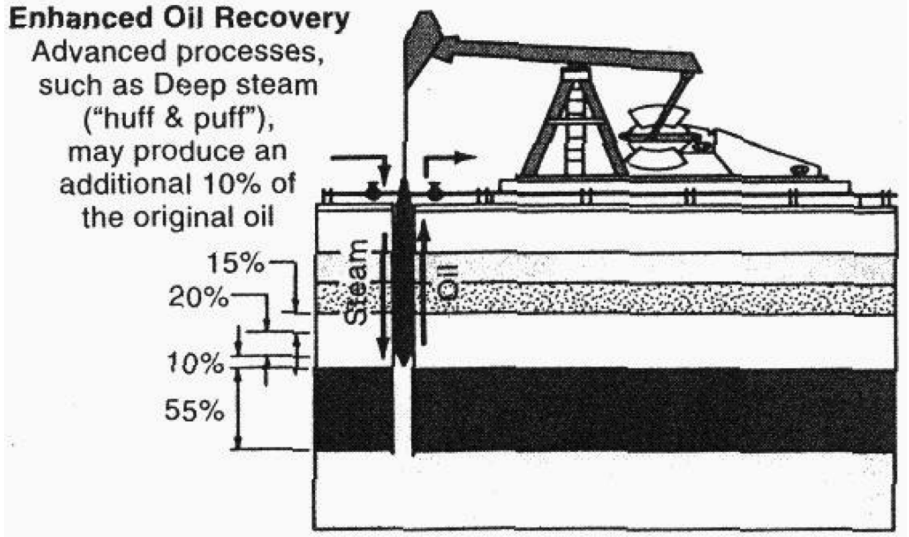
## Oil Recovery

Why does a geologic resource from a given area become harder to recover with time?



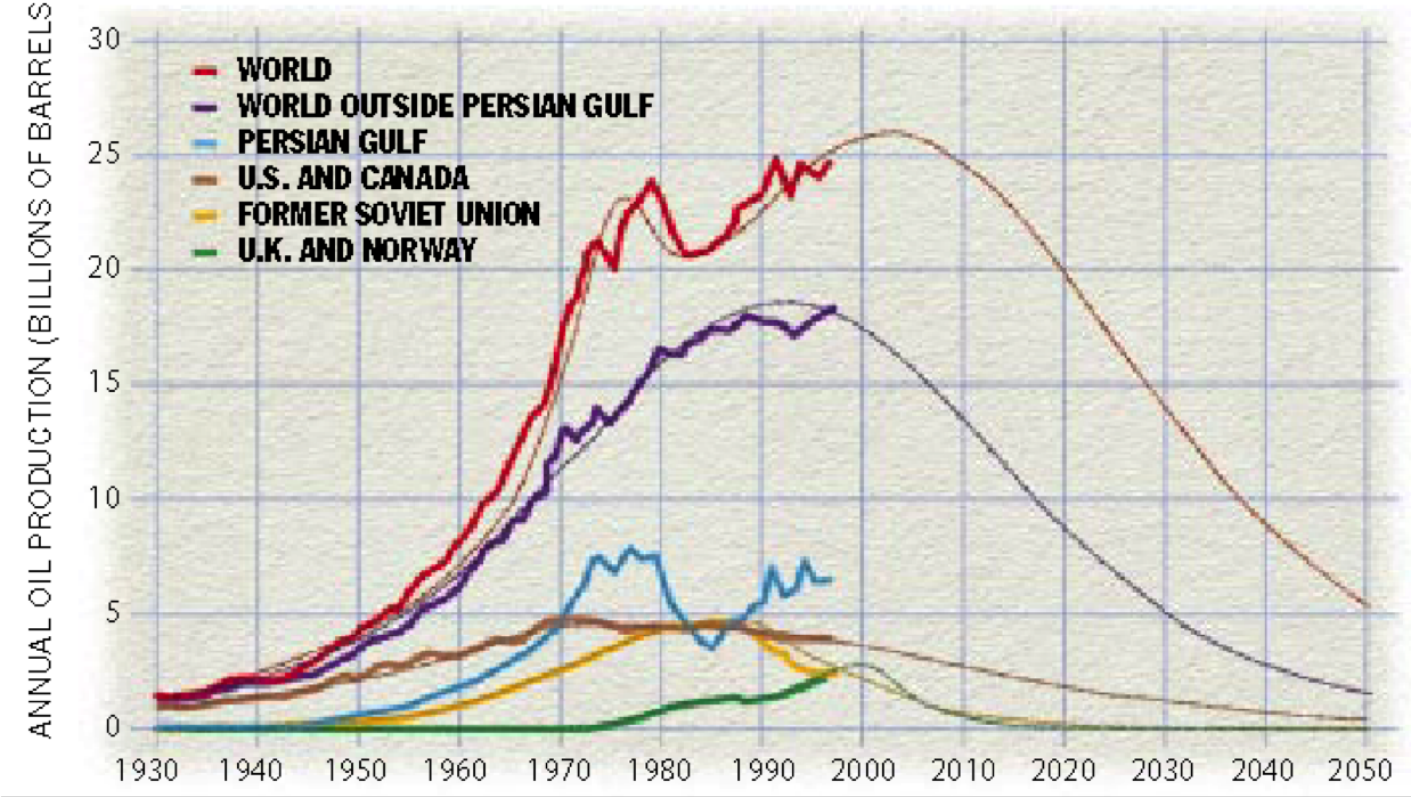



## Lecture Question: Peak Oil

What is meant by the term *peak oil*? What is its significance?

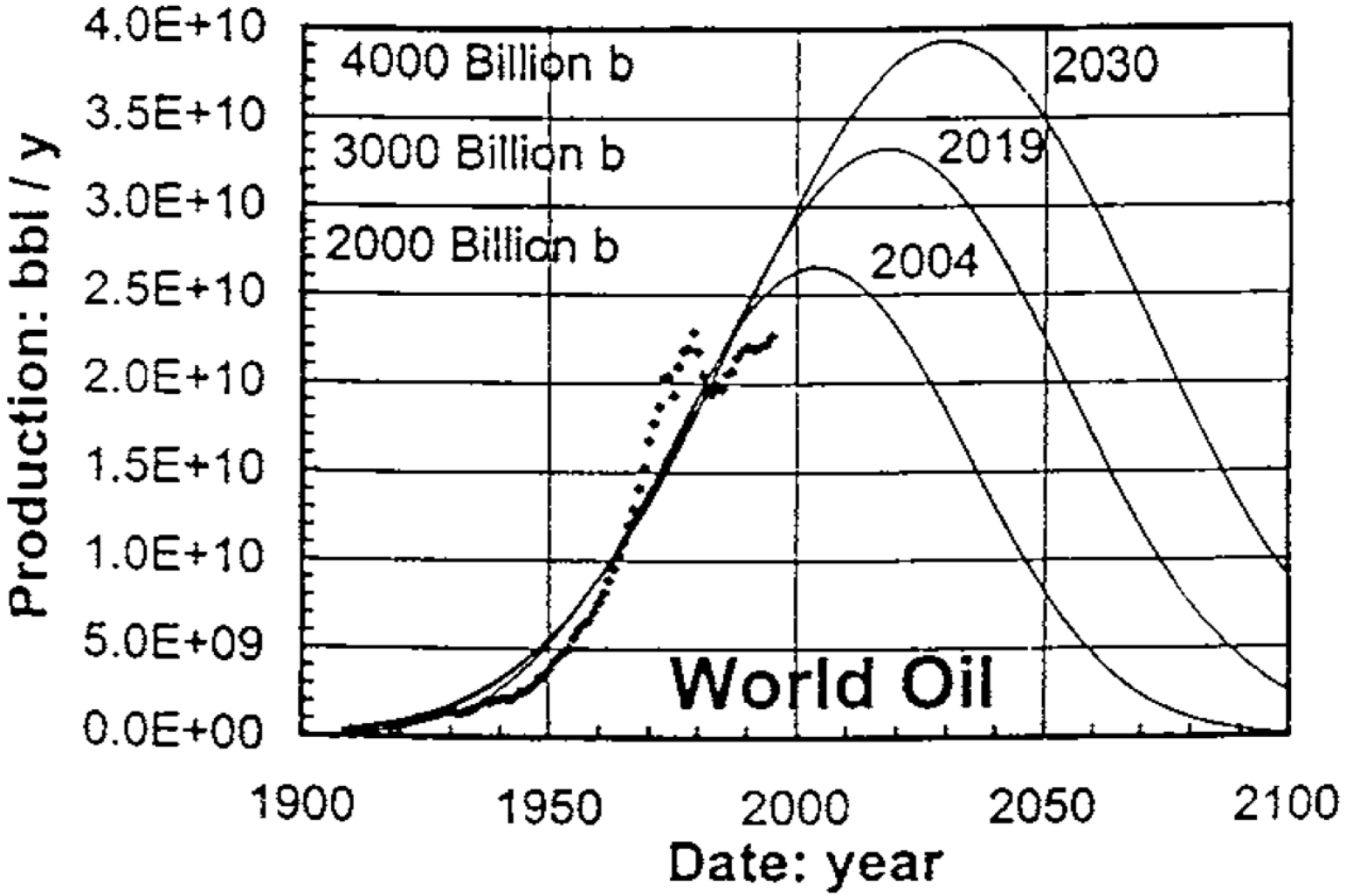
Question is really, *When will peak oil production occur?*



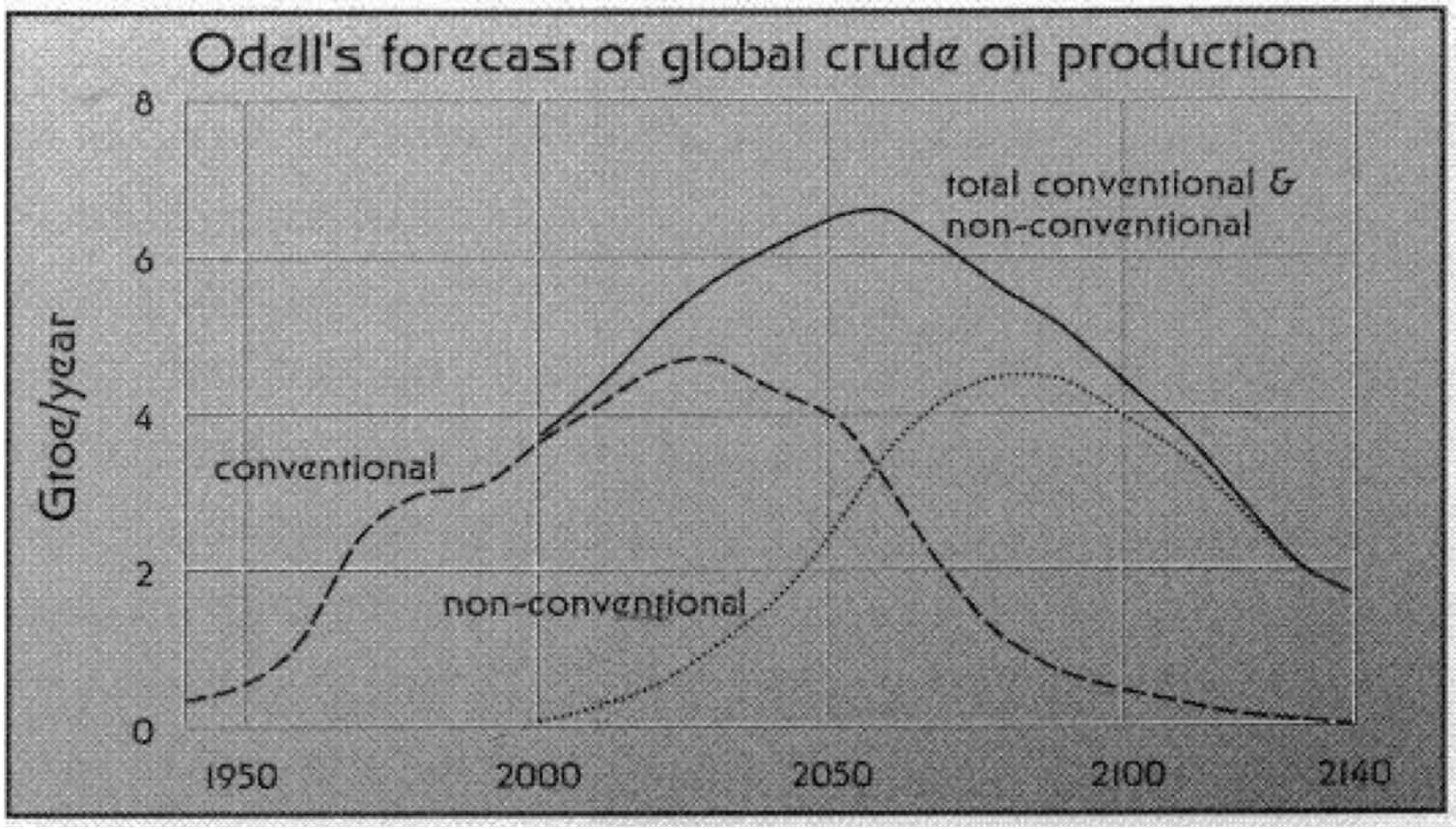

- March 1998: two retired petroleum geologists claimed that oil would peak in the first decade of the 21st century
- Based on *Hubbert curves* (above) and estimates of total global oil resources.

## Effects of Reserves on Peak Oil

How much of a difference does the estimate of global oil reserves make?



## What about so-called 'unconventional' sources of oil?




- Oil shales, tar sands, heavy oil
- Potentially a very large resource
- Extends peak production by 2-3 decades
- More energy intensive (thus more expensive); more environmentally damaging

## Biomass Energy: Lecture Questions

What is biofuel? What are the major sources? What are the advantages and disadvantages of biofuels?

- Biofuel is derived from recently living biological material.
- Example of fuels: ethanol, biodiesel, biogas, others. Solid/liquid/gaseous fuels all possible.
- Biomass sources: crops, trash, dung, wood, grasses, algae, others.

Potential advantages:

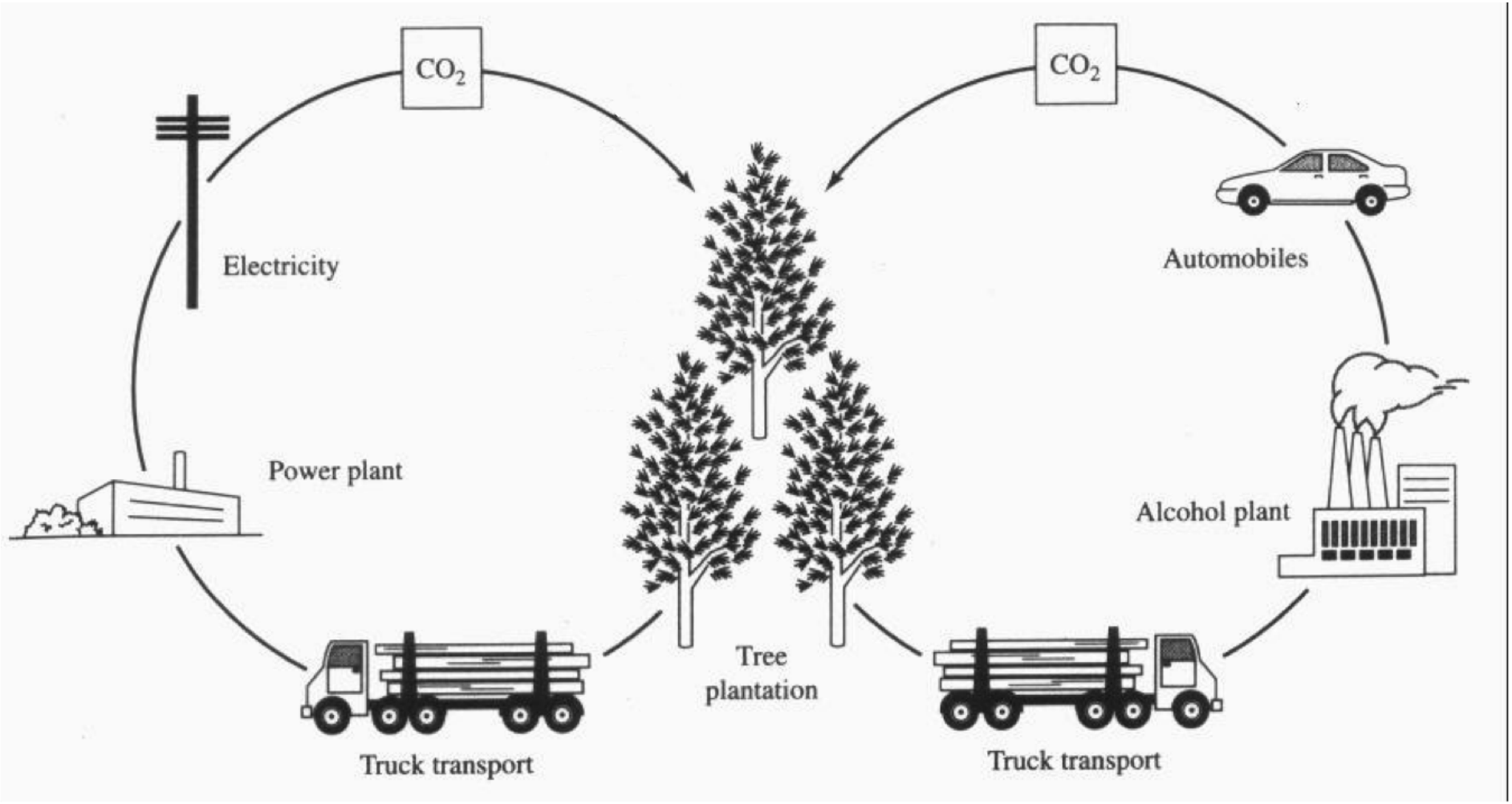
- Renewable/sustainable energy source
- More versatile than other renewable sources
- Theoretically/ideally only minor impact on global carbon cycle

Potential disadvantages:

- Air quality problems from combustion
- Water quality problems from intensive agriculture
- Increase in food prices
- Generally: envmtl/social impact very dependent on biomass source

# Biomass Energy and the Carbon Cycle

Biomass energy is conceivably 'carbon neutral.' How?




The idea is that we use carbon from a 'fast pool' to generate energy. This has less impact on the global carbon cycle or atmospheric $CO_2$ levels.

## Algal Biofuel

Is biofuel derived from algae potentially a game changer?

- Can be grown in a bioreactor
- Needs much less land
- Can use marginal land, less impact on food prices
- Pesticides not needed
- Generally reduced envmtl impact
- Research still ongoing, but main barrier currently is economic