
FOSSIL FUELS AND NUCLEAR

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Learning Outcomes

- Characterize the four major fossil fuel types (Coal, Petroleum, Natural Gas, Tar Sands) based on their formation, extraction, and application.
- Analyze the economic mechanisms, such as Energy Return on Investment (EROI), that favor fossil fuel utilization.
- Explain the operational principles of nuclear energy and contrast its reliability and risk profile with fossil fuel systems.

Reading

- Fossil fuels review article
- Nuclear energy review article

1 Coal

Coal has been used for many years to provide power to millions of homes and businesses. Coal is the most abundant fossil fuel in the United States. Fossil fuels are formed from the remains of ancient plants and animals, buried and altered over millions of years. The three main types of fossil fuels are coal, oil, and natural gas.

The United States has more coal than the rest of the world has oil. There is still enough coal underground in this country to provide energy for the next 250 years or more per the U.S. Department of Energy. There is enough coal in the world to last us more than 1,000 years.

1.1 Coal Types

Peat

Bituminous Coal

Chemical Structure, CHNSOHg



Figure 1: Image of peat from [https://commons.wikimedia.org/wiki/File:Peat_\(49302157252\).jpg](https://commons.wikimedia.org/wiki/File:Peat_(49302157252).jpg).



Figure 2: Image of coal from [https://commons.wikimedia.org/wiki/File:Bituminous_coal_\(Ferron_Sandstone_Member,_Mancos_](https://commons.wikimedia.org/wiki/File:Bituminous_coal_(Ferron_Sandstone_Member,_Mancos_)

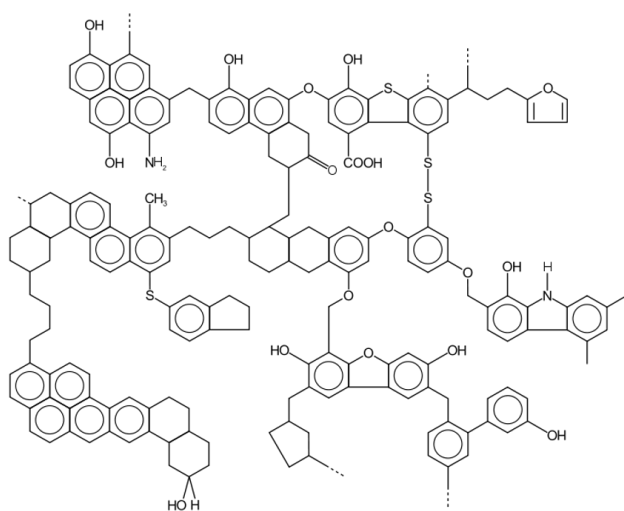


Figure 3: Chemical structure of coal showing the main chemical structures present.

- Sulfur
- Nitrogen
- Mercury
- CO₂ (Coal emits 60% more CO₂ than natural gas per kWh (0.37 kg/kWh compared to 0.23 kg/kWh))
- Ash

1.2 Coal History

- 300 BC - Greek scientist Theophrastus reportedly said: "Among the materials that are dug because they are useful, those known as coals are made of earth, and, once set on fire, they burn like charcoal."
- Newcomen Engine (1712)
- 1769 James Watt invents the steam engine, which ran on coal.
- 1882 Thomas Edison opens the first commercial power plant in New York City, which was powered by coal.

1.3 Coal Use

- Principally used for electricity generation
- >8 billion tons per year are used ([source](#)).
- China uses 4 billion tons per year ([source](#))
- Taking into account the thermodynamic efficiency of electricity generation, coal produces approximately 2 kWh per kg.
- Current US coal-fired power plant capacity is <200,000 MW
- >2400 coal-fired power plants in the world

1.4 Coal Technology Frontiers

- Combined Cycle Gas Turbine (CCGT) and Integrated Gasification Combined Cycle (IGCC)
- Clean coal/Carbon capture and sequestration (CCS)
- Gasification and liquefaction for fuels and chemicals

1.5 Power Plant

2 Petroleum

Petroleum, a naturally occurring mixture of hydrocarbons, is a primary energy source due to its high energy density. Through refining, it provides fuels for transportation (gasoline, diesel, jet fuel) and serves as a feedstock for lubricants, plastics, and various petrochemicals. Chemical engineers seek to optimize its extraction and refining processes while mitigating its environmental impact.

Petroleum production around the world ranges from:

- 23 million barrels per day in the Middle East
- 16 million barrels per day in the Americas
- 20 million barrels per day in Russia and Africa

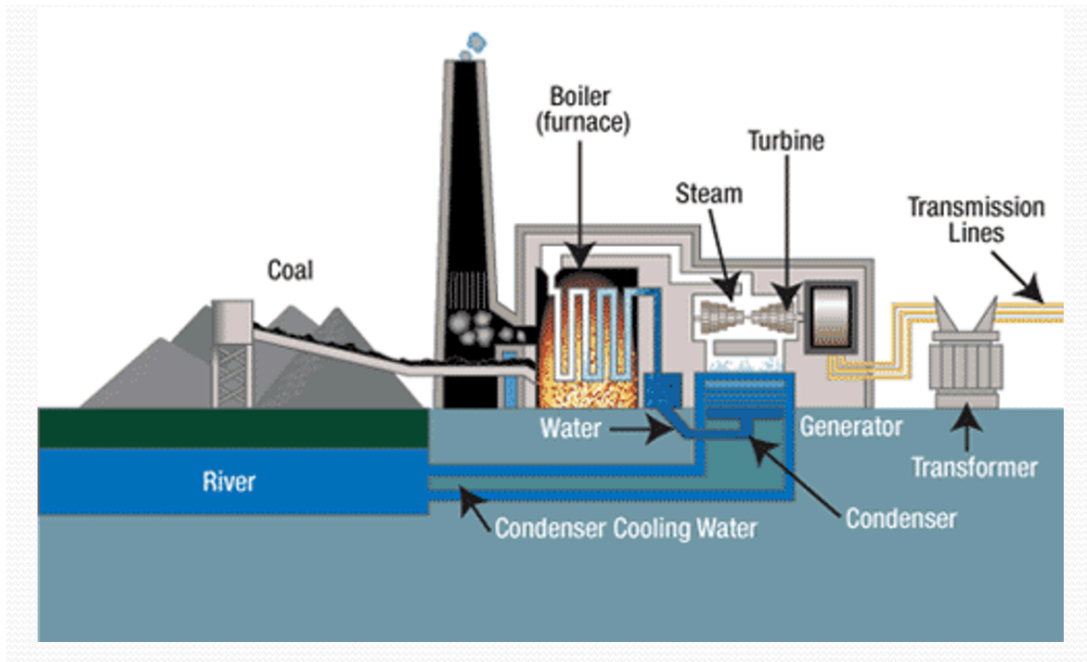


Figure 4: Image of a power plant as a general process flow diagram.

2.1 Petroleum Revenue

350 billion dollars in revenue in US alone in 2022 (<https://www.statista.com/statistics/294614/revenue-of-the-gas-and-oil-industry-in-the-us/>)

2.2 Petroleum Reserves

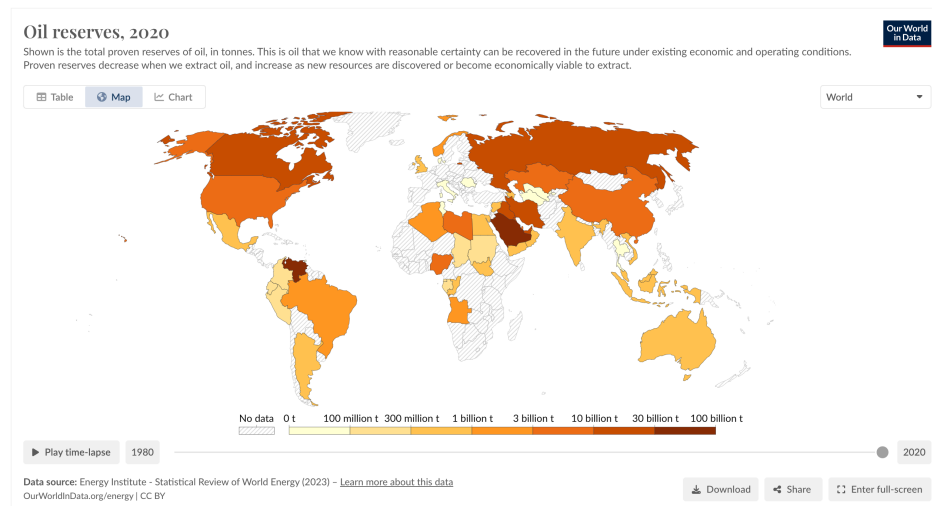


Figure 5: Oil reserves map as of 2020. See: <https://ourworldindata.org/grapher/oil-proved-reserves?time=2020>

2.3 Upstream Operations

- Exploration
 - Seismic surveys

- Borehole Logging
- Drilling
- Production

2.4 Downstream Operations

- Refining
- Transportation
- Distribution

Products from refining:

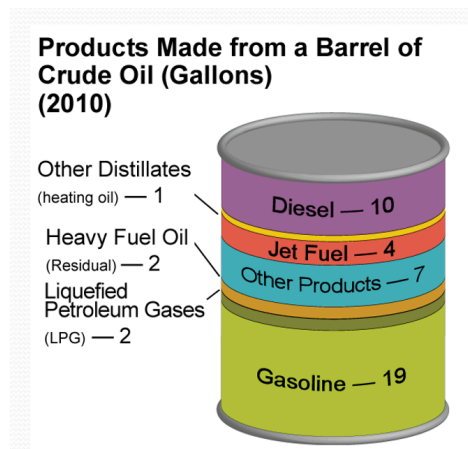


Figure 6: Image of products from petroleum refining.

3 Natural Gas

- Principally methane, but contains varying amounts of other compounds, including heavier hydrocarbons (ethane, propane, butane, pentane) and other gases (carbon dioxide, hydrogen sulfide).
- Natural gas can be “associated” with oil deposits or isolated, “non-associated” resources. It can also be associated with coal beds.
- Until recently, associated natural gas was burned off because it was not economical to transport it to where it was usable.
- Used for electricity generation; home heating, cooking, and clothes drying; transportation; and fertilizer manufacture
- Peaking power plants are commonly natural gas plants
- Can be used to make liquid fuels using Fischer-Tropsch process
- LNG transportation is huge and growing business

3.1 Natural Gas Reserves

- 7,000 trillion cubic feet (tcf) of proven reserves
- Current world production is near 120 tcf per year

4 Tar Sands

- Canada and Venezuela have the largest reserves
- Must be heated to flow
- Polycyclic Aromatic Hydrocarbons (PAHs or Asphalt)
- Estimated to be twice the reserves of conventional oil

5 Fossil Fuel Concerns

Fossil fuel use is very widespread and is a key piece of our energy infrastructure. However, there are concerns about the environmental impact of fossil fuel use. These include:

- Air pollution
- Water pollution
- Greenhouse gas emissions
- Land use
- Resource depletion (limited supply)

6 Cooking with Solid Fuels

- Used for cooking in many parts of the world (1/3 of the world's population or 2.5 billion people)
- Include wood, charcoal, coal, dung, and crop residues
- Often burned in open fires or simple stoves
- Often burned in poorly ventilated spaces, leading to indoor air pollution
- Often burned in rural areas in developing countries, where access to cleaner fuels is limited

7 Nuclear Energy

Nuclear energy has many benefits over conventional fossil fuels. However, it is also currently limited due to the very remote risks that could have far-reaching consequences. The Nuclear Regulatory Commission (NRC) is the U.S. government agency responsible for regulating nuclear power plants. It can take decades to build a nuclear power plant due to the regulatory process.

7.1 Fission of Large Atoms

Fission occurs when a neutron strikes the nucleus of a uranium-235 atom, causing it to split into two smaller nuclei and release energy in the form of heat and gamma radiation. This releases additional neutrons, which can then strike other uranium-235 nuclei, causing a chain reaction. The heat is used to produce steam, which spins a turbine to produce electricity.

7.2 Massive Energy Density

1 kg of uranium-235 can produce the same amount of energy as 2.7 million kg of coal. Or 3 million kg of oil. Or 17,000,000 m³ of natural gas.

7.3 Nuclear Energy is Clean

Nuclear energy is clean in that it does not produce greenhouse gases or other emissions. The waste produced is small in volume and can be stored safely.

7.4 Nuclear Energy is Safe and Reliable

Lowest risk of death of industrial power processes.

Nuclear power plants operate at full power 90% of the time. This is much higher than other types of power plants.

7.5 Comments (Dr. Matt Memmott)

- There is enthusiasm for nuclear power in the US energy plan, BUT...
- Large reactor solutions are not likely in developed countries (different story for China, UAE, South Korea, etc)
- Industry can't justify development based on cost vs. return
- Market's no longer favor large baseload nuclear
- Any nuclear future must include
 - Smaller installations
 - Non-electricity products (in addition to electricity)
 - Inherent safety
 - Load-follow capabilities