Energy Consumption and Sources of Renewable Energy

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What is Energy?

The Physics Definition: The capacity to do Work.

So, what is Work? To produce a Force on an object to move it a Distance.

Force? Accelerates an object of mass M. 
F = ma.
Different Types of Energy.

- **Kinetic Energy.**
  - Energy of a moving thing: \( KE = \frac{1}{2} \cdot mv^2 \)

- **Potential Energy.**
  - Stored Up Energy that can be converted into KE.

  **Examples:**
  - Mass on a hill (gravitational PE),
  - Compressed spring (mechanical PE),
  - Stick of dynamite (chemical PE),
  - Battery (electrical PE)

**Energy Unit:** Joules
**Power:** Joules/second = Watts.
Energy Use Through the Ages.

• Prehistory to Industrial Revolution:
  Heat: Direct Sun, Indirect (burnt biomass)
  Mechanical/Transport Systems: Biological
    (water, wind, animals)
  *Units used: horsepower (746 Watts).*

• Early Industrial Revolution (1800s):
  Fossil Fuels (coal) → Steam Engine.
  *Units used: BTU (1055 Joules).*

• Late Industrial Revolution (1880s):
  Fossil Fuels → Turbines → Electricity.
  → Internal Combustion → cars.
  *Units used: Joules, Watts.*
Energy Use Effects Population.

Settlements in Fertile Crescent, Asia, shore regions.

Population Increases Gradually.

More settlement in temperate shore regions.
Organized Agriculture, reduction of forests.
Pre-Industrial Age Population

1700
600 million
Dawn of Industrial Age.

1800
900 million
Industrial Age

Fossil Fuels → Electricity in use for Industry, Transport, Food, Medicine.

Allows previously non-habitable areas to be settled.
Post WWII

The Recent Past, and Today.

Improvements in efficiency (agriculture, medicine, transport). Air conditioning allows arid climates to be settled.
The Near Future

Energy effectively decoupled from geography.
Why Fossil Fuels?

• What’s so special about fossil fuels?
  Energy content. Coal: 15,000 BTU/lb = 15 MJoules/lb
  Gasoline: 115,000 BTU/gal = 120 MJoules/gal

• Wood has roughly half the energy content of coal.

• A “horse” working for an hour would give: 2.5 MJoules.
• A “human” would probably give less than a tenth of that.

Fossil Fuels deliver lots of energy in a small volume.
Fossil Fuels are transportable.
How Do Fossil Fuels Work?

CH₄  Methane, the simplest Hydrocarbon, burns (all hydrocarbons burn):

*Burning* is a process of combining with oxygen.

1 Methane + 2 O₂  \(\rightarrow\)  2 H₂O  + CO₂ + *Energy*

Hydrocarbons burn fast.  
Hydrocarbon burning releases water and CO₂.
More Hydrocarbons

2 Carbon Atoms
ETHANE

3 Carbon Atoms
PROPANE

4 Carbon Atoms
BUTANE

And so on.
Five Carbon Atoms give you PENTANE.
Six Carbon Atoms give you HEXANE.
Seven give you HEPTANE.
Bigger is Better

The bigger the hydrocarbons get:
- The more energy per molecule you get from burning.
- The easier it is to **Liquefy** them.

Methane is very difficult to liquefy.
Propane will liquefy at 40 below zero.
Butane will liquefy on a cold winter day.
The World’s Favorite Hydrocarbon

**Octane.** Eight Carbons.
The main ingredient in gasoline.
The Trouble with Hydrocarbons

It’s all those Carbon atoms.

\( \text{CO}_2 \) is a greenhouse gas.

They trap infrared radiation in the troposphere, heating lower atmosphere.

Earth’s Surface absorbs visible light. emits thermal radiation in infrared.
Is Greenhouse Effect Bad?

Let’s compare Mars, Earth, Venus.

A little greenhouse effect is good. →’s show surface temperature without the greenhouse effect.

A lot of greenhouse effect is very bad. Example: Venus.
Can We See the Increase in CO₂

Carbon dioxide concentration as measured at Mauna Loa, Hawaii. These measurements represent the globally mixed concentration.

Source: Dave Keeling and Tim Whorf (Scripps Institution of Oceanography)
CO₂ Levels Historically

- 1800: 280 ppm
- 1850s: 290 ppm
- 1850 – 1960: 310 ppm
- 1960 – 2000: 365 ppm
Does it Affect Temperature?

Problem: We’ve only been looking for a few decades.
Answer: Paleoclimatology: ice cores, tree rings, etc.

THE EPA SAYS:
Rising global temperatures are expected to raise sea level, and change precipitation and other local climate conditions…. Deserts may expand into existing rangelands….

Most of the United States is expected to warm, …. likely to be an overall trend toward increased precipitation and evaporation, more intense rainstorms, and drier soils.

Unfortunately, many of the potentially most important impacts depend upon whether rainfall increases or decreases, which can not be reliably projected for specific areas.

http://yosemite.epa.gov/oar/globalwarming.nsf/content/impacts.html
Alternate Forms of Energy

- Fossil fuels will be hard to replace.
  Small volume $\rightarrow$ large energy release.
- Atomic nuclei? Most are very stable.
  A few large ones can be induced to fission.
Nuclear Power

- Excellent energy output: $10^{14}$ J/kg, $= 10,000$ gallons of gasoline.
- Need good, solid containment vessels.
- Final products are still radioactive, (alpha, beta decay). Need long term disposal solution.
Solar Power

• Sun’s main process: Turning H to He (fusion).
• Sun’s output 4 x 10^{26} Watts (or Joules/sec).
• We see ~200 W/m^2 (in the US).

So at 15% efficiency, 1 m^2, 10 hrs of sunlight \( \Rightarrow \) 1 MJoule/day.

**Problem:**
Night, clouds.

**Answer:**
Storage.
(batteries, fuel cells).
Wind Power

- Turbines can provide approximately $\frac{1}{2}$ MWatt when running.
- Wind farms can have up to 200 turbines.
  - over 500 gallons of gas/day.

**BBC NEWS:** The Irish Government has approved plans for the world's largest offshore electricity-generating wind farm, to be built on a sandbank in the Irish Sea south of Dublin. When completed, the 200 turbines will produce 10% of the country's electricity needs.

- **Problem:** calm.
- **Answer:** storage.
Wave and Geothermal Power

- Wave farms: Convert wave motion to circular $\Rightarrow$ drive turbines: $\sim 50$ kWatts/m

- At tectonic plate boundaries, geothermal plants can tap the heat of the earth’s interior
Problem with Alternatives to Hydrocarbons

• Hydrocarbons: 1) store a lot of energy compactly. 2) are cheap.

• Alternatives: 1) have large footprint. 2) enough total energy, but at low power rates. 3) low duty cycle.
Fuel Cells

• A simple but effective chemical reaction:
  \[ 2 \text{H}_2 + \text{O}_2 \rightarrow 2 \text{H}_2\text{O} + \text{Energy} \]

• Principal components:
  Anode, Cathode, & Membrane.

• Can be run in reverse!

**Anode:** Strips the e- from the hydrogen sends it through a wire, provides power.

**Membrane:** Separates Anode and Cathode. Takes the proton (hydrogen stripped of e-) and pushes it through to the Cathode.

**Cathode:** Strips O\(_2\) into two O (platinum catalyst). Grabs two protons through the membrane combine with one O to make one water molecule.
1. Hydrogen goes to Anode, (can use hydrocarbon fuel) Oxygen goes to Cathode.

2. Anode strips electrons from hydrogen, H+ ions enter the membrane

3. Since electrons cannot enter the membrane they go through the external circuit.

4. When electrons get back to the Cathode, they combine with H+ and O to form water.
Fuel Cell Points

• Each individual cell provides $\sim 0.7$ V.
  $\rightarrow$ **Use many in a stack.**

• Where do you get Hydrogen?
  $\rightarrow$ can use hydrocarbons, wastewater digesters, landfills, biomass.

  $\rightarrow$ can also run the fuel cell **backward**
  (use solar, wind, etc. power to convert water to H and O).
Possibilities with Fuel Cells

- Clean power (solar, wind, etc.) have
  - large footprint.
  - small duty cycle.

- Can use this power to run a fuel cell backwards!
  - Disassociate water into $\text{H}_2$ and $\text{O}_2$ gas.
  - Store the gases until needed (safely).
  - Pump gases into fuel cell and make electricity.

Hindenburg burns over Lakehurst NJ May 6 1937
Demonstrations

1. Solar Cell:

2. Solar Cell output makes $\text{H}_2$, $\text{O}_2$, at Fuel Cell A, and the $\text{H}_2$, $\text{O}_2$, gases make electricity at Fuel Cell B.
Conclusion

• Fossil fuels have been great. Have enabled mass of humanity to move beyond subsistence living.
  ➔ But we really need to figure out how to live without them.

• Carbon loading of the atmosphere is reaching terrifying levels.
  ➔ Scientific consensus on global warming.

• Clean alternatives like solar, wind, etc. have problems of rate, efficiency.
  ➔ Hydrogen is abundant. Problems of storage, distribution, etc. can be solved.