Energy
on this world and elsewhere

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September 20, 2011
Announcements

• Quiz one is graded and I will try to post it on Collab later today.
• My apologies, but I have not quite gotten the problem set posted. I’ll send an email out when it is done.
The Carnot Efficiency for a heat engine:

Carnot efficiency: \( \epsilon = 1 - \frac{T_C}{T_H} \)
Assumptions that led to the Carnot Efficiency

Conservation of energy

Heat flows from hot to cold

Carnot efficiency: \[ \epsilon = 1 - \frac{T_C}{T_H} \]
More rigorously:

- Conservation of energy (1st law)
- 2nd Law of Thermodynamics

Carnot efficiency: \[ \epsilon = 1 - \frac{T_C}{T_H} \]
Asimov’s Favorite Story: “The Last Question”

The Last Question

ASIMOV
Clicker question

What principle or law that we have discussed is central to the short story “The Last Question”

A. The conservation of energy.
B. The first law of thermodynamics.
C. The second law of thermodynamics.
D. The third law of thermodynamics.
In what way does the 2nd law of thermodynamics figure into Asimov’s story.
What are the implications of the second law for the universe?
What does the Carnot efficiency tell us about the universe? How is this related to what we were just discussing?
What do you think Asimov is saying with the ending?
Isaac Asimov’s “The Last Question”

• First posed by Alexander Adell and Bertram Lupov on the occasion during which
  - “The energy of the Sun was stored, converted, and utilized directly on a planet-wide scale. All Earth turned off its burning of coal its fissioning uranium, and flipped the switch that connected all of it to a small station, one mile in diameter, circling the Earth at half the distance of the Moon. All Earth ran by invisible beams of sunpower.”

• The question was posed to “Mulitvac”, the most advanced computer. They asked the question, by the way, by typing into a teletype machine. The question was:
  - Will mankind one day without the net expenditure of energy be able to restore the Sun to its full youthfulness even after it had died of old age?
  - Alternatively, “How can the net amount of entropy of the universe be massively decreased?”
Isaac Asimov’s “The Last Question”

- Question is repeated by Jerrodd, who with his family, is emigrating to the star X-23.
- Question is repeated again by VJ-23 of who doesn’t want to submit a pessimistic report to the Galactic Council, once his friend points out that the galaxy will be filled up within five years.
- Again, the question is asked by Zee Prime, some type of ethereal being who’s exact nature is not exactly clarified.

In each case, the answer is roughly: “insufficient data for a meaningful answer”
Isaac Asimov’s “The Last Question”

• In the final few lines of the story, the Cosmic AC, which exists solely in hyperspace, finally says: “Let there be light”, and there was light.
• Is this a religious statement? Is it an actual speculation about our future? Is it just a cheap trick on the part of the author?

Whether or not it is a cheap trick, I would suggest that Asimov is admitting to two facts:

• There are things about the physical universe that we do not understand, such as the Big Bang and many things about black holes.
• It is a fact that we exist, and in a certain sense, we do not know why.
Back to Heat Engines
There are many types of heat engines

- **External Combustion Engines.**
  - Cannonball Engine.
  - Steam-driven turbines in power plants, where the heat can come from:
    - Coal
    - Nuclear
    - Solar thermal
  - Sterling Engines

- **Internal Combustion Engines**
  - “Otto Cycle” engines in our cars and trucks.
  - “Diesel cycle” engines in our cars and trucks.
  - Turbines in jet aircraft, helicopters, tanks, etc.
  - Turbines in natural-gas turbine-based power plants.
4-stroke internal combustion engine

1. Intake stroke
2. Compression stroke
3. Power or work
4. Exhaust stroke
Stirling Engine

Note that this is CLOSE CYCLE. That is, while heat is absorbed and expelled, the medium (a gas) that expands and contracts stays within the engine.
Stirling Engine
Small-scale solar-powered Stirling Engine
Solar-thermal technology: one example
FOR IMMEDIATE RELEASE

Tessera Solar and Stirling Energy Systems Unveil World’s First Commercial-Scale SunCatcher™ Plant, Maricopa Solar, with Utility Partner Salt River Project

Arizona Governor Jan Brewer and the U.S. Department of Energy Commemorate Milestone

PEORIA, AZ (January 22, 2010) — Only four months after breaking ground, Tessera Solar and Stirling Energy Systems (SES) showcased the highly anticipated Maricopa Solar power plant today at a special event for key partners, stakeholders and media. Maricopa Solar is the first commercial project for the SunCatcher™ concentrating solar power (CSP) technology designed and manufactured by SES. Joining in the celebration were Arizona Governor Jan Brewer and officials from Salt River Project (SRP), local and state government, the U.S. Department of Energy, Sandia National Laboratories, utility customers, suppliers and NTR plc, Tessera Solar and SES’s majority shareholder.

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Heat engines are used to generate the vast bulk of all electricity
There are many types of heat engines for producing electricity

- Coal-fired power plants
- Nuclear power plants
- Solar-thermal power plants
- Gas-fired power plants
- Combined-cycle gas-fired plants
- Integrated gasification combined-cycle power plants
Schematic of steam-driven power generation plant

The shaded box represents a generic boiler to heat the water and convert it to steam. The heat might come from coal, oil, gas, nuclear, or even solar.

Mechanism to cool the water. Could be cooling towers, or heat exchange with cool water.

Steam driven turbine

Shaft transmits mechanical power to the generator.

Electrical Generator

Electrical power is generated at these terminals.

Cool water
Nuclear Reactor driven power generating facility

Just as illustrated in the previous slide, a source of heat (the nuclear reactor) is used to create steam, which then drives an electrical generator. Efficiency is in the mid 30% range.
Coal-fired power plants

In a coal plant there is a HUGE fire box filled with flame, and lined with pipes for generating steam. Efficiencies in the mid 30% range except for very high-tech versions.
GE Combined Cycle Gas Turbine (CCGT) H System

World’s Most Advanced Combined Cycle Gas Turbine Technology

GE’s H System™—the world’s most advanced combined cycle system and the first capable of breaking the 60% efficiency barrier—integrates the gas turbine, steam turbine and heat recovery steam generator into a seamless system, optimizing each component’s performance. Undoubtedly the leading technology for both 50 and 60 Hz applications, the H delivers higher efficiency and output to reduce the cost of electricity of this gas-fired power generation system.

• Natural gas is burned to drive a gas turbine (much like a jet engine.)
• The exhaust is subsequently used to generate steam which drives a steam turbine.
• Everything is contained in one integral assembly.
• The efficiency can be as high as 60% !!!!!!
Solar-thermal technology

Based on Sterling engines, these “Sun Catchers” achieve efficiencies of around 30-33%, much better than all but the most high-tech (and very expensive) photovoltaics.
Production and use of electricity in the United States
Figure 8.0  Electricity Flow, 2009
(Quadrillion Btu)

1 Blast furnace gas, propane gas, and other manufactured and waste gases derived from fossil fuels.
2 Batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, miscellaneous technologies, and non-renewable waste (municipal solid waste from non-biogenic sources, and tire-derived fuels).
3 Data collection frame differences and nonsampling error. Derived for the diagram by subtracting the “T & D Losses” estimate from “T & D Losses and Unaccounted for” derived from Table 8.1.
4 Electric energy used in the operation of power plants.
5 Transmission and distribution losses (electricity losses that occur between the point of generation and delivery to the customer) are estimated as 7 percent of gross generation.
6 Use of electricity that is 1) self-generated, 2) produced by either the same entity that consumes the power or an affiliate, and 3) used in direct support of a service or industrial process located within the same facility or group of facilities that house the generating equipment. Direct use is exclusive of station use.

Notes: • Data are preliminary. • See Note, “Electrical System Energy Losses,” at the end of Section 2. • Net generation of electricity includes pumped storage facility production minus energy used for pumping. • Values are derived from source data prior to rounding for publication. • Totals may not equal sum of components due to independent rounding.

Sources: Tables 8.1, 8.4a, 8.9, A6 (column 4), and U.S. Energy Information Administration, Form EIA-923, “Power Plant Operations Report.”
There are, however, ways of generating electricity that do not rely on heat engines

- Hydroelectric power
- Wind turbines
- Photovoltaic panels
- Tidal- or wave-based systems
One final note

• Notice that not all heat engines use non-renewable resources.

• Later, we will see that it is possible to use fossil fuels in devices that generate electricity that are not heat engines (fuel cells).

• Thus, heat engines and non-heat engines should not be equated in our minds with non-renewable and renewable.