Physics 301 Tu 29/3/05

ENERGY

The Conservation of Energy

- Rumford, Mayer, Joule, Helmholtz
- AKA The First Law of Thermodynamics

This law is the reason why Energy is the central concept in physical science.

The total amount of energy in any closed system cannot change, but can only be converted from one form to another.
It is a purely empirical law, depending on the absence of any perpetual motion machine. It is not a provable theorem.
It can never be proved, but it could be disproved.
AND evryone believes it.
It is <u>astonishing</u> that it is true and that it is so simple.
(Bohr himself twice considered that it might be violated.)

Energy supply is an urgent matter now. The degree of popular ignorance of the problems involved is terrifying.

Enthusiasts,

Entrepreneurs,

and, yes, even some

Environmentalists

make arbitrary statements that the news media repeat without competent criticism. It is important that those (you!) who do have some understanding, inject informed reason into the discussion.

1. The Conservation of Energy (a physical law)
   VERSUS
   energy conservation (a social policy)
   - Careful and efficient use of energy
   - Most folks don't know of (much less understand) this distinction.
   - Energy conservation policy is probably a good idea, but some economists think it will lead only to more uses of energy.

2. The amount of energy we use
   VERSUS
   the amount of energy we buy (or otherwise acquire).
   We use much more energy than we buy:
   The Sun heats our planet, grows our food, and cleans our water.
   The total solar power incident on the earth is
   1.7×10^{17} Watt (easy to remember)
   and this is $1.35\ kW/m^2$.

3. All the discussion of the "energy problem" is about the energy we buy. It is almost entirely from fossil fuels, which
   - put us at international risk, and
   - pollute the atmosphere
     (We're not necesarily talking about global warming or the greenhouse effect, but just plain old asthma-producing air pollution: gases and soot in the air.)

4. We are going to need much, much more energy than we buy now as
   - the world wants to match our share
   - the need for hydrogen increases
   - the need for desalination of sea water increases.

SOURCES OF ENERGY

Most of the energy we buy comes from fossil fuels. These fossil fuels damage the atmosphere and they engage us in international difficulties. They must be phased out as soon as possible. Actually, petroleum and natural gas are probably already beginning to phase themselves out; but coal, the most damaging, will be available for a long time.

There are two other energy sources, each large enough to generate the world's needs, and without air pollution: They are Solar and Nuclear.

The contrast between these two is interesting:

The development of solar has been left to entrepreneurs (private enterprise). The reason is that solar cannot be made into a weapon of war. On the other hand, entrepreneurs will not work on anything that does not promise prompt profits. The phrase is that solar will not be "economically successful". Thus solar has remained undeveloped.

Nuclear is highly developed because it could be used to make weapons (not only the bomb but also submarines and carriers) ; and so it has enjoyed heavy and long-term support from the government. Therefore nuclear is developed and ready to provide practical large-scale power generation.

Could solar be developed to useful degree by large and long-term support?
Almost certainly, Yes.

Will it?
Almost certainly, No.

ENERGY QUANTITIES : VARIOUS MEASURES OF ENERGY

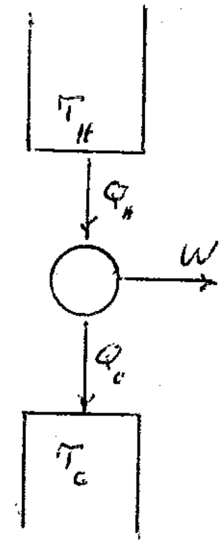
Joule = the metric unit (= 0.7376 foot pound) (erg=10^{-7}Joule)
Foot pound = 1.356 Joule
(British thermal unit=) Btu = 1055 Joule
Kilocalorie = 4184 Joule (= food calorie)
KiloWatt hour = 3.6 MegaJoule (as on Electric bill)
Therm = energy released by the combustion of 100 cubic feet of pure natural gas (methane: CH_4)(as on gas bill)
= 10^5 Btu = 105.5 MegaJoule (= 29.3 kWhr)
Barrel of crude oil ≐ 6 GigaJoule
ExaJoule = 10^{18} Joule (Older: Quad= 10^{15}Btu=1.055×10^{18}Joule)
One Watt is a power of one Joule/second.

Electron-volt = 1.6×10^{-19} Joule
≐ the amount of energy storable on a single atom
Corresponds to 100 MegaJoule/kilomole.(Nuclear fission corresponds to 10^{10}MegaJoule/kilomole)

The US buys about 100 ExaJoule of energy per year.
That is a power of 3.4 TeraWatt

The Second Law of Thermodynamics

(Carnot-Clausius-Kelvin)



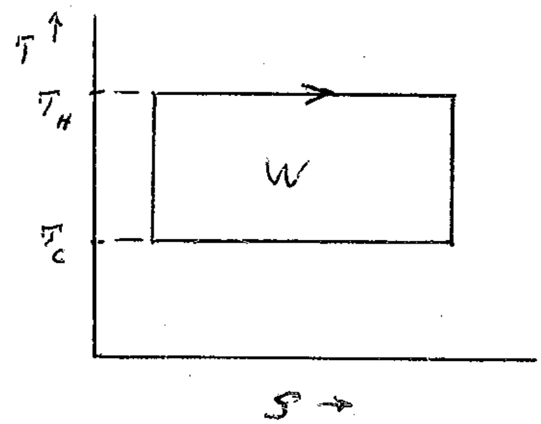
Thermodyn efficiency $= \eta = \frac{W}{Q_H} < 1$

Disorganization costs.

MWt (or MWth) VERSUS MWe ($\approx$1/3 MWt)
A major electric-power generating plant is
3 GWt and 1 GWe : half a million persons @ 2 kW/c

Carnot Cycle: A rectangle on the abs temp vs entropy plane. All the thermal energy ("heat") in at the same high temp T_H and all the output thermal energy at the same low temp T_C (low-temp heat !)

The Second Law: $\eta \leq \eta_{Carnot} = 1 - \frac{T_C}{T_H}$



BUT this is for a zero-speed and thus zero power engine.
For maximum power at given temperatures

$$\eta \leq 1 - \sqrt{\frac{T_C}{T_H}}$$

- a memorably simple result
- a much lower efficiency.

The noun "heat" means thermal energy, the energy of random molecular motion.
The word heat should only be used as a verb: to add thermal energy to.

"GENERATIONS" OF NUCLEAR FISSION REACTORS

Generation One	Nautilus & Shippingport Obninsk 1954
Generation Two	Now in use Mostly Light Water Reactors (LWR) with enriched Uranium Presurized (PWR) and Boiling (BWR) Once-through operation (no reprocessing) Big waste-disposal problem
Generation Three	Advanced ("evolutionary") LWR Elaborate passive-safety features. Still once through and disposal problem.
Generation Four	Revolutionary (new concepts) Still not clear, maybe LMFBR Liquid Metal (sodium) Fast Breeder Reactor.
Generation N	Maybe IFR : Integral Fast Reactor Consumes its Actinides (very long lived waste) Chas Till , Argonne National Lab. See Richard Rhodes' book

For Latest Models of Nuclear Reactors

By MATTHEW L. WALD

WASHINGTON, March 14 — Like the taxis in Havana, American nuclear power reactors are in heavy use, important to the economy and really, really old. The most modern was ordered in 1973.

Now after decades, four huge electric companies are expressing strong interest in new reactors, and they would like a new plant to reflect some of what has been learned of the operation.

Entergy, Exelon and Dominion have each applied for advance approval on sites where they might build reactors, although they have not committed to actually ordering one. The fourth, Duke Power, met with the Nuclear Regulatory Commission on Monday to describe how it was in the early stages of preparing an application for a reactor license, although it did not say what type it wanted to build, or where it would go.

On the drawing boards are all kinds of exotic designs, using graphite and helium, or plutonium and molten sodium, and making hydrogen rather than electricity. But the experts generally agree that if a reactor is ordered soon, its design changes will be evolutionary, not revolutionary.

The utilities are not ready for a giant technology leap; they want a plant that does what the existing ones do, but slightly better. So if new orders materialize in the next five years, it will be the mechanics and engineers who will get to show what they have learned. The physicists will have to wait.

"The pitfall is too much innovation," said Jeffrey S. Merrifield, one of the five members of the Nuclear Regulatory Commission, addressing 1,400 industry professionals at a meeting last Tuesday at the commission's headquarters. He compared new designs with the "concept vehicles" that car companies display at auto shows; buyers are drawn to them, but when it is time to buy, they pick a Ford F-150 or a Toyota Camry instead, he said.

In a telephone interview, another expert, Dr. Andrew C. Kadak, a professor at the Massachusetts Institute of Technology and the former president of the Yankee Atomic Electric Company, which helped run several reactors, laid out some practical considerations.

"If I were shopping today," Dr. Kadak said, "I would like a reactor that minimizes the dependency on active cooling systems for emergency core cooling."

It would also have some smaller changes to increase efficiency and ease of working, in the nature of interior decorating. For example, Dr. Kadak said, reactors would be a lot easier to maintain if designers stopped putting pumps and valves far from platforms and stairs.

"Give me some more space, so I can at least take this pump out without having to move three other parts," he said.

Fundamental innovations that may be introduced in the long term include the "pebble-bed," which uses fuel that cannot melt at the temperatures the reactor can achieve, and the use of liquid sodium for heat transfer, allowing operation at much higher temperatures and making more efficient use of uranium or plutonium.

Westinghouse is one of the companies trying to market a reactor, the AP1000, with more modest technical goals. It has an output of a little over 1,000 megawatts with what is called a passive approach to safety. It requires only half as many safety-related valves, 83 percent less safety-related pipe and one-third fewer pumps.

In the new design, water for emergency cooling has been moved to a tank inside the containment, above the reactor vessel. The changes will allow the emergency core cooling system to run even if all alternating current power fails, Westinghouse says.

Seeking a reactor that's better, but not too different.

The company is trying to sell four AP1000 reactors to China.

The AP1000 is competing with the EPR, for European Pressurized Water Reactor, a creation of Framatome of France and Siemens of Germany, which both became expert in the technology as those countries continued to build reactors after the United States stopped. Their joint venture is called Areva.

Their reactor has four emergency core cooling systems, instead of the usual two. That could help safety, further reducing the small chance that the system will not be available in an emergency. But there is a more practical reason. One cooling system can be shut down for maintenance while the reactor is running without reducing the safety margin to an unacceptable degree.

The EPR is being built now at Olkiluoto, Finland. It has a containment building designed to withstand the impact of a commercial jet, and a set of features intended to cope with a molten core in case of meltdown, preventing a "China syndrome" of a core burning through the floor and into the earth beneath. The reactor has a "core-spreading area" where the molten material would spread out and be cooled by water running above and below the area.

Approval by the Nuclear Regulatory Commission is many months away, but Areva hopes American companies will buy it because of the track record in Finland. And, executives say, they have taken full advantage of everything learned in the last few decades.

The third entry is General Electric's Economic Simplified Boiling Water Reactor, derived from its boiling water reactor design.

It is tweaked for better natural circulation in case of an accident, so there will be less reliance on pumps. A typical weak spot in existing reactors is the emergency diesel generators, but this model does not need them for emergency operations.

The reactor has a higher water inventory, as a safety measure, and eliminates large pipes below the level of the core, to reduce the chance of a leak. If the reactor shuts down automatically, then the decay heat, or heat given off by radioactive material after the reaction stopped, can be removed automatically for 72 hours, with no operator action, according to General Electric. Decay heat is what melted the core of the Three Mile Island reactor.

GE portrays its new design as an improvement on its previous evolutionary version, the advanced boiling water reactor. Peter G. Wells, who is in charge of marketing the new model, said that two of the previous versions were built at Kashiwazaki in Japan in the late 1990's. "They have 15 reactor years of proven operation," he said. Two more are under construction at Lungmen in Taiwan.

It is not certain, of course, whether anyone in the United States will order a new reactor in the next few years, although high prices for natural gas and uncertainty about what rules will apply to coal plants are creating interest.

Most nuclear advocates are expecting federal help, perhaps in the form of a production tax credit, like the one given for windmills, for the first four or five reactors, on the theory that once the first few plants are built, costs will fall and other reactors will follow, unsubsidized, with a benefit to clean air and the national economy.

Cost and construction time are only projections. David Lochbaum, who once worked as a start-up specialist for General Electric reactors and is now at the Union of Concerned Scientists, a group that frequently petitions to have plants shut for safety reasons, said that the best reactor is one that has not been built yet; its problems are still undiscovered.

Designing Tomorrow's Nuclear Plant

Although physicists have been busy creating revolutionary designs for future nuclear plants, the next ones ordered in the United States will most likely be evolutionary, improving on existing designs. Three leading contenders and how they compare to the last nuclear plant ordered and built:

Design	AP-1000 *Westinghouse*	European Pressurized Water Reactor (EPR) *Framatome and Siemens*	Economic Simplified Boiling Water Reactor *General Electric*	IN OPERATION Palo Verde 3 *Combustion Engineering*
Features	• Uses passive instead of active safety technology (water cooling tank resides in containment unit) • Fewer valves, pipes, pumps and cables	• Four cooling systems instead of two • Containment unit can withstand impact of a commercial jet • Core-spreading area to cool molten material	• Less reliance on pumps in case of accident • Does not need emergency diesel generators • No large pipes under core • Higher water inventory as safety measure	• Pressurized light-water reactor
Time to build	3 years	3.8 years	3 years	11.5 years
Electrical output *In megawatts*	1,175	1,600	1,500	1,270
Cost to build* *Per kilowatt*	$1,400	Not available	$1,150-1,250	$1,550
Lifetime	60 years	60 years	60 years	40 years**
Status	Design approved by the Nuclear Regulatory Commission	Will apply this summer; one currently under construction in Finland	Awaiting design approval from the NRC	In commercial operation since January 1988

Sources: Westinghouse; Areva; General Electric; Arizona Public Service

*Cost for first plant of its kind. Future plants would cost less. Excludes owners' costs.

**20-year extension possible.

The New York Times

What's Wrong with the Electric Grid?

The warnings were certainly there. In 1998, former utility executive John Casazza predicted that "blackout risks will be increased" if plans for deregulating electric power went ahead. And the warnings continued to be heard from other energy experts and planners.

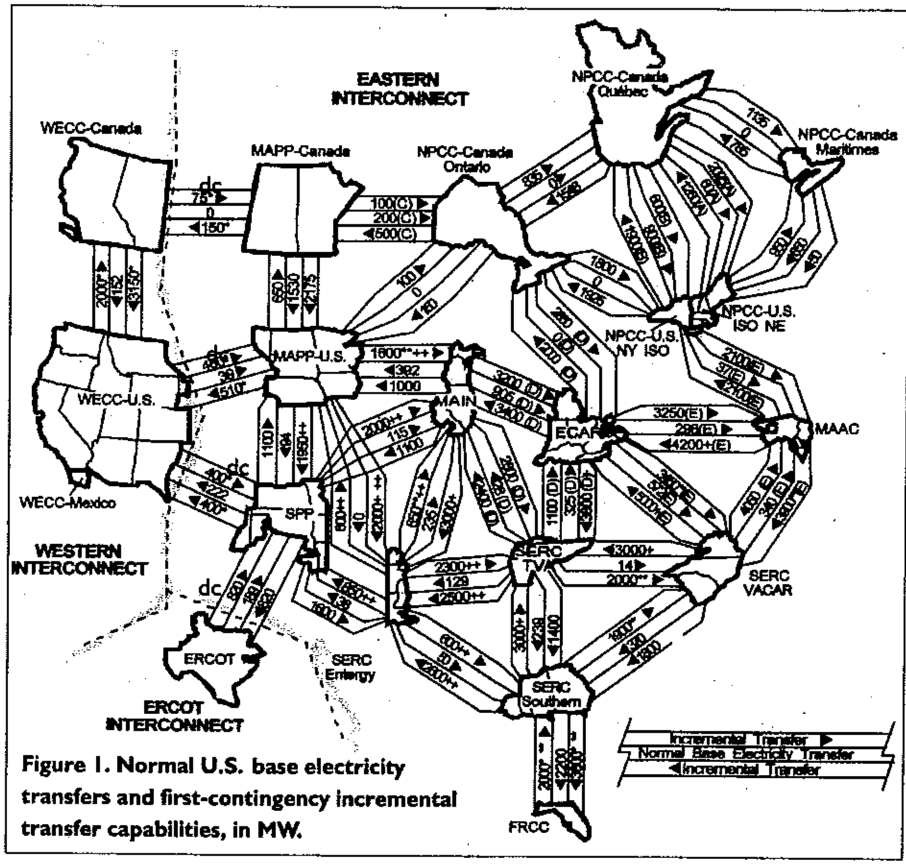


Figure 1. Normal U.S. base electricity transfers and first-contingency incremental transfer capabilities, in MW.

North American Electric Reliability Council

So it could not have been a great surprise to the electric-power industry when, on August 14, a blackout that covered much of the Northeast United States dramatically confirmed these warnings. Experts widely agree that such failures of the power-transmission system are a nearly unavoidable product of a collision between the physics of the system and the economic rules that now regulate it. To avoid future incidents, the nation must either physically transform the system to accommodate the new rules, or change the rules to better mesh with the power grid's physical behavior.

Understanding the grid's problems starts with its physical behavior. The vast system of electricity generation, transmission, and distribution that covers the United States and Canada is essentially a single machine—by many measures, the world's biggest machine. This single network is physically and administratively subdivided into three "interconnects"— the Eastern, covering the eastern two-thirds of the United States and Canada; the Western, encompassing most of the rest of the two countries; and the Electric Reliability Council of Texas (ERCOT), covering most of Texas (Figure 1). Within each interconnect, power flows through ac lines, so all generators are tightly synchronized to the same 60-Hz cycle. The interconnects are joined to each other by dc links, so the coupling is much looser among the interconnects than within them. (The capacity of the transmission lines between the interconnects is also far less than the capacity of the links within them.)

Prior to deregulation, which began in the 1990s, regional and local electric utilities were regulated, vertical monopolies. A single company controlled electricity generation, transmission, and distribution in a given geographical area. Each utility generally maintained sufficient generation capacity to meet its customers' needs, and long-distance energy shipments were usually reserved for emergencies, such as unexpected generation outages. In essence, the long-range connections served as insurance against sudden loss of power. The main exception was the net flows of power out of the large hydropower generators in Quebec and Ontario.

This limited use of long-distance connections aided system reliability, because the physical complexities of power transmission rise rapidly as distance and the complexity of interconnections grow. Power in an electric network does not travel along a set path, as coal does, for example. When utility A agrees to send electricity to utility B, utility A increases the amount of power generated while utility B decreases production or has an increased demand. The power then flows from the "source" (A) to the "sink" (B) along all the paths that can connect them. This means that changes in generation and transmission at any point in the system will change loads on generators and transmission lines at every other point—often in ways not anticipated or easily controlled (Figure 2).

To avoid system failures, the amount of power flowing over each transmission line must remain below the line's capacity.

TABLE 1. CAPACITY LIMITS FOR ELECTRICAL TRANSMISSION LINES

Voltage (kV)	Length (miles)	Maximum capacity (GW)
765	100	3.8
	400	2.0
500	100	1.3
	400	0.6
230	100	0.2
	400	0.1

Data from *Transmission Planning for a Restructuring U.S. Electricity Industry*, by Eric Hirst and Brendan Kirby, June 2001, prepared for Edison Electric Institute, Washington, DC.

SOME REFERENCES

Every Tuesday The NY Times has a separate science section. It is often interesting and the reporting is usually of pretty high quality.

Annual Review of Energy and the Environment.
Annual Energy Review--- from the Energy Info Admin DOE

BOOKS

"Limits to Growth" Donella Meadows et al
"Nuclear Renewal" Richard Rhodes
"MegaWatts and Megatons" Garwin & Charpak
"Hard Green" Peter Huber- a bitingly contrarian view

Scientific American
Physics World

Nature
Science