CHAPTER I

Introduction to Electrical Power

Electrical power is the prime source of energy that supports almost all of our technologies.

Electricity is the most convenient and omnipresent energy available today.

The high efficiency:
1. The machines-generators are over 98%
2. Transformer efficiencies routinely reach 98% and can reach over 99.5%,
3. An electric motors have efficiencies that are routinely over 8O% and many are over 9O%

This makes the conversion of energy to electricity for transportation and reconversion to heat, light, and mechanical power cost effective.

The alternative to electrical energy conversion for mechanical power is thermodynamic conversion of fossil fuel, hydro, and wind power.

Thermal engines, because of temperature and pressure differences currently obtainable, are limited to thermodynamic efficiencies of 40%.

Historical Facts

In **600 B.C**. Thales discovered that amber, when rubbed, attracted small objects. He had discovered static electricity.

In **1600** the first systematic discussion of electromagnetism based on experimental work was published by Englishman William Gilbert, who is called the father of modern electromagnetism.

In **1825** Andre Ampere discovered the attractive and repulsive force, depending on current direction, between two conductors carrying a steady current.

George Ohm published his discovery that current flow in a conductor is directly proportional to the applied potential and inversely proportional to its resistance in **1827**. This relationship, called “Ohm’s law,” is still used.

Around **1873** a Belgian born engineer, Zenobe Theophile Gramme, developed the first practical electric generator and motor.

Historical Facts (continued)

The year **1876** is known primarily for the invention of the telephone by Alexander Graham Bell.

Thomas Edison perfected the incandescent lamp in **1879.**
That same year the first company opened for the purpose of selling electricity.

The year **1879** was also the year that Thompson, Westinghouse, and Stanley developed a practical transformer.

In **1881** Frenchman Lucien Gaulard and Englishman John D. Gibbs patented an alternating current (ac) transmission system in England.

Historical Facts (continued)

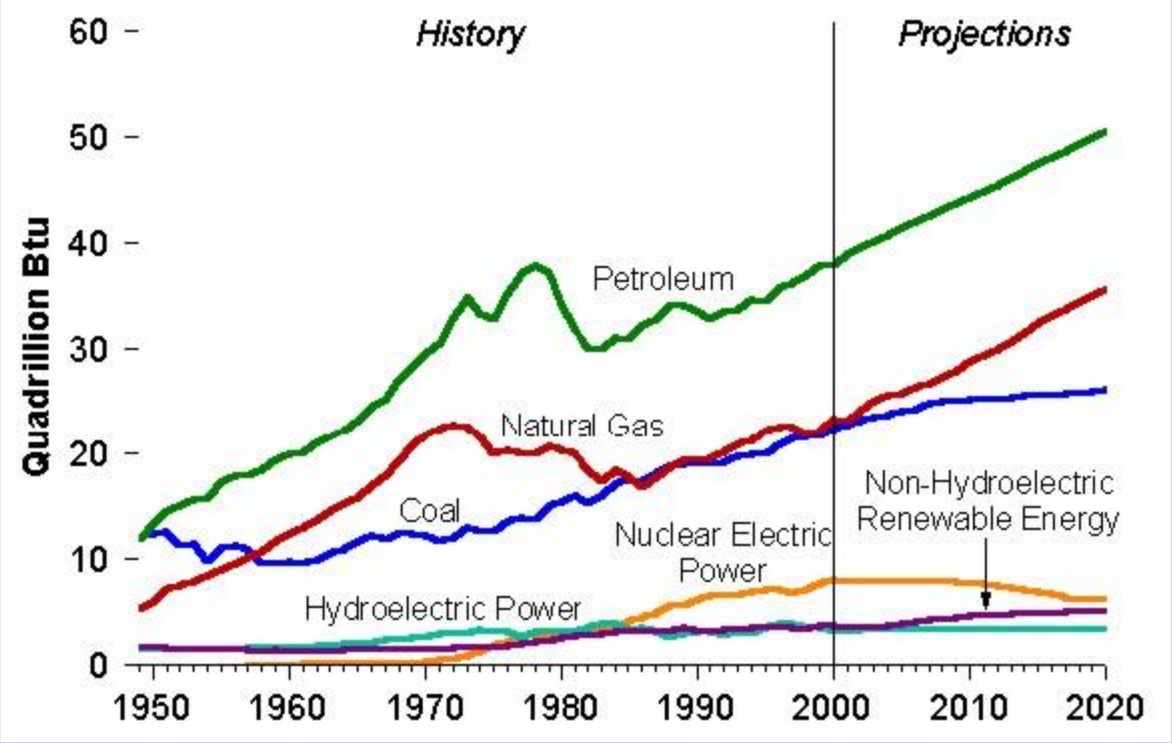
The first hydroelectric plant was installed in Niagara Falls in 1886.

Transmission voltages rose rapidly. In the United States the first 345 kV line began operating in **1953**, the first 500 kV line in 1965, and the first 765 kV line in **1969**.

By **1939** virtually all US industries were powered, most by electricity.
By **1945** 75% of all US farms had electricity (96% by 1960), and virtually all urban homes had electricity.

Electrical power has become an important part of the technology and the daily lives of the citizens of all developed nations.

The U.S. Energy Outlook as of 2001 (production)



The projections in *Annual Energy Outlook (AEO)2001*, which assume known trends in technology and demographics and current laws, regulations, and policies, suggest: greater consumption, production, and imports, and higher emissions.
Real energy prices are expected either to increase slowly (petroleum and natural gas) or to decline (coal and electricity).

http://www.eia.doe.gov/

http://www.eia.doe.gov/overview_hd.html

Information published at http://www.eia.doe.gov/emeu/aer/eh/frame.html

ELECTRICAL POWER SYSTEM CONSIDERATIONS

Societies must use energy resources in the form in which they appear: as water, wind, oil, coal, or uranium. The desirable tasks are:

1. *Heating*
2. *Cooling*
3. *Lighting*
4. *Manufacturing*
5. *Transportation of people and materials.*

Finding and converting the raw energy resources to usable energy is a vital function, as is the design, production, and use of efficient equipment to convert energy to useful work (motors, heaters, air conditioners, etc.).

Electricity does exist in nature as lightning and static electricity, but it cannot be controlled well enough to be put to practical use.
Thus electricity must be generated by converting another raw energy resource.

Electricity can be stored in batteries, but only in relatively small quantities.

Units and abbreviations

Most common in science:

$$1J$$
$$1kJ = 10^3 J$$
$$1MJ = 10^6 J$$

1MJ=5000lb truck traveling 60 miles per hour
=0.5lb of high explosive

One calorie is the amount of heat required to raise the temperature of one gram of water at 15 degrees through one Celsius degree

Most common in practice:

$$1kwh = 3.6MJ$$

In industry:

$$Quad = 10^{15} BTU$$

$$1cal = 4.186J$$

$$1Btu = 1.055 \times 10^3 J = 0.252cal$$

British thermal units

1 BTU ⟷ 1 match chip

1 million BTU ⟷ 8 gallons of gasoline

examples

Energy is the capacity to do work

Energy

Potential Energy

FE: Reservoir with water
located at some altitude

Kinetic Energy

FE: Moving car

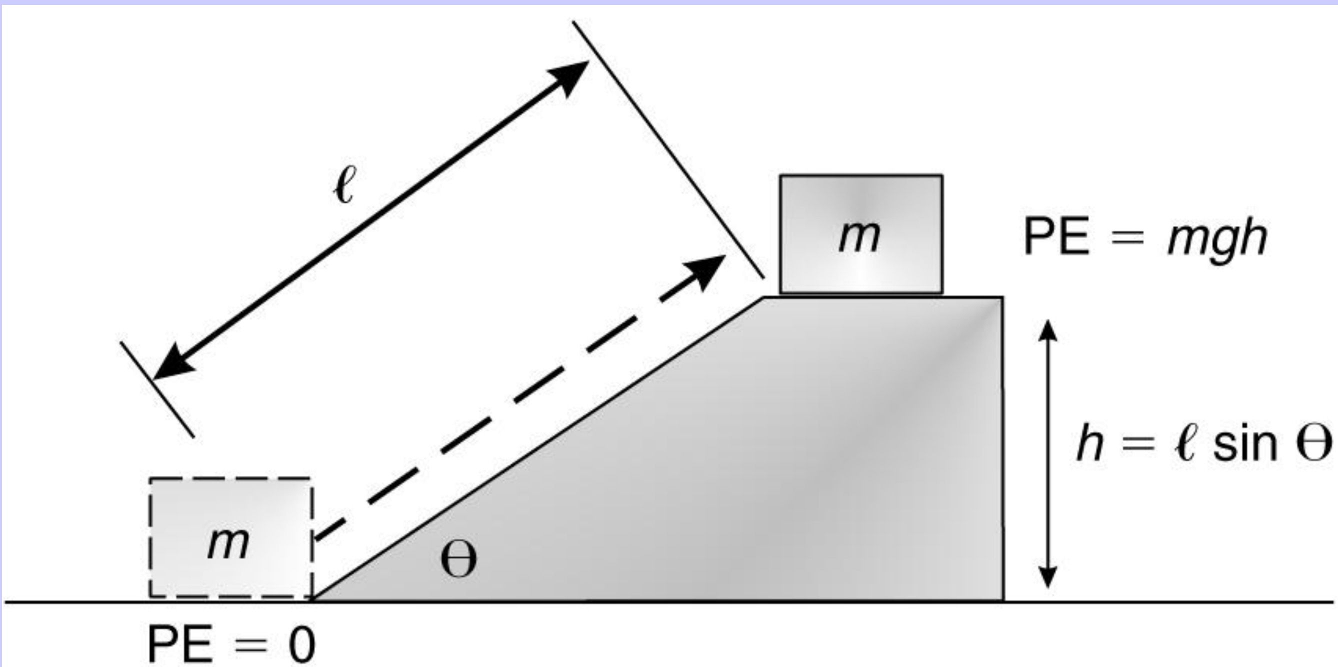
Energy exists in many forms and can be changed from one form to another.

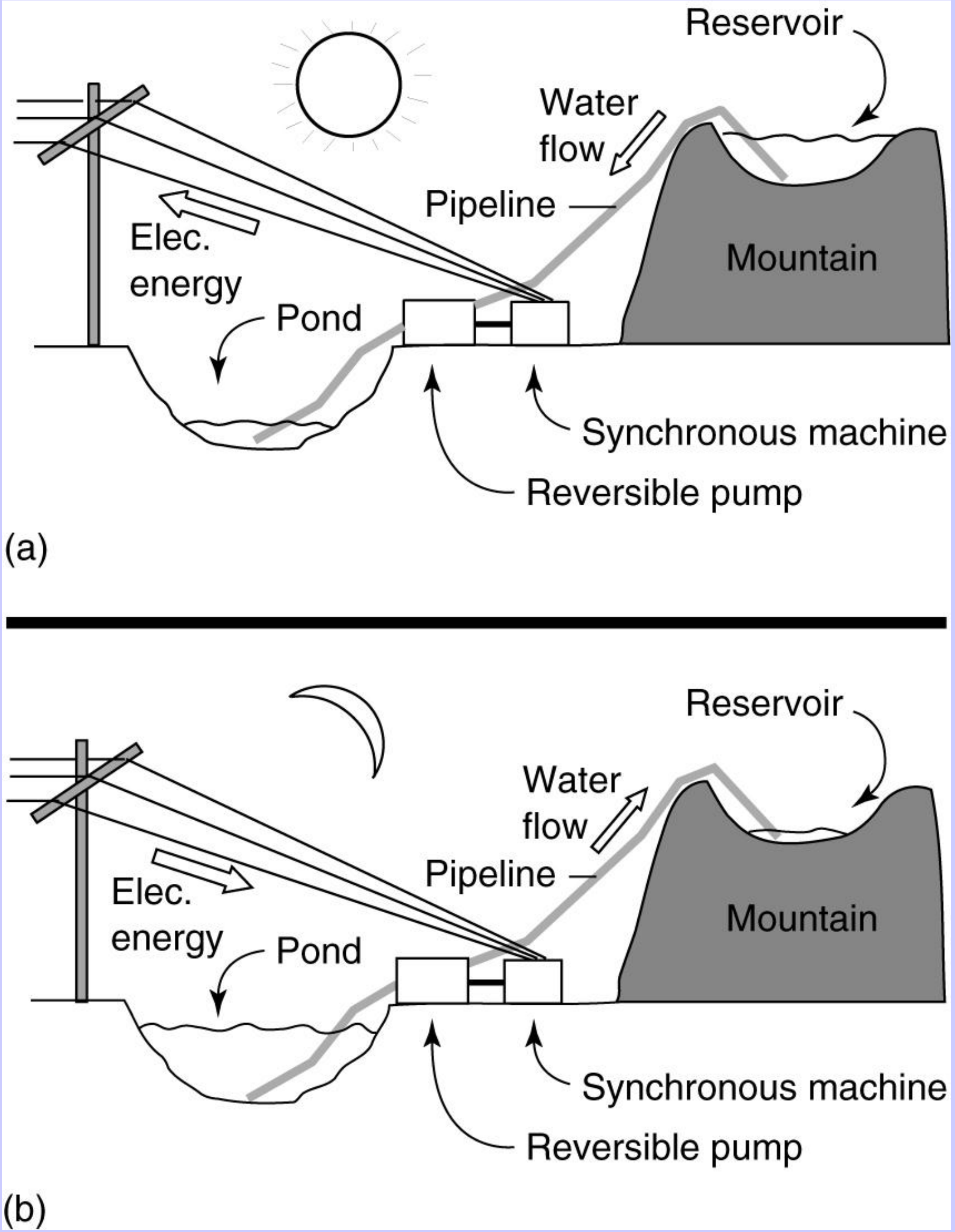
Forms of energy:

-Heat
-Light
-Sound
-Electric and magnetic fields
-Chemical

Potential Energy

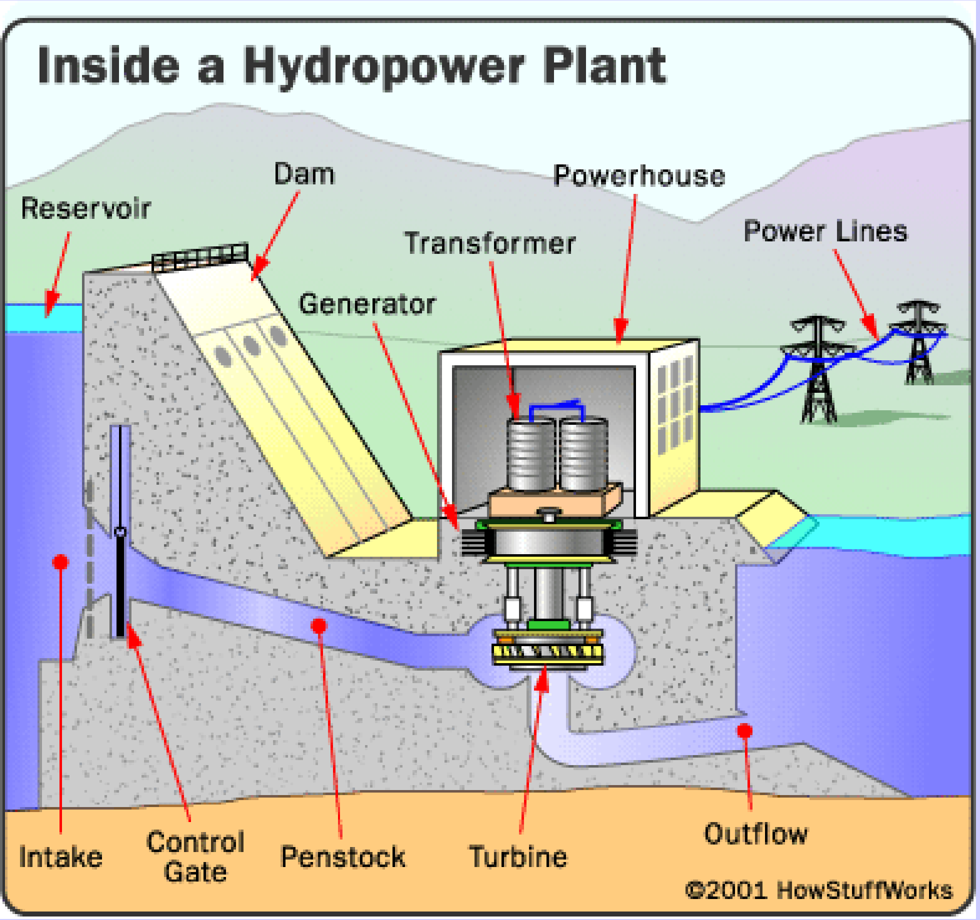
Potential energy is the amount of energy stored by the moving a mass to a higher altitude and is independent on how the mass got to this position




Reservoir
Water
flow
Pipeline
Mountain
Elec.
energy
Pond
Synchronous machine
Reversible pump
(a)
Reservoir
Water
flow
Pipeline
Mountain
Elec.
energy
Pond
Synchronous machine
Reversible pump
(b)

GENERATION : Hydroelectric Power

Pumped storage refers to one of the few ways massive amounts of energy can be stored. ***A hydro unit*** that is used for peak power production can be used to pump water up into a lake or holding reservoir during times that electricity demand is low. A water **turbine** that can be reversed and used as a pump is required. The pumped water is then used to power the hydroelectric generator during the next demand peak.



Dam - Most hydropower plants rely on a dam that holds back water, creating a large **reservoir**.

Intake - Gates on the dam open and gravity pulls the water through the **penstock**, a pipeline that leads to the turbine. Water builds up pressure as it flows through this pipe.

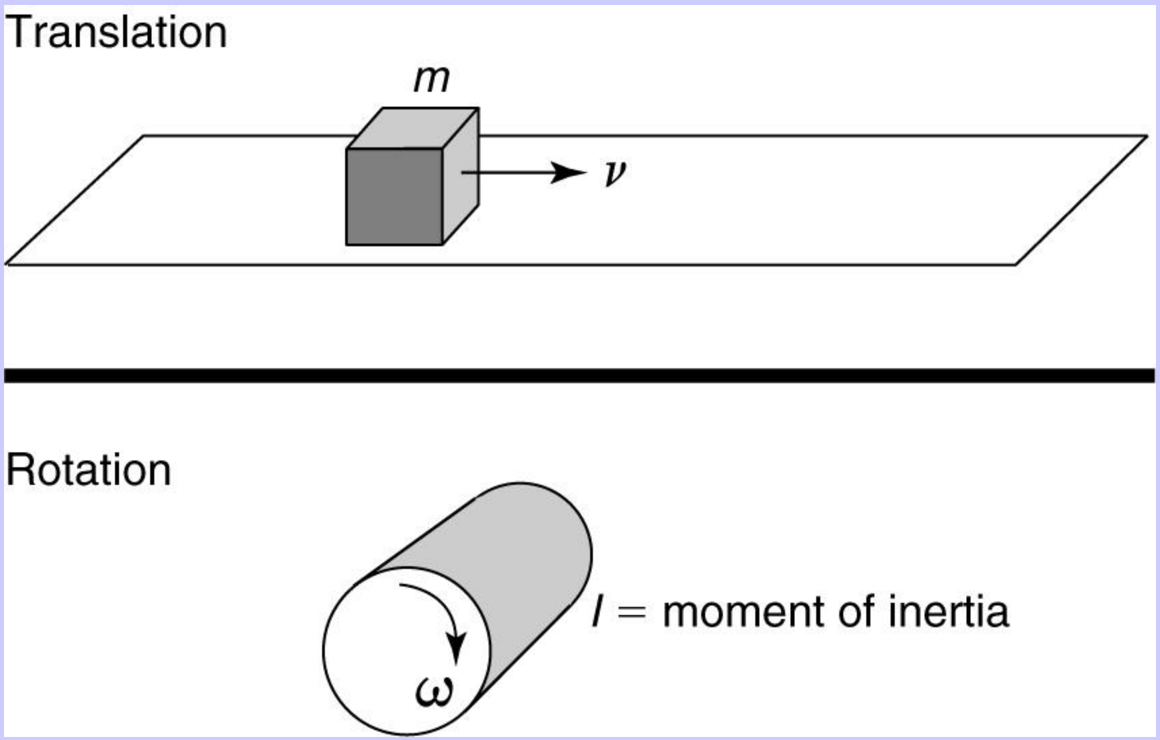
Turbine - The water strikes and turns the large blades of a turbine, which is attached to a generator above it by way of a shaft.

Generators - As the turbine blades turn, so do a series of magnets inside the generator. Giant magnets rotate past copper coils, producing alternating current by moving electrons.

Transformer - the transformer inside the powerhouse takes the AC and converts it to higher-voltage current that is transmitted through the power lines.

Kinetic Energy

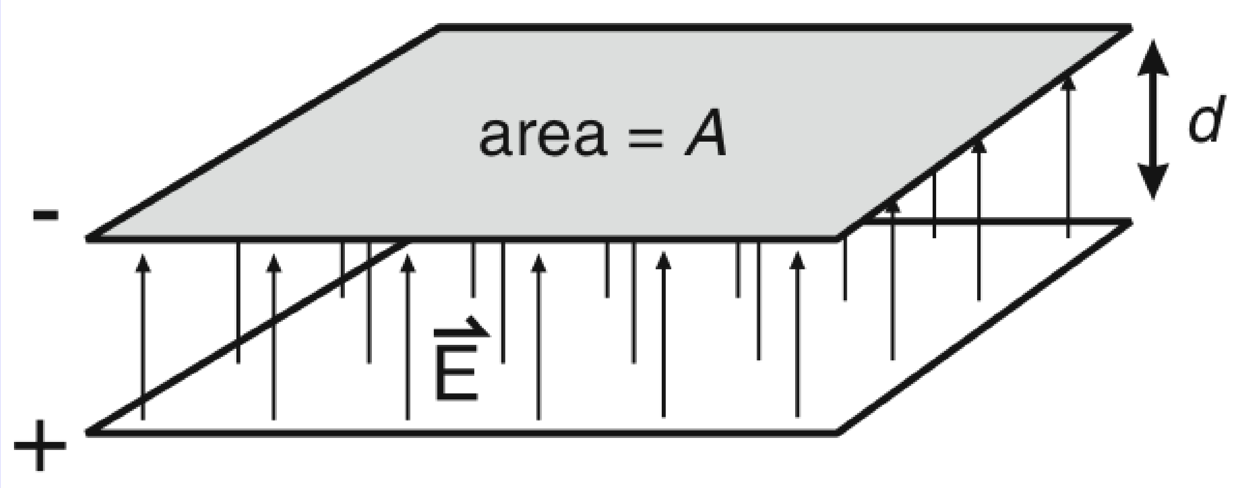
Any body in motion possesses **kinetic energy**.



$$E = \frac{1}{2}mv^2$$

$$E = \frac{1}{2}Iw^2$$

Electric Field Energy



DC voltage is applied to the plates

↓

Charge builds up on the surfaces of the two plates.

↓

Electric field is formed

$$W_{elec} = \frac{1}{2}CV^2$$

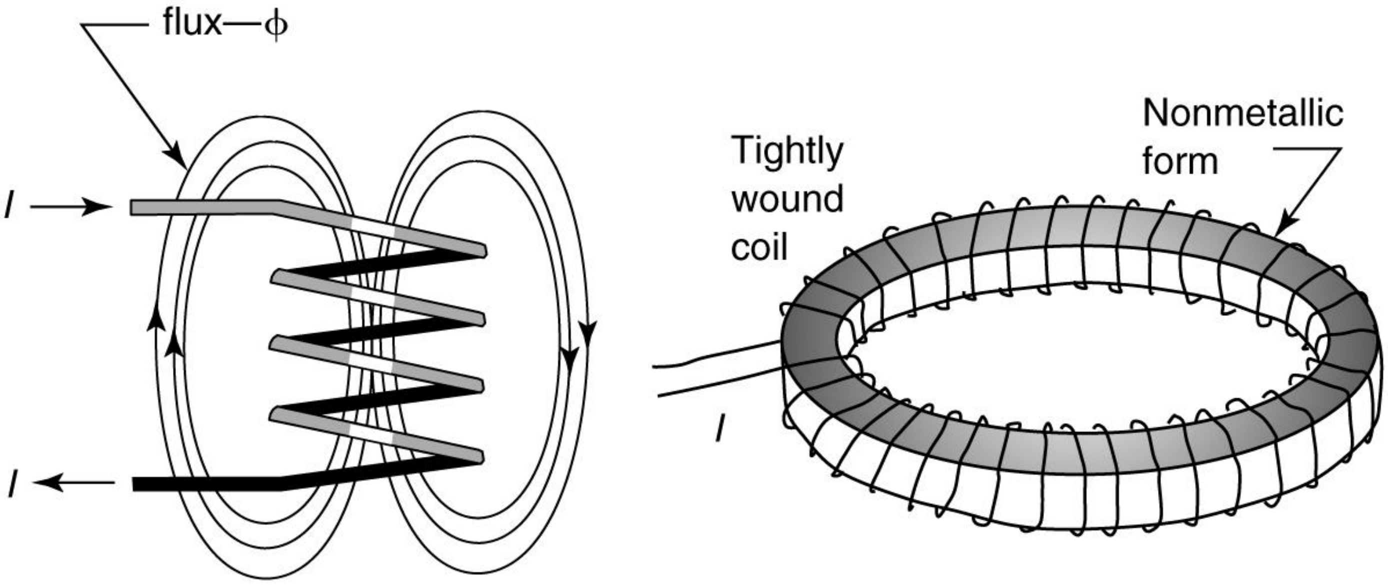
Permittivity of the material between the parallel plates

Area of the plates

$$C = \frac{\epsilon A}{d}$$

Distance between the plates

Magnetic Field Energy



(a) Loosely wound coil and the magnetic field resulting from the coil current

(b) A tightly wound, toroidal coil in which the magnetic field Is confined to the interior of the coil

$$W_{mag} = \frac{1}{2} L I^2$$

Inductance: $$L = \frac{\mu_0 N^2 A}{2\pi r}$$

- permeability of free space (μ_0)
- number of turns in the coil (N)
- cross-sectional area of the coil (A)
- average radius of the toroid (r)

Power

- Power = rate at which energy is consumed.
- The total energy delivered to a load divided by the time required to deliver it yields the average power delivered

$$P_{avg} = \frac{W_{in}}{\triangle t}$$

Efficiency of the delivered power

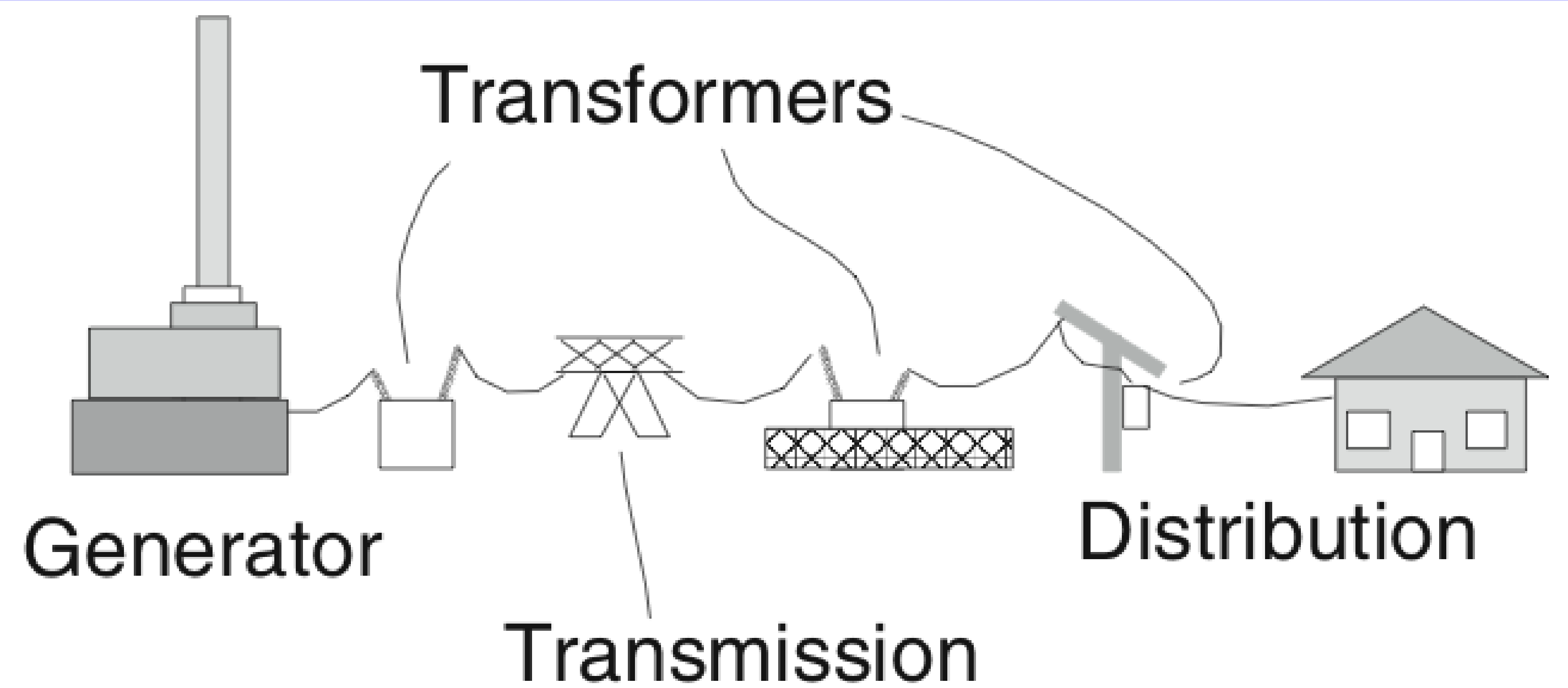
$$W_{in} = \frac{W_{out}}{\eta}$$

Efficiency of the system (η)

Units: horsepower, watts

1 Watt = 1 Joule delivered in a 1 second pulse

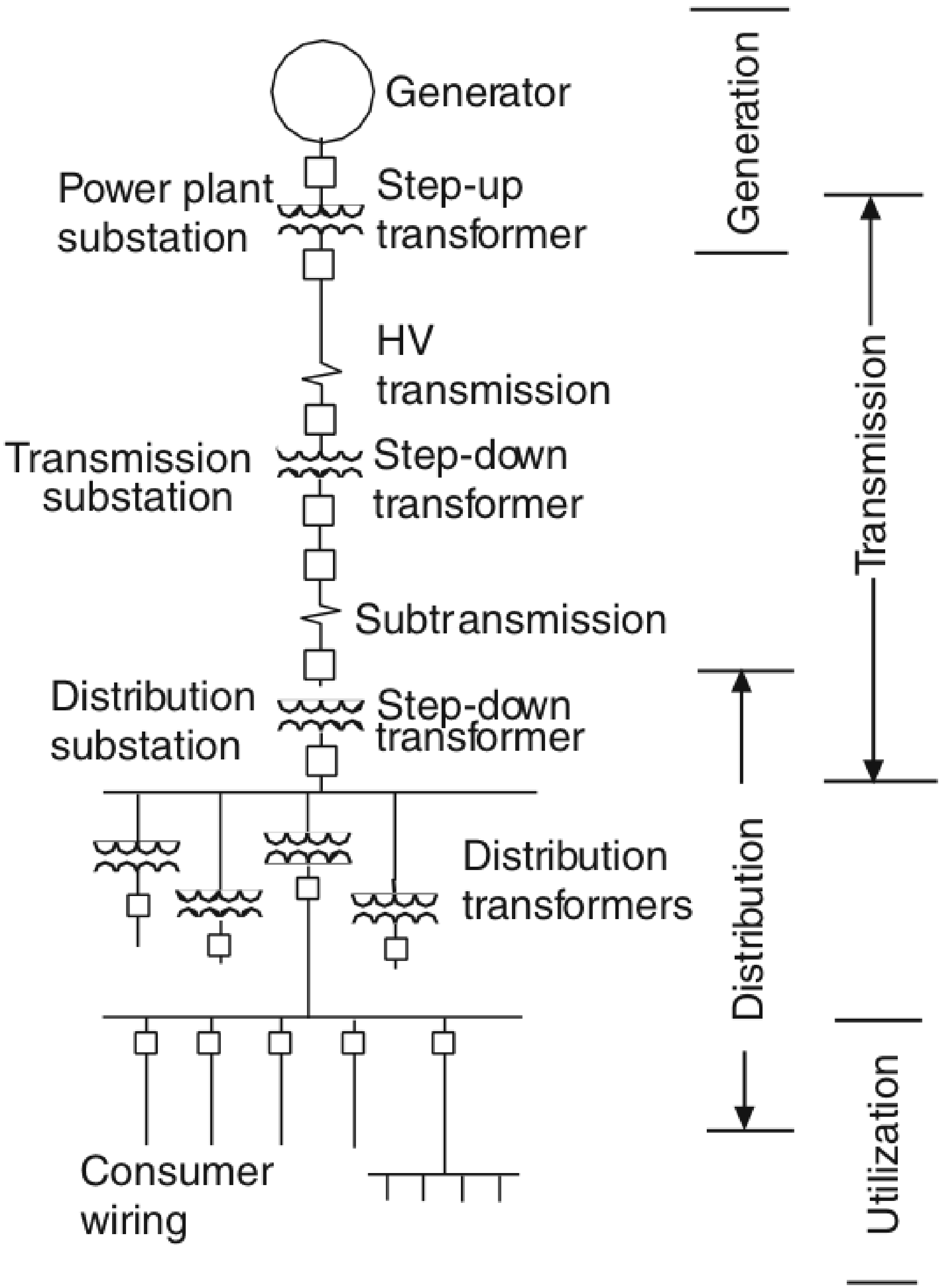
The Power System



The power network consists of several stages:

1. Power must be generated
2. Transformation (voltage must be stepped up for transmission)
3. Transmitting power
4. Transformation (voltage must be stepped down before distribution)
5. Distribution of the power.

On-line diagram of the power system



Standard voltage classes and typical operating voltages for the U.S. Power System:

Low voltage (LV) ***Consumer***

120/240,208,240, 277/480,600 (in volts)

Medium voltage (MV) ***Distribution***

2.4, 4.16, 4.8, 6.9, 12.47,13.2, 13.8, 23.0, 24.94, 34.5, 46.0, 69.0 (in kV)

High voltage (HV) ***Subtransmission***

115, 138, 161, 230 (in kV)

Extra high voltage (EHV) ***Transmission***

345, 500, 765 (in kV)

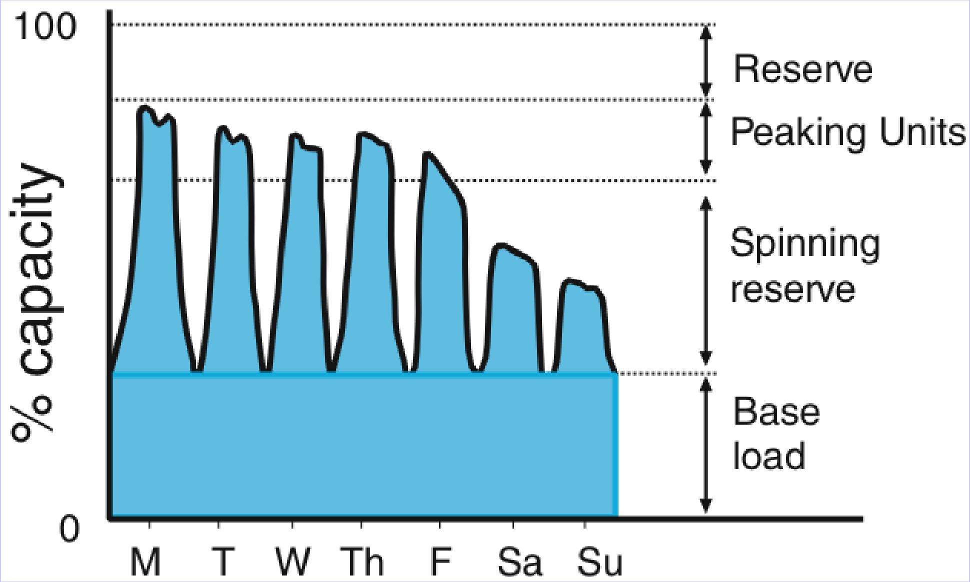
The National Power Grid

Electric power is produced by many independent power companies, including invest-owned, cooperative, municipal, and federal agencies.

Why to connect the individual companies in a single power network?

1. **To ensure the loads can be satisfied.**

Load varies with weather, time of day, time of year, etc



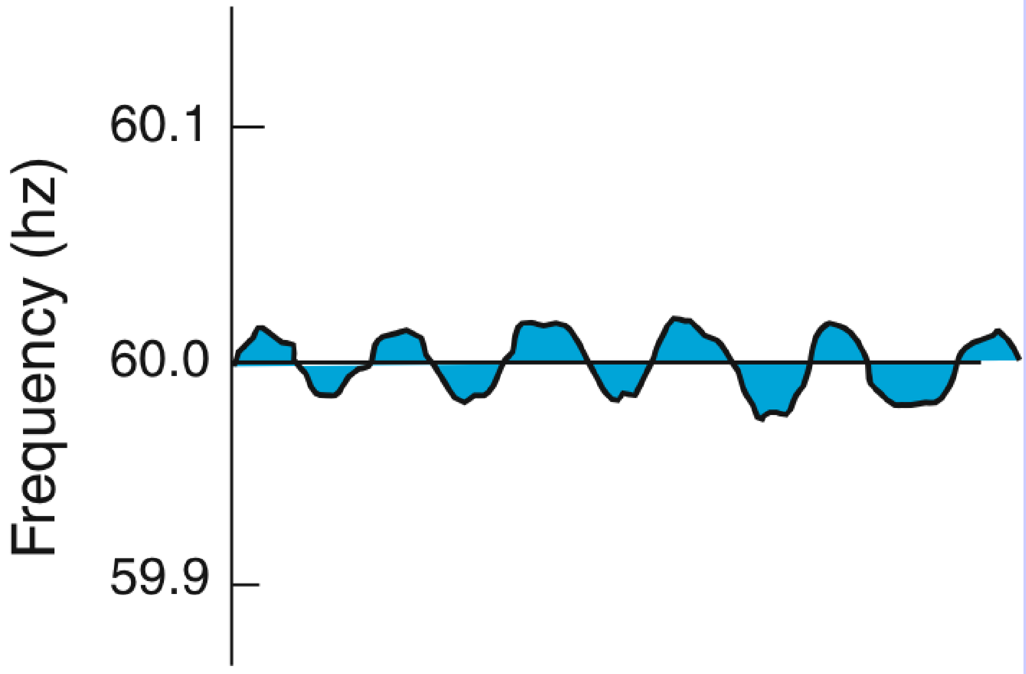
Peaking units are capable of rapid start to meet occasional heavy demand.

Spinning reserve is responsible for a short-term need in additional power.

Base load – minimum load that utilities will always provide.

2. **Frequency consideration**.

It is normally 60Hz but actually fluctuates over time.
It changes as loads are added and removed, because the input power can not change instantaneously to meet the requirements of the loads.



Keeping the frequency error low requires a time-keeper. By connecting all utilities together, it is possible to have all of the generators synchronized, providing the same time everywhere.

3. **To maintain the system voltage.**

Normally we expect 120V out of the outlet, but in the reality the voltage varies in the range of 5%. During times of heavy electric usage the drop can be as large as 10% (***Brownout condition***)

4. **Economics.**

Interconnecting the utilities allows generator operation and power routing to be optimized to produce electricity at the lowest possible cost.

GENERATION : Fossil Fuel and Steam Cycle

Generation of electrical energy involves rotating a magnetic flux (from an electromagnet) inside a set of conductors held in place by a magnetic stator.

Modem synchronous generators are extremely efficient.

Steam turbines operating at 3600 rpm are the most used prime movers for generators. (Efficiencies around 87%, and can be built as large as 1000 MW).

Efficiency has improved dramatically over the years.

In 1888 15 lb. of coal were required to generate 1 kWh of electricity,

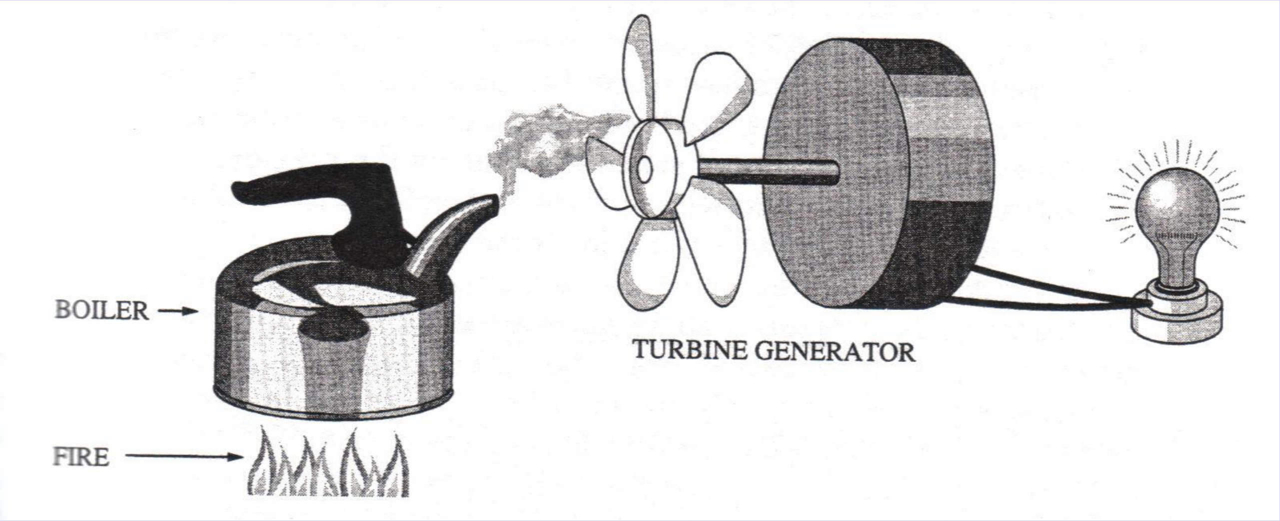
1903 7 lb. were required

1923 only 2.2 lb. were needed

1980 0.3 lb.

2008 - ??????

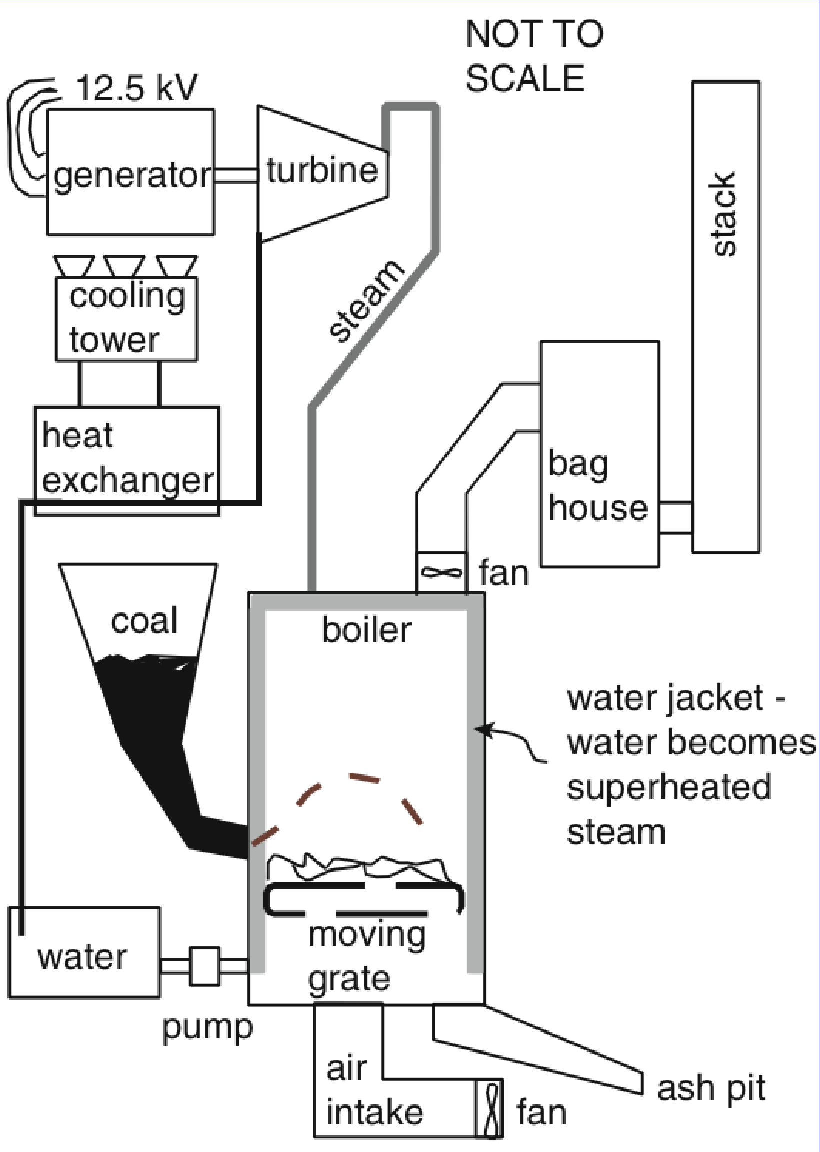
GENERATION : Fossil Fuel and Steam Cycle (continued)



The process of generation is the conversion of energy from a primary energy source such as coal by a chemical process such as burning to thermal energy, usually in the form of high pressure steam.

The thermal energy is then converted to mechanical energy by a turbine, and from mechanical energy to electricity by a generator.

Conceptual diagram of a typical coal-fired power plant.



1. The coal is treated to powder like stage and stored in a large bunker over the boiler.

2. The coal is thrown into the air above the boiler bed, and the significant portion burns before it falls to the bed.

3. The ash and unburned coal fall to the back of a moving bed and collected by the ash pit.

4. Burning the coal requires large amount of air, so an intake fan blows air into the bed.

5. The fan on the top of the boiler pulls the exhaust out into the pollution controls(bag house consisted of a set of filters that remove most of the particles from the flue gas). The remaining gas is then exhausted up the stack.

7. The walls of the boiler are lined with steel tubes into which water is pumped to become superheated steam.

8. The steam coming out of the boiler is routed to the turbine where it expands and gives up its energy to drive the generator.

9. The partially condensed steam that comes out of the turbine is then run through a heat exchanger to fully condense it for reuse in the boiler.

Photo courtesy U.S. Bureau of Reclamation

GENERATION : Hydroelectric Power

The work done by the falling water depends on the **head** (how far it falls) and the **rate of flow**. The energy of the falling water is converted to rotating form to drive generators by specialized water turbines.
Water is the most nearly ***free source of energy*** available that can provide large amounts of generating power. The costs are: *capital investment, labor, and maintenance*; **the fuel cost is zero.**

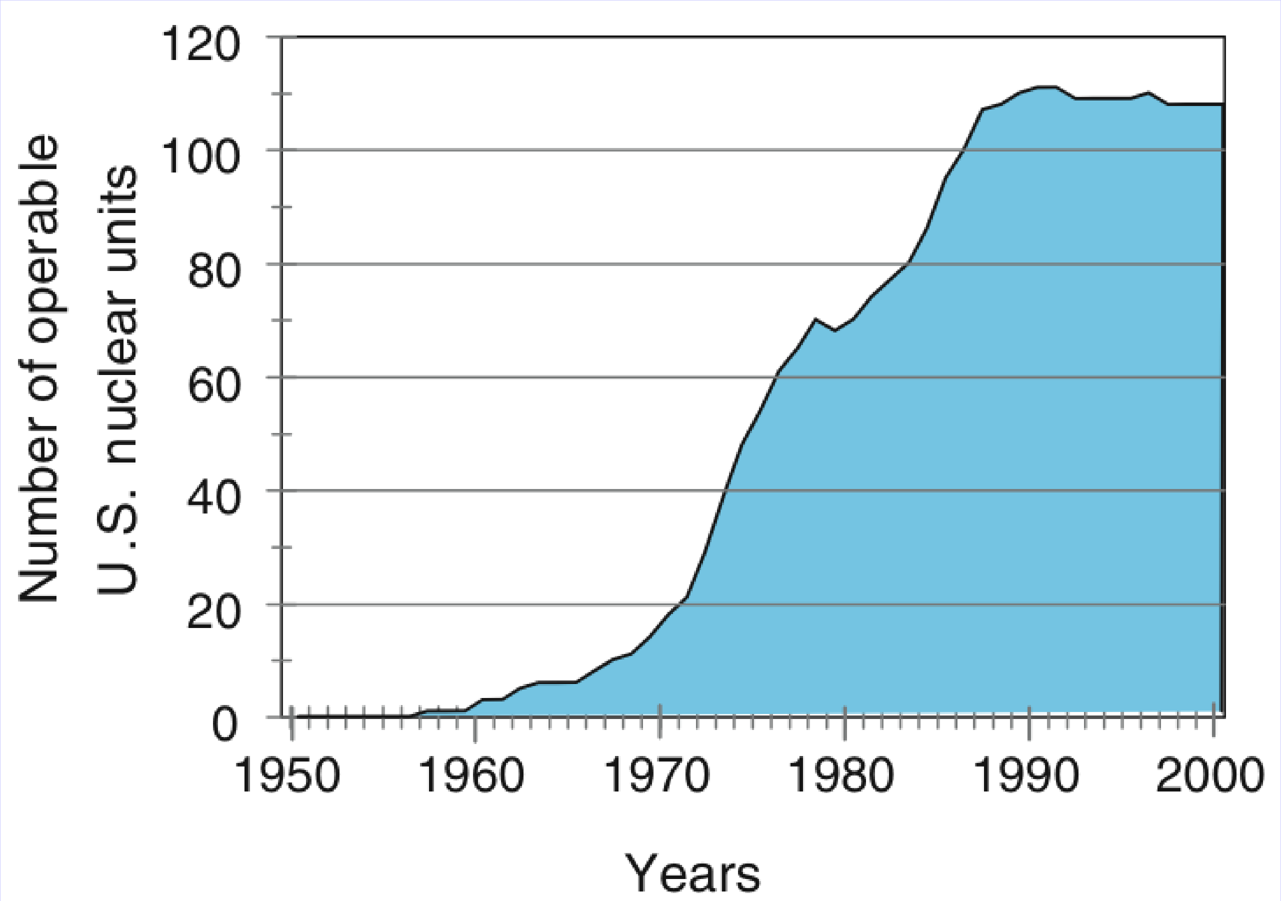
Worldwide, hydropower plants produce about 24 % of the world's electricity and supply more than 1 billion people with power. The world's hydropower plants output **675,000 megawatts**, (the energy equivalent of 3.6 billion barrels of oil).There are more than 2,000 hydropower plants operate in the United States.

Hoover Dam(Boulder Dam) The dam, located 30 miles (48 km) southeast of Las Vegas and was built in 1935

GENERATION : Nuclear Energy

Nuclear power plants provide about **17% of the world's electricity**.
Some countries depend more on nuclear power for electricity than others.
In France, for instance, about 75% of the electricity is generated from nuclear power.
In the United States, nuclear power supplies about 20% of the electricity overall, but some states get more power from nuclear plants than others. There are more than 400 nuclear power plants around the world, with more than 100 in the United States.

GENERATION : Nuclear Energy



- Cheap Energy
- Extremely Efficient
- Do not produce air pollution or greenhouse gases

- Dangerous
- Difficult nuclear waste disposal.

GENERATION : Alternative Energy Sources

Any source of energy can be used to generate electricity: wind, water, chemical, thermal, nuclear, or solar.

In the 1930's wind power was used extensively in rural America.

Solar energy is produced two ways:

1. By direct conversion to dc with semiconductor solar cells, which can provide as much as several kilowatts of electricity;
2. By using mirrors to reflect sunlight on to thermal collectors, which heat a working fluid to drive a turbine to generate up to 100 MW of electricity.

Solar energy is important for providing power to remote installations, such as space stations, but it is not predicted to provide more than a small fraction of the world's energy needs.

TRANSMISSION

Large amounts of electric power must be moved from the sites where it is generated to the points where it is distributed for use and it HAS TO BE DONE EFFICIENTLY.

Example:
If a transmission line is to move 1000 MW at 95% efficiency and an additional investment can improve the efficiency to 96%, the additional investment must be seriously considered.

The 1% saving is 10 MW. At five cents per kWh this represents a saving of
0.05 x 10,000 kW = $500 per hour.

If the line has an expected life time of 40 years the total savings will be:
$5OO/h x 24h/ day X 365 days/year X 40 years = $175.2 million.

Thus a lot of money is spent to obtain as much efficiency as possible in transmission lines.

TRANSMISSION

The sources of ***loss*** are the same for both transmission and distribution lines, but because the distances and loads *are greater for transmission lines* the efficiency must be higher.

The sources of loss:

1. Resistance

The resistance of a conductor depends on the resistivity of the conductor material, its length, temperature, and the skin effect.

Recall that dc resistance is directly proportional to the resistivity of the material and length and inversely proportional to the cross-sectional area of the conductor:

$$R = \frac{\rho l}{A}$$

Skin effect refers to the fact that as frequency increases current flow shifts toward the surface of a conductor.

The skin effect at a fixed frequency is proportional to the conductor diameter.

The skin effect can result in the ac resistance of a large conductor being 20% higher than the dc resistance at 60 Hz.

Resistance losses are kept low by making transmission voltages as high as practical.

2. Reactance

The magnetic flux produced by the ac current produces series inductive reactance because of both self inductance (which causes skin effect) along a conductor and mutual inductance between conductors.

3. Capacitance

Conductors separated by a distance have capacitance. The capacitance of a transmission line depends on conductor size, spacing, height above the ground, and voltage.

4. Corona

Corona is caused by the breakdown of the air around a transmission line because of high voltage.

The effect is most severe around small conductors and at sharp points and comers.

Separating conductors with spacers placed periodically along the line, can dramatically reduce corona loss.

DISTRIBUTION

A distribution system is subject to all of the losses that a transmission system has but since it carries lower voltages bundling of conductors to prevent corona is not necessary.

The shorter distances and lower power per line involved in distribution allows the design emphasis to shift from maximum efficiency.