Energy and the Environment

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Direct uses of solar radiation

Indirect/Less direct uses of solar radiation

- **Hydroelectricity**
- **Wind energy**
- Biomass
- Ocean thermal gradients
- Ocean currents
- Ocean waves

Ocean tides

Geothermal resources

} Renewable Energy

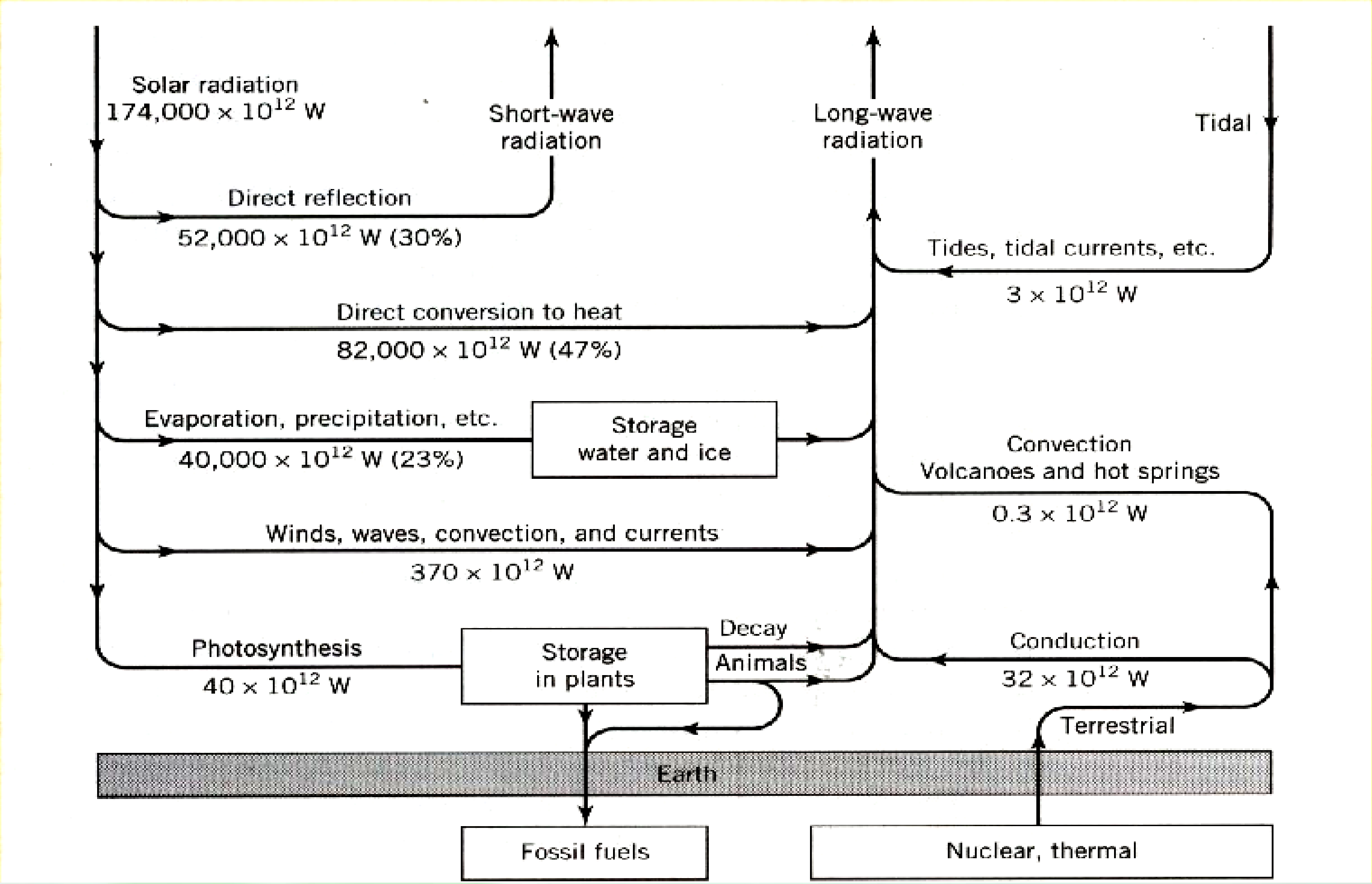


Figure5.1 Natural energy flow(in units of power) to and from the earth. (*Source*:M.K. Hubbert, "Man's Conquest of Energy: Its Ecological and Human Consequences," in *The Environmental and Ecological Forum 1971-1972*. Washington D.C.: U.S. Atomic Energy Commission Publication TID-25857, 1972.)

Hydropower

It dates back to the beginnings of the electric power industry more than 100 years ago.

In US.:

About **7%** of the electric power now generated comes from damming the rivers as they flow to the ocean and then releasing the water to turn turbines connected to electric generators.

In other countries:

electricity from water power

Norway	99%
Nepal	95%
Brazil	93%
New Zealand	78%
Canada	58%
Sweden	50%

Hydropower was important long before electricity generation possible

Moving water acting on a waterwheel can be used to ease human labor was found about 2000 years ago.

Waterwheel mechanisms → Grinding grain, Sawing wood

13th century, to operate hammers in ironworks of western Europe

16th century, the primary source of industrial power

Finally it was replaced by steam engine in many application.

Now, we use water power almost exclusively for the **generation of electricity**.

Hydropower

A consequence of the natural cyclical transport of water between the earth's surface and the atmosphere.

Heated by sunlight, followed by precipitation and the downward course of the water in rivers and streams under the force of gravity.

In a sense the water is the working fluid in an enormous heat engine powered by sunlight.

$$E = mg\Delta h = \frac{1}{2}mv^2$$

Modern hydroelectric installations convert the potential energy of water to electric energy at an efficiency of 80 to 90%.

Hydropower

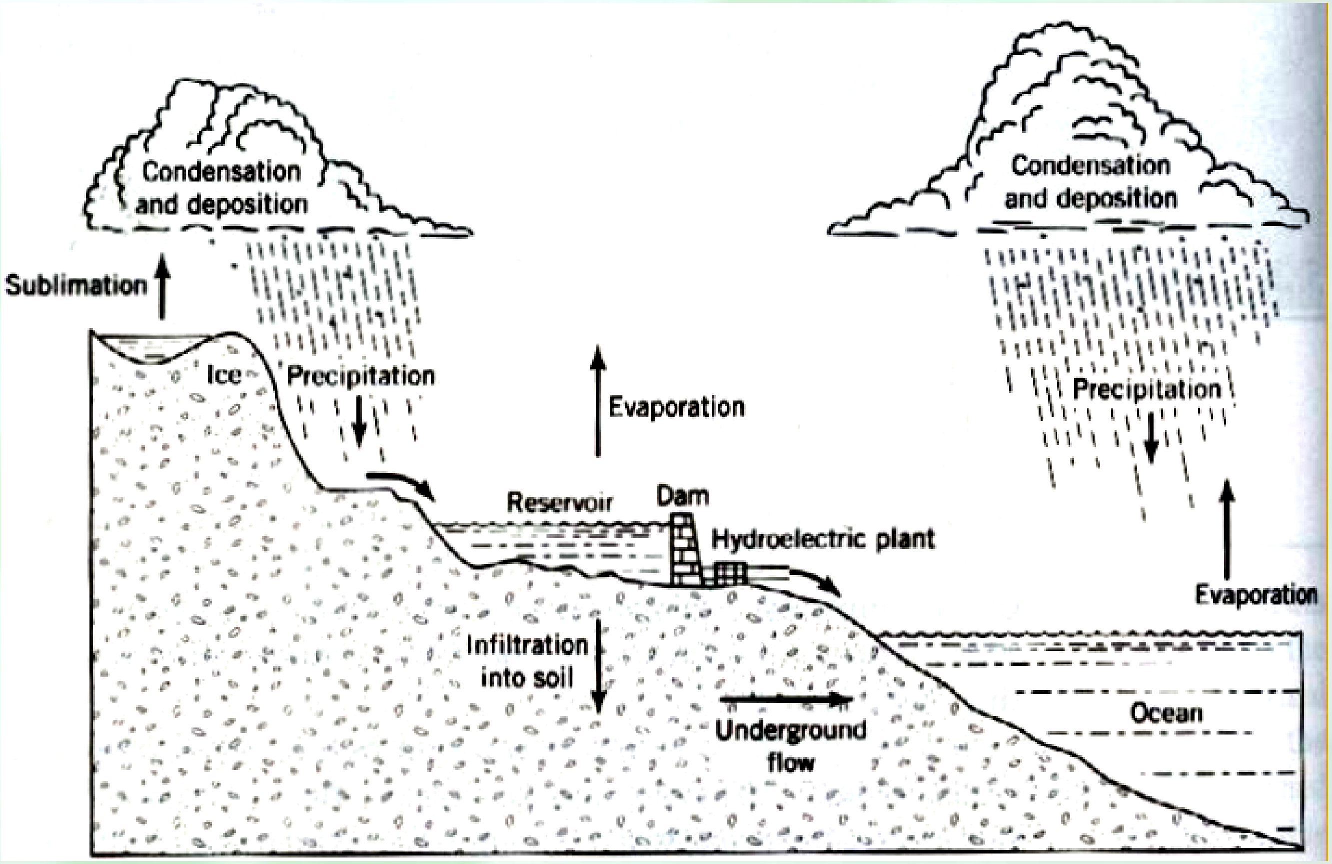


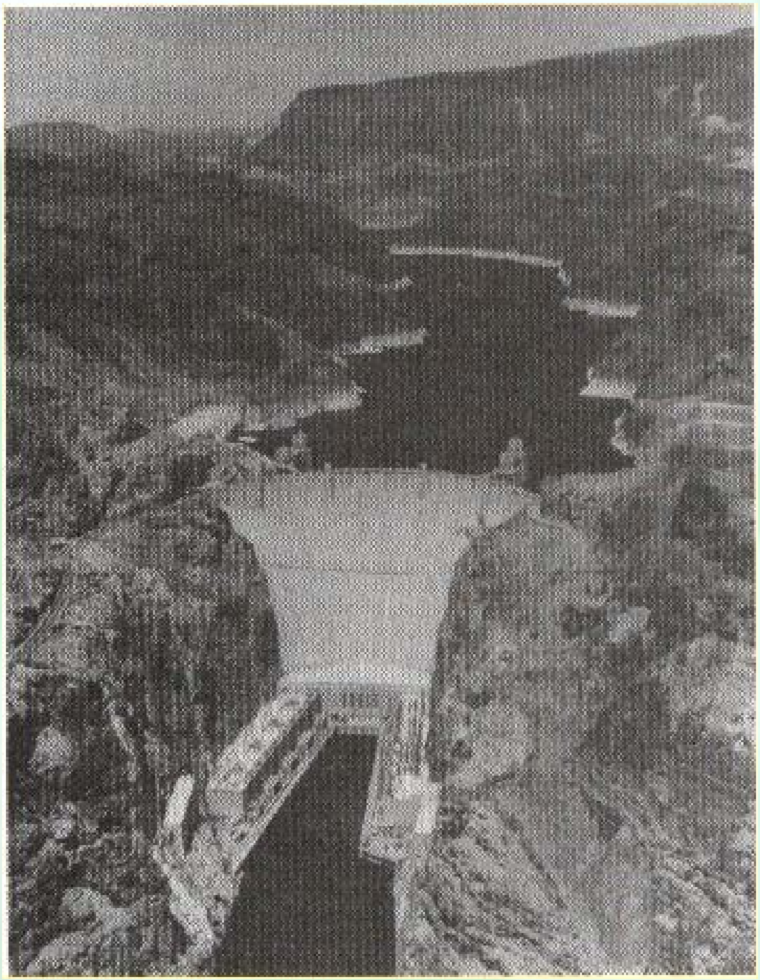
Figure 5.2 The hydrologic cycle. Electricity is produced in the hydroelectric plant by the action of water against a turbine connected to a generator. In this way the stored potential energy of the water in the reservoir becomes electrical energy.

eg. Calculate the flow rate of water (in liters/sec = kilograms/sec) required to provide 1kW of electric power if the water falls a vertical distance of 90m. Assume 80% conversion efficiency. (1.42liters/sec)

Advantages:

No polluting emissions into the air or water
No waste heat is rejected as thermal pollution
Lifetimes of many decades
small maintenance requirements.
Respond well to sudden changes in demand, making hydroelectricity well suited to matching peak loads.

The dams can serve multiple purposes;
Water stored for irrigation,
flood control,
municipal drinking water supply,
power a hydroelectric plant.



In the late 1980s, Boulder. 6MW, 8% of electricity power used in the city

The payback time for this system is 10 years, the city is making a profit on its investment. Through sales of electricity to the electric utility Xcel Energy, this hydroelectric system earned revenue of $1.7 million for the city in 2004.

Figure 5.3 Hoover Dam and Lake Mead on the Colorado River at the Arizona-Nevada border. This installation produces 2080 MW of electrical power as well as storing water for other purposes, including flood protection, irrigation, and recreation. (source: Courtesy Bureau of Reclamation/ U.S. Department of Energy)

Table 5.1 Some Large Hydroelectric Projects in the U.S.

Project	River	First Year of Operation	Rated Capacity (MW_e)
Grand Coulee	Columbia	1942	7100
John Day	Columbia	1969	2500
Chief Joseph	Columbia	1955	2300
Moses–Niagara	St. Lawrence	1961	2160
Bath County, VA	Buck Creek	1985	2100
Hoover	Colorado	1936	2080
The Dalles	Columbia	1957	1870
Racoon Mt.	Tennessee	1979	1530
Glen Canyon	Colorado	1964	1300
McNary, OR	Columbia	1954	1130
Northfield, MA	Briggs	1971	1080

Sources: U.S. Energy Information Administration (2000); United States Bureau of Reclamation (2004).

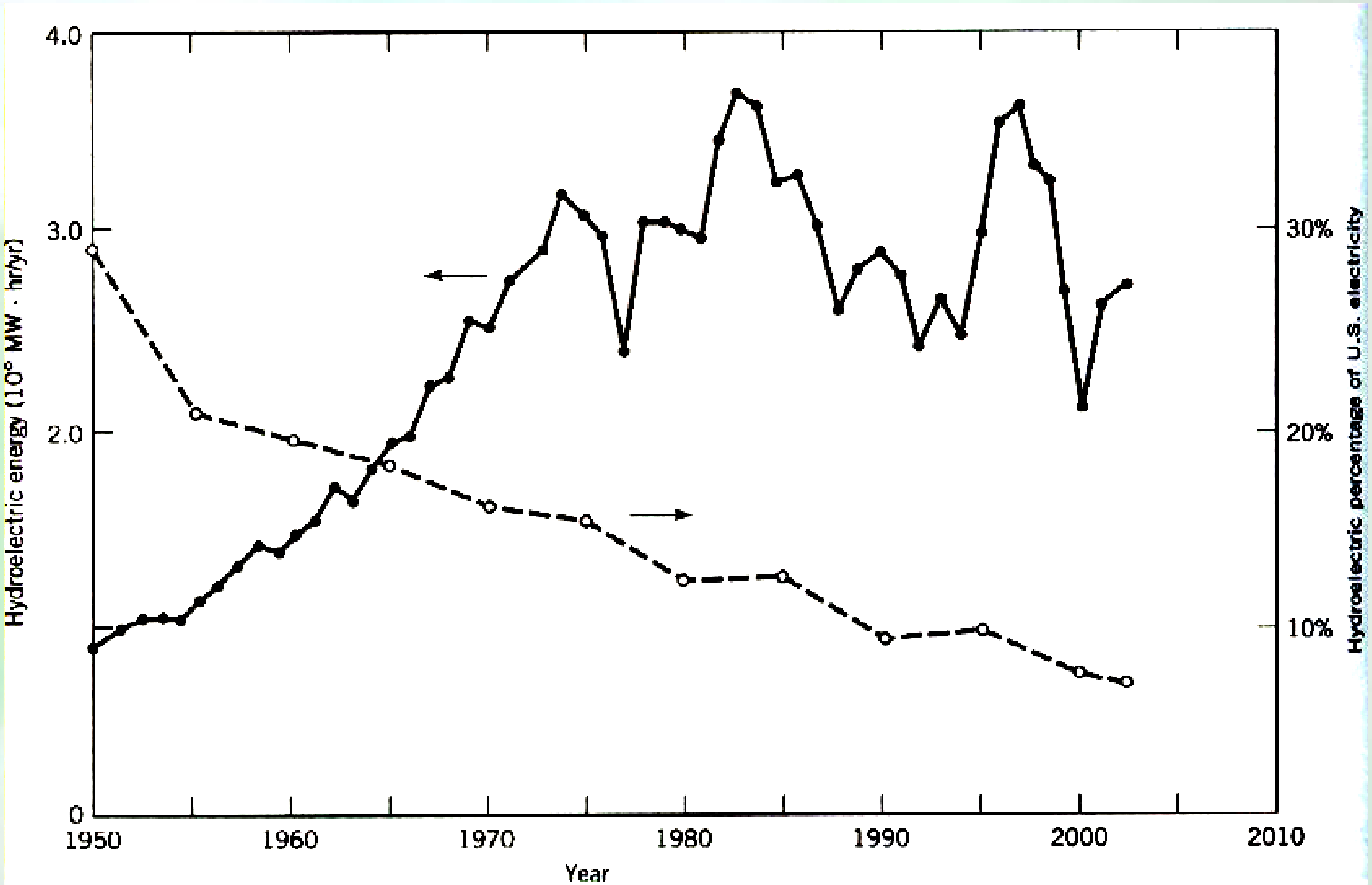


Figure 5.4 Electric energy from hydroelectric installations in the United States (solid line). The percentage of U.S. electricity provided by hydropower is shown as the dashed line. (*Source*: Data for 1950 to 1990 from *Annual Energy Review*, 1990; data for 1991 to 2003 from U.S. Energy Information Administration)

Table 5.2 Hydroelectric Potential in the United States, GW

Region	Potential	Developed	Undeveloped	% Developed
New England	6.3	1.9	4.4	30.1
Middle Atlantic	9.8	4.9	4.9	50.0
East North Central	2.9	1.2	1.7	41.3
West North Central	6.2	3.1	3.1	50.0
South Atlantic	13.9	6.7	7.2	48.2
East South Central	8.3	5.9	2.4	71.1
West South Central	7.3	2.7	4.6	36.9
Mountain	28.6	9.5	19.1	33.2
Pacific	64.4	38.2	26.2	59.3
Total	147.7	74.1	73.6	50.2

Source: Statistical Abstracts of the United States, 1995.

Life times: 50-200 years

Because their storage volumes become steadily filled with silt washed downstream by the rivers that feed the reservoirs.

Severe problem! With no solution in sight.

Downstream areas must be protected from the sudden release of enormous volumes of silt that could flow downstream in the event of dam failure.

Other objections to hydroelectric power include the loss of free-flowing streams and the loss of the land flooded by the reservoirs.

Native aquatic life – Salmon → fish ladders, not entirely successful.

Considerable risk in the event of dam failure such as earthquake.

Situated upstream from major population centers.

1918-1958, 33 major dam in US with 1680 resulting deaths.

1959-1965, 9 large dam failed throughout the world.

Now population more than 100,000 persons at risk from dam failure.

Wind Power

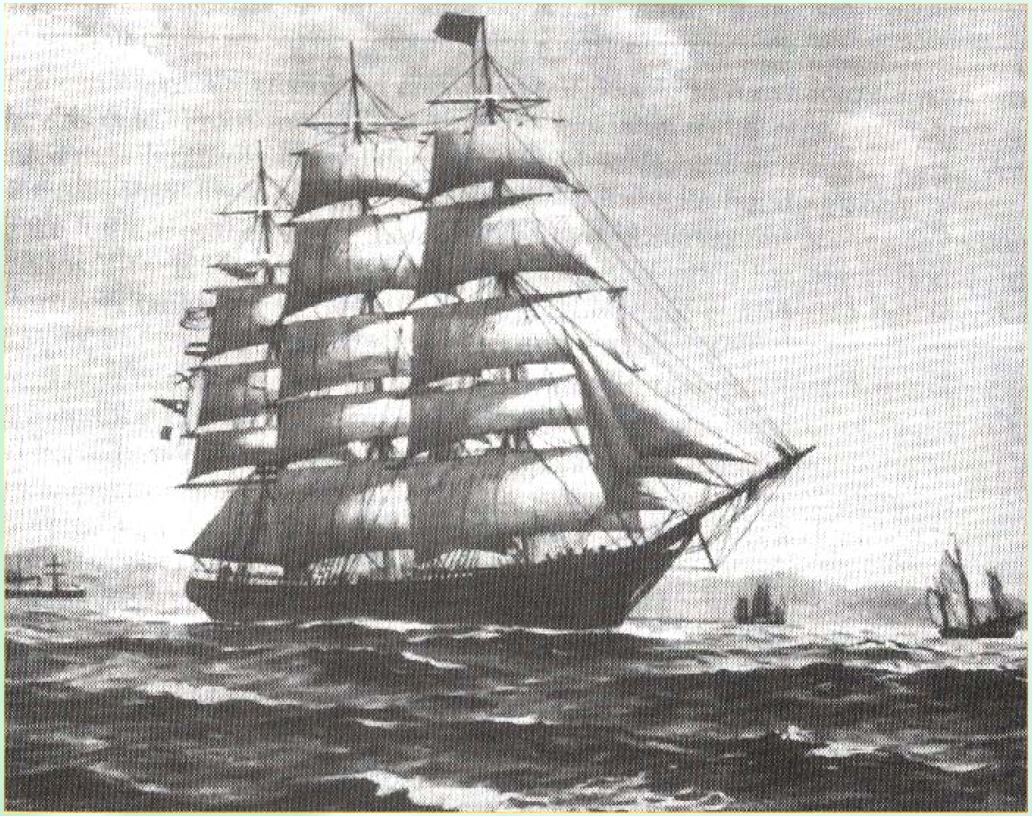


Figure 5.5 A fully rigged American sailing ship of the early 19th century. Under good conditions this ship could extract thousands of horsepower from the wind. (*Source*: Corbis-Bettmann)

Wind Power

Rig sails on their rafts, wind power has been put to use by our ancient ancestors.

The large sailing vessels of the 19th century could extract as much as 10,000 horsepower from the wind.

Stationary wind machines now represent the main use of the wind's energy dates back many hundreds, perhaps thousands , of years. Pumping water et al.

Starting about 1890, the use of windmills has been increasingly directed toward the generation of electricity.

Today the development of wind machines is almost exclusively concentrated on electricity generation.

Wind Power

The earth's winds are a direct consequence of solar energy.

Winds are generated because the sun heats certain areas of the earth's surface and atmosphere more than others.

The differential heating induces both vertical and horizontal air currents, with the patterns of the currents modified by the earth's rotation and contours of the land.

Land-sea breeze cycle

A Small fraction of the solar energy incident on the earth's upper atmosphere

Kinetic energy of the winds

Warming the atmosphere

Against features of the earth's surface

The rate at which solar energy goes into wind energy over the U.S. is about 30 times the rate of our present energy consumption.

The power of the wind is proportional to the third power of the velocity.
Kinetic energy and the flow rate.

$$\mathrm{P/m}^2 = 6.1\times10^{-4}v^3$$

For average conditions, the expression can be used to find the power in **KW per square meter** of cross section oriented perpendicular to the wind's direction.
Density, moisture content of the air, etc.

Total power, can not be extracted all by any devices.
eg. Windmill

Efficiency

An exact theoretical analysis of windmill performance shows that no more than **59 %** of the kinetic energy of the windmill is recoverable as mechanical energy;

Reason

Modern windmills can attain an efficiency of perhaps 50% to 70% of the theoretical maximum.

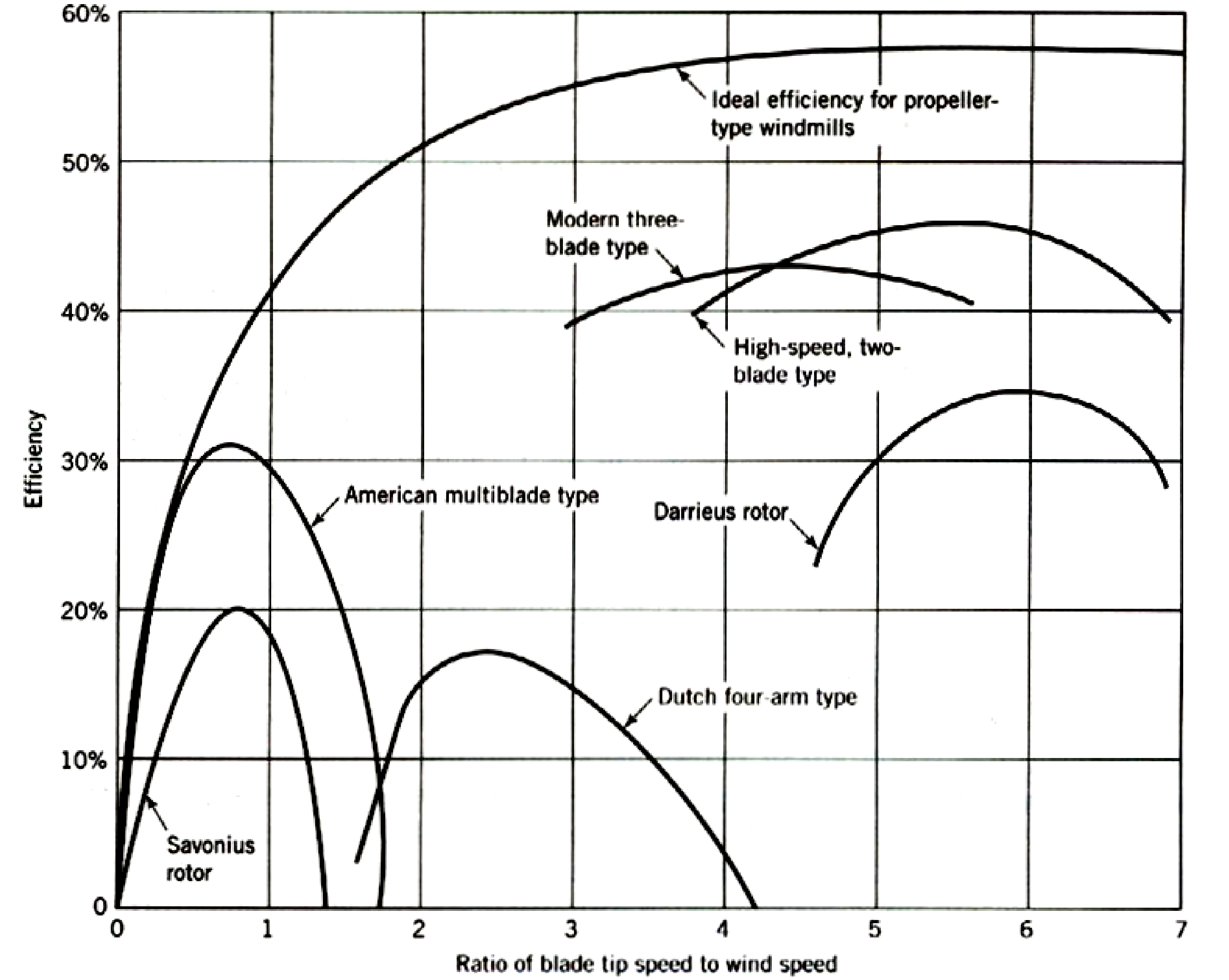


Figure 5.6 Typical efficiencies of several types of windmills plotted against their tip-speed ratio. The maximum efficiencies are seen to vary from about 16 to 46%. The ideal efficiency shown is a mathematical ideal, never to be achieved in practice. (*Source*: Basic data from R. Wilson and P. Lissaman, *Applied Aerodynamics of Wind power Machines*, Oregon State University.)

Savonius and Darrieus rotor are mounted on a vertical axis.

The vertical axis machines have the advantage that generator is at ground level, and thus easy to service. Also, no mechanism is needed to keep them pointed into the wind.

The ratio of the blade's tip speed to the wind speed must be considered in the design of wind machines.

The most efficient type, the high-speed propeller, can typically attain **70%** of the theoretical maximum efficiency, thereby utilizing about 42 % of the power in the wind.

American multiblade type used for pumping water in rural areas, Utilizing 30% of the wind power. (High starting torque)
The picturesque Dutch four-arm, about 16%

The high-speed propeller type is suitable for small-scale electricity generation.

When windmill is used for generating electricity, one must consider two efficiencies:

η_1, Wind power to mechanical power,   (? %)
η_2, Mechanical power to electric power. (typically 90%)

The product of there two numbers is the overall efficiency for converting wind energy to electric energy.

eg: Calculate the electric power produced per square meter of windmill disk area for a windmill operating at 70% of the theoretical maximum mechanical efficiency, with an electric generating efficiency of 90% when the wind velocity is 10m/sec.

$$P/m^2 = 6.1\times10^{-4} v^3 \qquad 227 W/m^2$$

The result is far above the average performance to be expected year-round in the US, because a wind velocity of this magnitude is experienced near ground only a small percentage of the time.

Typical annual average energy output for windmill:
100 kWh/m^2 for relatively calm areas
500 kWh/m^2 for relatively windy areas.

Correspond to electric power 11.4W/m^2 and 57 W/m^2,respectively.

Choose a site for a windmill, A constancy of a good wind throughout the day and throughout the year is more important than occasionally high peak speeds.

Detailed wind measurements over a number of years are needed.

Height, surface(buildings, trees)

300m, where the full potential of the wind is realized. Impractical! Commercial wind turbine towers are about 50 meters or more high, high enough so that about 80% of the full potential is reached.

Wind turbines:
Small wind machines for use by individual not connected to grid
Larger machines generating bulk power for electric power utility.

1850-1970 more than 6 million wind machines of less than 1kW output in use in the US. Common in the early decades of the 20th century, through 1940s.

Pumping Water, generating electricity

Extension of electric utility service into rural areas and increasing load demands by users have significantly reduced the use of home-type wind machines.

In 1970s, large wind turbines, wind farm 50 to 600 kW. About half of the wind machines now installed in the California wind farms are of Danish design. Many of the newest wind farms have 1 MW and greater generating capacity.

The US wind energy generating capacity is rapidly increasing, 25% since 2000. 1800MWe added in, 6400MWe 2003, In spite of encouraging signs of growth, the contribution of wind energy to the total US electrical energy consumption is still substantially less than 1%

Some analysts expect wind energy triple contribution in next 10Y.

Too optimistic picture

Conventional generating capacity operates 24x7 of the year.

The Pacific Gas and Electric Company:
Wind farm 20% rated capacity, only 1/5.

What is the potential for having a much larger share of our electricity generating capacity provided by the wind?

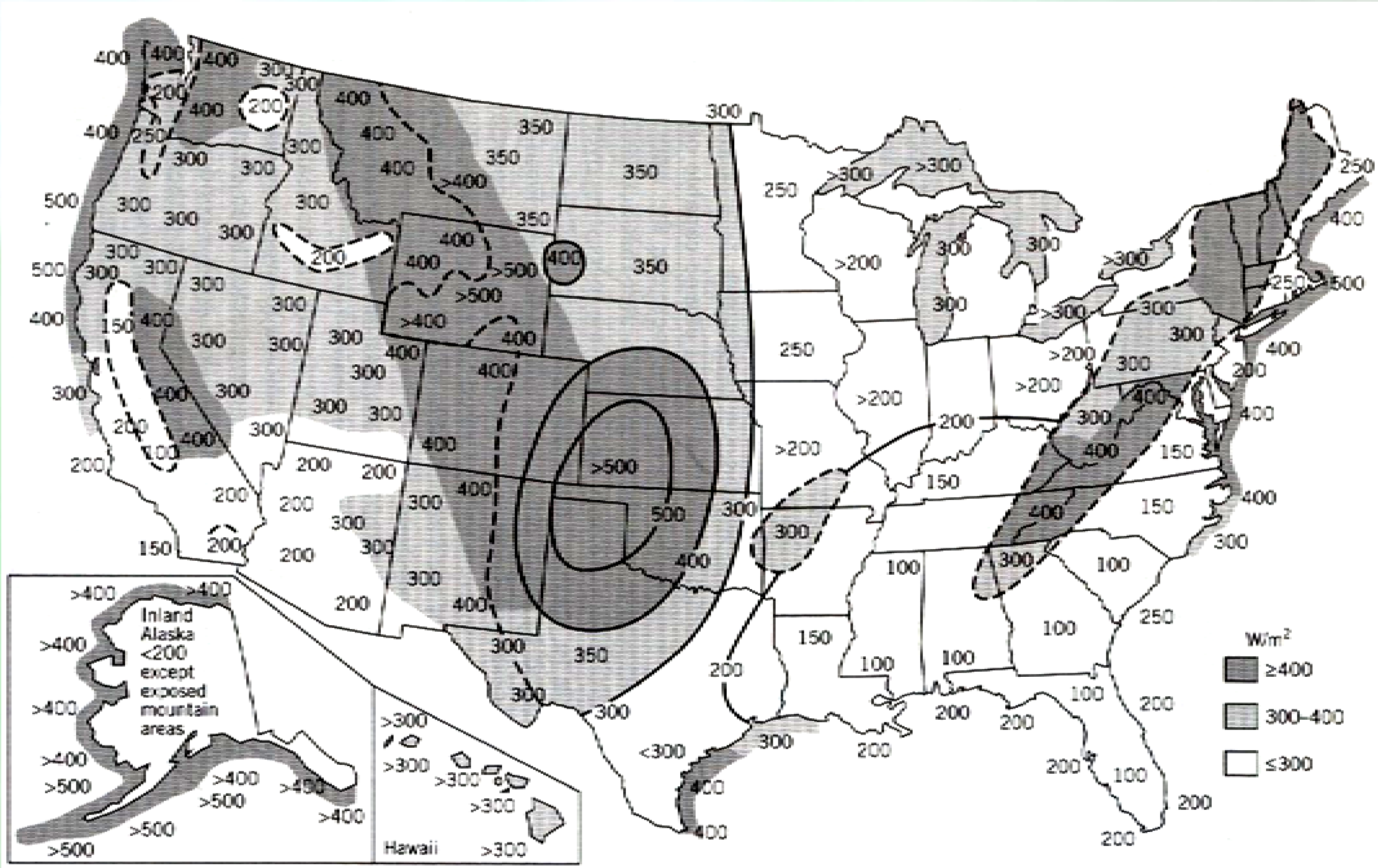


Figure 5.7 Annual average wind power density (watts per square meter) at 50 meters altitude. (*Source*:Figure supplied by the National Renewable Energy laboratory.)

The classification scheme also takes into account the variability of the wind speed and the average density of the air.
625,000 km^2 in the US have class 3(300-400 W/m^2) or higher wind resources and which are within 10km of electric transmission lines.
~734,000 MW_e

The total installed capacity of all electric power plants in US 948,000 MW_e, larger than what might be expected from this potential wind power resource.

Wind Power

Advantage:

Over solar photovoltaic generation

Day and night, sunny or cloudy.

During the coldest and darkest nights of winter when energy is needed the most.

In the commonly overcast and high latitudes, where solar power cannot be relied on, wind energy is often available.

Intermittent in their power delivery and require energy storage for many applications.

Disadvantage

Energy storage/transformation problems

Variability of the wind speeds

Environmental problems ?

- Differential pressure gradients around the wind turbines, birds
- The noise affects both people and animals
- The necessary transmission lines

Thank you!