Energy Fundamentals, Energy Use in an Industrial Society

1. Introduction

Energy enters our lives in many different ways.

- Energy in food: essential for the existence of all humankind and animals throughout our evolution on this planet.
- Energy in engine fuel: power automobiles, heat homes, manufacture products, generate electricity …

The fossil fuels: coal, natural gas, and oil supply most of the energy used globally (86% in the United States).

- These resources evolved hundreds of millions of years ago.
- Since the beginning of the machine age, industrial societies have become increasingly dependent on fossil fuels.

Various forms of energy consumed in the United States since 1850. QBtu means quadrillion British thermal units.

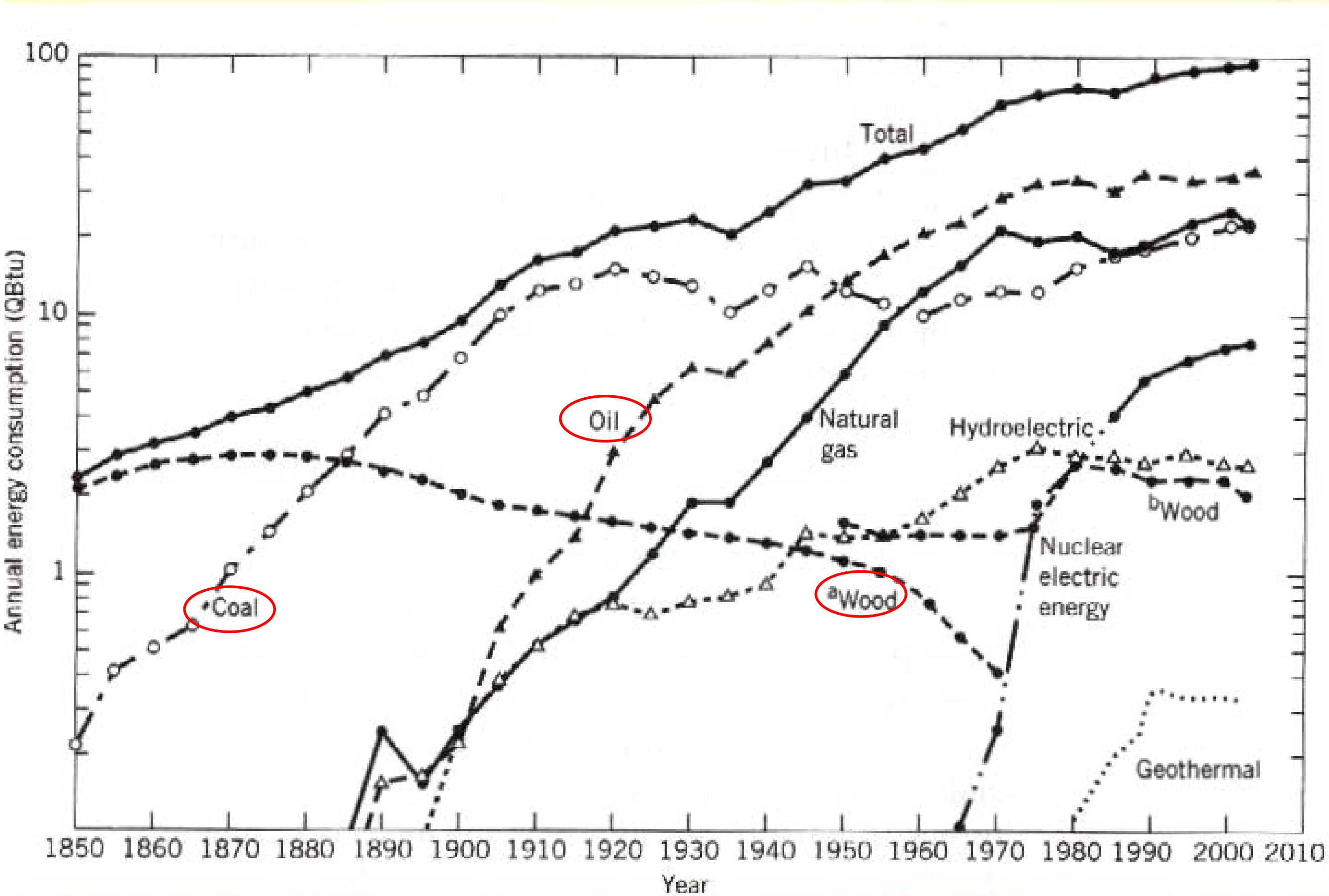
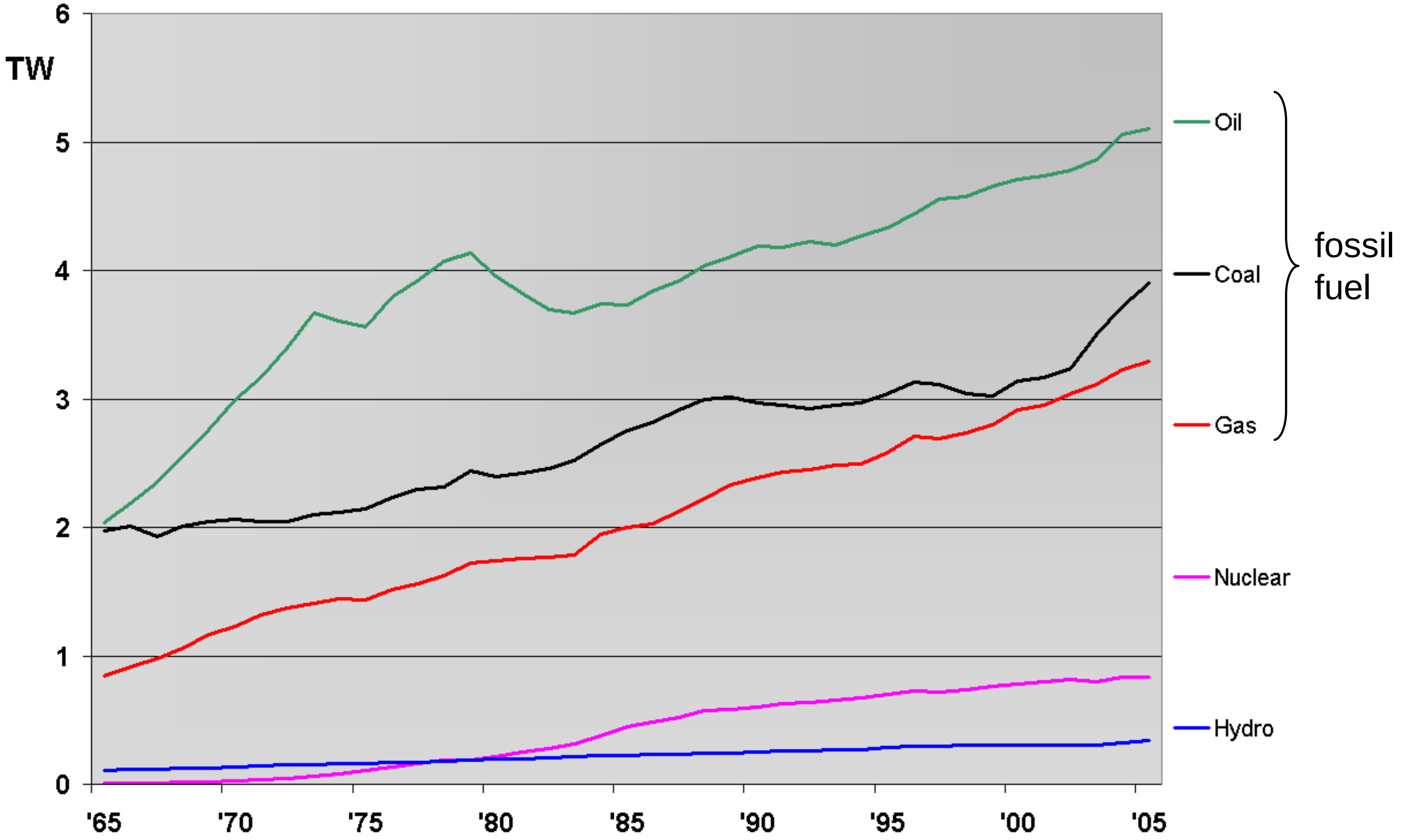


Figure 1.1 Various forms of energy consumed in the US since 1850.

Tetrawatt (10^{12} W)



Energy Consumption in the World

Why should we be concerned that so much of our energy is coming from fossil fuels?

First, the fossil fuel resource is limited in amount.
On a global scale, we will have some coal for a few centuries, but natural gas and oil will be in short supply in only a few decades.

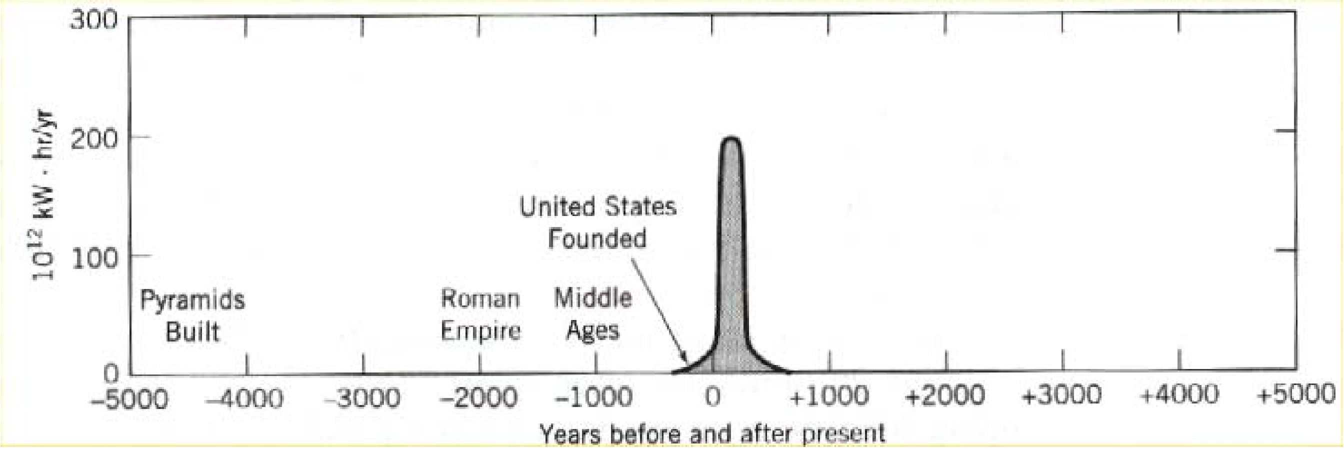


Figure 1.2 The complete exploitation of the world's fossil fuels will span only a relatively brief time in the 10,000 year period shown centered around the present.

Why should we be concerned that so much of our energy is coming from fossil fuels?

Second, unintended environmental consequences result from the extensive scale of our use of the fossil fuels.
Air pollution, health problems, and global climate changes.

Can we find solutions to these problems of resource depletion and environmental pollution?
The purpose of this course: to gain understanding concerning the essential points.

2. Why Do We (US) Use So Much Energy?

We don't use our energy resources as efficiently as we could.

There is a large discrepancy between the rate of energy use by a typical citizen of an industrialized society and the typical citizen of a developing country.

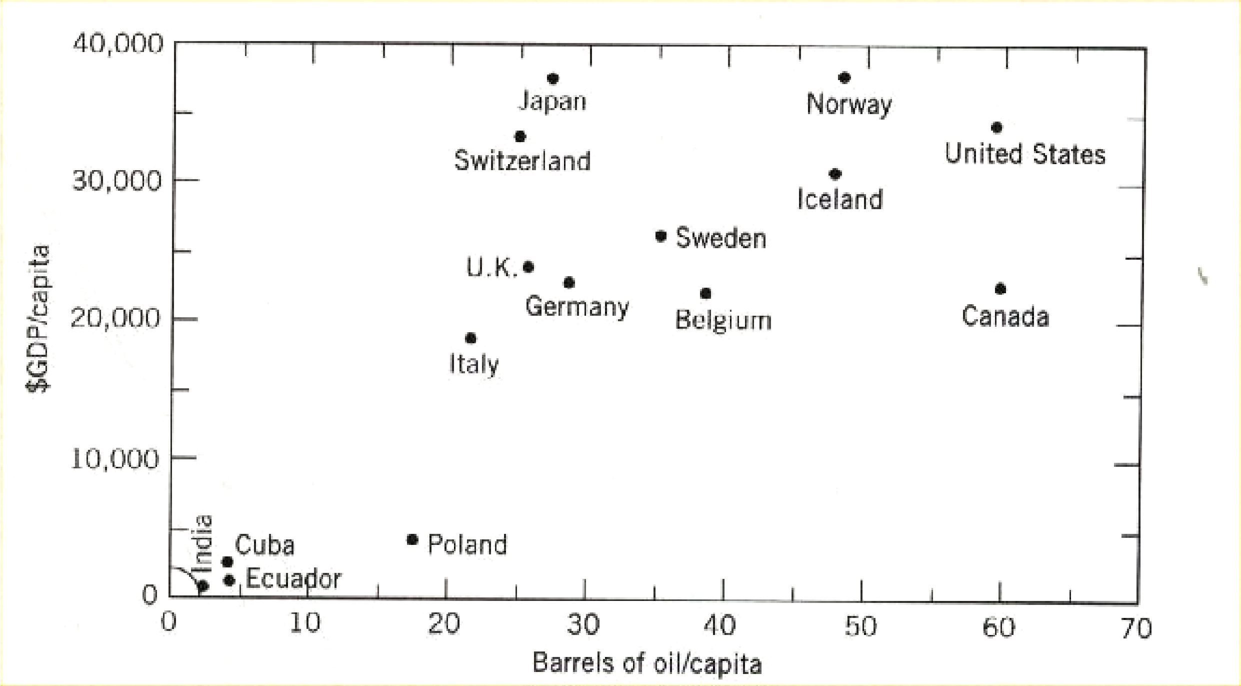
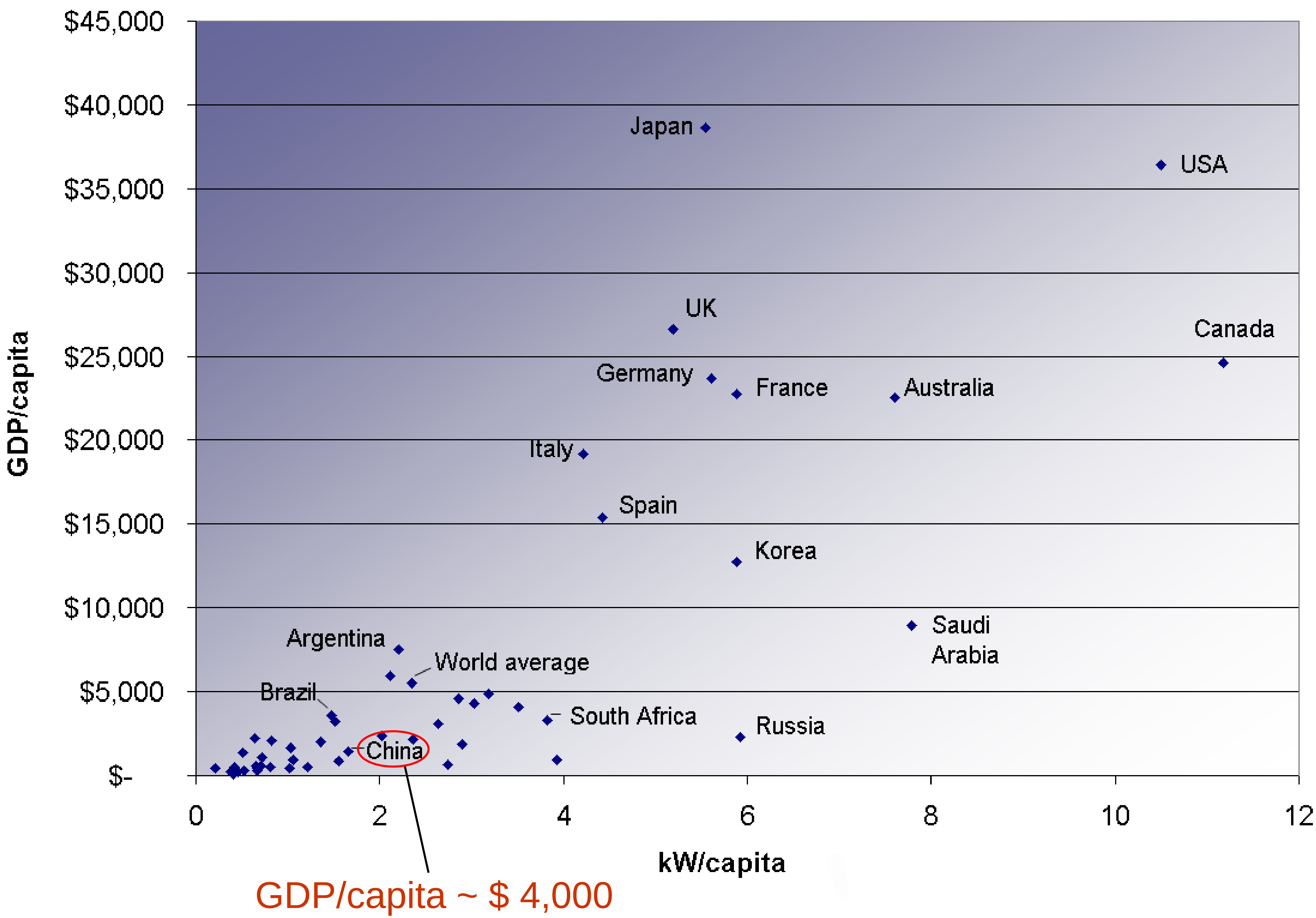


Figure 1.3 The Gross Domestic Product (GDP) per capita in U.S. dollars is compared to the total energy consumed per capita in equivalent barrels of oil for several countries.


$45,000
$40,000
$35,000
$30,000
$25,000
$20,000
$15,000
$10,000
$5,000
$-
GDP/capita
0
2
4
6
8
10
12
kW/capita
Japan
USA
UK
Canada
Germany
France
Australia
Italy
Spain
Korea
Argentina
World average
Saudi Arabia
Brazil
South Africa
Russia
China
GDP/capita ~ $ 4,000

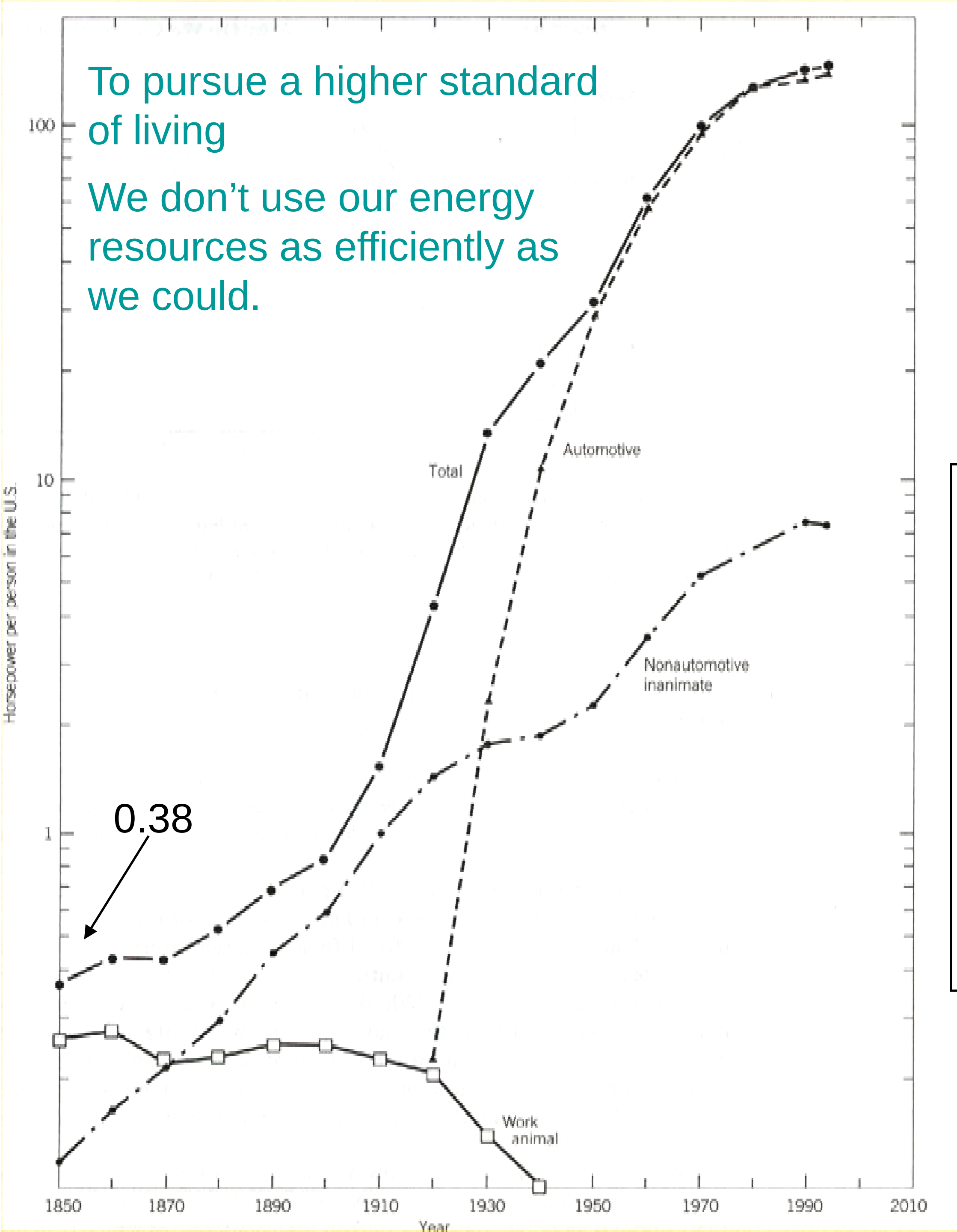


Figure 1.4 Horsepower per capita of all prime movers in the US since 1850..

The combustion of a single pound of coal, supposing it to take place in minute, is equivalent to the work of three hundred horses; and the force set free in the burning of 300 pounds of coal is equivalent to the work of an able-bodied man for a lifetime.

- quote from an early physics textbook

3. Energy Basics

Energy: the capacity to do *work*

Work: the product of *force* times the *distance* through which the force acts. Both the force and the distance must have nonzero values if work is to be done.

Forms of Energy:

Chemical Energy: energy stored in certain chemicals or materials that can be released by chemical reaction, often combustion.

Heat Energy: energy associated with random molecular motions within any medium. Heat energy is related to the concept of temperature.

Mass Energy: mass–energy equivalence discovered by Albert Einstein is the concept that the mass of a body is a measure of its energy content.

$E = mc^2$ ($\Delta E = \Delta mc^2$),

Nuclear reactions in the sun: $D + T \rightarrow He + n +$ Energy, with 7% less mass, 4 million tons of Hydrogen/second

Forms of Energy:

Kinetic Energy: a form of mechanical energy. It has to do with mass in motion. ($KE = 1/2mv^2$)

Potential Energy: associated with position in a force field. For gravitational field: $PE = w \cdot h$

Electric Energy: If an electric charge, q, is taken to a higher electric potential (higher voltage), V, then it is capable of releasing its potential energy, given by $PE = q \cdot V$, in some other form such as heat or mechanical energy.

Electromagnetic Radiation: takes the form of self-propagation waves in a vacuum or in matter. It consists of electric and magnetic components which oscillate in phase perpendicular to each other and perpendicular to the direction of energy propagation. The electromagnetic spectrum covers a very wide range of frequency, and visible light is only a small part of the entire spectrum. The energy per photon can be calculated from the Planck-Einstein equation: $E = hv$

Power:

Power is the time rate of using, or delivering , energy.

Power = Energy / Time ($P = E / t$)

In metric system, we use units of *watts* for power, where one watt is one joule per second.

In the United States, automobile engines and electric motor are often rated in horsepower.

1 horse power = 550 ft·lb/s = 745.7 watts

4. Units of Energy

The metric units are known as the Systeme' International, usually abbreviated SI, becoming standard throughout the world.

The Joule: the metric unit of energy. One newton acting through one meter is equivalent to the expenditure of one joule.

The British Thermal Unit (Btu): One Btu is defined to be the amount of heat energy required to raise the temperature of one pound of water by one degree Fahrenheit. *1 Btu = 1055 joules*

The Calorie: One calorie is the amount of energy required to raise the temperature of one gram water by one degree Celsius.

1 calorie = 4.184 joule, 1 ***food*** *Calorie (Calorie) = 1000 calorie (kcal)*

The Foot-Pound: A force of one pound acting through a distance of one foot by definition expends one foot-pound energy, and one foot-pound of work is done. *1 Btu = 778* ft·lb

The Electron-Volt: Moving one electron through and electronic potential difference of one volt. *1 Joule =* $6X10^8$ *eV*

5. Energy Consumption in the *US*

Table 1.1 U.S. Energy Consumption in 2003

Source	Amount	QBtu	Percent	1 QBtu Equiv.
Coal	1.08×10^9 tons	22.6	23.0	47.8×10^6 tons
Natural gas	21.8×10^{12} ft^3	22.5	22.9	0.97×10^{12} ft^3
Petroleum	6.72×10^9 bbl	39.1	39.8	172×10^6 bbl
Nuclear elec.	757×10^9 kWh	7.97	8.1	95×10^9 kWh
Renewables	578×10^9 kWh	6.15	6.3	94×10^9 kWh
Total		98.3	100	

The values in the third column for coal, natural gas and petroleum are for the heat energy released by the burning of the given fuel. The numbers given for nuclear and renewable are different.

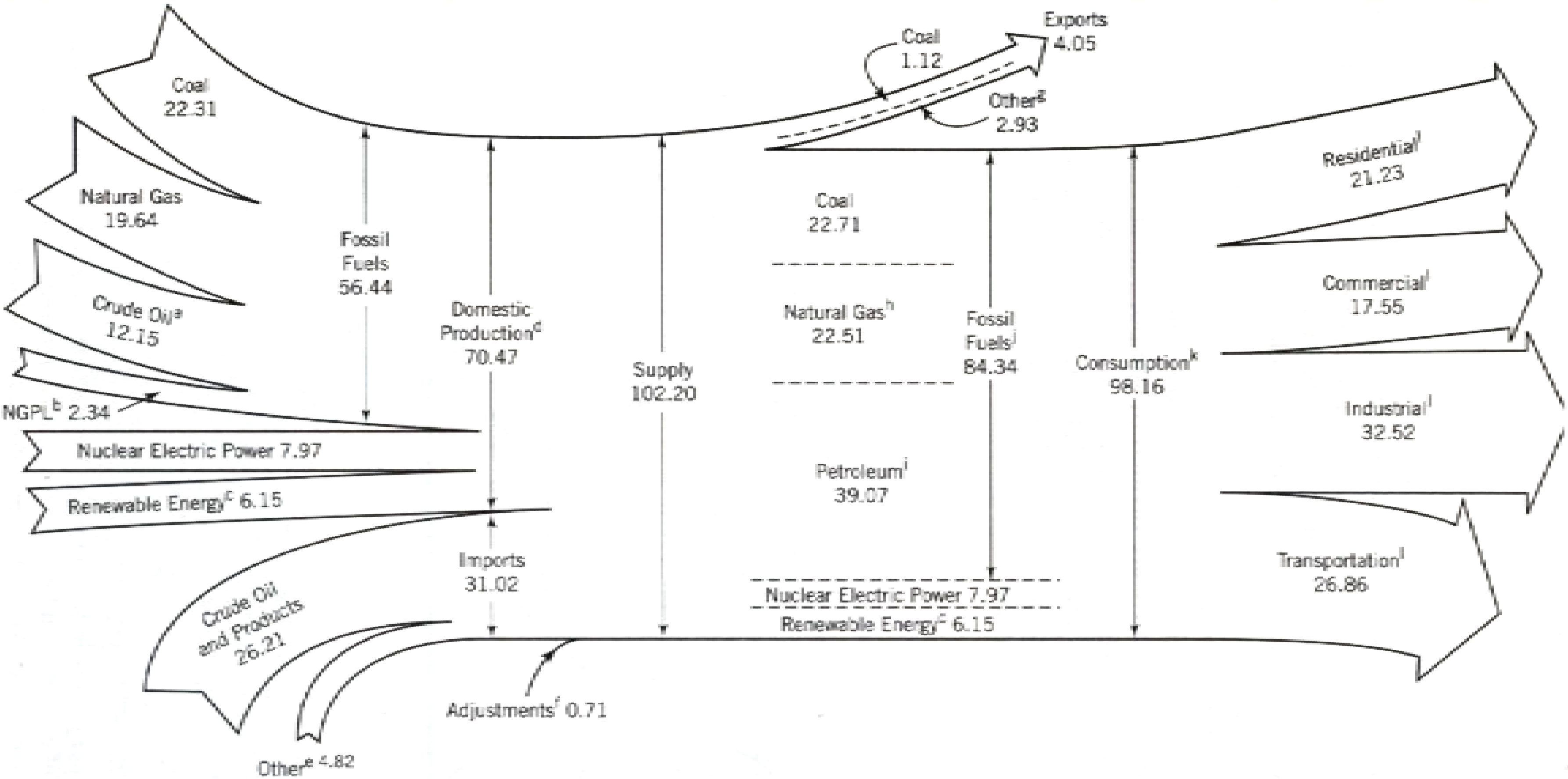
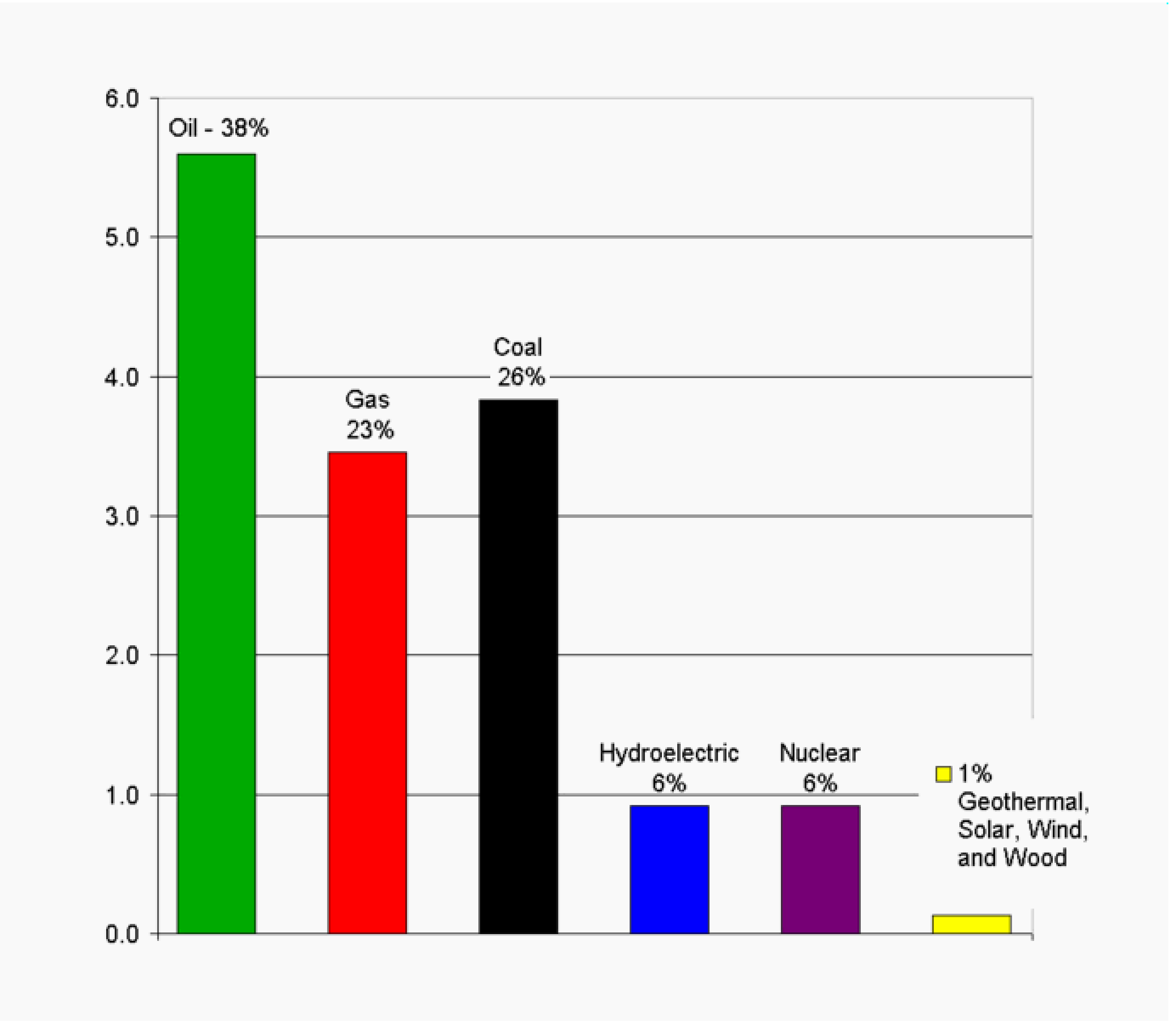


Fig 1.5 Energy flow from source to use in the US in 2003 in units of QBtu.



2004 World Wide Energy Sources

Table 1.2 U.S. Energy Consumption per Person in 2003

Source	Amount
Coal	3.7 tons
Natural gas	74,900 ft^3
Petroleum	23.2 bbl
Nuclear electric	2600 kWh
Renewables	1986 kWh

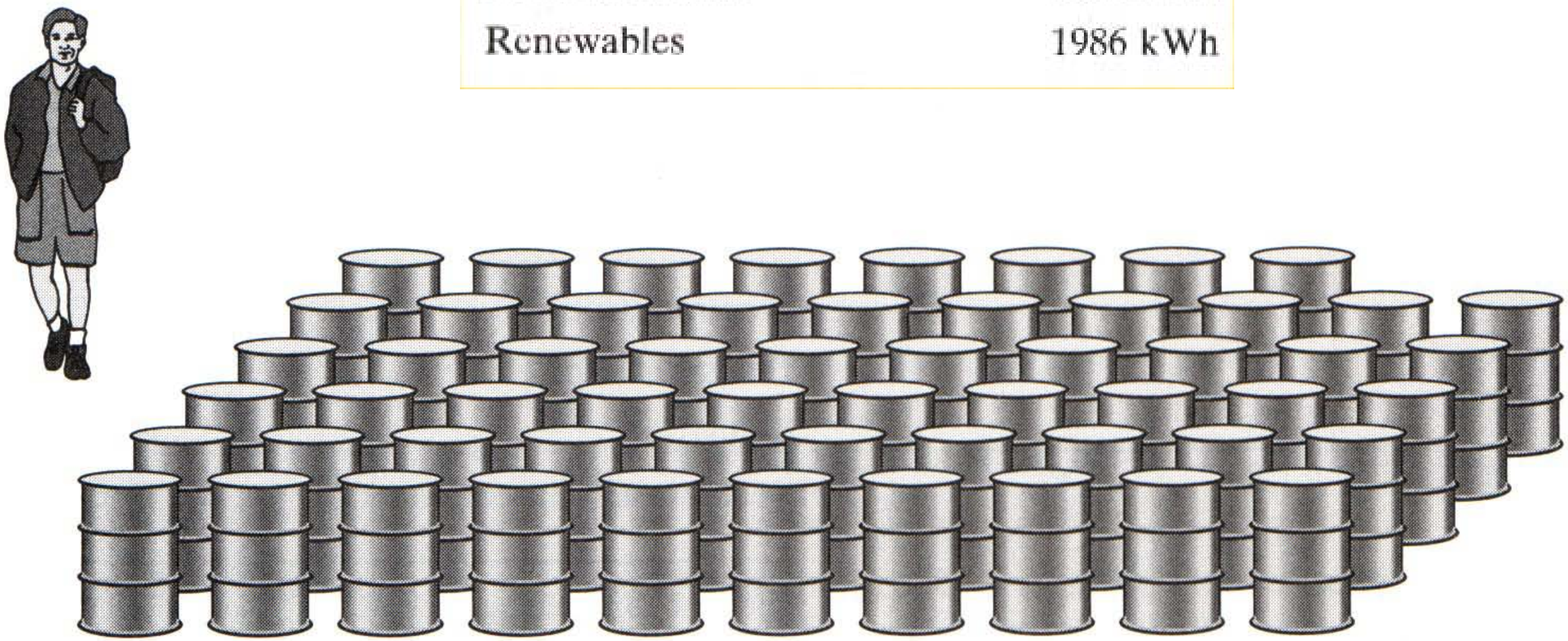


Figure 1.7 Each person in the United States consumes an energy equivalent of 58 barrels of oil burned as fuel each year.

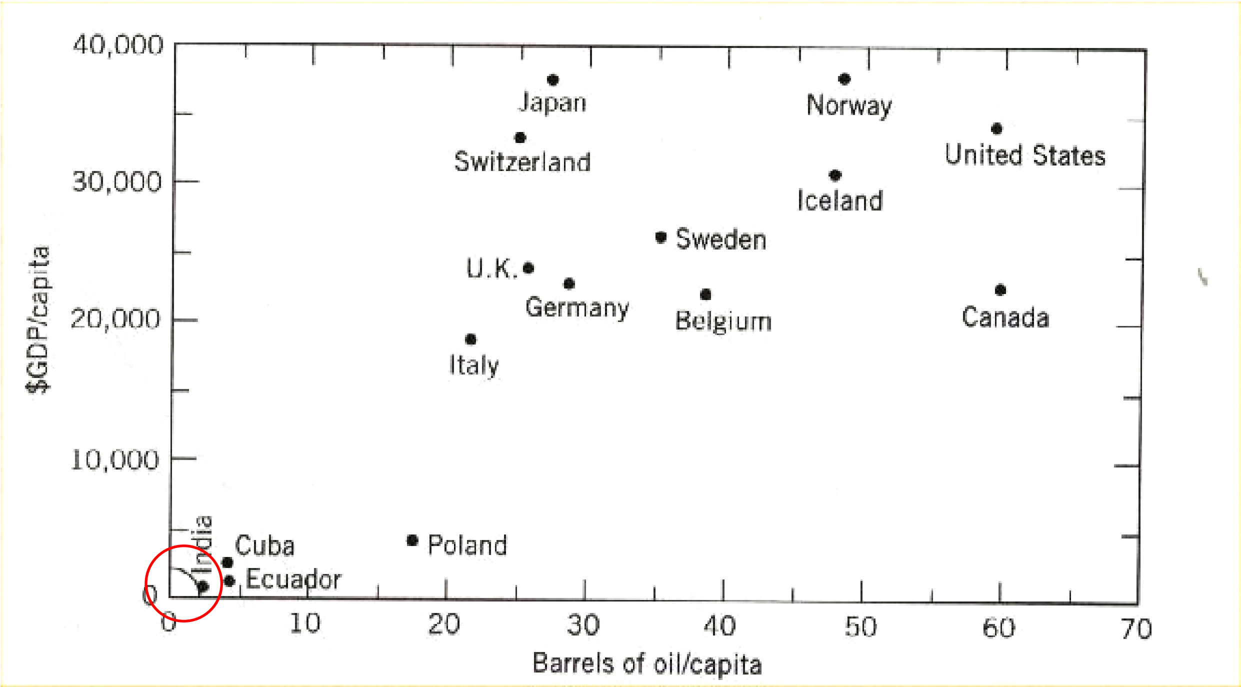


Figure 1.3 The Gross Domestic Product (GDP) per capita in U.S. dollars is compared to the total energy consumed per capita in equivalent barrels of oil for several countries.

It could be argued that in order to have a large per capital GDP, a relative large per capita energy consumption is also needed. However, Switzerland consumes less than half the per capita energy of the US, but has about the same per capita GDP. A number of developing countries such as Angola, Haiti, and Somalia fall within the little quarter-circle at the lower left corner.

Table 1.3 Percentage U.S. Energy Use in Various Sectors in 2003

Sector	Amount
Electric utilities	39.0%
Transportation	27.3%
Industrial	22.1%
Residential and commercial	11.6%

The energy resource for
Electric: 50% coal, 20% nuclear, 18% natural gas, 7% hydroelectric, 3% petroleum, and 3% other
Transportation: almost entirely by petroleum
Industry: coal, natural gas, and petroleum
Residential and commercial: mostly natural gas and petroleum

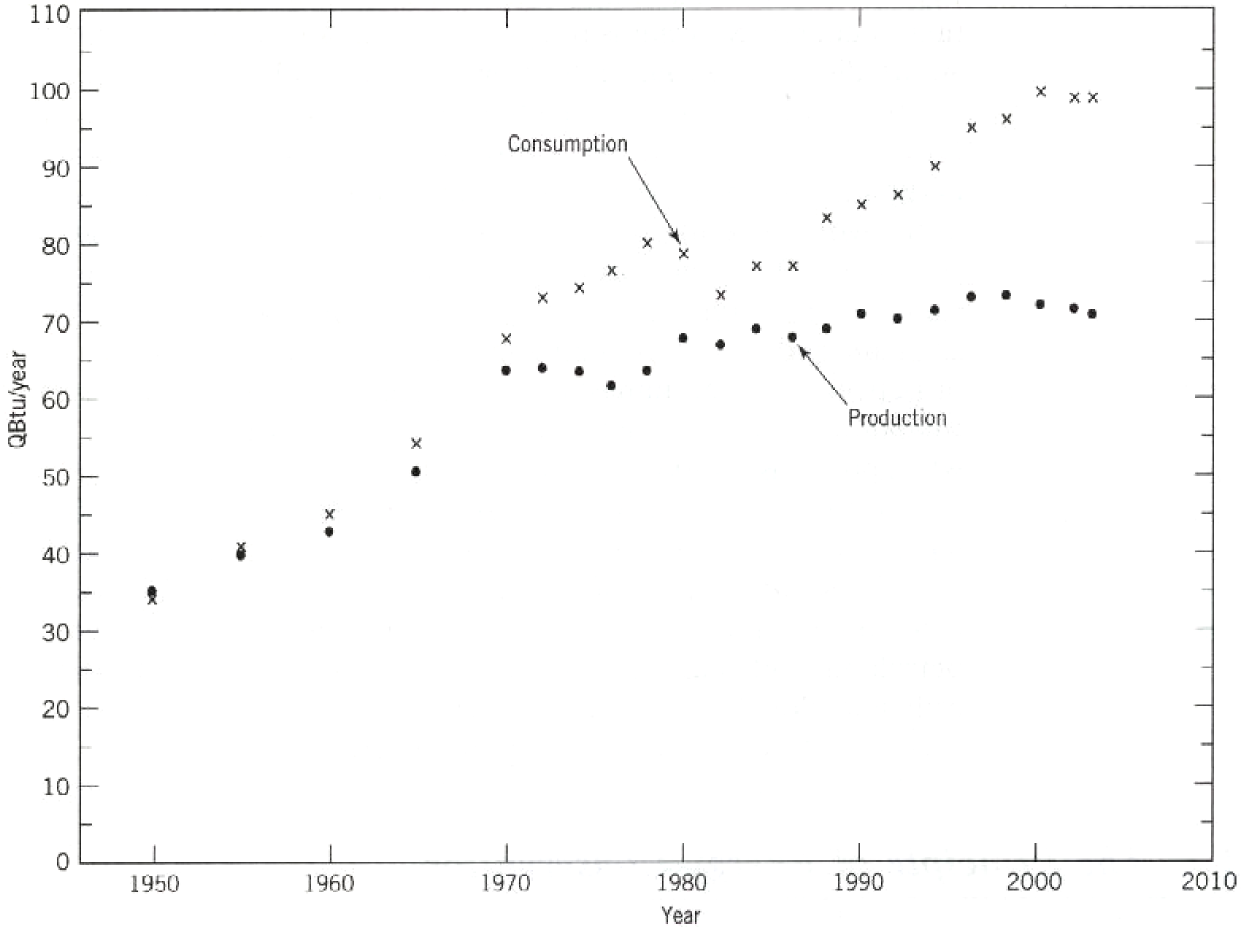


Figure 1.8 The total energy consumption and production in the US since 1950 in QBtu per year.

- A persistent pattern of consuming more energy than producing in the US.
- The difference is made up from imports.
- The decrease in the 1980s reflected a movement to greater energy conservation following increases in fuel costs and the “energy crisis” that started in 1973.
- After the easiest and least expensive *energy conservation measures* had been implemented, the energy consumption curve began to rise again.

How about the Energy Consumption in ***China***?

Topic for Oral Presentation!

6. The Principle of Energy Conservation

The total energy in an isolated system cannot change.

the amount of energy ≠ the usefulness of energy

Our other common use of the word *energy conservation* is distinct from *The Principle of Energy Conservation* and applies to the idea of using less energy to perform a given task.

We will discuss in detail the practical ways of achieving energy conservation goals later.

7. Transformation of Energy from One to Another

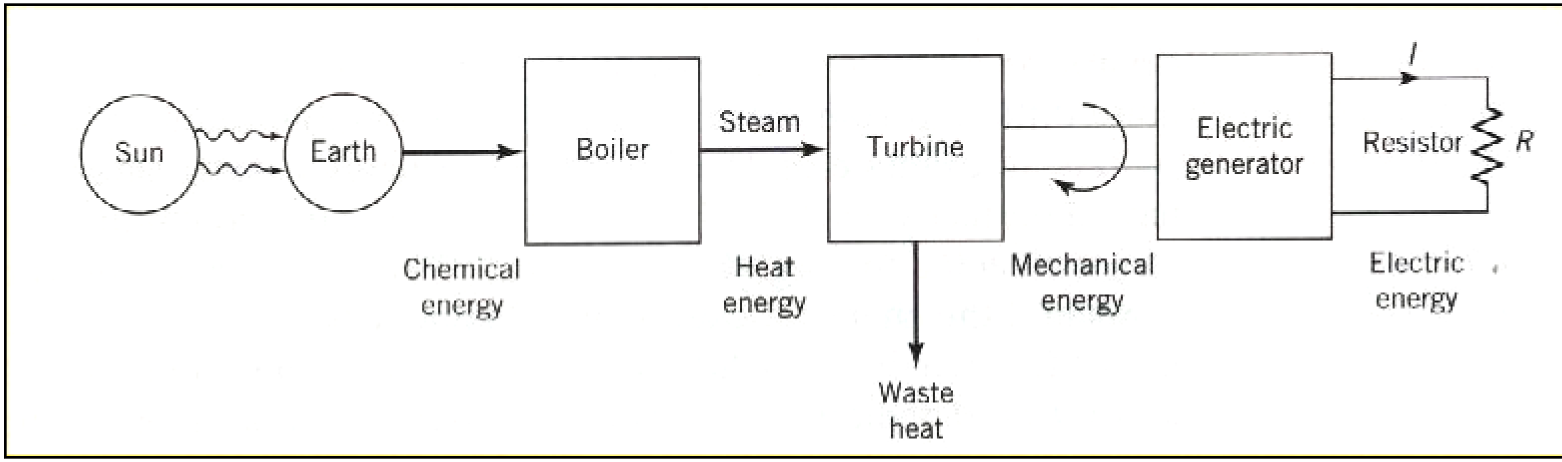


Figure 1.9 Steps in the transformation of the nuclear fusion energy in the sun to the electric energy used in residence or industry. This example involves a time period hundreds of millions of years.

How many forms of energy were involved in the above processes?

mass energy → nuclear fusion energy → electromagnetic radiation energy → <u>chemical energy</u> → heat energy → mechanical energy → electric energy

Energy is conserved in each transformation.

8. Renewable and Nonrenewable Energy Sources

Nonrenewable resources: could be exhausted within a relatively short time as a result of our exploiting them.

Examples: all the fossil fuels (coal, oil, natural gas, shale oil 页岩油, tar sands 沥青沙, etc.), uranium-235 (nuclear fission fuel), deuterium (nuclear fusion fuel), and some types of geothermal energy.

- It takes hundreds of million years for natural processes to produce useful amounts of petroleum, natural gas, or coal.
- We might estimate a time of several centuries to exhaust the entire stock of fossil fuels, several decades for the earth's uranium-235, and a few decades to use up the heat energy at *some local* geothermal sites.

Nonrenewable energy will get more expensive when they are near exhaustion.

Renewable resources: could never be consumed to completion.

Examples: solar, geothermal, and tidal.

- All energy sources based on solar energy incident on earth – *direct sunlight, wind, hydroelectric power, ocean current, ocean thermal gradients and biomass* – are renewable. In these cases the time to exhaustion depends on the life of the sun.
- Some local geothermal energy sites can be available again after being depleted through use.
- The energy in the oceans' tides has its origin in the gravitational interaction between the earth and the moon and , to a less extent, between the earth and the sun.

Then more renewable energy we use, the cheaper it will be.