

Applied Chemistry: A Textbook for Engineers and Technologists

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**Gesser: Applied Chemistry: A Textbook for
Engineers and Technologists**

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To Esther, Isaac, Sarah and Avi



Preface

This book is the result of teaching a one semester course in Applied Chemistry (Chemistry 224) to second year engineering students for over 15 years. The contents of the course evolved as the interests and needs of both the students and Engineering Faculty changed. All the students had at least one semester of Introductory Chemistry and it has been assumed in this text that the students have been exposed to Thermodynamics, Chemical Kinetics, Solution Equilibrium, and Organic Chemistry. These topics must be discussed either before starting the Applied subjects or developed as required if the students are not familiar with these prerequisites.

Engineering students often ask "Why is another Chemistry course required for Non-Chemical Engineers?"

There are many answers to this question but foremost is that the Professional Engineer must know when to consult a Chemist and be able to communicate with him. When this is not done the consequences can be a disaster due to faulty design, poor choice of materials or inadequate safety factors.

Examples of blunders abound and only a few will be described in an attempt to convince the student to take the subject matter seriously.

The Challenger space shuttle disaster which occurred in January 1986 was attributed to the cold overnight weather which had hardened the O-rings on the booster rockets while the space craft sat on the launch-pad. During flight the O-ring seals failed, causing fuel to leak out and ignite. The use of a material with a lower glass transition temperature (T_g) could have prevented the disaster.

A similar problem may exist in automatic transmissions used in vehicles. The use of silicone rubber O-rings instead of neoprene may add to the cost of the transmission but this would be more than compensated for by an improved and more reliable performance at -40°C where neoprene begins to harden; whereas the silicone rubber is still flexible.

A new asphalt product from Europe incorporates the slow release of calcium chloride (CaCl_2) to prevent icing on the roads and bridges. Predictably, this would have little use in Winnipeg, Canada, where -40°C is not uncommon in winter.

The heavy water plant at Glace Bay, Nova Scotia was designed to extract D_2O from sea water. The corrosion of the plant eventually delayed production and the redesign and use of more appropriate materials added millions to the cost of the plant.

A chemistry colleague examined his refrigerator which failed after less than 10 years of use. He noted that a compressor coil made of copper was soldered to an expansion tube made of iron. Condensing water had corroded the — guess what? — iron

tube. Was this an example of designed obsolescence or sheer stupidity. One wonders, since the savings by using iron instead of copper is a few cents and when the company is a well known prominent world manufacturer of electrical appliances and equipment.

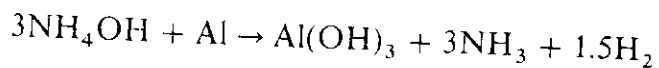
With the energy problems now facing our industry and the resulting economic problem that results, the engineer will be required to make judgements which can alter the cost benefit ratio for his employer. One must realize that perpetual motion is impossible even though the US Supreme Court has ruled that a patent should be granted for a devise which the Patent Office considered to be a Perpetual Motion Machine. An example of this type of proposal appeared in a local newspaper which described an invention for a car which ran on water. This is accomplished by a battery which is initially used to electrolyze water to produce H_2 and O_2 that is then fed into a fuel cell which drives an electrical motor which propels the car. While the car is moving, an alternator driven by the automobile's motion, charges the battery. Thus, the only consumable item is water. This is an excellent example of perpetual motion.

A similar invention of an automobile powered by an air engine has been described. A compressed air cylinder powers an engine which drives the automobile. A compressor which is run by the moving car recompresses the gas into a second cylinder which is used when the first cylinder is empty. Such perpetual motion systems will abound and the public must be made aware of the pitfalls.

Have you heard of the Magnatron? Using 17 oz of deuterium (from heavy water) and 1.5 oz of gallium will allow you to drive an engine 110,000 miles at a cost of \$110. Are you sceptical? You should be, because it is an example of the well-known Computer GIGO Principle (meaning garbage in = garbage out).

An engineer responsible for the application of a thin film of a liquid adhesive to a plastic was experiencing problems. Bubbles were being formed which disrupted the even smooth adhesive coat. The answer was found in the dissolved gases since air at high pressure was used to force the adhesive out of the spreading nozzle. The engineer did not believe that the air was actually soluble in the hexane used to dissolve the glue. When helium was used instead of air, no bubbles formed because of the lower solubility of He compared to O_2 and N_2 in the solvent. Everything is soluble in all solvents, only the extent of solution varies from non-detectable (by present methods of measurement) to completely soluble. The same principle applies to the permeability of one substance through another.

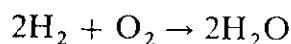
An aluminum tank car exploded when the broken dome's door hinge was being welded. The tank car, which had been used to carry fertilizer (aqueous ammonium nitrate and urea), was washed and cleaned with water — so why had it exploded? Dilute ammonium hydroxide is more corrosive to aluminum than the concentrated solution. Hence, the reaction



produces hydrogen which exploded when the welding arc ignited the H_2/O_2 mixture. The broad explosive range of hydrogen in air makes it a dangerous gas when confined.

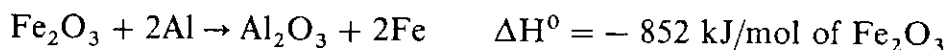
Batteries are often used as a back-up power source for relays and, hence, stand idle for long periods. To keep them ready for use they are continuously charged. However, they are known to explode occasionally when they are switched into service because of

the excess hydrogen produced due to overcharging. This can be avoided by either catalyzing the recombination of the H_2 and O_2 to form water



by a nickel, platinum or palladium catalyst in the battery caps, or by keeping the charging current equal to the inherent discharge rate which is about 1% per month for the lead-acid battery.

It has recently been shown that the flaming disaster of the Hindenburg Zeppelin in 1937, in which 36 lives were lost, may have been caused by static electricity igniting the outer fabric. This was shown to contain an iron oxide pigment and reflecting powdered aluminum. Such a combination, known as a Thermite mixture, results in the highly exothermic Gouldshmidt reaction (first reported in 1898)



In the early days of the railway, rails were welded with the molten iron formed in this reaction. The combination of powdered aluminum and a metal oxide has been used as a rocket fuel and evidence has been obtained to indicate that after the disaster the Germans replaced the aluminum by bronze which does not react with metal oxides. Thus, the bad reputation hydrogen has had as a result of the accident is undeserved and the resulting limiting use of the airship was due to faulty chemistry and could have been avoided.

The original design and structure of the Statue of Liberty, built about 100 years ago, took into account the need to avoid using different metals in direct contact with each other. However, the salt sea spray penetrated the structure and corroded the iron frame which supported the outer copper shell. Chloride ions catalyzed the corrosion of iron. The use of brass in a steam line valve resulted in corrosion and the formation of a green solid product. The architect was apparently unaware of the standard practice to use amines such as morpholine as a corrosion inhibitor for steam lines. Amines react with copper in the brass at high temperatures in the presence of oxygen to form copper-amine complexes similar to the dark blue copper ammonium complex, $Cu(NH_3)_4^{2+}$.

Numbers are a fundamental component of measurements and of the physical properties of materials. However, numbers without units are meaningless. Few quantities do not have units, e.g., specific gravity of a substance is the ratio of the mass of a substance to the mass of an equal volume of water at 4°C. Another unitless quantity is Reynolds Number, $R_e = \rho vl/\eta$ where ρ is the density; v is the velocity; η is the viscosity of the fluid and l is the length or diameter of a body or internal breath of a pipe. The ratio $\eta/\rho = \mu$ the kinematic viscosity with units of l^2/t . $R = vl/\mu$ and has no units if the units of v , l , and μ are consistent.

To ignore units is to invite disaster. Two examples will illustrate the hazards of the careless- or non-use of units. During the transition from Imperial to SI (metric) units in Canada, an Air Canada commercial jet (Boeing 767) on a trans Canada flight (No 143) from Montreal to Edmonton on July 23, 1983 ran out of fuel over Winnipeg.

Fortunately the pilot was able to glide the airplane to an abandoned airfield (Gimli, MB) used for training pilots during World War II. The cause of the near disaster was a mix-up in the two types of units involved for loading the fuel and the use of a unitless conversion factor. (See Appendix A for a detailed account of this error).

The second example of an error in units cost the USA (NASA) \$94,000,000. A Mars climate probe missed its target orbit of 150 km from the Mars' surface and approached to within 60 km and burned up. The error was due to the different units used by two contractors and which was not inter-converted by the NASA systems engineering staff. This book uses various sets of units and the equivalences are given in Appendix A. This is designed to keep the student constantly aware of the need to watch and be aware of units.

The above examples show how what may be a simple design or system can fail due to insufficient knowledge of chemistry. This textbook is not intended to solve all the problems you might encounter during your career. It will, however, give you the vocabulary and basis on which you can build your expertise in engineering.

The exercises presented at the end of each chapter are intended to test the students' understanding of the material and to extend the topics beyond their initial levels.

The author is indebted to the office staff in the Chemistry Department of the University of Manitoba who took pencilled scrawls and converted them into legible and meaningful text. These include Cheryl Armstrong, Tricia Lewis and Debbie Dobson. I also wish to thank my colleagues and friends who contributed by critical discussions over coffee. I also wish to express my thanks to Roberta Wover who gave me many helpful comments on reading the manuscript and checking the exercises and Web sites. Mark Matousek having survived Chem. 224 several years ago, applied some of his acquired drawing skills to many of the illustrations shown. Nevertheless, I must accept full responsibility for any errors or omissions, and I would be very grateful if these would be brought to my attention.

Some general references are listed below:

- Kirk & Othmer, *Encyclopedia of Chemical Technology*, 4th Ed., 30 Vol., J. Wiley & Sons, New York (1995).
- Ullmann's *Encyclopedia of Industrial Chemistry*, 26 Vol., VCH, Germany (1992).
- Encyclopedia of Physical Science and Technology*. 15 Vol., + Year Books, Academic Press, Orlando, Florida (1987).
- V. Hopp and I. Hennig, *Handbook of Applied Chemistry*, Hemisphere Publ. Co., Washington (1983).
- McGraw-Hill *Encyclopedia of Science and Technology*. 15 Vol., + Year Books, New York (1982).
- W. Steedman, R.B. Snadden and I. H. Anderson, *Chemistry for the Engineering and Applied Sciences*, 2nd Ed., Pergamon Press, Oxford (1980).
- I. P. Muklyonov, Editor, *Chemical Technology*, 3rd Ed., 2 Vol., Mir Publ., Moscow (1979), in English.
- R. M. E. Diamant, *Applied Chemistry for Engineers*, 3rd Ed., Pitman, London (1972).
- G. R. Palin, *Chemistry for Technologists*, Pergamon Press, Oxford, (1972).
- Chemical Technology: An Encyclopedic Treatment*, 7 Vol., Barnes and Noble Inc. New York (1972).
- F. G. Butler and G. R. Cowie, *A Manual of Applied Chemistry for Engineers*, Oliver and Boyd, London, (1965).
- L. A. Munro, *Chemistry in Engineering*, Prentice Hall, Englewood Cliffs, New Jersey (1964).

E. Cartwell, *Chemistry for Engineers—An Introductory Course*, 2nd Ed. Butterworths, London, (1964).

E. S. Gyngell, *Applied Chemistry for Engineers*, 3rd Ed., Edward Arnold, London (1960).

Thorpe's *Dictionary of Applied Chemistry*, 4th Ed., 11 Vol., Longmans, Green, London, (1957)

The World Wide Web is an excellent source of technical information though it is important to recognize that discretion must be exercised in selecting and using the information since the material presented is not always accurate or up-to-date. Some selected web sites are added to the Further Readings lists at the end of each chapter.

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Abbreviations Used in this Text

AAGR	Average annual growth rate
AAS	Atomic absorption spectrometry
ABS	Acrylonitrile-butadiene-styrene polymer
AEM	Anion exchange membrane
AFC	Atomic fluorescence spectrometry
AFR	Air fuel ratio
AGR	Advanced gas reactor
ANFO	Ammonium nitrate fuel oil
ASTM	American Society for Testing and Materials
bbbl	Barrel for oil, see Appendix A
BC	Bimetallic corrosion
BET	Brunauer-Emmett-Teller
BLEVE	Boiling liquid expanding vapor explosion
BOD	Biochemical oxygen demand
BP	Boiling point
BWR	Boiling water reactor
CANDU	Canadian deuterium uranium reactor
CASING	Crosslinking by activated species of inert gases
CC	Crevice corrosion
CEM	Cation exchange membrane
CN	Cetane number
CNG	Compressed natural gas
COD	Chemical oxygen demand
CPVC	Chlorinated polyvinylchloride
CR	Compression ratio
DC	Direct current
DNA	Deoxyribonucleic acid
DP	Degree of polymerization
DR	Drag Reducer
DR	Distribution ratio
DTA	Differential thermal analysis
ECE	Economic Commission for Europe
ECM	Electrochemical machining

EDS	Exxon Donner Solvent	P
EHL	Elastohydrodynamic lubrication	P
EIS	Electrochemical impedance spectroscopy	P
ENM	Electrochemical noise method	P
EO	Extreme pressure (lubrication)	P
ER	Electrorheological fluid	p
ETBE	Ethyl tert butyl ether	P
EV	Expected value	p
EV	Electric vehicle	P
FAC	Free available chlorine	P
FEP	Hexafluoropropylene + PTFE	P
FP	Flash point	P
GAC	Granulated activated carbon	P
GBC	Grain boundary corrosion	P
GNP	Gross National Product	C
GR	Gas cooled reactor	R
h ν	photon	R
HAR	High aspect ratio	R
HDI	Hexane diisocyanate	R
HLW	High level waste	r
HMN	Heptamethylnonane	F
HRI	Hydrocarbon Research Inc	F
HWR	Heavy water reactor	S
ICAPS	Inductively coupled argon plasma spectrometry	S
ICE	Internal combustion engine	S
I _s	Specific impulse	S
LEL	Lower explosion limit	S
LH ₂	Liquid hydrogen	S
LNG	Liquified natural gas	S
LWR	Light water reactor	S
M-85	Methanol with 15% gasoline	S
MDF	Macro defect free	S
MeV	Million electron volts	S
MI	Machinability index	S
MMT	Methylcyclopentadiene Manganese II tricarbonyl	-
MON	Motor octane number	-
MPC	Maximum permissible concentration	-
MPN	Most probable number	-
MTBE	Methyl tertiary butyl ether	-
MW	Megawatt, 10 ⁶ W	-
NMOG	Non-methane organic gases	-
NTP	Normal conditions of temperature and pressure, 25°C and 1 atm pressure.	-
OB	Oxygen balance	-
OECD	Organization for Economic Cooperation and Development	-
ON	Octane number (average of MON + RON)	-
OPEC	Organization of Petroleum Exporting Countries	1
OTEC	Ocean thermal energy conversion	1

PAH	Polynuclear aromatic hydrocarbons
PAN	Polyacrylonitrile
PC	Pitting corrosion
PCB	Polychlorinated biphenyl
PF	Phenol-formaldehyde
pH	$\text{pH} = -\log_{10} [\text{H}^+]$, neutral water has $\text{pH} = 7$
PMMA	Polymethylmethacrylate
ppm	parts per million, $\mu\text{g/g}$ or mL/m^3
PS	Polystyrene
PTFE	Polytetrafluoroethylene
PV	Pressure volume (product)
PVAc	Polyvinylacetate
PVC	Polyvinyl chloride
PWR	Pressurized water reactor
Quad Q,	Unit of energy, see Appendix A
Rad	Radiation absorbed dose
RBE	Relative biological effectiveness
RDX	Cyclonite or hexogen
Rem	Roentgen equivalent to man
rpm	Revolutions per minute
RO	Reverse osmosis
RON	Research octane number
SAN	Styrene-acrylonitrile copolymer
SCC	Stress corrosion cracking
SCE	Saturated calomel electrode
SHE	Standard hydrogen electrode
SI	Spark ignition
SIT	Spontaneous ignition temperature
SNG	Synthetic natural gas
SOAP	Spectrographic oil analysis program
SP	Smoke point
SRC	Solvent refined coal
SSPP	Solar sea power plants
STP	Standard condition of temperature and pressure, 0°C and 1 atm pressure
TDC	Top dead center
TDI	Toluene diisocyanate
TEL	Tetraethyl lead
TGA	Thermal gravimetric analysis
THM	Trihalomethanes
TLV	Threshold limit value
TML	Tetramethyl lead
TNG	Trinitroglycerol
TNT	Trinitrotoluene
TOE	Tons of oil equivalent (energy)
TW	Terawatts, 10^{12} W
UC	Uniform corrosion
UEL	Upper explosion limit

UFFI	Urea-formaldehyde foam insulation
UN	United Nations
UV	Ultraviolet light, $\lambda < 380$ nm
VCI	Vapor corrosion inhibitors
VI	Viscosity index
VOC	Volatile organic compounds
VOD	Velocity of detonation
WHO	World Health Organization

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Table 1-1, Table 1-2, International Energy Annual. Table 1.3, Fig. 1.16, Royal Society London and H. Tabor, Non-convecting solar pond, *Phil. Trans. Roy. Soc. London* **A295** 423 (1980). Table 1.4, G. L. Wick and J. D. Isaacs, Salinity Power, (1975), Institute of Marine Resources #75-9, University of California, La Jolla, CA USA. Fig. 1.3, Physics in Canada and J. Jovanovich, Is Nuclear Power Essential? Sept. (1988). Fig. 1.8, Embassy of France (Ottawa). Fig. 1.9, B de Jong, Net radiation by a horizontal surface at the earth, Delft University Press (1973). Fig. 1.11, Goodyear-Akron OH. Fig. 1.10, A. D. Walt, *IEEE Spectrum* **8** 51 (Copyright © 1971 IEEE). Fig. 1.14, American Wind Energy Association, Washington DC, USA. Fig. 1.15, A. Lavi and C. Zener, *IEEE Spectrum* **10** 23 (Copyright © 1973 IEEE). Fig. 1.17, Embassy of Israel (Ottawa). Fig. 1.18, Scripps Oceanographic Institute, University of California, La Jolla CA, and A. Fisher, Energy from the sea, *Popular Science*, May (1975). Fig. 1.20, Reprinted with permission from R. S. Norman, *Science* **186** 351 (1974), (Copyright © 1974, AAAS, American Association for the Advancement of Science). Table 2.1, International Energy Annual. Table 2.2, A.S.T.M. West Conshohocken PA. Table 2.4, Ontario Hydro Research, Toronto, ON. Fig. 2.3, National Peat Board, Ireland. Fig. 3.1, Restek Inc. Bellefonte PA. Fig. 3.2, Fig. 3.5, Natural Resources Canada. Reproduced with the permission of the Minister of Public Works and Government Services Canada (1977). Table 3.2, International Energy Annual. Table 3.5, Table 3.6, Fig. 3.6, Royal Society London and R. C. Neavel, Exxon Donor Solvent Liquefaction Process, *Phil. Trans. R. Soc. London* **A300** 141 (1981). Fig. 3.7, *Royal Society London* and B. K. Schmid and D. M. Jackson, The SCR-II Process, *Phil. Trans. R. Soc. London* **A300** 129 (1981). Fig. 3.8, S. H. Moss and W. G. Schlinger, Coal Gasification, *Lubrication* **66** 25 (1980) Texaco Inc. White Plains NY, Courtesy of Equilon Enterprises LLC, Shell and Texaco working together. Fig. 3.9, Royal Society London and J. C. Hoogendoorn, Motor Fuels and Chemicals from Coal via Sasol Synthetic Route, *Phil. Trans. R. Soc. London* **A300** 104 (1981). Fig. 3.10, Sasol Ltd, Sasolburg, South Africa. Fig. 4.5, Reprinted with permission from C. F. Kettering, On the power and efficiency of internal combustion engines, *Industrial and Engineering Chemistry* **36** 1079, Copyright (1944) American Chemical Society. Fig. 4.6, Reprinted with permission from R. Lobinski et al., Organolead in Wine, *Nature* **370** 24 (1994). Copyright (1994) Macmillan Magazines Ltd. Table 4.7, Reprinted with permission from C. K. Westbrook and W. J. Pitz, The Chemical Kinetics of Engine Knock, *Energy & Technology Review*, Feb./Mar. (1991) (The US Government retain non-exclusive, royalty-free copyrights). University of California, Lawrence Livermore National Laboratory, Livermore CA. Table 4.8,

International Energy Outlook, Paris (1994). Table 4.9, Biomass Energy Institute Inc., Bio-Joule (1983). Table 5.1, Reprinted with permission from: T. Y. Chang et al., **Alternative Transportation Fuels and Air Quality**, *Environ. Sci. Technology* **25** 1190, Copyright (1991) American Chemical Society and Ford Motor Co. Fig. 6.1A, Shell International, London. Fig. 6.1B, Tokyo Gas Co., Japan. Fig. 6.2, Tokyo Gas Co., Japan. Fig. 6.8, L. Belkbir et al. Comparative Study of the Formation-Decomposition Mechanisms and Kinetics in LaNi_5 , and Magnesium Reversible Hydrides, *Int. J. Hydrogen Energy*, **6** 285 (1981), with permission from The International Association of Hydrogen Energy. Table 6.2, Reprinted from Shell Petroleum Handbook, 6th Edition © 1983 with permission from Elsevier Science. Fig. 6.5, Shali Fu, Wuhan, China. Table 6.8, Linde/Union Carbide Corp. Table 7.1, International Atomic Energy Agency (I.A.E.A.). Table 7.4, A.E.C.L. Table 7.13, A.E.C.B. Table 7.14, A.E.C.L. Fig. 7.1, Based on data from I.A.E.A. Fig. 7.5, Atomic Industrial Forum/Nuclear Energy Institute. Fig. 7.6, Fig. 7.7, Fig. 7.8, Fig. 7.9, A.E.C.L. Fig. 7.10, H. Inhaber, Energy Risk Assessment, With permission from Gordon & Breach Sci. Publ. NY (1982) © OPA (Overseas Publishers Association NV). Fig. 7.11, E.P.R.I. (Electric Power Research Institute) Journal (1976). Fig. 8.4, Fig. 8.5, Fig. 8.7, Fig. 8.8, Texaco Inc. *Lubrication* **67** #1 (1981). Fig. 8.2, Fig. 8.3, Fig. 8.9, J. Hickman and K. Middleton, Some Surface Chemical Aspects of Lubrication, *Advancement of Science*, June (1970) British Association for the Advancement of Science, London. Table 9.3, Fig. 9.2, Fig. 9.3, Fig. 9.4, Fig. 9.5, Fig. 9.6, Y. Sugie et al., Characteristics in Electrochemical Machining for Various Steels, *Denki Kagaku*, **46** 147 (1978) with permission from the Electrochemical Society of Japan. Table 9.8, In part from E.P.R.I. Journal, Oct. (1976). Chapter 10, Cartoon, *Science Dimension* **14** 12 (1983) N.R.C. (Ottawa). Fig. 10.3, Y. Waseda and K. T. Aust, Review. Corrosion Behavior of Metallic Glasses, *J. Material Sci.* **16** 2338 (1981) With permission from Chapman & Hall Publ. Table 11.5, Table 11.6, Table 11.7, Fig. 11.9, with permission from General Electric, Schenectady, NY. Fig. 11.4, W. Watt, Production and Properties of High Modulus Carbon Fibres. *Proc. Roy Soc. London* **A319** 8 (1970), British Crown Copyright/Defence Evaluation and Research Agency, reproduced with permission of the Controller, Her (Britannic) Majesty's Stationery Office and the Royal Society of London. Fig. 11.10, Cadillac Plastics. Fig. 12.2, Witco Corp. Fig. 15.3 and Fig. 15.4, H. V. Thurman, *Introductory Oceanography*, 8th Edition, © 1990, Reprinted by permission of Prentice-Hall Inc., Upper Saddle River, NJ, 07458. Fig. 15.8, Delta Engineering (Ottawa). Fig. 15.1, Fig. 16.1, Mir Publ. Moscow. Table 16.2, Fig. 16.2, J. D. Birchall, A. J. Howard and K. Kendall, New cements— inorganic plastics of the future, *Chemistry in Britain*, Dec. (1982) The Royal Society of Chemistry. Table 16.3, Fig. 16.6, Corning Glass Works. Fig. 16.5, Reprinted with permission from American Machinist (1997)— A Penton Publication. Fig. 16.8, Michelin North America (Canada) Inc. Fig. B.4, Fig. B.5, Fig. B.6, Union Carbide Corp. Table B.1, C.R.C. Handbook of Chemistry and Physics, 71st Edition. (1990–91).

**Applied Chemistry: A Textbook
for Engineers and Technologists**

Energy: An Overview

1.1. INTRODUCTION

World energy pundits have long proclaimed that the fossil fuels in the Earth's crust are limited and will be exhausted some day. This argument is similar to the accepted pronouncements of cosmologists that "the entropy of the Universe is increasing towards a maximum" or that "the sun will one day burn itself out." The world energy crisis of 1973 was precipitated when OPEC curtailed oil production and fixed their own price for oil for the first time, and within a year the price of oil went from about \$1.20/bbl to about \$10/bbl. This was aggravated by the increase in oil imports to the USA, which ceased to be self-sufficient in oil in the late 1960s. The present world price for oil is about \$30/bbl (after reaching a maximum of about \$40/bbl and dropping to less than \$15/bbl) and it is expected to eventually increase again. The price of oil will depend on demand as well as the financial needs of the oil producers. The successful development of alternate energy sources, e.g., fusion, could bring the price down to \$5/bbl. Since energy is an integral part of every function and product from food (which requires fertilizer) to plastics which are petroleum based, to steel or other metals which require energy for extraction, beneficiation, reduction and fabrication, worldwide inflation can be directly attributed to the rising price of oil.

An illustration of the importance of energy to the economy of a country is shown in Fig. 1.1, where the annual Gross National Product (GNP) of a country is plotted against the total annual energy consumed by that country per unit population. Some small anomalies are apparent but in general the higher the GNP* of a country the larger is its per capita energy consumption. Energy is essential to progress and there is no substitute for energy. Society's use of energy has continuously increased but sources have invariably changed with time. This is illustrated in Fig. 1.2.

It is interesting to note (see Fig. 1.3) that the per capita use of commercial energy for UK and USA has been essentially constant for 100 years whereas that for Germany, Russia, and Japan showed an exponential growth (doubling time of 12 years) towards the constant US/UK values. The effect of the world's population growth on energy usage is obvious.

Energy can conveniently be classified into renewable and nonrenewable sources as shown in Fig. 1.4. Such a division is quite arbitrary and is based on a time scale which distinguishes hundreds of years from millions. The world's reserve supply of oil is

*The Gross National Product (GNP) is the sum total of the market value of goods and services produced per annum for final consumption, capital investment or for government use.

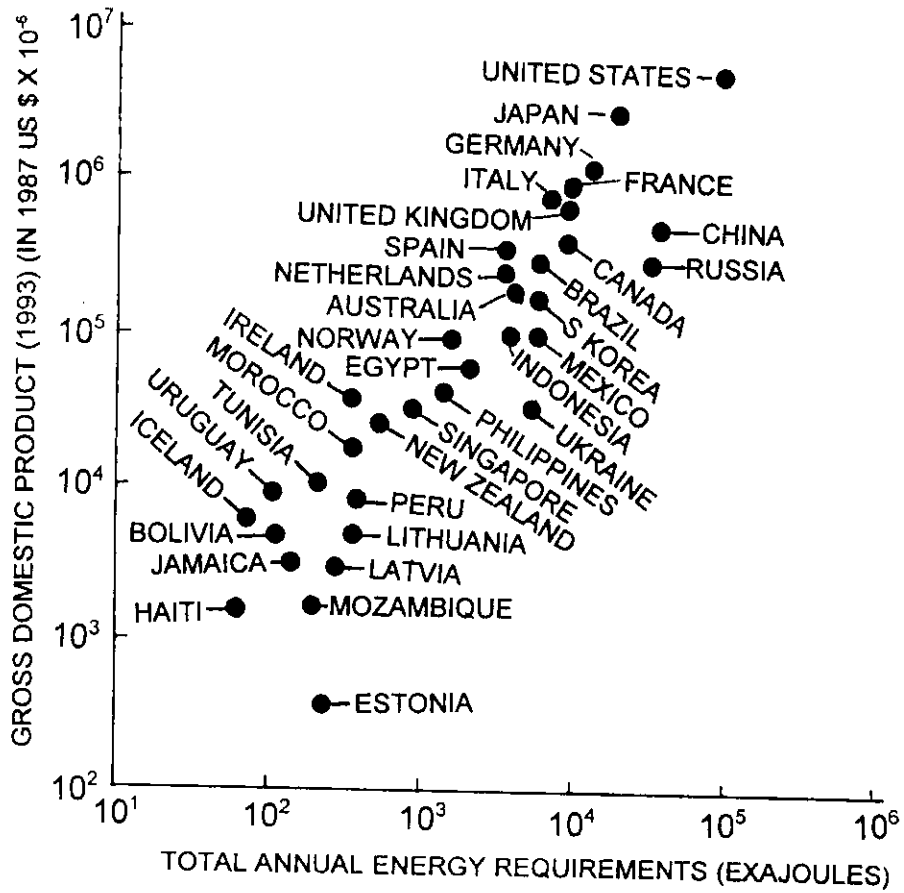


FIGURE 1.1. Relationship of GNP to energy available per capita in 1994 for various countries.

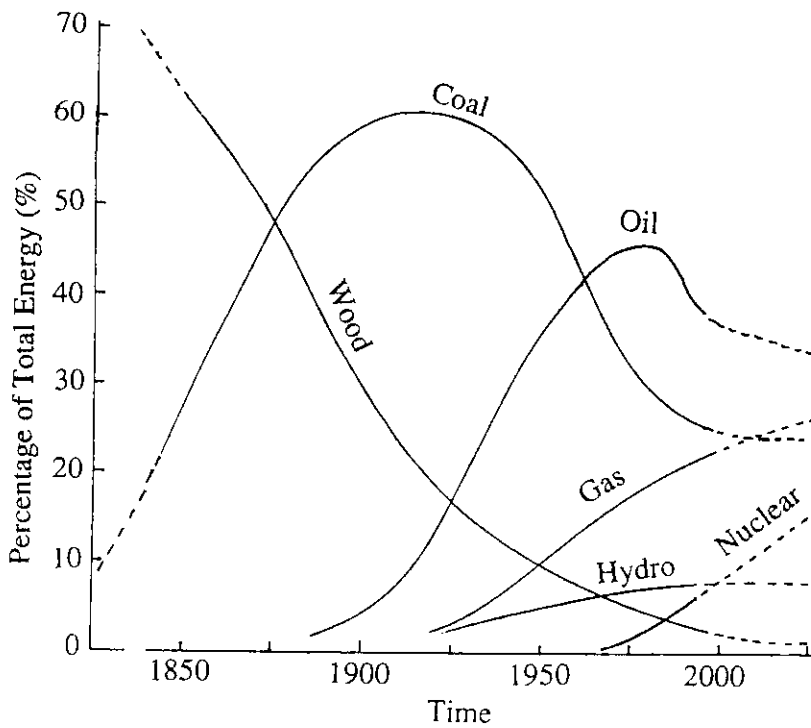


FIGURE 1.2. The changing patterns of world energy consumption as a percentage of total usage.

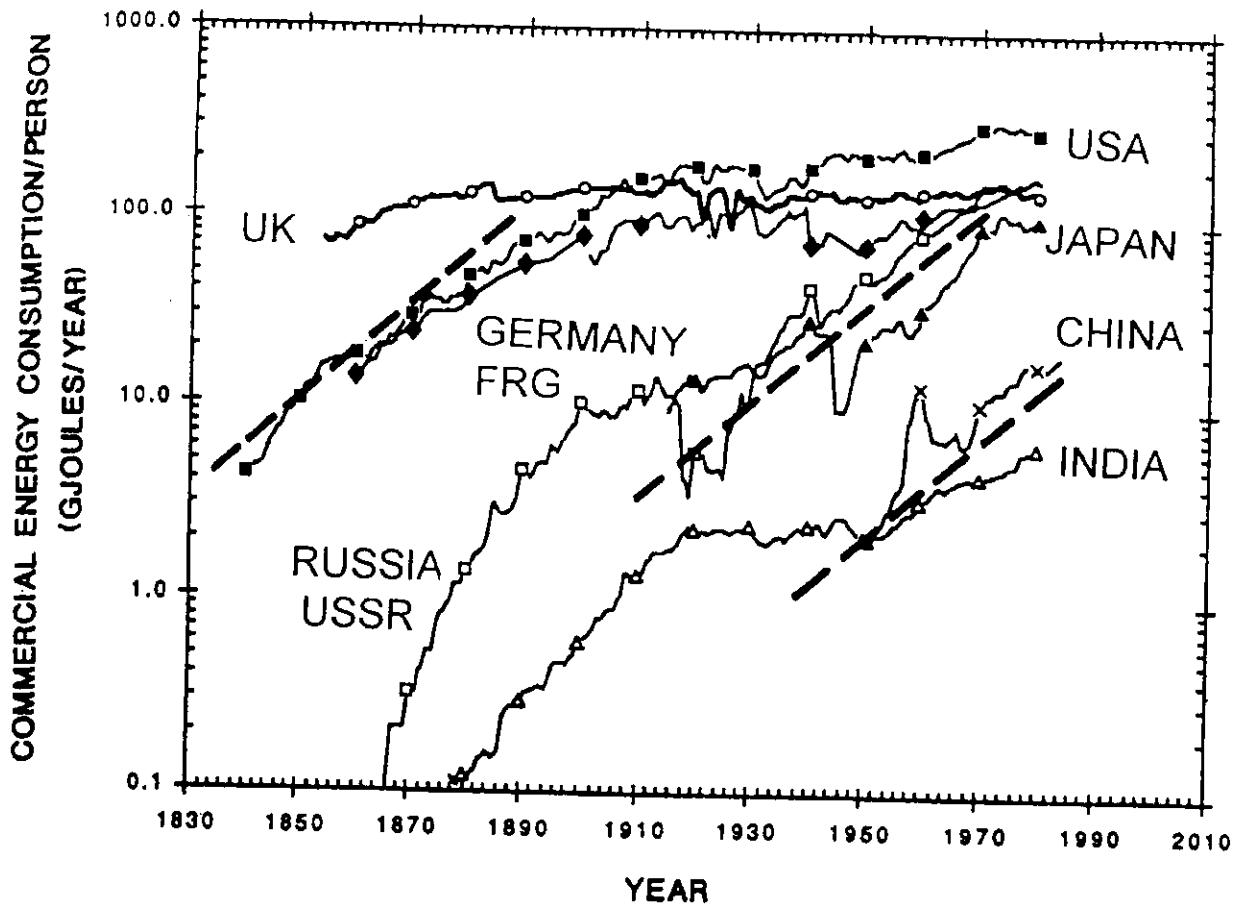


FIGURE 1.3. The commercial (industrial) energy consumption per capita in Gigajoules per person per year is plotted (note logarithmic scale) as a function of time.

estimated at about 5.8×10^3 Quads and that of natural gas at about 5.1×10^3 Quads (see Table 1.1). Oil and gas production has still been slowly rising with oil production expected to peak in 2035. Gas production is expected to peak by 2050 and so will last slightly longer, assuming that more oil and gas resources are made available. Coal is the major fossil fuel on earth and consists of over 75% of the available fossil fuel energy (see Table 1.1). Recent world energy consumption is given in Table 1.2.

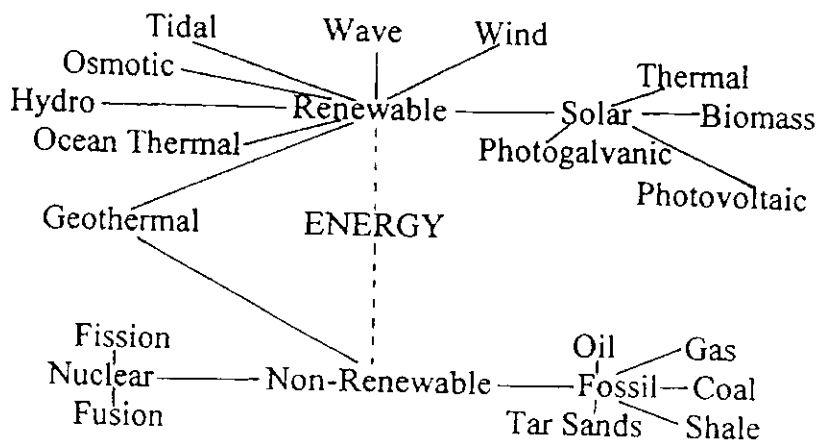


FIGURE 1.4. A classification of energy sources.

TABLE 1.1
World Reserves of Fossil Fuels in Quads (1998)

Area	Natural Gas	Oil	Coal
North America	297	395	7900
Latin America	221	430	660
Western Europe	166	110	2755
East Europe, CIS	1950	355	8000
Africa	350	425	1870
Middle East	1723	3770	5
Australia, Far East	430	290	8910
Total	5137	5775	30,100

Conservative considerations of our energy consumption predict that coal will supply 1/4 to 1/3 of the world's energy requirements by the year 2050. Its use can be relied upon as an energy source for about another 200 years; however, other considerations (such as the greenhouse effect and acid rain) may restrict the uncontrolled use of fossil fuel in general and coal in particular.

The increase in use of fossil fuel during the past few decades has resulted in a steady increase in the CO₂ concentration in the atmosphere. This is shown in Fig. 1.5. In 1850 the concentration of CO₂ was about 290 ppm and by the year 2025 the estimated concentration will be about double present values (350 ppm) if fossil fuels are burned at the present rate of 5 Gton of C/year. By the year 2025 the world's energy demands will have increased to over 800 Quads from 250 Quads in 1980. If a large fraction of this energy is fossil fuel, i.e., coal, then the annual increase in the concentration of CO₂ in the atmosphere is calculated to be greater than 10 ppm.

The CO₂ in the atmosphere is believed to have an adverse effect on the World's climate balance. The atmosphere allows the solar visible and near ultraviolet rays to penetrate to the earth where they are absorbed and degraded into thermal energy, emitting infrared radiation which is partially absorbed by the CO₂, water vapor and other gases such as CH₄ in the atmosphere (see Fig. 1.6).

There is at present a thermal balance between the constant energy reaching the earth and the energy lost by radiation. The increase in CO₂ in the atmosphere causes

TABLE 1.2
World Consumption of Energy by Sources in 1986, 1995, and 1997 (Quads)

	1986	%	1995	%	1997	%
Oil	126.6	40.4	141.1	38.9	148.7	39.3
Coal	86.3	27.5	77.5	21.4	92.8	24.6
Natural gas	62.3	19.9	93.1	25.7	83.9	22.2
Hydroelectric energy	21.3	6.8	25.7	7.2	26.6	7.1
Nuclear energy	16.3	5.2	23.2	6.4	24.0	6.3
Renewable sources	0.7	0.2	1.6	0.4	1.8	0.5
Total	313.5	100	362.2	100	377.8	100

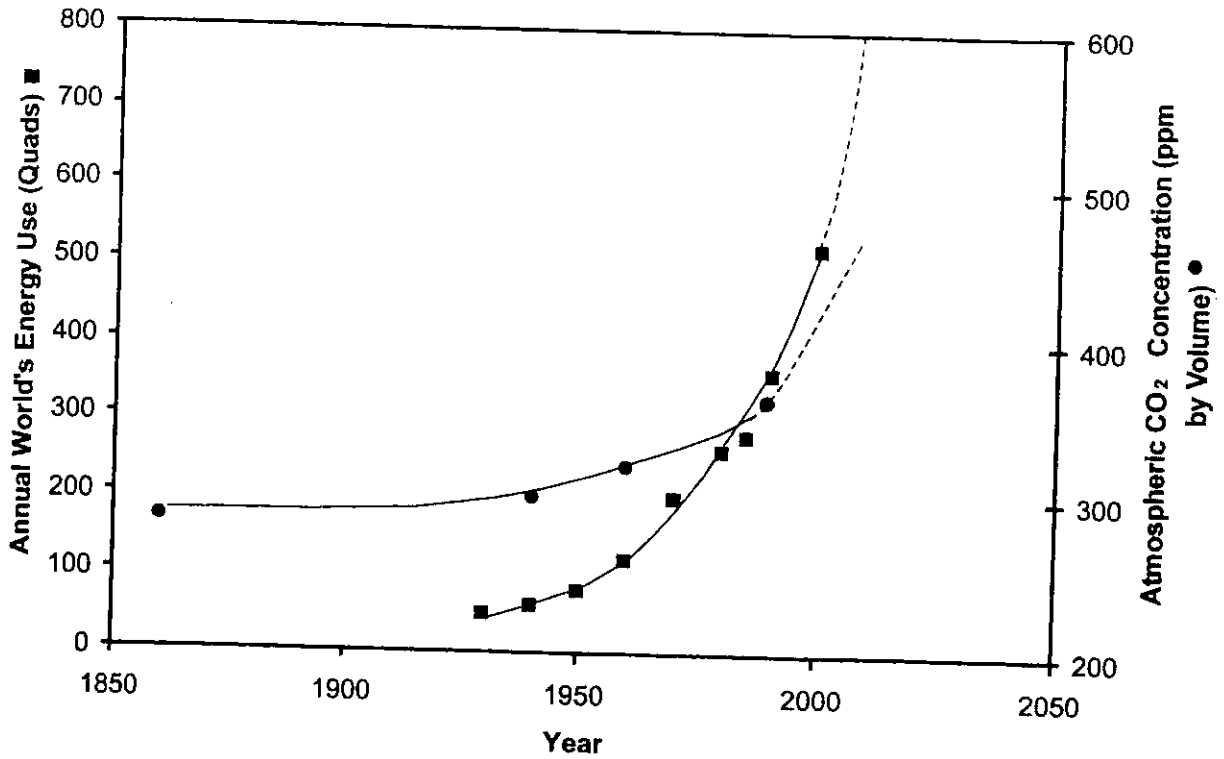


FIGURE 1.5. The concentration of carbon dioxide in the earth's atmosphere as a function of time (●) and a plot of the total annual world's energy use against time (■). The extrapolated values are speculative and subject to large errors.

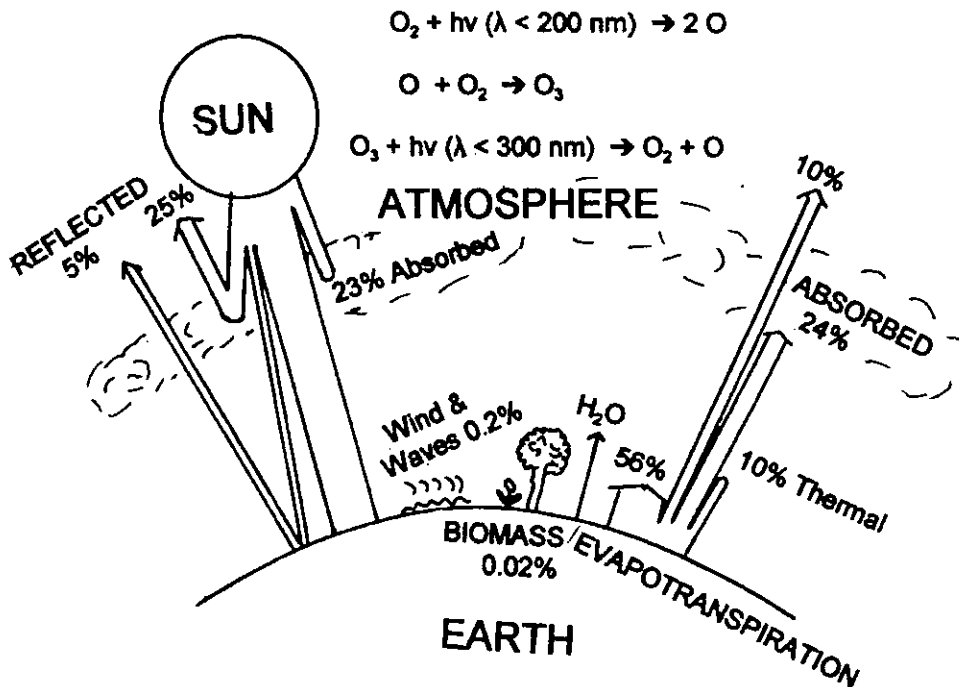


FIGURE 1.6. The Greenhouse Effect—A Schematic Representation. The CO₂ and other greenhouse gases, such as CH₄, absorb infrared radiation and become vibrationally excited. The excitation energy is then degraded into heat (kinetic energy).

an increase in the absorption of the radiated infrared from the earth (black body radiation) and a rise in the thermal energy or temperature of the atmosphere. This is called the *greenhouse effect*. Temperature effects are difficult to calculate and estimates of temperature changes vary considerably, although most agree that a few degrees rise in the atmospheric temperature (e.g., 3°C by the year 2025) could create deserts out of the prairies and convert the temperate zones into tropics, melt the polar ice caps and flood coastal areas. For example, for a 1°C rise in the earth's temperature the yield of wheat would be expected to drop by 20%, though rice yields might rise by 10%. If the average temperature of the oceans increased by 1°C, the expansion would cause a rise in sea level of about 60 cm (assuming no melting of glacier ice).

One uncertain factor in the modelling and predictions is that there is a lack in a material balance for CO₂, i.e., some CO₂ is unaccounted for indicating that some CO₂ sinks (i.e., systems which hold or consumed CO₂) have not been identified. The oceans and forests (biomass growth) consume most of the CO₂ and it is possible that these sinks for CO₂ may become saturated or on the other hand some new sinks may become available. With such uncertainties it is obvious that reliable predictions cannot be made. However, the climate changes which will occur as the CO₂ concentration increases are real and a threat to world survival. Recent measurements by satellites of the temperature of the upper atmosphere over a ten-year period have indicated no overall increase in temperature. This measurement has yet to be confirmed.

Coal is considered the "ugly duckling" of fossil fuel as it contains many impurities which are released into the atmosphere when it is burned. An important impurity is sulfur which introduces SO₂ and SO₃ into the atmosphere, resulting in acid rain that can actually change the pH of lakes sufficiently to destroy the aquatic life. The acid rain is also responsible for the destruction of the forests in Europe and the eastern parts of Canada and USA. The clean conversion of coal to other fuels may circumvent the pollution problems but would not overcome the greenhouse effect since CO₂ ultimately enters the atmosphere.

Thus, the depletion of fossil fuels may not be soon enough and tremendous efforts are being made in the search for viable economic alternatives such as nuclear energy, or renewable energy such as solar, wind, tidal, and others.

1.2. RENEWABLE ENERGY SOURCES

Ultimate sources of renewable energy are the earth, which gives rise to geothermal energy, the moon, which is responsible for tidal power, and the sun, which is the final cause of all other—hydro, wind, wave, thermal, and solar photodevices. A brief discussion of each source is essential for an overall appreciation of the difficulties we are facing and possible solutions to our energy requirements.

1.3. GEOTHERMAL

Thermal energy from within the earth's crust is classified as geothermal energy. At depths greater than 10 km the temperature of the magma is above 1000°C and is a potential source not yet fully exploited. The temperature of the earth's core is about

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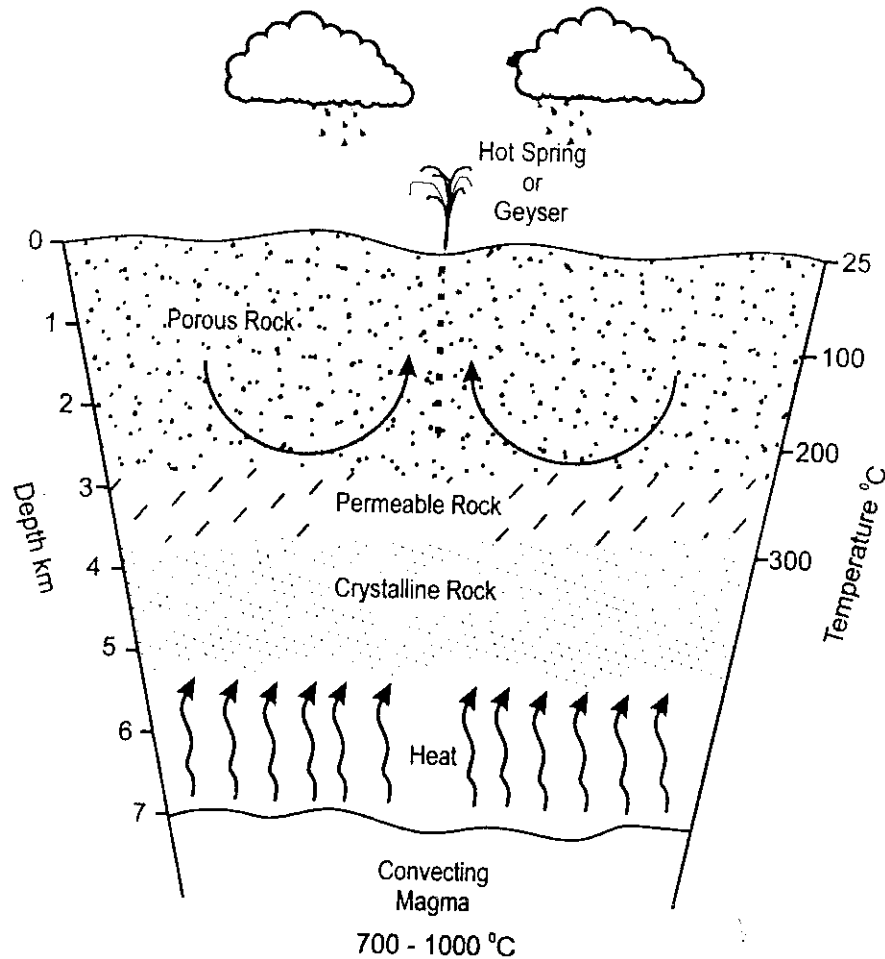


FIGURE 1.7. Schematic representation of Geothermal Energy.

4000°C. Drilling to depths of 7.5 km is presently possible and may some day reach 15 to 20 km. The surface source of thermal energy is due to the decay of natural radioactive elements and to the frictional dissipation of energy due to the movement of plate tectonics. The heat is usually transmitted to subsurface water which is often transformed into steam that can force water to the surface. Old Faithful at Yellowstone National Park, WY, USA, is an example of a geyser erupting 50 m every hour for 5 min (see Fig. 1.7). Geothermal energy is exploited near San Francisco where a 565 MW power plant is run on geothermal steam and 15 MW of thermal energy from hot water reservoirs is used for heating and industrial heat processes. At present there are five geothermal plants in operation in Mexico with a total output of more than 500 MW. Similar uses of geothermal energy have been developed in Italy, Japan, Iceland, USSR, and New Zealand, and it is rapidly being exploited in many other parts of the world.

It has been estimated that the geothermal energy in the outer 10 km of the earth is approximately 10^{23} kJ or about 2000 times the thermal energy of the total world coal resources. However, only a small fraction of this energy would be feasible for commercial utilization. Estimates of geothermal energy presently in use and converted into electrical power is about 2×10^3 MW. The greater use of geothermal energy could help save much of our energy needs and would reduce the rate of increase of CO_2 in the atmosphere.

1.4. TIDAL POWER

Tidal power is believed to have been used by the Anglo Saxons in about 1050. Tidal power is a remarkable source of hydroelectrical energy. The French Rance River power plant in the Gulf of St. Malo in Brittany consists of 24 power units, each of 10 MW. A dam equipped with special reversible turbines allows the power to be generated by the tidal flow in both directions (see Fig. 1.8).

Several tidal projects have been in the planning stages for many years and include the Bay of Fundy (Canada-USA), the Severn Barrage (Great Britain), and San Jose Gulf (Argentina). Though tidal power is reliable, it is not continuous, and some energy storage system would make it much more practical. However, as the price of fossil fuels rises, the economics of tidal power becomes more favorable.

1.5. SOLAR ENERGY

The Sun is approximately 4.6×10^9 years old and will continue in its present state for another 5×10^9 years. The Sun produces about 4×10^{23} kJ/sec of radiant energy, of which about 5×10^{21} kJ/year reaches the outer atmosphere of the earth. This is about 15,000 times more than man's present use of energy on earth. We are fortunate however that only a small fraction of this energy actually reaches the earth's surface

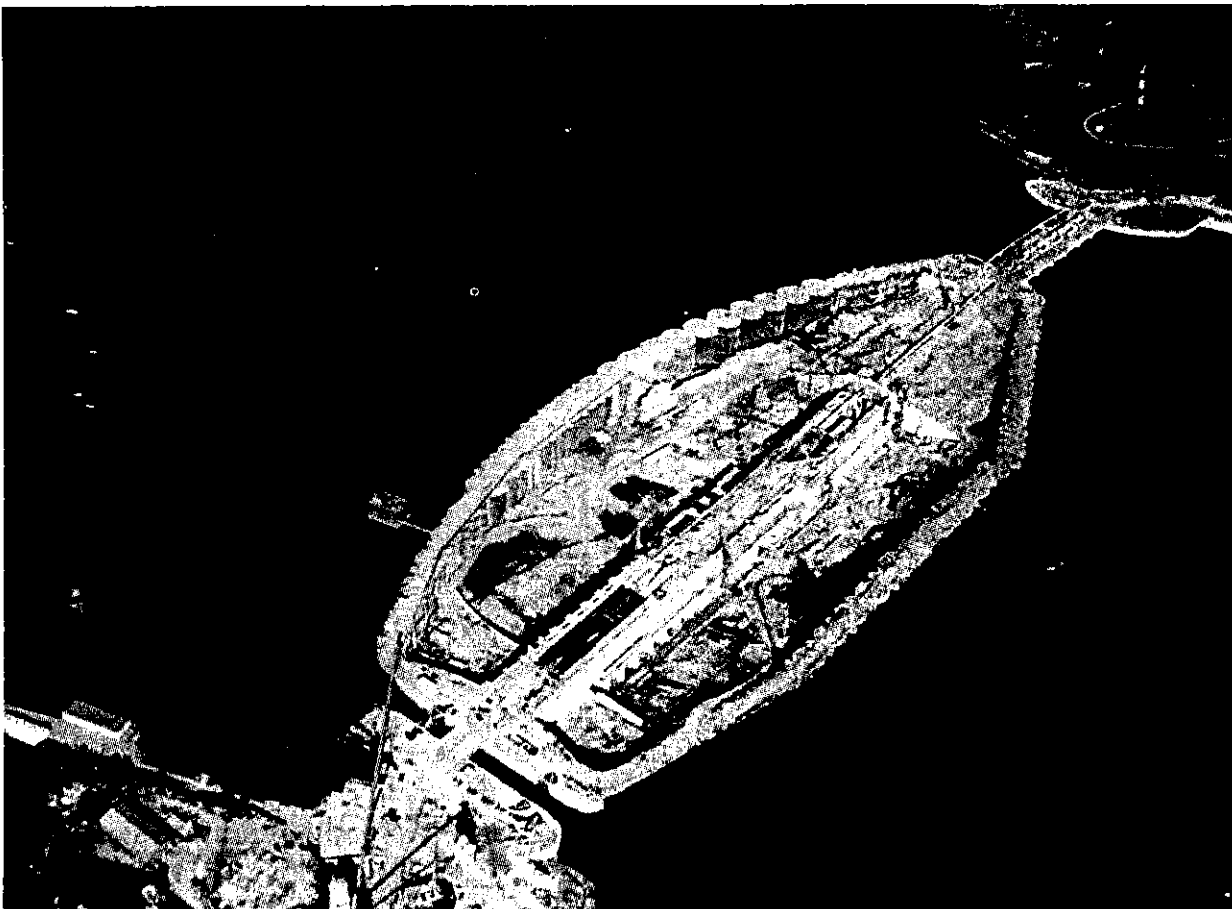


FIGURE 1.8. An aerial view of the dam during construction of the Rance Tidal power plant.

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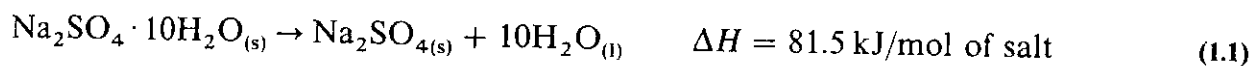
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(see Fig. 1.6). About 30% is reflected back into space from clouds, ice, and snow, about 23% is absorbed by O_2 , O_3 , H_2O , and upper atmosphere gases and dust, and about 47% is absorbed at or near the earth's surface and is responsible for heating and supporting life on earth. Of the energy absorbed by the earth about 56% is used to evaporate water from the sea and plants (evapotranspiration). Another 10% is dissipated as sensible heat flux. The remainder is radiated back into space, about 10% into the upper atmosphere and about 24% is absorbed by our atmosphere. A small but important fraction of the Sun's energy, about 0.2%, is consumed in producing winds and ocean waves. An even smaller fraction, 0.02%, is absorbed by plants in the process of photosynthesis of which about 0.5% of the fixed carbon is consumed as nutrient energy by the earth's 6×10^9 people. The variation in solar intensity reaching the Earth due to its elliptical orbit about the Sun is only 3.3%. The production of fixed carbon by photosynthesis is about 10 times present world consumption of energy by human society. Thus, solar energy is sufficient for man's present and future needs on earth. The main difficulty is in the collection and storage of this energy.

Solar energy can be utilized directly in flat bed collectors for heating and hot water, or concentrated by parabolic mirrors to generate temperatures over 2000°C . The thermal storage of solar energy is best accomplished with materials of high heat capacity such as rocks, water, or salts such as Glauber's salt, which undergo phase changes, e.g.,



(The transition temperature for Glauber's salt is 32.383°C).

Solar energy can also be directly converted into electrical energy by photovoltaic and photogalvanic cells, or transformed into gaseous fuels such as hydrogen by the photoelectrolysis or photocatalytic decomposition of water.

The Sun consists of about 80% hydrogen, 20% helium, and about 1% carbon, nitrogen, and oxygen. The fusion of hydrogen into helium, which accounts for the energy liberated, can occur several ways. Two probable mechanisms are:

The Bethe mechanism: (1939)	<u>Q(MeV)</u>
$^{12}\text{C} + ^1\text{H} \rightarrow ^{13}\text{N} + \gamma$	1.94
$^{13}\text{N} \rightarrow ^{13}\text{C} + e^+ + \nu$ ($t_{1/2} = 9.9 \text{ min}$)	1.20
$^{13}\text{C} + ^1\text{H} \rightarrow ^{14}\text{N} + \gamma$	7.55
$^{14}\text{N} + ^1\text{H} \rightarrow ^{15}\text{O} + \gamma$	7.29
$^{15}\text{O} \rightarrow ^{15}\text{N} + e^+ + \nu$ ($t_{1/2} = 2.2 \text{ min}$)	1.74
$^{15}\text{N} + ^1\text{H} \rightarrow ^{12}\text{C} + ^4\text{He}$	<u>4.96</u>
$4 ^1\text{H} \rightarrow ^4\text{He} + 2e^+ + 2\nu$	24.68
$2e^+ + 2e^- \rightarrow 2\gamma$ ($+2 \times 1.02$)	<u>2.04</u>
Total energy	<u>26.72</u>
The Salpeter mechanism: (1953)	<u>Q(MeV)</u>
$^1\text{H} + ^1\text{H} \rightarrow ^2\text{H} + e^+ + \nu$	0.42
$^2\text{H} + ^1\text{H} \rightarrow ^3\text{He} + \gamma$	5.49
$^3\text{He} + ^3\text{He} \rightarrow ^4\text{He} + 2^1\text{H}$	<u>12.86</u>
$4 ^1\text{H} \rightarrow ^4\text{He} + 2e^+ + 2\nu$	24.68

Both reactions occur, though the Bethe mechanism requires a higher temperature and therefore predominates in the central regions of large stars.

The solar constant is $2.0 \text{ cal/cm}^2 \text{ min}$ or 1370 W/m^2 above the earth's atmosphere and about 1.1 kW/m^2 normal to the Sun's beam at the equator. At other latitudes this value is reduced due to the filtering effect of the longer atmospheric path. Two maps shown in Fig. 1.9 indicate the world's distribution of solar energy in July and January at sea level. The spectral distribution is given in Fig. 1.10 where the black body radiation from the earth is also shown.

Ideal sites for solar energy collection are desert areas such as one in northern Chile which has low rainfall (1 mm/year) and 364 days/year of bright sunshine. The Chile site ($160 \times 450 \text{ km}^2$) receives about $5 \times 10^{17} \text{ kJ/year}$ ($1 \text{ kJ/m}^2/\text{hr} \times 60 \text{ min/h} \times 8 \text{ h/day} \times 365 \text{ day/year} \times 72,000 \text{ km}^2 \times 10^6 \text{ m}^2/\text{km}^2$). This is about a third of the world's use of energy in 1995. Thus, theoretically the desert areas or nonarid lands could be used to supply the world with all its energy requirements and there is no doubt that before the next century has passed solar energy will probably dominate a large portion of the world's energy sources.

Figure 1.4 shows the subclassification of solar energy into thermal, biomass, photovoltaic and photogalvanic. The most familiar aspect of solar energy is the formation of biomass or the conversion of carbon dioxide, water and sunlight into cellulose or food, fuel and fiber. Thus, wood was man's major fuel about 200 years ago to be displaced by coal, the modified plants of previous geological ages. Wood is a renewable energy source but it is not replenished quickly enough to be an important fuel today. A cord of wood is 128 ft^3 ($8' \times 4' \times 4'$) of stacked firewood. It is not recognized as a legal measure. A cord contains about 72 ft^3 of solid wood or about 4300 lb to which must be added about 700 lb of bark or a total of about 5000 lb, varying with the wood and its moisture content. The thermal energy of wood is from 8000 to 9000 Btu/lb. It has been argued that biomass used for fuel is not practicable because it displaces land which could be used for agriculture—a most essential requirement of man whose nutritional demands are continuously increasing. This objection is not valid if the desert is used, as in the case of the Jojoba bean which produces an oil that has remarkable properties, including a cure for baldness, lubrication, and fuel.

Plants which produce hydrocarbons directly are well known—the best example is the rubber tree which produces an aqueous emulsion of latex—a polymer of isoprene (mol. wt. $2 \times 10^6 \text{ D}$) (see Fig. 1.11). The annual harvest of rubber in Malaysia was 200 lb/acre/year before World War II but by improving plant breeding and agricultural practices, the production has increased to 10 times this value.

Melvin Calvin, Nobel prize winner in Chemistry in 1961 for his work on the mechanism of photosynthesis, has been one of the principal workers in the search for plants which produce more suitable hydrocarbons, e.g., a latex with a mol. wt. of 2000 Daltons which can be used as a substitute for oil. One plant he has studied, *Euphorbia* (*E. Lathyris*) yields, on semiarid land, an emulsion which can be converted into an oil at about 15 bbl/acre. Another tree, Capaiba, from the Amazon Basin, produces an oil (not an aqueous emulsion) directly from a hole drilled in the trunk about 1 m from the ground. The yield is approximately 25 L in 2 to 3 hours every 6 months. This oil is a

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