PN-AAM-386

ISN 45987

Resource Assessment

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Training in Alternative Energy Technologies Program

3rd Session, May 1981

University of Florida

Gainesville, Florida, USA

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1. Acknowledgements

1.1 We would like to extend our appreciation to Drs. Farber, Pagano, Rajvanshi, Kusumowardhoyo and the rest of TAET staff for their assistance in researching and preparing the report.

1.1.1 In the course of this training program and preparation of this report, we concluded that assessment of national renewable resources with intention to develop these resources to substitute for imported fuels be considered as a priority energy policy objective in all the oil importing developing countries.

Resource Assessment

2. Executive Summary

The net oil importing developing countries (OIDCs) are definitely using a non-appropriate technology. This is not due to the fact that petroleum is non-renewable or expensive (petroleum is yet one of the cheapest sources of energy), but because the OIDCs are heavily dependent on an imported source of energy for which they have insufficient foreign exchange to pay, and what is worse, they lack the political power to ensure a continuous supply of this petroleum.

Many of these countries are spending excessively large proportions of their export revenues, in some cases approximately 50 percent, on imported petroleum. Some countries use petroleum as the source of energy for nearly all their transportation, in major industry and agriculture, and generating electricity. The OIDCs are permanently menaced by economic collapse, and subsequent social turmoil.

From this gloomy but realistic picture, the conclusion is: decreasing the dependence on imported petroleum is the greatest national problem of these countries, if they have to survive as independent nations. For the OIDCs it is not important if the world petroleum resources will finish in the year 2000 or 2020. For them, from the economic viewpoint, the foreign petroleum resources finished in 1973!

Decreasing and, if possible, elimination of this reliance on imported energy can be achievable by many different approaches, and each country must ascertain the most appropriate approach for its particular situation. Broadly, the most important are:

(A) Prospecting for, and exploitation of non-renewable national sources of energy;

(B) Assessment and utilization;

(C) Efficient use of existing systems, and measures of energy conservation;

(D) Control of energy demand.

This report covers parts of b, c and d from the viewpoint of the OIDCs. It is a first draft and very incomplete due to the relatively short time available for its preparation.

(A) Prospecting For and Exploitation of Non-Renewable Sources of Energy

The most important sources of non-renewable energy are: petroleum, natural gas, coal and uranium. Naturally, the best substitute for imported petroleum is national petroleum. Consequently, exploration for petroleum in the OIDCs must have the highest priority. The 1973 petroleum price increase improved the economic potential of petroleum resources in many countries in that the resources which were considered uneconomic prior to 1973 can now be economically exploited through the utilization of sophisticated and previously expensive exploration and production technologies such as off-shore drilling. However, petroleum exploration requires large capital investment, expertise and skilled personnel, software and equipment, all of which are not readily available in the majority of the OIDCs. There are relatively few companies in the world with petroleum exploration and production capabilities. The governments of the OIDCs within the framework of their energy policies have to decide whether or not to negotiate with these companies.

The increase in petroleum prices pushed up the prices of all other fuels, for instance coal. The coal deposits that were considered uneconomical to exploit in the sixties, in the present economic environment can be mined economically. Coal can substitute the heavier fractions of

petroleum used in many countries to produce electricity and process heat in industry.

Nuclear generation of electricity is a good option for countries that consume large quantities of electricity (above 500 megawatts) generated from petroleum fired plants, on the consideration they are endowed with national uranium deposits. The purchasing of nuclear reactors and fuel processing plants can be negotiated between the particular OIDC and developed countries in current usage of nuclear electricity such as U.S.A., U.S.S.R., Canada, European countries and others.

(B) Assessment and Utilization of Renewable Sources of Energy

The predominant renewable sources of energy are: (i) hydro (ii) biomass (iii) solar (thermal and photovoltaics) (iv) wind (v) geothermal (vi) OTEC, hydrogen, tidal and wave.

(i) Hydro

Many developing countries have unexploited hydro potential that can produce electricity at competitive costs today, both large scale and small scale (mini-hydro). Site evaluation is critical with hydro as river flow rates vary throughout the year on a seasonal basis.

(ii) Biomass

This term, biomass, covers a broad spectrum of biologically based energy forms, such as energy plantations, agricultural residues, forests, rural and municipal organic residues, etc. The utilization of these resources for energy production is environmentally and economically practical in many cases, but there is inconclusive evidence regarding the energy balances of many of these systems, in particular energy plantations and the production of alcohol. Whether or not countries with high population densities will utilize land for energy instead of food is a question

that will have to be answered by the individual countries. Nevertheless, small scale biomass energy systems such as biogas, gasification, and charcoal will have increasing application in the near future. Large scale projects should be implemented in cases where appropriate crops are chosen and mechanization is kept to a minimum, as in the case of alcohol production in Brazil.

(iii) Solar

(a) Thermal: The utilization of flat plate collectors for low temperature (<80°C) requirements is feasible for many applications today, including domestic hot water, agricultural drying and space heating. High temperature applications which require concentrating devices are not competitive today due to the high cost and unreliability of the systems. The collection of reliable data for solar insolation may be accomplished fairly easily and most countries already have some information available at local airports and weather bureaus.

(b) Photovoltaics: Photovoltaic devices for producing electricity directly from sunlight is cost competitive today only in small applications, where the sites are distant from existing power lines. As the cost of petroleum increases and the cost of production of the photovoltaic cells comes down, more widespread applications for large power generating systems are foreseen.

(iv) Wind

The production of small amounts of mechanical and electrical power using windmills is a proven, cost competitive technology. However, the production of significant amounts of electricity from large windmills is not a proven technology. Wind energy is very site specific in nature and careful site analysis is required before such systems are installed.

(v) Geothermal

The utilization of geothermal energy for power generation is a well developed technology, and provides a cheap source of energy. Geothermal energy is expected to find increasing applications for the production of domestic hot water, process heat in industry and air heating as more low temperature fields are discovered. Geothermal fields are very much dependent on local geological conditions, and extensive site surveys should be conducted before wells are drilled.

(vi) Others: (a) OTEC (b) Hydrogen (c) Tidal and Wave

(a) OTEC: This is a very interesting concept that offers great potential for the generation of large quantities (>100 MW) of electricity very cheaply. OTEC is most suited to countries with coastlines in the tropical seas, but the technology is still in the early stages of development.

(b) Hydrogen: At present hydrogen is not a competitive technology due to the high production costs. However, it offers great potential as a concentrated source of energy that is virtually non-polluting.

(c) Tidal and Wave: Both of these technologies have the potential to produce sizeable quantities of electricity, but the technologies still need to be developed and their applications are limited to those countries with coastlines.

(C) Efficient Use of Existing Systems and Measures of Energy Conservation

Increasing the engineering and economic efficiency of existing systems and adopting measures of energy conservation can reduce the energy consumption in a very short term (one to two years) without high capital investment, and these measures can produce very positive effects on the

economy. Some estimates indicate that a reduction of energy consumption on the order of 20 - 25 percent is achievable with measures of conservation and efficient uses of energy.

Many systems and equipment, until recently, were designed to maximize productivity with little attention paid to their energy consumption efficiency, as in the cement, textile and iron industries.

In many countries certain fractions of petroleum such as diesel, kerosene and others, are subsidized and their prices are artificially low such that the consumers are not encouraged to conserve energy. In the domestic sector, properly designed educational programs can produce positive results.

Successful reductions of energy consumption by efficient use of existing systems and conservation measures are achievable through pricing and incentive policies, combined with educational programs.

(D) Control of Demand

This is the fastest method for reducing the energy consumption, but indiscriminate cuts of energy can penalize the more efficient users that sometimes fail to absorb such cuts, and subsequently affect the economy adversely. Before deciding on reductions, a careful auditing program must be developed to identify in each sector of the economy those segments that are inefficient energy users.

3 Technical Assessment of Renewable Resources

3.1 Solar

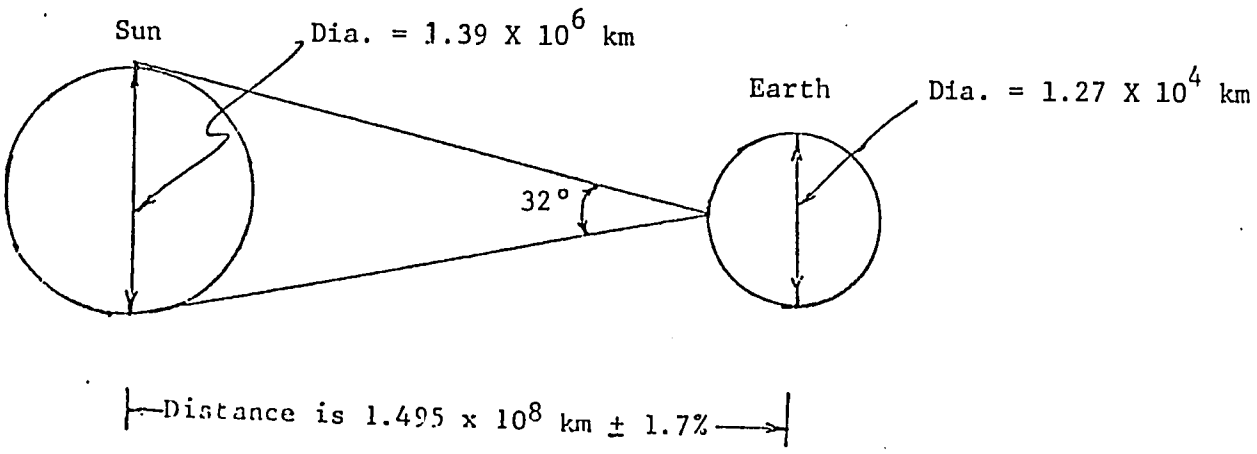
Solar Energy has, for more than 300 years now, been recognized to be a potential source of energy and power. Essentially inexhaustible, it could supply a considerable portion of the world's energy needs through appropriate conversion processes, with quite a minimum impact on the environment.

The challenge that has faced man then is the development of practical and economical ways of harnessing and converting solar irradiance to usable forms of energy, both directly and otherwise. Efforts have since been and still are being concentrated towards the achievement of such endeavors. Today, solar energy technology has gone a long way. Conversion techniques have continuously been improved, simpler and more appropriate processes, developed.

For communities with a paradox of energy, it seems a necessity to consider solar energy in its various forms as an alternate energy source. To do this, however, one must have a full understanding of the nature of the sun and the flows of its natural energy which provides for human needs. The following discussion then tries to discuss solar energy, the direct conversion processes involved to transform it into usable forms, its limitations, and its environmental effects. As there are numerous forms of solar energy, this section would only touch on direct utilization of the sun's heat. Other energy forms such as wind, biomass, OTEC, etc. would be discussed in other chapters of the report.

Availability of Solar Energy

The sun-earth relationship, given in Figure 3.1.1. below, shows the various characteristics of the sun and its spatial relationship to the earth:



Solar constant, I_{SC} = 1353 watts $(meter)^2$ + 1.5%

Figure 3.1.1 Sun-Earth Relationship

Solar energy, which is the energy emitted from the sun, reaches the earth's atmosphere as electromagnetic radiation in the spectral band from 0.12 to 100 μm. Of this, 8.7% is in the ultraviolet spectrum below 0.40 μm; 38.15% is in the visible region between 0.40 and 0.70 μm, with the peak intensity at 0.48 μm. The remaining 53.1% is in the infrared region between 0.70 and 100 μm, with less than 1% of the energy at wavelengths exceeding about 3.3 μm.

At sea level, the attenuation caused by the atmosphere eliminates virtually all of the ultraviolet shorter in wavelength than 0.3 μm and all the infrared beyond 2.5 μm. Thus, 7.55% of the clear day terrestial radiation (at air mass 1) is in the ultraviolet below 0.4 μm, and 44.7% is in the infrared as shown in Figure 3.1.2. (As the air mass increases, the peak intensity shifts towards the red portion of the spectrum.) It is then this clear day terrestial radiation which could be captured and directly

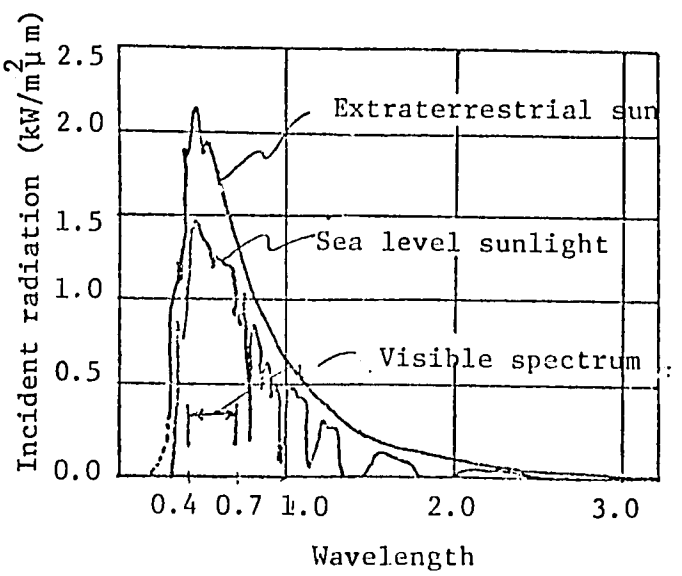


Figure 3.1.2. The intensity of solar radiation of various wavelengths reaching the earth's atmosphere (extraterrestial sun) and reaching the earth's surface (sea-level sunlight). Dips in the the ground-level radiation are due to energy absorption by oxygen, ozone, water vapor, and carbon dioxide in the air.

converted to useful work through the use of appropriate energy conversion systems. A solar constant, which is the energy received from the sun per unit time, on a unit surface area perpendicular to the radiation at the average sun-earth distance outside of the atmosphere has been measured to be about 1353 w/m^2, with an estimated error of + 1.5%.

Solar radiation may generally be classified as direct and diffuse. Direct radiation are those which are received from the sun without any change of direction while diffuse radiation are those whose direction has been changed due to reflection and scattering by the atmosphere. Depending on the type of conversion systems to be used, these two radiant energy forms may be measured through the use of instruments which could convert them to some of their energy form and then provide a measure of the energy flux which the radiation has produced.

Solar Radiation Measurements

In the design and planning of appropriate, economically competitive and efficient energy conversion systems, there is little doubt that solar energy technologists must have a knowledge of the amount of solar radiation falling on the earth's surface at anytime. Moreso, the kinds of radiation measurements and the accuracies needed to satisfy the requirements of solar systems is necessary. At present, however, the availability of such proper information is very limited thus creating a barrier to the wide use of solar systems.

Generally, the best possible way to determine the amount of usable solar energy at a particular site is to take measurements for several years. In fact, this may be the only way to get accurate site-specific data; however, this usually is not practical. The other approach may then be to use someone else's collection of solar data for a nearly (and similar) location and for consult the following stations:

- local airports or weather service
- local utility companies
- nearby college or universities
- state or provincial government
- national weather service
- World Meteorological Organization (WMO), Geneva, Switzerland

For the above stations, however, most of the solar radiation data are "clear day" values and does not take into account the effect of clouds. In determining the true level of insolation at a particular site, this local variation in cloud cover and atmospheric moisture and dust may be very important. Thus, local climate data are needed to correct the measured

values of clear day insolation for atmospheric conditions. Today, a number of stations have already been making daily records of the percentage of possible sunshine and the hours of sunshine, both of which gives measurements of the fraction of time between sunrise and sunset that the sun is bright enough to cast shadows, and the mean cloud cover, which is the average fraction of sky cover by clouds for a particular day or month. An example of existing records of such radiation measurements are given in Table 3.1.1 and Figure 3.1.3.

As we can see, several radiation data can be made available in several forms. Information important in the understanding and use of these data should, however, be provided. To obtain the most useful and relevant data, therefore, a knowledge of the different radiation instruments and methods of observation would be most vital.

Currently, there are basically two types of solar radiation measuring instruments commonly being used -- the pyranometer and the pyrheliometer. Some other useful devices, which may be of some importance for other solar systems, are also being employed, and are thus discussed to some limited extent.

TABLE 3.1.1

WORLDWIDE SOLAR RADIATION DATA

(Monthly averages of the total solar radiation on a horizontal surface for various cities in the world measured in cal/cm^2 day. Monthly averages of the hours of sunshine per day and percent of possible sunshine given when available.

SOURCE: G.O.G. Lof et al. World Distribution of Solar Radiation Report #12. Univ. of Wisconsin, Madison Wisconsin, 1966

STATION	LATITUDE	LONGITUDE	J	F	M	A	M	J	J	A	S	O	N	D	AN
Brazil															
Rio Grande	32°02'S	52°06'W	(600)* 8.7 (62%)	(540) 8.0 (60%)	(440) 7.0 (57%)	(350) 6.4 (57%)	(260) 5.6 (53%)	(220) 5.0 (49%)	(220) 4.7 (45%)	(290) 5.1 (46%)	(330) 4.6 (39%)	(480) 6.8 (54%)	(570) 8.3 (60%)	(620) 9.0 (63%)	(41 6. (54
Salvador	12°56'S	38°31'W	8.4	8.0	7.6	7.0	6.1	6.3	6.1	7.2	7.3	7.7	7.6	8.0	7.
British Guiana (Guyana)															
Georgetown	7°45'N	58°04'W	(390)	(430)	(440)	(450)	(410)	(400)	(440)	(470)	(490)	(460)	(420)	(370)	(43
Sri Lanka															
Batticaloa	07°43'N	81°42'E	(440) 56%	(510) 75%	(550) 83%	(540) 78%	(540) 83%	(510) 72%	(520) 73%	(530) 75%	(540) 79%	(500) 71%	(470) 68%	(420) 54%	(50 72
Colombo	06°51'N	79°52'E	(470) 70%	(530) 81%	(550) 84%	(530) 69%	(490) 64%	(470) 54%	(490) 59%	(500) 61%	(520) 67%	(480) 58%	(480) 73%	(460) 67%	(49 67
Taiwan															
Taipe	25°02'N	12P31'E	186	216	261	312	381	393	400	412	341	340	296	225	31
Ghana															
Accra	5°36'N	0°10'W	360 6.8	435 7.2	483 7.0	497 7.2	480 6.8	386 5.2	364 4.5	371 4.5	418 5.7	469 7.0	460 8.0	401 7.6	42 6.
India															
Delhi	28°40'N	77°15'E	(360) 7.7 (74%)	(430) 8.2 (74%)	(510) 8.2 (70%)	(580) 8.7 (68%)	(630) 9.2 (68%)	(610) 7.9 (56%)	(500) 6.0 (43%)	(500) 6.3 (47%)	(450) 6.9 (55%)	(480) 9.4 (81%)	(400) 8.7 (81%)	(350) 8.3 (81%)	(48 8. (67

TABLE 3.1.1 (CONTINUED)

WORLDWIDE SOLAR RADIATION DATA

STATION	LATITUDE	LONGITUDE	J	F	M	A	M	J	J	A	S	O	N	D	ANN
Kenya															
Nairobi	01'18'S	36°45'E	558	595	559	486	416	397	324	366	464	492	486	522	472
Panama															
Albrook A'B	8°39'N	79°34'W	392	476	525	496	404	336	370	372	448	388	380	420	426
Philippines															
Quezon City	14°40'N	121°05'E	308	302	436	518	460	433	352	364	355	364	353	347	383
Thailand															
Bangkok	13°44'N	100°30'E	428	486	452	484	483	454	388	402	375	382	456	434	435
Egypt															
Giza	30°02'N	31°13'E	290	380	503	583	621	654	641	600	529	419	309	266	486

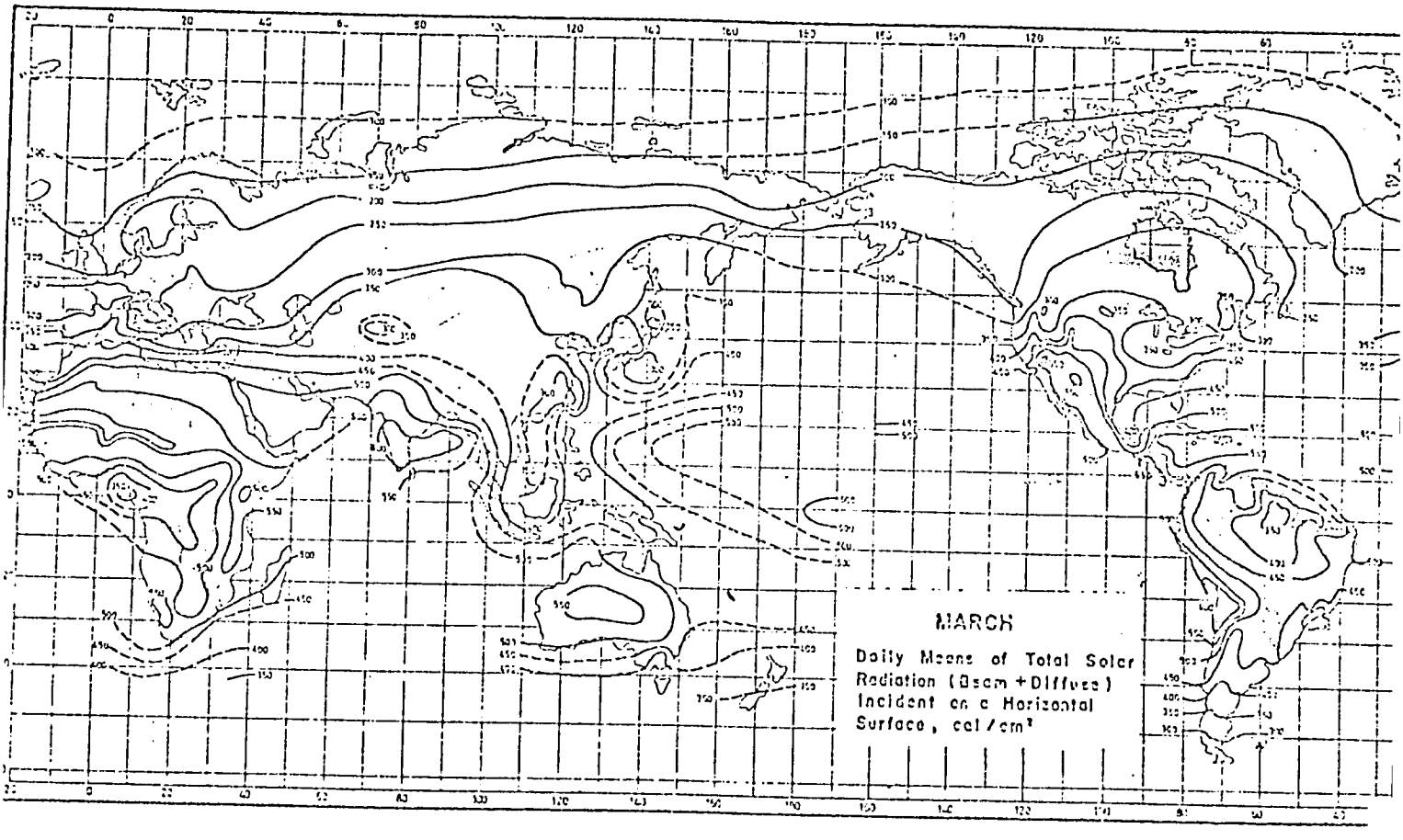


Figure 3.1.3. WORLDWIDE Solar Radiation Map. A Map of World Distribution of Solar Radiation Measured in Cal/Cm^2 Day on a horizontal surface for the month of March.

SOURCE: B. de Jong , Delft University Press, 1973

A. Pyranometers

Pyranometers are used to measure the total radiation (direct and diffuse) in energy per unit time per unit area, on a horizontal surface within its hemispherical field of view. The most common instruments of this type work based on the temperature difference between black surfaces (which absorb most of the solar radiation) and white surfaces (which generally reflects most solar radiation). This difference may be detected through the use of thermophiles, temperature-measuring devices consisting of thermocouples connected in series, which give millivolt signals that could readily be detected, recorded, and integrated over time. Usually calibrated in a horizontal position, errors may be produced if the pyranometer is used at some angles. Some manufacturers, however, have measured such effects and could thus provide corrections at various tilt angles.

Eppley pyranometers, one of the most widely known instruments of the kind, are widely available in the market. It comes in various kinds and depending on user needs, he may prefer one type from the other. Two examples of the Eppley pyranometers are given below in Figure 3.1.4a and Figure 3.1.4b.

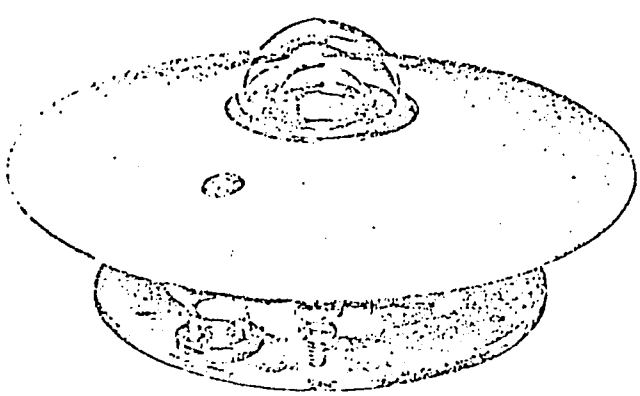


Figure 3.1.4a. The Eppley Precision Spectral Pyranometer

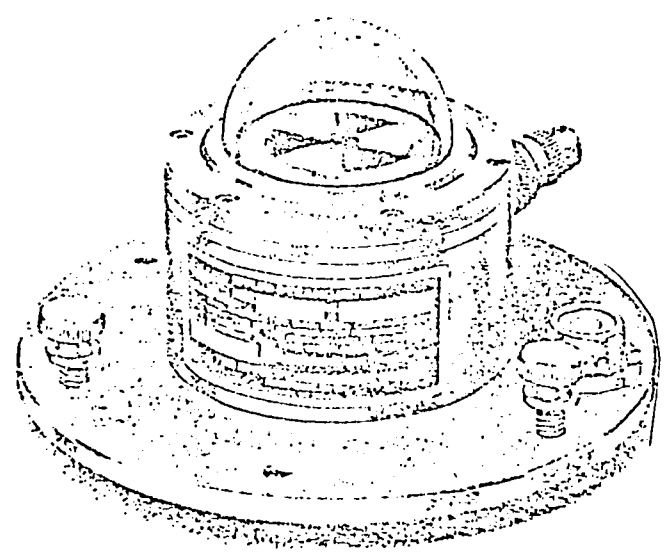


Figure 3.1.4b. The Eppley Black and White Star-Type Pyranometer

The Eppley Precision Spectral Pyranometer (PSP) uses a circular wire-wound multijunction thermophile developed by Eppley which is coated with a permanent Parsons-Eppley black lacquer. The sensing element is mounted under two removable precision-ground concentric hemispheres. It has a chromed brass stand with a white enameled guard disk which provides a hole through which the spirit level may be observed. The Eppley PSP's response time is about one second.

The Eppley Black and White Pyranometer uses three black (Eppley-Parsons permanent black) and three white (barium sulfate) segments. The thermophile is a newly developed radial wire-wound plate type with thermistor temperature compensation. The arc is a transparent precision- ground optical glass. The response time is usually three to four seconds. Orientation has no effect upon the instruments' output, since its segments are symmetrical.

B. Pyrheliometers

Pyrheliometers are used to measure the intensity of direct solar radiation at normal incidence. The most widely used pyrheliometer, the Eppley Normal Incidence Pyrheliometer (NIP), uses a multijunction thermophile mounted at the bottom of a brass tube, which is chrome-plated externally and blackened and diaphragmed internally. The ratio of the internal diameter of the tube to its length is 1 to 10, subtending an angle of 5.73°. The heat sink of the thermophile also contains a thermistor which compensates for the temperature dependence of the bismuth-silver wire and keep the response constant within ± 1 percent over the range of -20 to +40°C. The front flange of the instrument supports a rotatable disk with four appertures which can contain any three selected filters, while the fourth apperture is left open to permit the full spectral intensity to be measured. The sensitivity of the instrument is taken to be 4.7 millivolts per calorie/cm-min. The response time is one second.

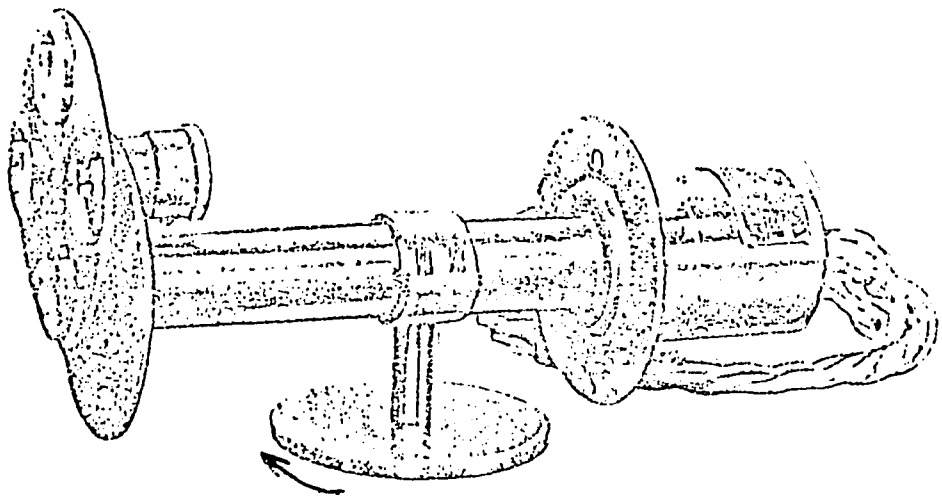


Figure 3.1.5. The Eppley Normal Incidence Pyrheliometer (NIP)

A normal incidence pyrheliometer must obviously "follow-the-sun" and so the front flange of the NIP has a small hole through which the sun's rays may pass to strike a clearly defined target on the rear flange when the alignment is correct. When the mounting is correctly adjusted for the local latitude and the declination corresponding to the date, the mounting will rotate precisely 15 degrees per hour to enable the instruments to track the apparent motion of the sun across the sky. Other pyrheliometers are also available and may be utilized depending on the system or user preference.

C. Photovoltaic Pyranometers

Photovoltaic pyranometers may be used such that silicon cells have short circuit currents in linear function with the incident radiation intensity. The inherent spectral sensitivity of silicon cells make them more responsive to the near infrared portion of the solar spectrum than to the visible ultraviolet, and this characteristic must be recognized when they are used as solar pyranometers. On a day long basis, however, it has been shown that their integrated output agrees within a few percentage with the output of thermophile pyranometers operating under the same conditions.

In addition, the use of a low resistance with negative temperature characteristics and in thermal but not in electrical contact with the cells virtually eliminates variation of cell output with changes in ambient temperature within the range encountered in actual practice.

D. Albedometers

Albedometers measure the amount of short wave radiation reflected by the ground immediately in front of the collector. This may also be significant since the reflectivity of the ground could increase the amount of short wave radiation received by the collector.

E. Pyrgeometers

Pyrgeometers measure the effective long wave outgoing radiation necessary to assess the amount of energy which a solar collector can lose by radiation during the night. Usually the net atmospheric radiation on a horizontal black surface facing upward is measured at the ambient air temperature.

F. Sunshine Recorders

Sunshine recorders are used to record the duration of bright sunshine during the day. Through this, calculation of global solar radiation can be made by the correlation of the radiation to the amounts of sunshine or clouds. Examples of these are the Campbell-Stokes Sunshine recorders.

G. Collectors of Solar Radiation

In general, solar collectors may be classified into focusing and non-focusing types. Non-focusing collectors, or flat plate collectors usually have a flat absorber surface which may or may not be covered by an optically transparent material. The absorber surface is usually coated a matt black to absorb as much of the solar radiation falling on the surface as possible. Maximum temperatures obtained with these collectors are in range 80-85°C, but although these temperatures developed are low, flat plate collectors absorb both direct and diffuse insolation and will operate on bright cloudy days. The energy collected is usually transported by a fluid which is generally water or air, and auxiliary pumps or fans may be used to move the fluid across the absorber plate. Figure 3.1.6 gives a picture of a typical flat plate collector.

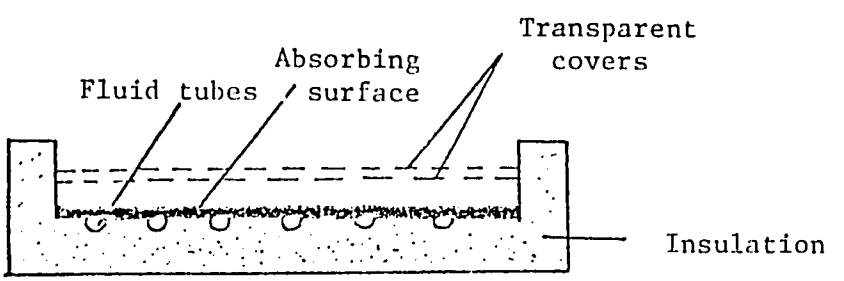


Figure 3.1.6. A Flat Plate Collector

Focusing collectors (or concentrators) focus direct solar radiation from a relatively larger area onto a receiver of much smaller area. These collectors usually consist of a concentrator, and a receiver-absorber. The concentrator, upon receiving the direct radiation from the sun, reflects and directs the radiation to the matt black receiver-absorber which contains a fluid medium to transport the energy absorbed. Due to this concentrating effect, these concentrators are capable of achieving temperatures in the range 200 - 3500°C, but they operate only on a direct beam radiation and require a tracking mechanism to "follow" the sun across the sky. Figure 3.1.7. shows various types of focusing collectors.

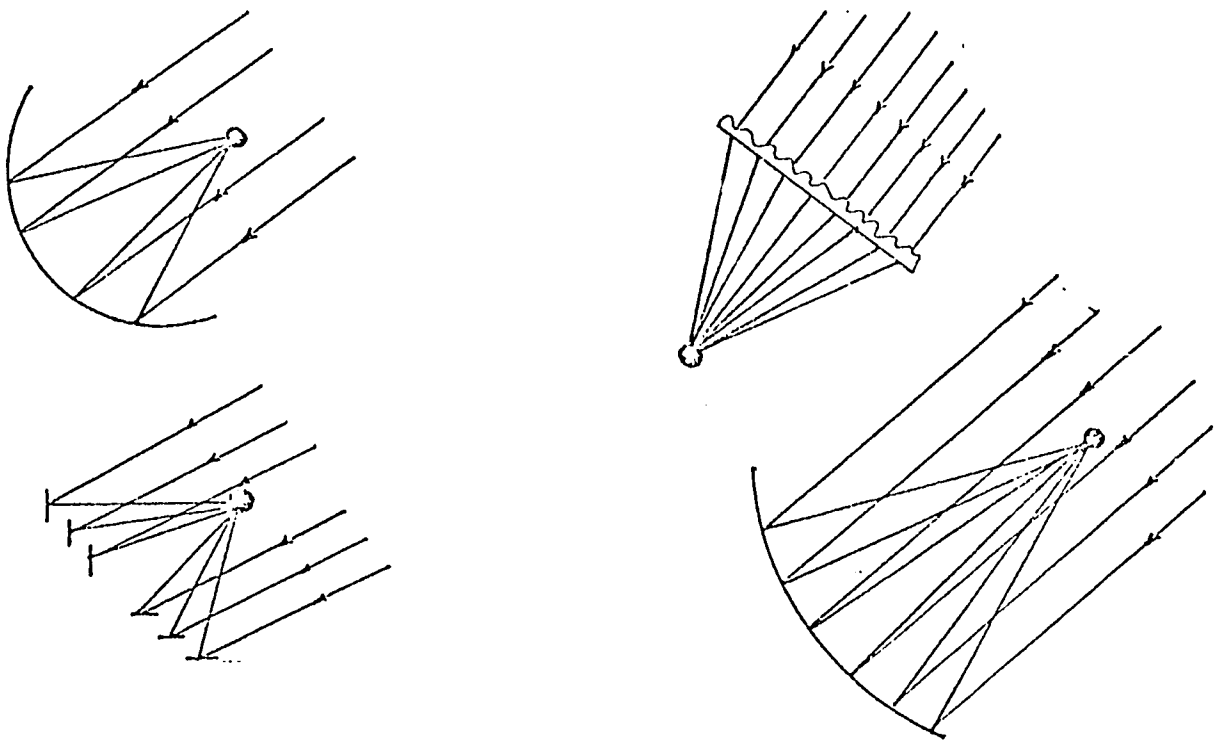


Figure 3.1.7 Focusing Collectors

Solar Energy Conversion Processes

A large number of processes are available for the conversion of both direct and diffuse radiation into usable forms of energy, each requiring different data measurements needed to assess the potential energy that the conversion system could utilize. These conversion processes have been classified and are discussed below:

A. Solar Thermal Conversion:

Probably the simplest method of harnessing solar energy is by solar thermal conversion systems that collect and utilize the sun's radiation in the form of heat. This heat or thermal energy then produced may be used in a variety of systems which require certain temperature ranges. Some of these systems may include water heating (≈ 100°C), and some industrial process heating (100 - 300°C). Today, solar water heating and air heating, particularly for agricultural applications, seem to be the most technologically and economically attractive solar energy applications.

Solar thermal conversion processes may be classified as either passive or active. As implied, passive systems utilize only natural energy flow and transfer heat, while active systems rely on external power sources to transport and distribute energy. Among solar thermal energy applications, passive solar heating and cooling systems have been regarded to be the most cost effective applications. Useful in any climatic conditions, the system would rely mainly on building designs to control solar energy flows.

For most present solar thermal systems, flat plate collectors are most commonly used. Solar radiation is absorbed by the collectors and the heat is subsequently transferred to a circulating fluid like air and water. The

thermal energy contained in the heated medium can then be used for service water heating and space heating or may be stored in rock, water or some other storage media for later use.

With active systems, solar water heating (Figure 3.1.8) has been proven to be presently competitive with electric heating for some areas in the world. Likewise, active space heating is already in wide use.

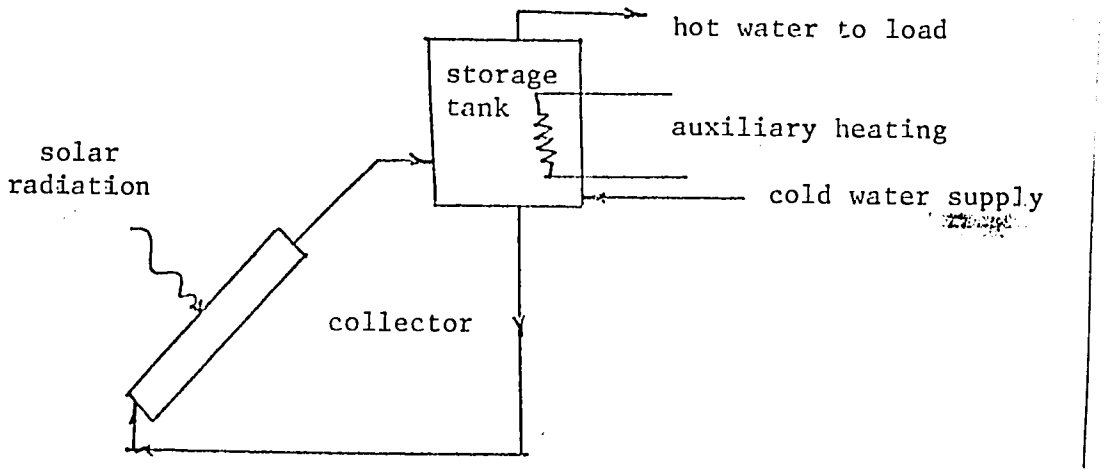


Figure 3.1.8 A Simple Solar Water Heating System

For tropical countries, space cooling may be a more important need than heating. Solar air conditioning/refrigeration, however, still needs to be developed and may, therefore, require some time before being of practical importance to man.

Another area where solar thermal energy systems can play a significant role is in providing process heat for agricultural applications. Grain drying (< 100°C), one of the most needed post-harvesting operations, can greatly utilize such systems. Other produce, such as fruits and other With the appropriate use of the resource, solar thermal systems could play such a significant part in the world's energy picture.

B. Solar Thermal Electric Conversion

Solar thermal electric systems use conventional steam turbine generators or heat engines to convert solar radiation to thermal energy and then to electricity (as shown in Figure 3.1.9). Aside from providing electricity, it could also provide mechanical energy in some systems, as in water pumping for irrigation purposes. This may be done through the use of heat engines that operate at intermediate temperature ranges (150°C for example). Irrigation systems would particularly be significant to the various rural areas of every country as this would contribute not only to the increased production of food, but also to the reduction of fossil fuel consumption.

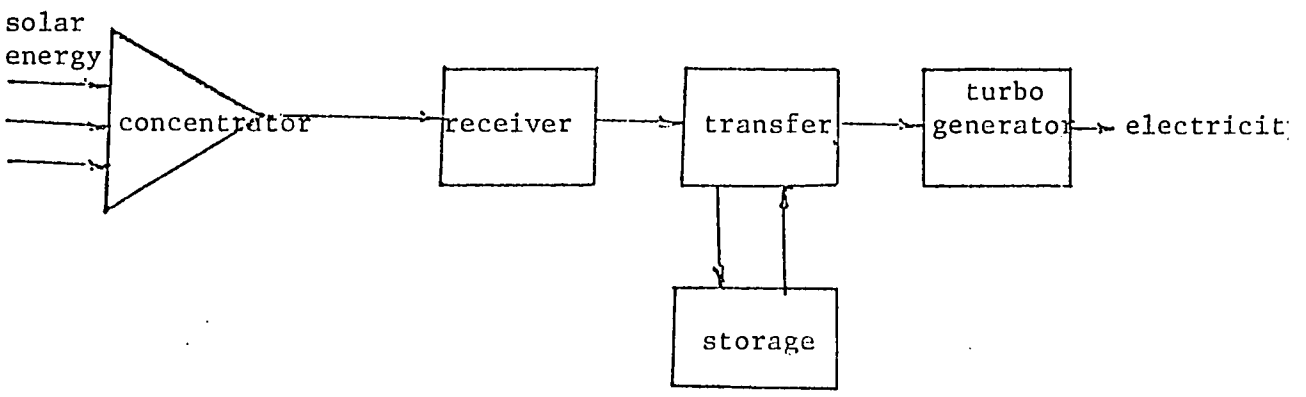


Figure 3.1.9 Thermal Electric Conversion Concept

Solar thermal electric systems have been built in a variety of scales, with smaller community scale applications holding considerable promise. It generally consists of two system types, both of which require the same basic elements. Solar collection conversion of solar to thermal energy, transport of thermal energy to a converter, thermal to electrical conversion, dispersal or use of rejected heat, and energy storage.

1. The distributed collector system (Figure 3.1.10) ia characterized by a large number of individual solar collectors (focusing, usually), each of

which collects and concentrates solar energy and converts it to thermal energy.

2. The central receiver system (Figure 3.1.11) is characterized by a large number of mirrors (heliostats) that reflect the solar energy to a single receiver mounted on a tall tower.

For both the above systems, the energy generated may be stored through thermal storage systems as in liquid metals or molten salts or pumped water storage. Solar thermal electric systems may hold some promise, but active development with government support is still needed.

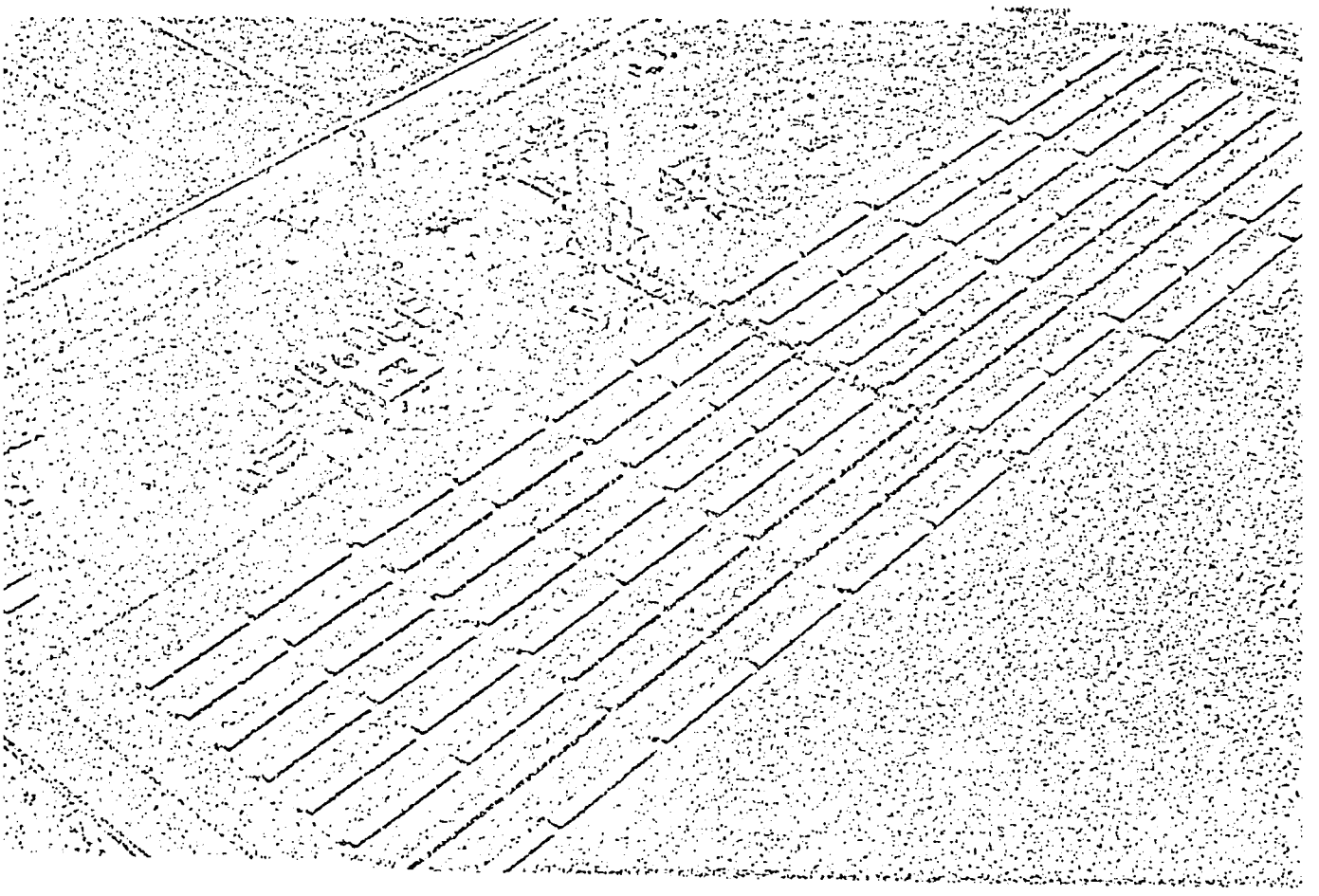


Figure 3.1.10, Distributed Collector System

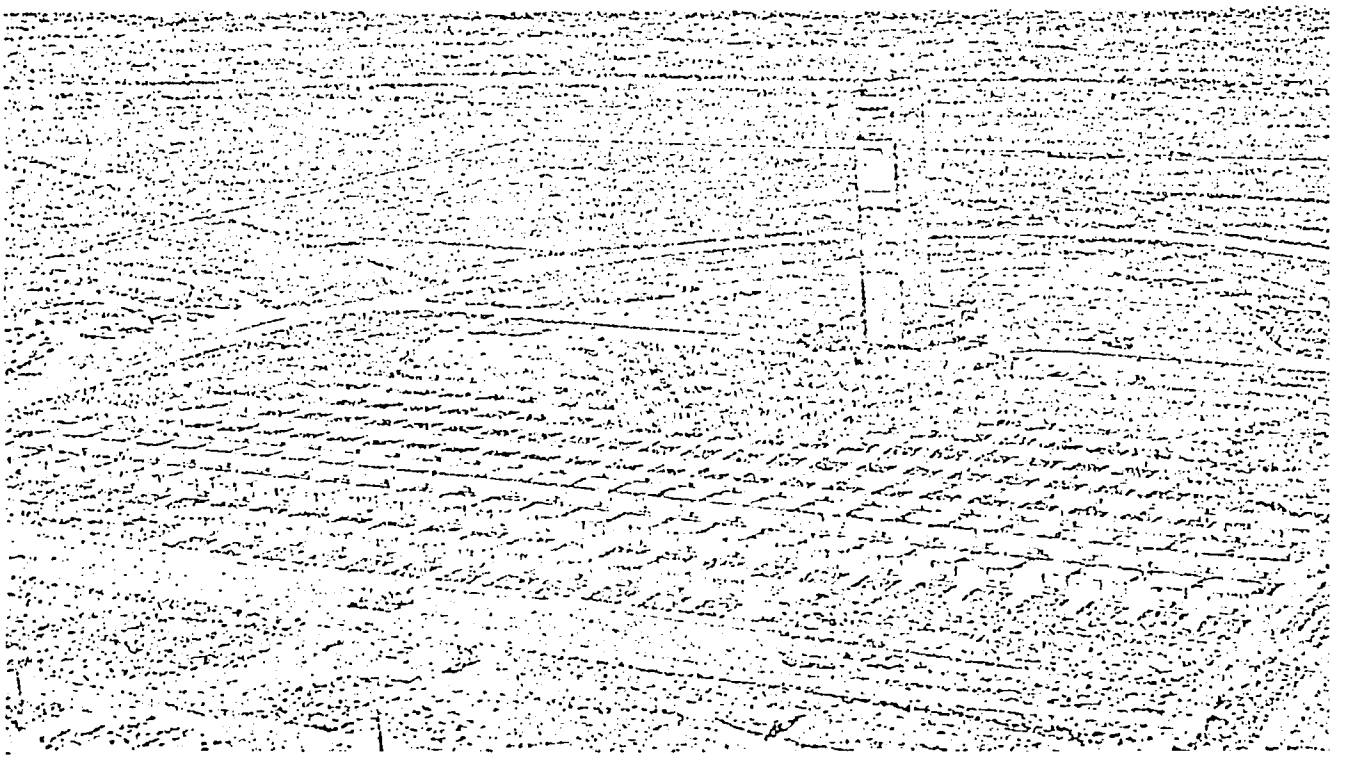


Figure 3.1.11 Central Receiver System

C. Photovoltaic Conversion

Photovoltaic cells, more commonly referred to as solar cells, are semiconductor devices which can convert sunlight directly to electricity.

In almost all present-day applications, these solar cells are fabricated from high-purity single crystals of the element silicon (Si), although other semiconducters such as amorphous silicon, and the compounds gallium arsenide (GaAs), cadmium sulfide (CdS) and cuprous sulfide (Cu_2S) are being considered as alternatives.

Most silicon solar cells are constructed by placing a layer of n-type silicon on to of a layer of p-type silicon (n-type and p-type silicons are created by doping molten silicon with trace amounts of boron and phosphorous, respectively). Since this results in the diffusion of the charge-carriers on both sides across the boundary between the layers, an electric field is created across it--this configuration is called a p-n junction. Other kinds of junctions are possible, including the schottley-barrier

junction (made of a semi-conductor and a thin metal film), the MIS junction (metal, insulator, semiconductor), and the hetero junction (made of two different semi-conductors).

When photons from the sun strike the surface of the solar cell and are absorbed by the silicon, some of them will have enough energy to create pairs of electrons and holes. If these newly created charged pairs are sufficiently close to the p-n junction, the electric field near the junction causes the charges to separate, and electrons move to the n-type side and the holes to the p-type side. If the two sides of the solar cell are now electrically connected, an electric current will flow in the external circuit as long as the sunlight is striking the cell as shown in Figure 3.1.12. This current produced may then be stored in storage batteries, after passing through a converter which will transform it from DC to AC electricity.

Current production of solar cells yield crystalline-silicon cells that have efficiences between 10% to 15%. The maximum possible theoretical value is about 23%, but experimental laboratory techniques have resulted in cells with only up to 18% efficiency.

Today the methods of fabrication of solar cells (Figure 3.1.13) are still very expensive and use large amounts of energy, time, and labor. Hence, the present art of silicon solar cells is still impractical for terrestial use.

Photovoltaic cells have a wide range of applications. As the cells produce electricity directly, they could power any system requiring such. Some of the more appropriate applications would be in the field of telecommunications as in radio relay stations, ground receiver stations, and radio and television transmitters. Others would be for use as signalling devices as in road warning lights, light houses, and radar stations, for use in

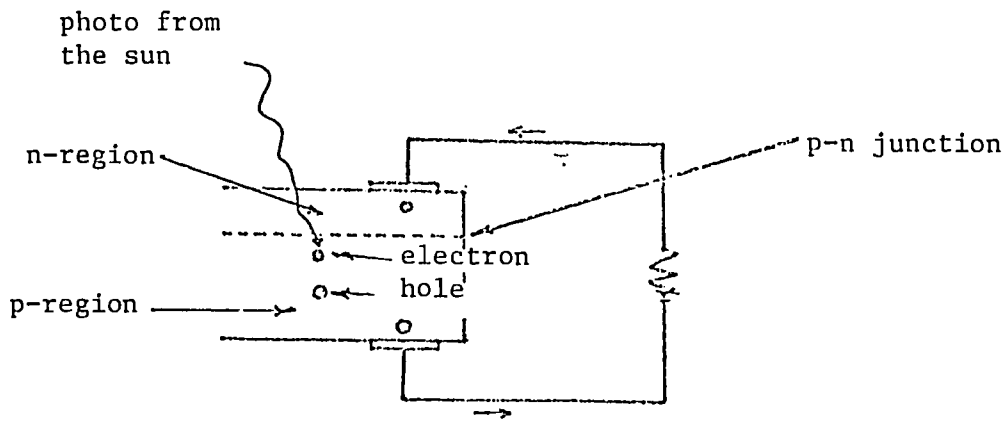


Figure 3.1.12. Schematic and Solar Cell Operation

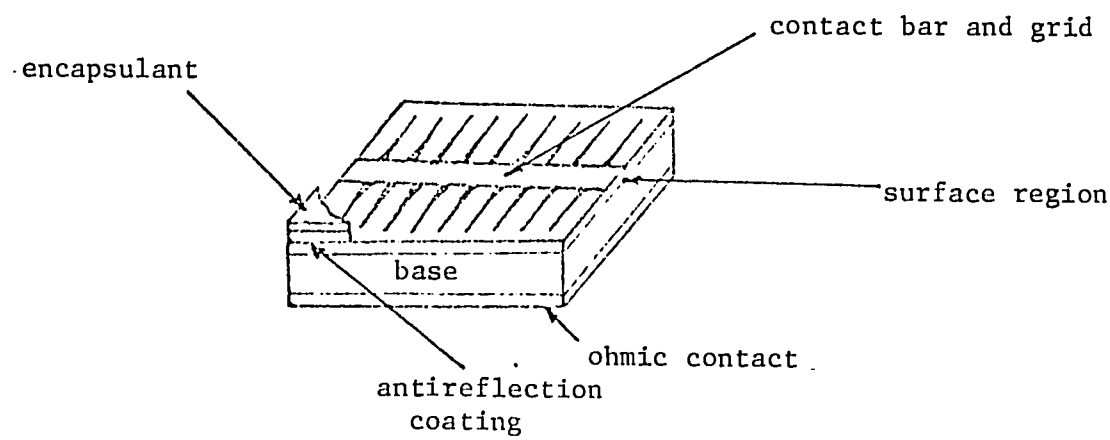


Figure 3.1.13. Schematic of a Typical Solar Cell

measuring stations as in weather stations and alarm systems, and for independent power supplies as in water pumps, water desalination and other energy needs in remote villages.

With the knowledge of the radiation measurement instruments and the conversion processes available to convert solar energy to useful forms, Table 3.1.12 is given, stating the data requirements for each system like temperature and collector types needed for each.

Limitations of Solar Energy

One of the first problems encountered in the design of solar energy systems is the low flux density of solar radiation falling on the earth's surface. In the case of large scale utilization, this makes it necessary to have large surfaces to collect solar energy. For this, the delivered energy becomes larger. One other problem is that the energy that could theoretically be provided by the sun to a surface is reduced by several factors, one of which is in the atmosphere. Approximately 25-50% of the energy is lost by scattering and absorption.

Another significant problem, especially with respect to large scale production of heat and power is the intermittency of solar radiation. Seasonal and daily variations in irradiance introduce some special problems with storage and energy distribution and this makes it a necessity to improve and develop these areas.

In the assessment of the prospect for using solar energy, it is particularly important to ascertain the application for which the unpredictable nature of the source will not introduce significant technical and economic problems. It is also a necessity that one recognize the fact that because of the peculiar characteristics of solar energy, it could not be relied upon

TABLE 3.1.12

TYPES OF SOLAR ENERGY CONVERSION AND THEIR DATA REQUIREMENTS

	TYPE OF MEASUREMENT	COLLECTOR	FREQ. & OBS.	TEMP. REQ.	STORAGE
1. Solar Thermal					
a. Space heating including hot water	inclined surface: derivable from total and direct insolation	flat plate; also supplementary focussing	hourly, daily, seasonal	<100°C	rock, water, others.
b. Space cooling	same as a plus long wave radiation for cooling to night sky	same as 'a'	same as 'a'	> 82°C	same as 'a'
c. Special purposes					
agricultural drying	total insolation	flat surface	daily, monthly or seasonal	<100°C	same as 'a'
solar distillation	total insolation	flat surface	daily, monthly, or seasonal	<100°C	
cooking	total insolation	focussing, flat reflective surfaces	same as 'a'	≥205°C	
2. Solar Thermal Electric	normal incident	focussing	minute by minute	200-3500°C	hydro,
	circumsolar		hourly or daily	<100°C	liquid
			real time for operational control		metals
					molten salts
3. Photovoltaic	same as 'a', but with the sun's spectral distribution	same as 'a'	same as 'a'	100°C	Storage batteries

as a sole energy source and will, therefore, need supplementation from other sources.

Environmental Impacts

In general, utilization of solar energy have quite minimal environmental impacts. Solar thermal systems create no significant land problem because of the fact that solar collectors may be integrated in existing buildings. The principal environmental effect may then be those associated with the manufacture of solar equipment. Substantial quantities of steel, glass and aluminum may be required for large scale manufacture of the collectors and related equipment, but presently these materials seem to be adequate and could supply some large scale production.

With solar thermal electric systems, however, the large amounts of land needed for large scale power generation would be quite serious. However, when compared with a coal-fired plant of an equivalent output, its impact could be considered less destructive, considering the fact that with the latter system, land would be damaged after mining. Of great importance, also, would be the effect of large scale thermal electric plants to the local thermal energy balance. The proportion of solar radiation absorbed to that reflected on the earth's surface is considerably increased. If this proves serious, however, it would be theoretically possible to offset this by adding reflective surfaces to areas around the collectors. When compared with conventional fossil fuel and nuclear plants, on the other hand, this effect in the thermal energy balance would be small. Another effect on the environment of the above system would be the large quantities of water that it utilizes to produce steam for electricity generation. For places where water supply is scarce, such systems could not be employed.

From an environmental viewpoint, photovoltaic systems have remarkably benign effects. Its operation produces no noise, pollution, or other wastes and requires no water. In several cases, the photovoltaic devices may also be incorporated in existing structures. At present, the most significant problem relating to photovoltaic systems is the cost effectiveness. Silicon production, which gives about the highest energy conversion efficiency, is the most commonly used semiconductor in solar cells. The cost of production, however, is yet to be improved.

3.2 Wind Energy

3.2.1 Introduction

Winds are the motion of air about the Earth caused by its rotation and the uneven heating of the planet's surface by the sun. The idea of using wind as a form of power is not new, and until the advent of the steam engine, windmills ranked second only to wood as an energy source. The traditional applications of wind were primarily as sources of kinetic energy for rural, agricultural and a limited number of industrial uses such as pumping water and grinding grain.

The estimated total power potential of the winds has been put at 10^{11} gigawatts. This represents an enormous resource, but the problems of utilizing the winds are many and varied. Wind energy is very diffuse in nature and local topographical features significantly alter the prevailing winds, thus leading to the extremely site specific nature of wind energy.

Nevertheless, for countries which do have good wind regimes, wind energy, if harnessed, can provide significant quantities of electric or mechanical power at a cost which is now comparable to that of utilizing energy from petroleum.

3.2.2 Characteristics of Wind Energy

The energy in the wind is that kinetic energy due to a stream of air particles, of density (ρ), moving with a velocity (v) (Figure 3.2.1), through an area (A) swept by the rotor of diameter (D).

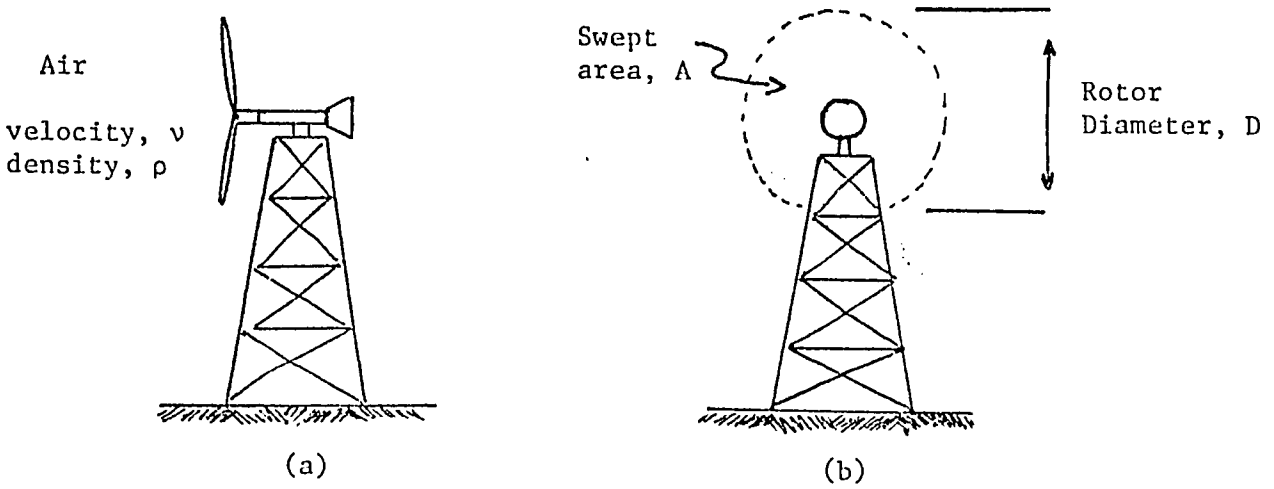


Figure 3.2.1: Energy in the Wind Due to (a) Air Velocity and Air Density; (b) Swept Area

The mass flux, M, of the air is given by

$$M = \rho A \nu$$

and the power in the wind, P_m, is given by

$$P_m = 0.5\ M\nu^2$$

$$\text{or } P_m = 0.5\ \rho A \nu^3$$

The theoretical maximum power that may be captured by a wind machine was shown by Betz in 1920 [1] to be 16/27 or 59.3% of the incoming energy in the wind. Thus the theoretical maximum available power for energy conversion, P, is given by:

$$P = 0.593 \frac{\rho A \nu^3}{2}$$

The major factor influencing energy in the wind is the wind velocity. As shown above, the power is a factor of the cube of the velocity, so doubling the wind speed will increase the available power eight times. However, wind energy is very diffuse in nature and also the velocities are extremely variable.

This leads to the design of machines which have to be located in

specially selected sites and, for large power outputs, these large machines are required. A 2.5 MW wind dynamo, known as MOD-2 (Figure 3.2.2) is now being constructed for the U.S. Department of Energy (DOE). The machine is designed to operate in a wind speed of 28 m.p.h. and has a blade diameter of 300 feet (91.6 meters). This illustrates the magnitude of large wind machines today (and the problems inherent with such systems).

3.2.3 Data Collection/Analysis

As air moves across the surface of the Earth, its speed and direction are changed by local topography as well as by local heating and cooling. At any particular site, trees, buildings, terrain, proximity to large bodies of water, or other small scale influences can disturb the flow of air. The combined effects can lead to highly variable winds, and results in the site specificity of potential wind energy sites.

Topographic surface roughness increases the friction on the boundary layers of air at the surface, and shearing of the boundary layers may result. Figure 3.2.3 indicates this effect, and the need to site windmills and the measuring equipment above the affected regions.

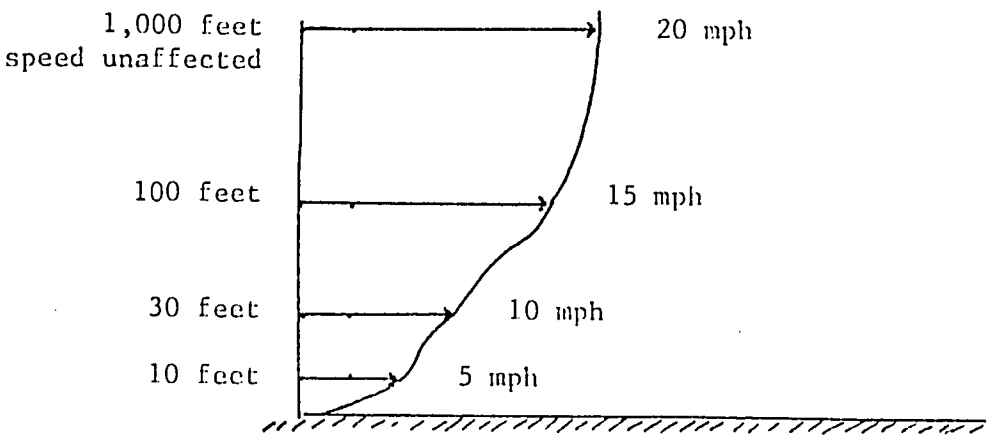


Figure 3.2.3: Effect of surface roughness on wind velocity

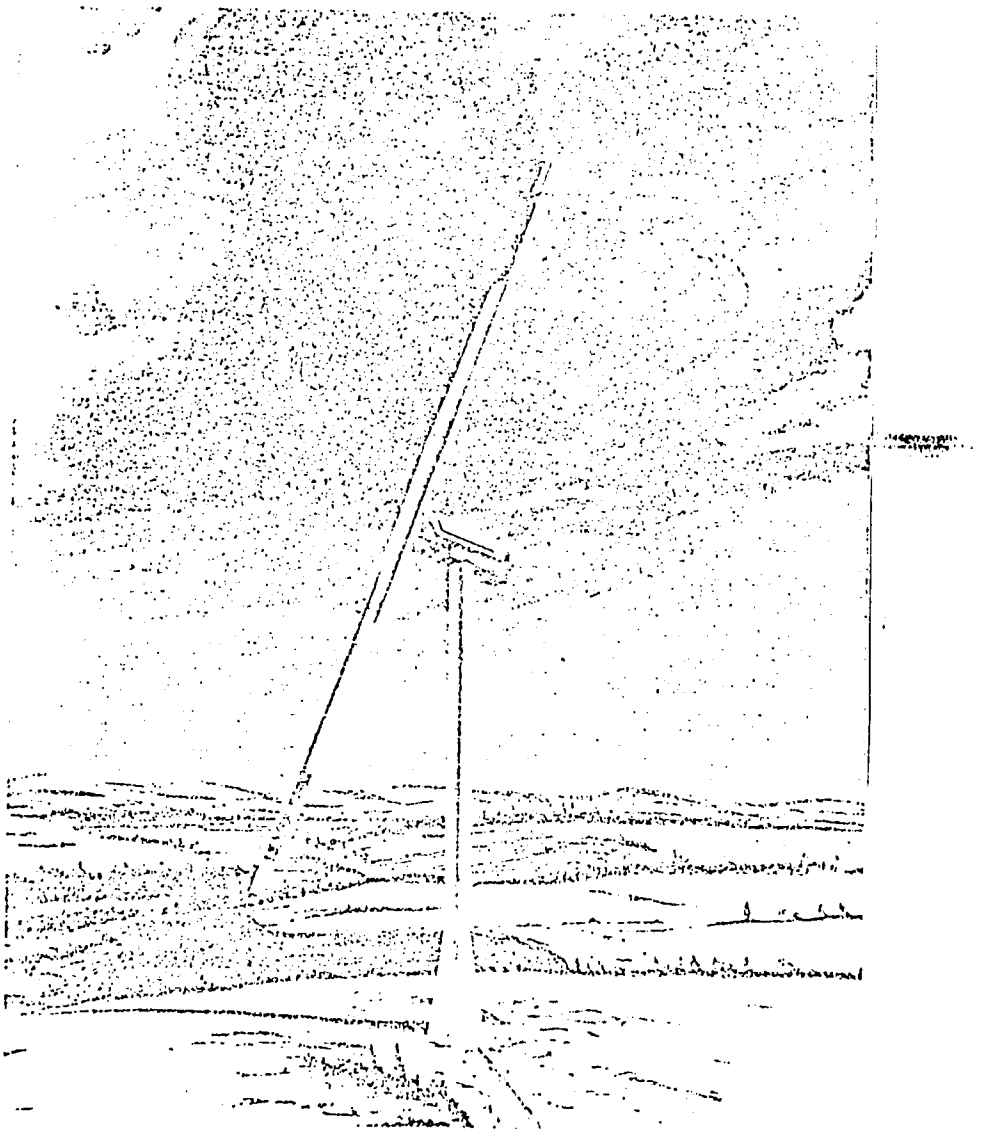


Figure 3.2.2: Boeing Engineering and Construction design for a wind machine with 300 foot rotor, rated at 2,500 kW in a wind speed of 28 mph.

In areas of hilly or mountainous terrains, wind velocities and directions will be seriously altered by local topography. Such features affect airflows on a much larger scale than surface roughness, but their combined effects should always be taken into account. Non-flat terrain can be divided into two categories:

(i) elevated terrain

(ii) depressions.

(i) Elevated Terrain: The main topographical features associated with elevated terrain are ridges, hills and cliffs. Their effects are generally twofold. Namely:

1. The elevated terrain can act as huge towers, thereby exposing a windmill to winds of high velocities.
2. Airflow can be accelerated when moving around elevated terrain, thus enhancing the wind velocities.

However, elevated terrain can also have adverse effects, as slowing of the winds, turbulence and wind shear can occur, but proper site analysis can eliminate these hazards.

(ii) Depressions: Terrain features such as valleys, basins, gorges and passes are associated with depressions. Generally, depressions will lead to areas which are sheltered from the prevailing winds, and are most likely to be affected by the diurnal changes in wind patterns. While some valleys may have a funnelling effect on the winds and increase their velocities, depressions do not usually offer good sites for wind energy.

3.2.3.1 Estimation of Wind Speed

Assessing wind speeds accurately is crucial to the analysis of a proposed site, whether it be for choosing and installing a commercially

available system, or for designing an appropriate system for that site. Table 3.2.1 presents three approaches to site analysis.

When considering small wind energy conversion systems (<30 kW), approach 1 or 2 may suffice, but for larger systems method 3 is advisable for its greater accuracy.

In assessing a suitable location for a wind recorder, local ecological indicators of site suitability should be taken into account. One excellent guide for a site is that of trees which have grown at an angle due to the strength of the prevailing winds. Other guidelines to use are the Beaufort Scale (Table 3.2.2) and the Deformation Ratio, set out in Figure 3.2.4 and Table 3.2.3. The Deformation Ratio provides only possible estimates of what mean wind speeds may be, and is the result of research work on two species of conifer, the Douglas Fir and the Ponderosa Pine. If the Deformation Ratio is applied, several trees in the area should be sampled and the average taken.

3.2.3.2 Data Analysis

The most commonly applied technique for assessing wind energy is to first tabulate the available data, and then calculate monthly, daily and, in some cases, hourly average wind speeds. These mean wind speeds are plotted on a graph of "Mean Wind Speed vs. Time", or alternatively the wind speeds can be adjusted to provide mean power densities (i.e. power per unit area) and the results then analysed. Integrating these figures over the particular time period gives the power densities available over that time period.

However, when considering a wind energy system, these figures alone are not sufficient, as each wind energy conversion system (WECS) will have a cut-in speed, rated speed and cut-out speed. Analysing the data along with the specifications of different WECS is much more useful, and the actual

Table 3.2.1: Three Approaches to Site Analysis

	Approach	Advantages	Disadvantages
1.	Use data from an existing nearby station	Little time or expense involved. If used properly, can be adequate for small systems.	Only works well in large areas of flat terrain, where annual wind speed <10 mph.
2.	Make limited (3 months min.) onsite measurements, and establish rough correlation with nearby station.	If there is a high correlation, this method gives good, quick results.	Of questionable accuracy, particularly if correlation is only seasonal.
3.	Collect wind data onsite for at least one year.	Most reliable method.	Time consuming and most expensive method. Results for one year may not be typical for site.

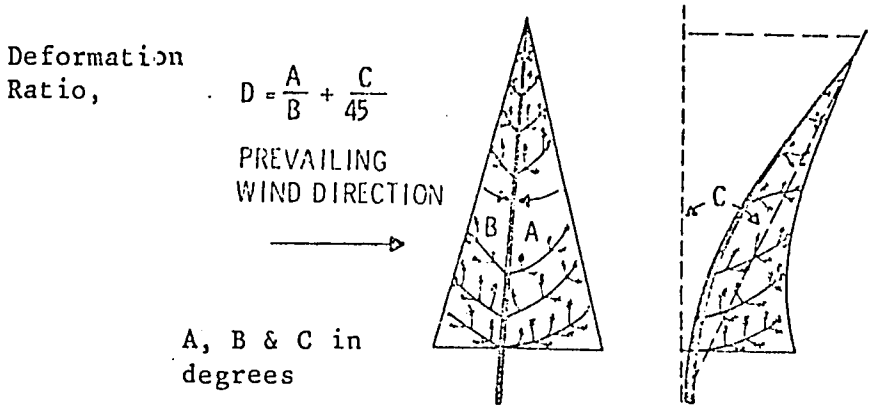


Figure 3.2.4: Deformation Ratio computed as a measure of the degree of flagging and throwing (Hewson, Wade and Baker, 1977)

Table 3.2.2: Mean annual wind speed versus the Deformation Ratio[a]

Deformation Ratio (as in Figure 34)	I	II	III	IV	V	VI
Probable Mean Annual Wind Speed Range (mph)	5-9	8-11	10-13	12-16	14-18	15-21

[a]These data were prepared by E. W. Hewson, J. E. Wade, and R. W. Baker of Oregon State University.

energy output from the WECS may be calculated for the time period over which the data was taken.

3.2.3.3 Wind Measurement Equipment

The type of equipment to be used for estimating the power in the winds depends largely on the type of data required. If the WECS is to be used for estimating annual power output, mean wind speeds and wind speed distributions for one year are required. If the WECS is to be used for providing power to match peak power periods, more detailed records of the diurnal changes are required. For small power applications (e.g. pumping of water) mean annual or monthly wind speeds are sufficient.

Wind measurement apparatus consist of wind sensors and displays or recorders. The wind sensors are cup or propellor anemometers which sense wind speed, and wind vanes for sensing wind direction. A typical wind recording set is shown in Figure 3.2.5.

The wind sensors usually produce an electrical signal, but in some cases it is mechanical, which is monitored by a recorder. These recorders may be counters, strip chart recorders, or magnetic tape recorders, and provide a record of the winds which can be analysed. The simplest recorder is the wind-run anemometer which has a mechanical counter measuring the amount of wind passing the sensor. For obtaining average wind speeds this system is adequate, but if a more detailed record is required, either the strip chart or magnetic tape recorders must be used. However, strip chart and magnetic recorders are more expensive and delicate instruments.

Strip chart recorders require manual tabulation of the recorded data, and this can be a tedious and inaccurate process. Magnetic tape recorders, on the other hand, are easily processed with computers, but such facilities

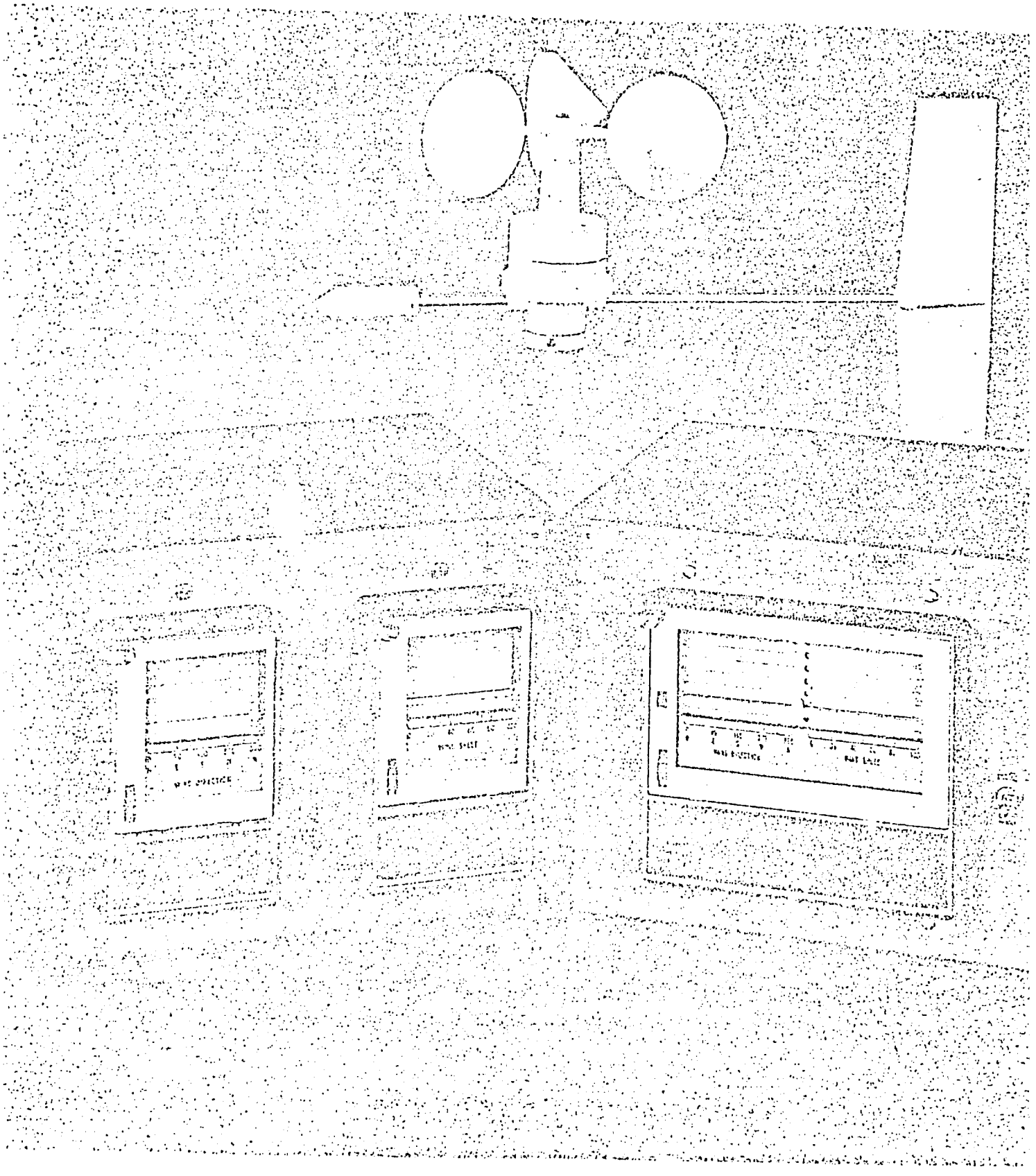
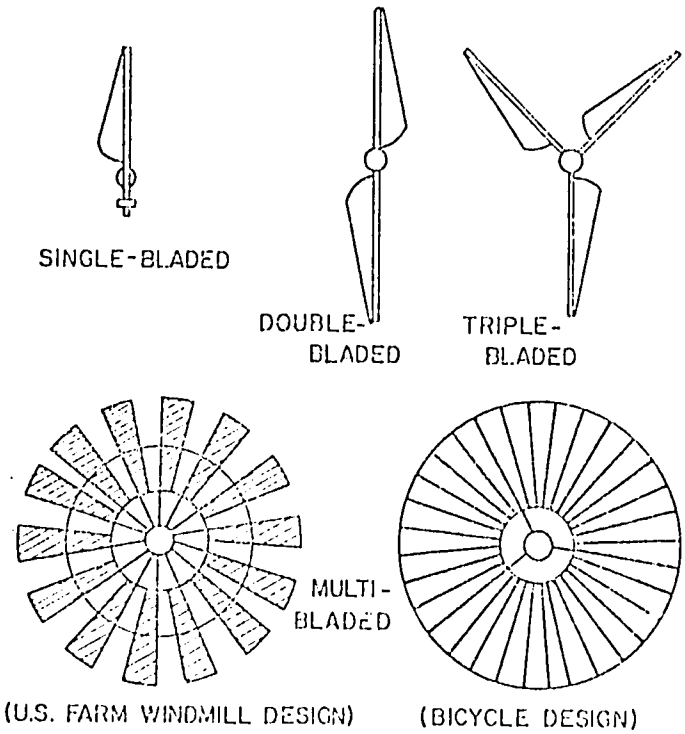


Figure 3.2.5: Typical cup and vane anemometer and wind recording sets

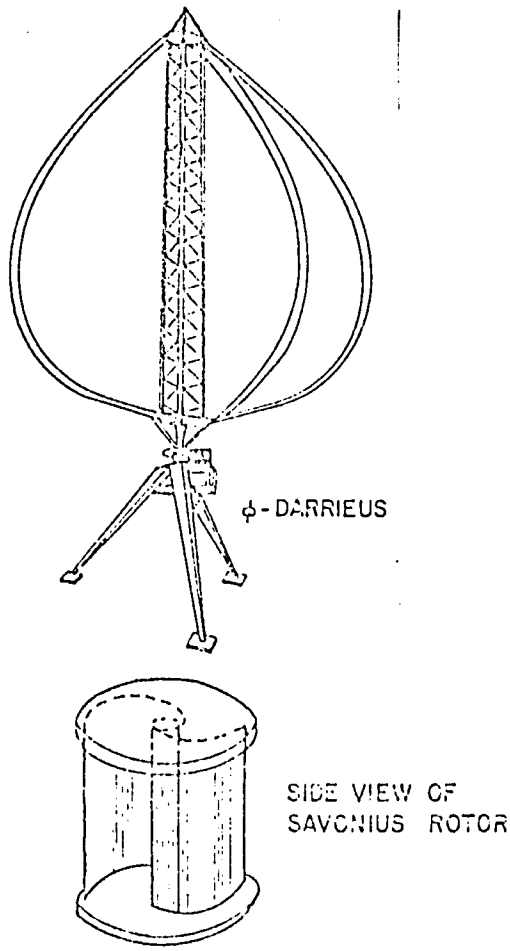
must be available.

In siting of the wind measurement sites, attention should be paid to the various topographical factors that affect wind speeds. The anemometers should be placed at a height where they will be least affected by the local environment, or at the height recommended by the manufacturer of the WECS, if a commercial system is being considered.

Whenever possible, wind data available from a local weather station should be consulted, and some kind of correlation made between the existing data. If a good correlation exists, then some indication of how typical the data is for that period will be obtained, and greater assurance in the accuracy of the data will then exist.



(a) Typical blade configurations for horizontal-axis rotors



(b) Two types of vertical-axis machines

Figure 3.2.6: Wind Energy Conversion Systems

3.2.4. Wind Energy Conversion Systems

The use of crude windmills to pump water and to power simple machines dates back a long time. A picture of a windmill on a Chinese vase of abou the third millenium B.C. is the earliest evidence, but the Persians were using windmills for grinding grain by the seventh century A.D. Up until the early twentieth century, windmills were in common use for providing electricity, on a small scale, and for pumping water in rural areas. In addition, the wind was the motive power for the European colonization of most of the World in the sixteenth and seventeenth centuries. In more recent times, the windmill is being assessed as a potential source of powe generation both on a large and small scale. In general, WECS are divided into two types, horizontal axis machines and vertical axis machines, and some typical examples of both types are shown in Figure 3.2.6. The horizontal axis machines are those in which the axis of rotation is parallel to the direction of the wind. These WECS suffer the disadvantage of having to be oriented into the wind when the wind direction changes, and in small machines this is usually accomplished by a simple tail vane held by spring tension. In large horizontal axis WECS, sophisticated electronic sensors and motors may be required to achieve the desired orientation.

Vertical-axis machines have their axis of rotation at right angles to both the Earth's surface and the direction of the wind, and they have the advantage that they do not have to be repositioned into the direction of the wind. The simplest vertical axis WECS is the Savonius-type rotor, which is a high torque, low speed machine that can be constructed very cheaply from old oil drums (see Figure 3.2.6). This machine is very

suitable for pumping water and generating small quantities of electricity (<5 kw). The efficiency, however, is very low at about 10-15% depending on the wind speed, so for larger requirements, the Savonius is not recommended. Larger vertical axis rotors, such as the Darrieus turbines are being developed extensively for large power generating systems, but their applicability may be hindered by the need for high average wind speeds (>24 mph) and an inherent efficiency which is lower that that for horizontal-axis propellor machines (Figure 3.2.7).

The earliest windmills were of the fixed blade variety, but to improve efficiency, particularly of large WECS, pitch modulation mechanisms are now being utilized. These mechanisms change the angle of attack of the blades according to changes in wind speed. This results in additional expense to the system, but the increased efficiency at low wind speeds usually offsets this cost disadvantage.

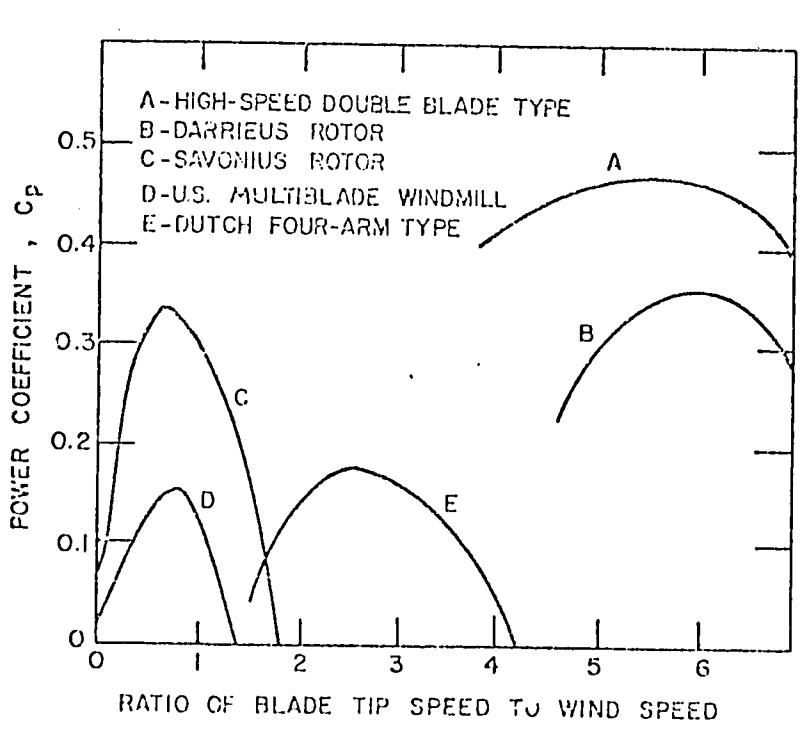


Figure 3.2.7: Typical performance curves for various wind turbines

SOURCE: Cherimisinoff, Fundamentals of Wind Energy

Figure 3.2.7 shows some performance curves for different WECS. The power coefficient, C_p, is a measure of the efficiency of the wind turbine, and it is seen that A, the high speed double blade type horizontal axis rotor, is the most efficient. For large power generating systems, this is the design that is now achieving the most interest. The simple Savonius rotors and US multiblade windmill are low efficiency machines, but for meeting small power requirements they are very well suited as they are the most inexpensive machines and may frequently be fabricated with a minimum of sophisticated equipment.

3.2.5 Environmental Impacts

Small WECS have no major adverse environmental impacts, but major problems that may be encountered with large WECS are noise pollution and interference to TV and radio transmissions. At present, there is not enough data to assess how bad the effect of such systems will be, but it is accepted that problems will arise. Research engineers are confident that the problems can be overcome, but it must be realized that a large array of wind turbines, e.g. a wind farm of 20 units producing say 60 MW of electricity, could have serious impacts on the local environment.

Another "problem" which has created some disagreement is the aesthetics of wind turbines. Many environmentalists feel that large turbines will destroy the sight of otherwise virgin landscapes, while others see wind turbines as a potential attraction that could be exploited. The latter is the case in the island of Crete, where the fields are covered with small sail rotors that provide an attraction for many tourists. This argument, however, is not a serious one, as many countries will be forced to utilize all available energy resources to try and reduce their oil importation bill.

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3.3 HYDROELECTRIC POWER

Hydroelectric power is the electricity generated by harnessing the energy in falling water.

3.3.1 Data Collection and Analysis

In order to predict the power available from a particular hydroelectric site, the historical water flow records need to be put into usable form. The usual approach, called "flow duration approach", is to prepare a flow duration curve based on at least a 10-year average of water flows at the particular site. The most reliable data can be obtained when the gauging station is close to the hydropower site. With appropriate adjustments, reasonable approximation can be made using gauging station information from a site within the same rainfall area. In addition, head duration information should be developed which could correspond to the flow duration characteristics in order to more reasonably predict the kilowatt hour output of the hydropower installation. Adjustments for flood flows, reduced head and dry periods provide a reasonably accurate historical representation usable for predicting future averages.

3.3.1.1 Power: The theoretical power (P) available from a hydropower unit depends on the mass flow rate (Q) and the height of the fall of water (h). The net power available at the turbine shaft is:

P(kW) = Minimum water flow (m/s) X net head (m) X turbine efficiency

The net head is obtained by deducting the energy losses from the gross head. A good assumption for turbine efficiency, when it is not known, is 80%.

3.3.1.2 Measuring Head (H): The head (H) is the height the water falls from the headwater to the tailwater. The head exerts a pressure which can be turned into useful power. The following methods can be used to measure the head of the

fall of water:

(i) A surveyor's leveling instrument can be used for measuring the head through which water usually falls. This instrument consists of a spirit level fastened parallel to a telescope and scale. The surveyor's level on a tripod is placed downstream from the power reservoir dam on which the headwater level is marked. After taking a reading, the level is turned at 180° in a horizontal plane. The scale is placed downstream from it at a suitable distance and a second reading is taken. This process is repeated until the tailwater level is reached.

(ii) This method is reliable but is more tedious than the above method. The apparatus required are carpenter's level, board and scale. The board is placed horizontally at the headwater; the vertical distance between the tip of the board and the ground is measured; and keeping a record, the process is repeated until the tailwater is reached.

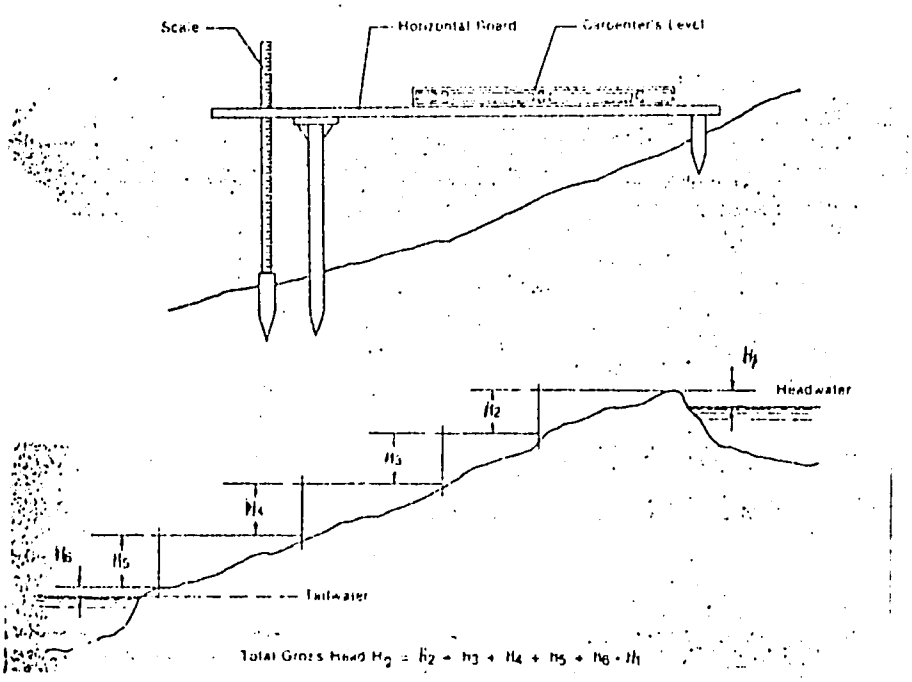

Figure 3.3.1: Measuring head with carpenter's level.

Having measured the gross head (H), we must now take into account the various losses which will result in a figure for the net head (h). The net head is the actual head or pressure available to drive the turbine or waterwheel when losses have been deducted from the gross head. The head losses are the open channel losses plus the friction losses from flow through the penstock. The friction losses are greater for increased flow rates and also for smaller pipe diameters. Elbows and bends in the pipe will also increase the friction losses. However, PVC pipes offer low friction losses. Other losses depend on the type of turbine or wheel used. In case of impulse turbines, there is a slight head loss due to the vertical distance between the nozzle jet and the tailwater. Whereas crossflow, Francis and propellor turbines with draft tubes have almost no inherent head losses.

3.3.1.3 Measuring Flow Rate: The flow rate is the quantity of water (generally measured in gallons or cubic feet or cubic meter) flowing past a point in a given time. The minimum quantity of water that will pass through the hydropower system should be determined in order to adequately assess the minimum continuous power output from the hydropower unit.

The flow rate can be determined by the following methods:

(i) Container method This method is suitable for only small mountain streams. Build a dam, divert the whole stream into a container of known size, and determine the flow rate by measuring the time taken by the water to fill this container.

(ii) Float method For larger streams, the float method can be used. However, this is not as accurate as the other methods. Mark off a section of the stream, at least 30 feet, where its course is straight and smooth. Choose a windless day for measuring the flow rate of the

water. Place a float upstream of the first marking and time its passage over the known distance. Repeat the procedure and find the average time. Reduce this time by a correctional factor of 0.8 for a stream with smooth bed and banks and by 0.6 for a rock strewn, hilly stream.

Now, ascertain the average depth of the river between its banks. This can be done by taking a number of depth measurements across the bed of the river, at equal intervals, adding up all the readings and dividing the total by the number of measurements. The cross sectional area is then calculated by multiplying the depth by the width of the river.

Then the stream flow rate can be determined by multiplying the cross-sectional area of the stream by its velocity.

(iii) Weir method This is the most accurate method to measure the flow rate in medium sized streams. The weir is built like a dam across the stream which causes all the water to flow over a rectangular notch of known dimensions. The weir is made from boards, logs or scrap lumber.

For measuring the depth of water flowing over the weir, drive a stake in the stream bed (about 1 or more meters upstream from the weir) to a depth such that a mark on the stake is exactly level with the bottom of notch B. Measure the depth of water (D) over the mark, and read the volume of flow of notch width. Multiply this volume by the notch width, to get the total stream flow.

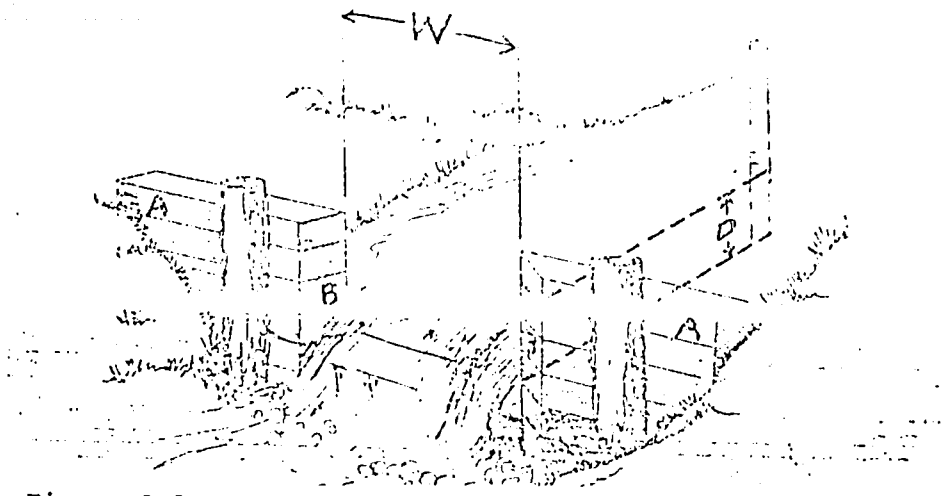

Figure 3.3.2: Weir method for measuring stream flow rate

3.3.2 Turbines and Wheels

A water turbine is basically a device that converts energy in falling water into rotating mechanical energy. This energy, available in a rotating shaft, may either be used directly to operate a mill and grinding equipment or hooked to a generator to produce electricity. In the hydroelectric power plants, the turbines and generators are the main items of equipment. A hydraulic turbine suffers loss of efficiency at heads over or below the designed value. At the correct head, there will be one point of best efficiency, somewhere between 80 and 90% of full load. The turbines are basically of two types: impulse and reaction.

In an impulse turbine, the total available energy head is converted into a kinetic energy head by controlling the nozzle. The impulse turbines are inherently relatively low speed, large diameter machines, as compared to reaction type turbines. Therefore, these turbines are best suited for high-head applications. A low capacity high-head hydropower unit will, however, operate at a high rpm (revolutions per minute). The impulse turbine runners must operate in air to be efficient. Thus, they must either be located above the maximum tail-water elevation or provision must be made for pressurizing the housing.

In a reaction turbine, only part of the total available energy head is converted into a kinetic energy head. Reaction turbines use pressure rather than velocity. These turbines have been designed to operate with radial, axial or mixed flow through the runner. These are usually used in very large hydropower installations. The Francis turbine and the propeller turbine are two types of reaction turbines that are widely used for hydropower plants. Francis turbines are usually designed in either an axial or mixed flow configuration, whereas the propeller turbines have either fixed blades or adjustable blades and are usually designed for axial flow. The adjustable runner blade design which is known as a Kaplan turbine, has individual blades. The blade configuration changes for the mixed flow designs due to the need for a larger hub to contain the blade operating mechanisms.

Preferential selection of a turbine depends on the available head. Peltron impulse type turbines are ordinarily installed at sites with heads over 300 meters. Francis reaction type turbines are commonly used at sites with heads ranging from 30 meters to 300 meters, while fixed blade propeller turbines or Kaplan turbines are preferred for heads up to 30 meters. Recently, horizontal axial flow bulb and tubular turbines have been developed for use at sites with energy heads between 5 meters and 15 meters.

Water wheels are the traditional technologies used for small hydropower units. The water wheels can operate in situations of large water flow rate variations and they require minimum maintenance. These are generally used for slow speed applications, such as for grinding grains and pumping water. There are two types of wheels generally used in hydropower plants: undershot wheel and overshot wheel.

The overshot wheel is the traditional and probably the most efficient water wheel. The water is supplied via a chute or flume to the buckets, which when

full, fall as a result of dead weight, thus turning the wheel. The supply of water to the wheel is regulated by a hand-operated sluice gate. These wheels are suitable for heads from six to eight feet or more.

The undershot wheel, the most basic and primitive of all wheels, has a maximum efficiency of about 25%. It can operate even on a one-foot head. The water* passing under the wheel strikes the blades or paddles, causing the wheel to rotate.

The disadvantage of the water wheels are that they are less efficient, operate at low speed and are bulky. The characteristics of turbines and water wheels are given in Table 3.3.1.

3.3.3 Dams

A dam is required in most cases to direct the water into the channel intake or to get a higher head. The dams may not be required for small hydropower installations if sufficient water is available. These are classified on the basis of materials used for construction. The basic dam classifications are the following: (i) concrete, (ii) masonry, (iii) earth and rockfill, and (iv) miscellaneous.

The dams are generally made of earth, wood, concrete or stone, depending upon the situation in a particular site.

3.3.4 Classification of Hydropower Systems

Hydropower systems can be divided into three broad categories: run-of-the river, controlled storage, and pumped storage.

*optimum head range is 2 to 5 meters

Table 3.3.1: Characteristics of Waterwheels and Some Water Turbines

Type	Flow rates (liters/ second)	Range of waterhead (meters)	Revolutions per minute	Percent efficiency	Power output (kilowatts)	Ability to handle changing conditions		Technological level of construction
						Flow	Head	
Waterwheels:								
Undershot	300-3,000		2-12	40-75	1-10	Good	Fair	Low/medium
Overshot	30-1,000		2-12	50-80	1-10	Good	None	Low
Water turbines (microplants only):								
Pelton	30-500	50-1,000	500-1,000	82-85	40-400	Good	None	Medium/high
Mitchell (Banki)	100-3,000	3-50	100-400	80-84	30-700	Good	Good	Medium
Francis	50-5,000	10-200	250-1,000	82-90	100-1,000	Medium	Poor	High
Kaplan or propeller	1,000-15,000	2-20	200-500	80-90	20-1,000	Medium	Medium	High

Source: Energy for World Agriculture (FAO Publication)
B.A. Stout

3.3.4.1 Run-Of-The River Hydropower Plants: As the name implies, the water passing through the plant turbines is all or a portion of the available uncontrolled stream flow. If the stream flow is uniform throughout the year and drought has either little or no impact on stream flow, such plants will produce power at a high plant factor. Very few streams meet these ideal conditions. Hence, run-of-the river plants cannot be used effectively as a reliable power supply to meet the load. With only a moderate storage pond or reservoir, the plant output can match the systems daily energy load requirements.

3.3.4.2 Controlled Storage Hydropower Plants: As the name implies, the stream is controlled to enable the release of water from storage at times when it is most valuable. Although the basic aim of storing the water is for hydropower units, the stored water can also be used for industrial, agricultural, navigational, flood control or other purposes. The role of the plant can be changed depending upon the load and other needs.

3.3.4.3 Pumped Storage Hydropower Plants: These are the electricity generation schemes installed to help meet sudden demand fluctuations and peak loads. Electricity produced during periods of low demand may be used to raise water from a low to a high reservoir, and during peak periods the water is allowed to fall back to the lower reservoir. These plants are useful for supplying only peaking or short-time capacity reserves. Because of losses, the energy output is only about two-thirds of the pumping energy required to store the water. However, such plants can prove economically attractive when compared with constructing peak load thermal plants operating at a low load factor.

3.3.5 Limitations of Hydropower

Dams to provide the water needed for large hydropower units pose environmental problems for wildlife and wilderness areas. The filling of reservoirs with silt is a problem in long-term power production and makes the resource effectively non-renewable. The other problems involve depriving the land downstream of valuable silt and fertilizer and destroying fish production. Large hydroelectric power installation involves high initial capital investment. Creation of a large reservoir may require relocation of highways, railroads, power lines and small towns and villages in some cases. Another fact to be considered is the remoteness of many otherwise desirable hydraulic sites, necessitating long transmission lines. Recreational facilities can also be adversely affected in reservoirs where downstream in the dry season, the water level is lowered. Moreover, power production may be curtailed or even discontinued in time of drought.

3.3.6 Environmental Impacts

The most important environmental issue associated with the development of hydropower systems concerns land use changes. The inundation of a large area of land affects agriculture, forestry and wildlife in a significant way. Clearing all trees and plants from the land used for a hydropower unit results in a tremendous loss of reservoir for aquatic habitat. Fish production may be limited, both by decreased food supply and lack of suitable refuge from predators. Standing or fallen trees or plants that are left are an obstacle to navigation, surface recreation and a potential hazard to turbine operation. It is, therefore, crucial that clearing practices are well planned at early stages of the hydropower installation.

The physical presence of a dam causes two major ecological issues:

blockage of fish migration and gas supersaturation.

The major features of hydropower operation that can affect the reservoir ecosystem are the amount of water released and the location of water withdrawal from the reservoir. Water level fluctuation due to hydropower releases can significantly affect reservoir use. This water level fluctuation can also have indirect impacts on biological production in the reservoir. The potential impacts due to water withdrawal from the reservoir are complex and very site specific. In a reservoir that is thermally stratified, discharge of bottom water can remove nutrients from a reservoir and indirectly affect overall reservoir productivity. Withdrawal can also affect oxygen distribution and the percentage of lower reservoir volume that provides a suitable fish habitat.

The downstream ecosystem may be affected by two potential modifications: changes in discharge regime and changes in water quality. Both modifications may affect the type of ecological system that can be sustained below the dam.

In order to understand and minimize the potential environmental impacts associated with the hydropower plant, ecologist and environmental scientists should be involved in the planning and development stages.

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FUELS FROM BIOMASS

3.4 Biomass

Biomass is a source of solar energy chemically stored in plants and other organic matters as a result of photosynthesis. Biomass energy sources include plants, agricultural and forestry wastes and municipal wastes, all of which can be used for their energy content.

3.4.1 Characteristics

Biomass produced through photosynthesis is an attractive source of energy because it can be stored in plants and it is renewable. Also, it is low in sulphur and ash and occurs in a wide variety of forms (wood, straw, municipal waste, etc.). Biomass can be utilized directly as a fuel or it can be converted into biogas, alcohol or other gases.

3.4.2 Classification

Biomass resources can be divided into the following broad categories:

- Plantation that produces energy crops, and
- organic wastes and residues.

The term energy plantation refers to an area that is used to grow biomass for energy purposes. Whereas organic wastes or residues include such sources as agricultural and crop residues, forest residues, urban refuse, manure wastes, and municipal and industrial wastes.

3.4.3 Data Collection

For the purpose of preparing a plan related to utilization of biomass as a fuel, it is necessary to collect adequate information and data. The data may be collected through contacts with biomass specialists, reviews of the national annual plan, institutional plan, review of other biomass literature, development of an "information user profile" data base from mailing list response cards, and direct contact with organizations and people involved with biomass energy systems.

3.4.3.1 Biomass Resource Potential

Energy Plantation

The concept of energy plantation involves the use of selected strains of tree and plant species grown on a short rotation system. While the original concept is based on the forest plantation for the production of biomass, considerable attention is now being paid to enlarge the scope and include even the agricultural crop as a potential fuel plantation. Many countries including Australia, Brazil, the USA, India, Philippines and Papua New Guinea have already taken up major programs of energy plantation.

The advantages of the energy plantation include: capable of storing energy, renewable, dependent in technologies already available. However, careful consideration of land sites would be needed for large scale biomass production. The success of the biomass plantation would depend upon the availability of land and water required to grow plants and trees.

The following are the criteria (defined by Salo et al) for land suitability for biomass production:

a) minimum of 25" of annual precipitation,

b) arable land, and

c) slope equal to, or less than, 30% (17°).

Precipitation, land quality and terrain directly affect the crop yield and cost. Precipitation is an important indication of a region's capacity to support high levels of biomass production.

The ultimate design of energy farms would depend on the specific site requirements and technological developments in biomass crop management, harvest, and transport. The important factors which determine the extent to which energy farms can impact the energy demand are crop yield or productivity and land availability. Productivity levels of biomass will vary with the species planted, cultural practices used, and the conditions specified by the farm site including climate, weather, soil characteristics, etc. The availability of land for energy plantation would depend on competing uses of biomass species and future crop land - forest land trends. The crop management practices are expected to vary depending on the species and the specific site. Site specific factors could be either modified by cultural practices such as irrigation, fertilization and liming, or accommodated by appropriate biomass species selection.

The selection of fuel crops should be based on what is called the energy budget. The total energy consumption in raising the crop, harvesting, transporting and its conversion into fuel should be compared with the actual calorific value of the fuel produced. Tree species that comprise conventional forest crops, in a particular region, are usually selected on the basis of desirable wood properties. Other criteria for selection of trees and plants include their rapid growth, ease of establishment and short rotation period. The other properties to be considered while selecting the biomass species are:

(i) A large proportion of available solar insolation must be absorbed by green tissues. This can be achieved by:

- using crops with high photosynthetic efficiency (for example C_4-type crops such as corn, sugar cane and sorghum,

- replacing such harvest with a new crop as quickly as possible,
- using or breeding plants with leaves whose shape and orientation make maximum use of sunlight.

(ii) Ability to conserve water in arid areas,

(iii) Maximum drain of nutrients from the soil, and ability to improve the soil quality.

Higher yield crops have better prospects because they require minimum area of land and lower the cost for land preparation and harvesting.

Animal Wastes

As mentioned on page 10, minimum quantity of animal wastes can be calculated from data available on physical and chemical characteristics of animal wastes, the average drippings per animal, and number of animals. The amount of wastes an animal can produce also depends on the size of the animal, feed, and the condition of confinement. Based on the Indian experience, the average dripping by each animal species is given on page . The production of dung from an animal is generally assumed to be directly proportional to the live weight of the animal. Since there is a wide variability in data on the quantities of wastes excreted by different animal species. It is not easy to assess the exact quantity of wastes available from animals in a particular region or country. The following organizations and persons may be contacted regarding the availability of animal waste:

Dairies

Piggeries

Government offices

Agricultural universities/colleges

Farmers

Veterinary hospitals

Poultries

Agricultural farms or animal feed producers

Forest Residues

The availability of forest residues which depend on the production of fuel wood can be estimated on the basis of tree or plant species, forest area, type of soil and availability of water. According to Parikh (India), a conventional tree plantation, without water and fertilizer, will produce small amounts of wood and other residues. However, various forms of management techniques such as fertilization, pest control, irrigation, genetic plant selection, and thinning can improve productivity considerably. The short rotation hardwoods can give yields up to 4 tons per acre a year. The higher the productivity, the less land area needed to produce a given amount of woody biomass.

Wood and bark residues are generated in mills, and also in forests along with some foliage residues. Logging residues also represent a widely and readily available source of forest residues. These generally consist of the above ground portions of trees not removed in such logging operations. Estimates of forest residues can be made from information or data available from the following:

Government forest offices

Private forest owners

Industries based on wood and forest products

Manufacturers of forest biomass production and collection equipment

Forest products engineers and consultants interested in biomass energy

Agricultural Crop Residues

As mentioned on page 8, the amount of agricultural residue depends on the extent of agricultural crop production. Therefore, the quantity of crop residues would also depend upon the type of crop sown. High productivity of agricultural crops can be accomplished by increasing leaf area, changing the ratio of the biomass of reproductive to that of vegetative organs, and by other morphophysiological properties. Table 3.4.1 represents the photosynthetic efficiency for different crops.

Table 3.4.1: Properties of Some Crops

Crop	Approximate yield per acre (ton)	Average duration of the growing season (days)	Photosynthetic efficiency
Wheat	3	120	0.44
Paddy (rice with husks)	8	120	1.77
Jowar	12	120	1.76
Sugar cane	40	365	2.0

Source: Second India Studies: Energy K.S. Purikh (India)

C_4-type plants such as corn, sugar cane and sorghum exhibit a very high photosynthetic efficiency. Intensive biomass production can give annual yields of up to 30 - 50 tons per acre for C_4-plants. The estimates of availability of agricultural crop residues can be made if the type of crop and land area to be utilized are known. For compilation of data regarding availability of agricultural crop residues in a particular region, the following should be contacted:

Government agricultural offices

Farmers

Private farm owners

Agricultural research organizations

Agricultural universities/colleges

Animal feed producers

Food and agricultural organizations (United Nations)

Urban Refuse/Municipal Wastes

The amount of waste produced in urban areas depends upon the population and standard of living. The quantity of waste produced daily by a person is estimated at 2.27 kg [2]. The composition of urban and municipal waste varies depending upon the season and also from one region to another. The availability of urban and municipal wastes can be assessed according to the population and waste generated per person per day. For this purpose, one may contact the following:

Urban planners

Incinerator manufacturers

Municipal offices or municipal planners

Municipal waste or sewage departments

Industrial Wastes

Similarly, for collecting information on availability of wastes from major industries, one may contact the following:

Industries management authority

Major industries in the region: pulp and paper industry, food processing industry, petro chemical industry, chemical industry, etc.

Incinerator manufacturers

Government printing offices

3.4.3.2 Residues and Wastes

Organic residues and wastes can be classified into the following major categories: agricultural crop residues, forestry residues, urban refuse, manure wastes and municipal and industrial wastes.

3.4.3.2 (i) Agricultural crop residues: Agricultural residues are considered one of the chief sources of biomass for energy production. Such residues consist of cornstalks, sugarcane stalks, leaves, straw, ricehusk and various other farming by-products.

The amount of agricultural residues would depend upon the extent of agricultural production. The quantity of waste material which arises with different crops varies with the crop. The allocation of available agricultural materials to different uses such as feedstocks for animals, etc. would depend upon the availability of alternative materials for these uses, the price of collection and the social convention.

3.4.3.2 (ii) Forest residues: Biomass (as an energy source) from natural forests and plantations has a great potential, in view of the particular attention being paid to forests as a dependable renewable resource. The use of forests for energy can become ecologically more acceptable mainly because of the limited environmental problems. A variety of residues are produced as a result of the growth and harvesting of trees. The forestry residues include sawdust, bark generated in sawmills, trees removed in intermediate cuttings, trees and shrubs removed from the understory in even-aged stands, and dead trees. Large numbers of trees die each year from natural causes, including disease, insect attack, fire and storms. Such trees can be salvaged and used for energy production.

The most important characteristics of forest residues are their heating value, ultimate analysis, moisture content, particle size, and bulk density. The heating value of the forest residues varies depending upon the wood species, relative contents of wood and bark and moisture content.

Besides wood and bark, forest residues may contain some proportion of foliage. Residues from thinnings would contain relatively large amounts of foliage. An analysis made by Young indicated that foliage represents about 37% of the aboveground dry weight of 10 ft. (3 meters) tall red spruce trees. However, this percentage declines with increased height to 12% for 40 ft. (12 meters) trees. The availability of bark in forest residues would depend upon the size of forest residues collected. Generally, the weight of bark as a percentage of total stem or branch weight varies inversely with the stem or branch diameter of a tree.

The woods of soft wood species have heating values between 8200 and 9700 BTU/lb (4510 and 5335 kcal/kg). However, the resinous woods exhibit the higher heating values, whereas the hardwood species have heating values between 7900 and 8800 BTU/lb (4345 and 4840 kcal/kg).

Bark generally has higher heating values than wood, ranging from 8280 to 10,260 BTU/lb (4554 to 5643 kcal/kg) for soft wood species and from 7070 to 9490 BTU/lb (3888.5 to 5219.5 kcal/kg) for hard wood species. The heating values for softwood foliages have been estimated in the range of 7999 to 9050 BTU/lb (4399.45 to 4977.5 kcal/kg).

3.4.3.2 (iii) Animal wastes: In many developing countries with serious fuelwood shortages, animal waste is burned at a very low efficiency mainly for cooking food. Through bioconversion route, it is possible to extract energy with no loss of fertilizer value. The animal waste is, therefore, another potentially

valuable source of energy.

Minimum quantity of animal wastes can be calculated from data available in the physical and chemical characteristics of animal wastes, the quantity produced by each animal species, and animal population statistics. The amount of wastes available from an animal depends upon the size of the animal, feeding given and whether the animal is stable-bound or freely grazing. Nevertheless, the following figures can be taken as broad averages for stable-bound grown-up animals of medium size (source; Gobar Gas, Why and How, Newsletter of KVIC, Bombay, India, Jan. 1979).

Buffalo	about 15 kg per day
Bullock or cow	about 10 kg per day
Calves	about 5 kg per day

The production of waste from an animal may be assumed directly proportional to the live weight of the animal. Under Indian conditions, most animals excrete daily about 1 to 1.5 kg of dry matter per 100 kg of live body weight. However, there is a great variability in the data on the quantities of wastes excreted by various animals. Animals also vary in size and live weight according to their age, as illustrated in the following figure.

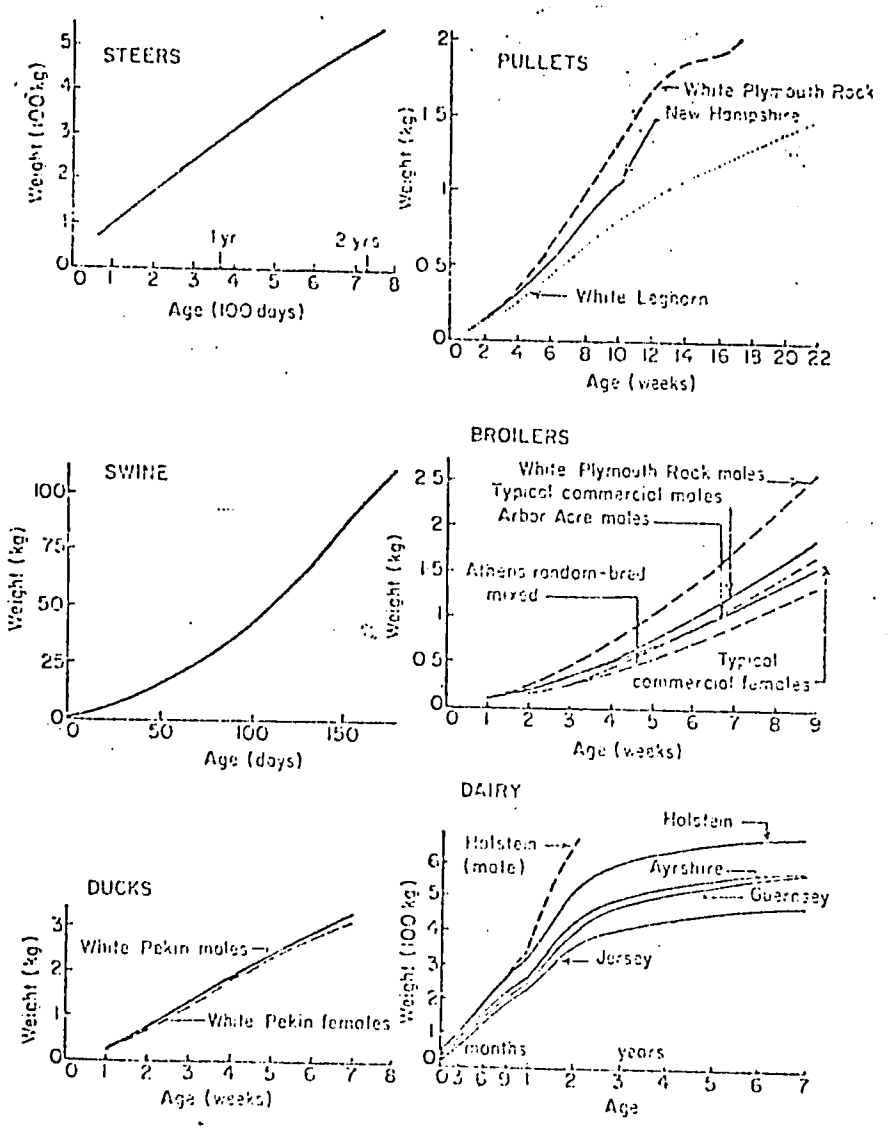


Figure 3.4.1: Age versus weight of animals (1 lb. = 454 kg.)

Source· Animal Wastes, edited by E. Paul Taigarieds, Ohio State University Columbus, Ohio, Applied Science Publishers, Ltd., London

3.4.3.2 (iv) Urban refuse: The amount of waste produced in urban areas is generally a function of population. The quantity of waste generated per person is estimated to be 5 lbs (2.27 kg) a day. At present the urban refuse is disposed of in landfills, and also by burning in municipal incineration. Landfills and incineration operations are not desirable because they contribute to environmental pollution and because the available space for landfills is scarce. Therefore, the conversion of urban refuse into most useful form of energy may solve the problem of disposal. The energy sources represented by this refuse is renewable.

3.4.3.2 (v) Industrial wastes: Industrial wastes consist of the materials discarded from industrial operations. These include wastes obtained from product processing, packaging, shipping, office and other wastes. Since the composition of wastes varies from one industry to another, they will exhibit different heating values.

3.4.3.2 (vi) Municipal solid waste: The most common material found in municipal solid waste is paper in a variety of forms such as newspaper, cardboards, magazine, etc. The most desirable quality of these wastes in their low sulphur content, usually less than 0.12 percent by weight. According to one analysis made by Environmental Protection Agency (USA), the heating value of these materials would be about 5300 BTU/lb (2915 kcal/kg). However, their heating value varies depending upon the composition of the municipal wastes. Their composition varies seasonally and regionally.

Municipal sewage contains organic material that is filtered and treated for removal. Sewage, however, is principally water. The treatment of sewages offers another potential source of energy.

Both municipal and industrial wastes possess relatively high heating values, which allows them to be incinerated with very little, if any, additional fuel. Incineration is a solution that can reduce the amount of refuse for disposal to about one-tenth of its original volume. The heat generated by incineration of refuse can be used for steam production which can also be used for power generation or heating purposes.

3.4.3.2 (vii) Floating water plants: At present, floating water plants (e.g. water hyacinths) are pest plants in many rivers, lakes and ponds in tropical and semitropical areas in the world. The rate of growth of water hyacinths is rapid and in nutrient-rich ponds net productivity of up to 25 tons of dry product per acre per year has been reported. The floating water plants can be used as a fuel for methane production and also as a cattle feed. However, in view of the land water constraints, large scale plantation of such plants may have little relevance unless these are grown in sewage or soil water.

3.4.3.2 (viii) Marine biomass: The production of marine biomass as an energy source has several attractive considerations, the most important being the large area of ocean available for such purposes. However, the disadvantages include the meager state of existing knowledge and the difficulty of operating under oceanic conditions.

3.4.4 Biomass Conversion Technologies

Biomass obtained from various sources, as mentioned above, can be converted directly into thermal energy by combustion or into more concentrated fuels by a number of ways. The choice of conversion technique is frequently dictated by the physical nature of the material. There are two major methods for converting

biomass into energy viz dry processes which involve transformation of materials under high temperatures, and wet processes which involve biological changes such as fermentation.

3.4.4.1 DRY PROCESSES

3.4.4.1 (i) Combustion: The direct combustion of fuelwood crop residues and animal and animal dung to produce energy is an ancient concept. Direct burning appears to be the cheapest and quickest way for rural poor to utilize these wastes. The organic solid wastes have water contents ranging from about 85 per cent for fresh agricultural plant and animal wastes to about 20% for much urban solid refuse. Therefore, a drying step is usually requested for their combustion.

At present wood combustion is carried out on a large scale, producing steam for various application. The production of steam can be accomplished by two approaches, namely, through the use of conventional boiler-furnace generation, and by fluid-bed incineration which involves the production of heated gases from wood combustion. Equipment generally used for wood combustion can be categorized as field erected boilers, packaged systems and special combustors. Wood fixed systems are generally similar to coal-fired units in designs. Both systems have low volume heat release rates and both are designed to complete burning. Ash removal and thermo-pile burning is accomplished by vibrating, reciprocating, oscillating or travelling grates. As firewoods have varying and high moisture content, pinhole grating systems are preferred. Most units for firing wood if properly designed can handle residues with moisture content as high as 50-55%.

Combustion rates are determined by temperature, pressure, availability of reactants (fuel and air), the the reaction mechanism itself. For combustion of solid fuels, materials are heated to a temperature high enough to drive off the

water in the fuel causing fuel to decompose and the volatile component of the fuel to evaporate. The remaining carbon either burns in its solid phase or reacts with air to form carbon monoxide, which mixes with oxygen and burns.

Table 3.4.2 gives the energy values for selected solid and liquid fuels. The properties of the selected waste fuels are described in Table 3.4.3.

The heat produced by combustion may be used for steam, which is required for industrial purposes and electricity production. Hot combustion gases are suitable for drying or heating purposes. The combustion of wood, agricultural crop residues and animal dung provides energy for cooking food, particularly in rural areas of the developing countries. Most of the stoves for these traditional fuels accomplish little more than holding the cooking vessel at an appropriate height above an essentially open fire. Thus, the widespread ancient technique is estimated to achieve only 5 - 10% efficiency. Therefore, there is a great need to increase efficiency of these stoves by further improvements, viz., enclosing the fire, regulating the flow of air, and adding a chimney.

According to a World Bank publication, two types of stoves with improved efficiency have been developed in a few developing countries. The first, referred to as a mud stove, is made from a mixture of sand and clay, available even in rural areas. The chimney for this type of stove can be made from a metal stove pipe, bamboo or it may also be built up with bricks. These stoves are relatively cheap and have great potential in developing countries.

The second type of stove is made with a shell, usually a metal can. A liner of ceramic or other material may be used to keep the fire away from the shell, reducing heat losses and increasing shell's life. The cooking pot and food can be placed on the top of the shell for frying or inside it for stewing and higher efficiency. Stoves of this kind can be designed to be packed with sawdust, rice hulls, or other loose fuels. Intensive efforts should be made

Table 3.4.2: Energy Values for Selected Solid and Liquid Fuels[a]

	Moisture Content Wet Basis %	Net[b] Heat Value	
Solid Fuels:		Btu/lb	kcal/kg
Sawmill Residue	50	4,500	2,475
Municipal Solid Waste	40	5,000	2,750
Coal	10	11,000	6.050
Cord Wood	20	6,700	3,685
Corn Stalks	20	7,245	3,985
Straw	12	7,500	4,125
Tomato Vines	0	6,730	3,702
Liquid Fuels		Btu/gal	kcal/gal
Diesel Fuel		140,000	35,280
Gasoline		120,000	30,240
Ethanol		77,000	19,404
Methanol		57,100	14,389

[a]Miles 1979 and Horsfield et al. 1977.

[b]Combustion calculations use either a higher or a lower heating value, depending on whether the heat of vaporization is included in the reported value. For the lower or net heat of combustion, it is assumed that all products of combustion remain in the gaseous state; however, for the higher or gross heat of combustion, the water vapor formed during the combustion is condensed to the liquid state. All comparisons in this study are based on the lower heating value.

Source: The costs of using crop residues in direct combustion applications (SERI publication) Silvio Flaim, David Urban

Table 3.4.3: Properties of Selected Waste Fuels[a]

Kind of fuel	Average composition and calorific value of crude fuel								Average composition and calorific value						Volatile content of combustible matter %
	C %	H %	O %	N %	S %	Ash %	Moisture %	Net calorific value, kcal/kg	C %	H %	O %	N %	S %	Gross calorific value, kcal/kg	
Wood waste (Shavings, trimmings, etc.)	42.1	5.0	34.8	0.5	---	2.6	15.0	3,498	51.0	6.1	42.3	0.6	---	4,813	70 - 85
	34.6	4.2	28.7	0.4	---	2.1	30.0	2,788							
	27.2	3.3	22.5	0.3	---	1.7	45.0	2,068							
Tan bark	16.3	1.9	13.0	0.3	0.1	2.4	66.0	1,031	51.7	5.9	41.3	0.9	0.2	4,785	76
Sunflower stalks	48.0	5.6	39.5	0.9	0.1	1.9	4.0	3,707	51.0	5.9	42.0	1.0	0.1	4,807	80
Flax stalks	43.9	5.3	36.0	0.9	0.1	2.8	11.0	3,812	51.0	6.1	41.8	1.0	0.1	4,840	83
Rice husks	35.9	4.4	30.6	0.5	0.1	8.5	10.0	3,102	50.3	6.1	42.8	0.7	0.1	4,730	80
Straw	43.3	5.3	36.2	0.9	0.1	4.2	10.0	3,658	50.5	6.2	42.2	1.0	0.1	4,692	

[a]Ordinanz, William O. "Characteristics of Unusual Waste Fuels." Power Generation. June 1949, p.59.

to develop and disseminate high efficiency stoves at low-cost, so that the rural poor can afford to purchase them.

3.4.4.1 (ii) Pyrolysis: Pyrolysis is a process of destructive distillation carried out in a closed vessel in an atmosphere devoid of oxygen. When organic wastes are subjected to this process, three types of fuels are produced, namely, tar and oils, char and carbonaceous gases. The relatives yields of each product are determined by the feed-type, preparation, and reaction temperature while the rate of heating influences the composition of the products. High heating rates generally correspond to an increase in carbon monoxide and a decrease in carbon dioxide.

Pyrolysis of biomass has largely been demonstrated in various countries, including Europe, Japan and the United States. It has been established that this process is also feasible as a method of processing of solid municipal wastes. Other biomass materials like animal wastes, crop residues, wood and wood waste and paper wastes have also been converted by this process to chars, oils and gases. The materials which are otherwise difficult to dispose of (plastics and tires) can be converted to useful fuel by this process. The liquids are oil-like materials and the solids are similar to charcoal. Whereas the gases are a mixture of hydrogen, methane, carbon monoxide, carbon dioxide, and the lower hydrocarbons. This process has long been applied to produce charcoal from wood. High heat transfer, short residue time, and use of very finely divided biomass are critically important to this process. Operating temperatures range from about 500°C to as high as 900°C or more.

Charcoal can be produced from various organic wastes, as mentioned above, but wood is the most suitable for charcoal production. Charcoal from wood is produced by the thermal decomposition of wood in kilns at temperatures in the

range of 160 - 430°C in the absence of air. The main types of kilns presently being used for charcoal production are earthern kilns, steel kilns, brick kilns and cement kilns. Modern types of kilns require 6 to $8m^3$ of dry wood to produce one ton of charcoal, whereas the traditional earthern kilns require up to $12m^3$ of wood for the production of one ton of charcoal. When wood is heated to about 250°C, moisture and volatile materials present in the wood evaporate, leaving carbon and inert materials in the form of charcoal. The other byproducts generated are wood tar, gases and pyroligneous acid. Pyroligneous acid can be distilled to recover methanol, acetic acid and acetone. A schematic diagram of solid waste pyrolysis process is shown in Figure 3.4.2.

Dr. D.E. Earl has listed the following results for dry tropical hard woods; giving yields of various products from pyrolysis of 1000 kg of dry wood.

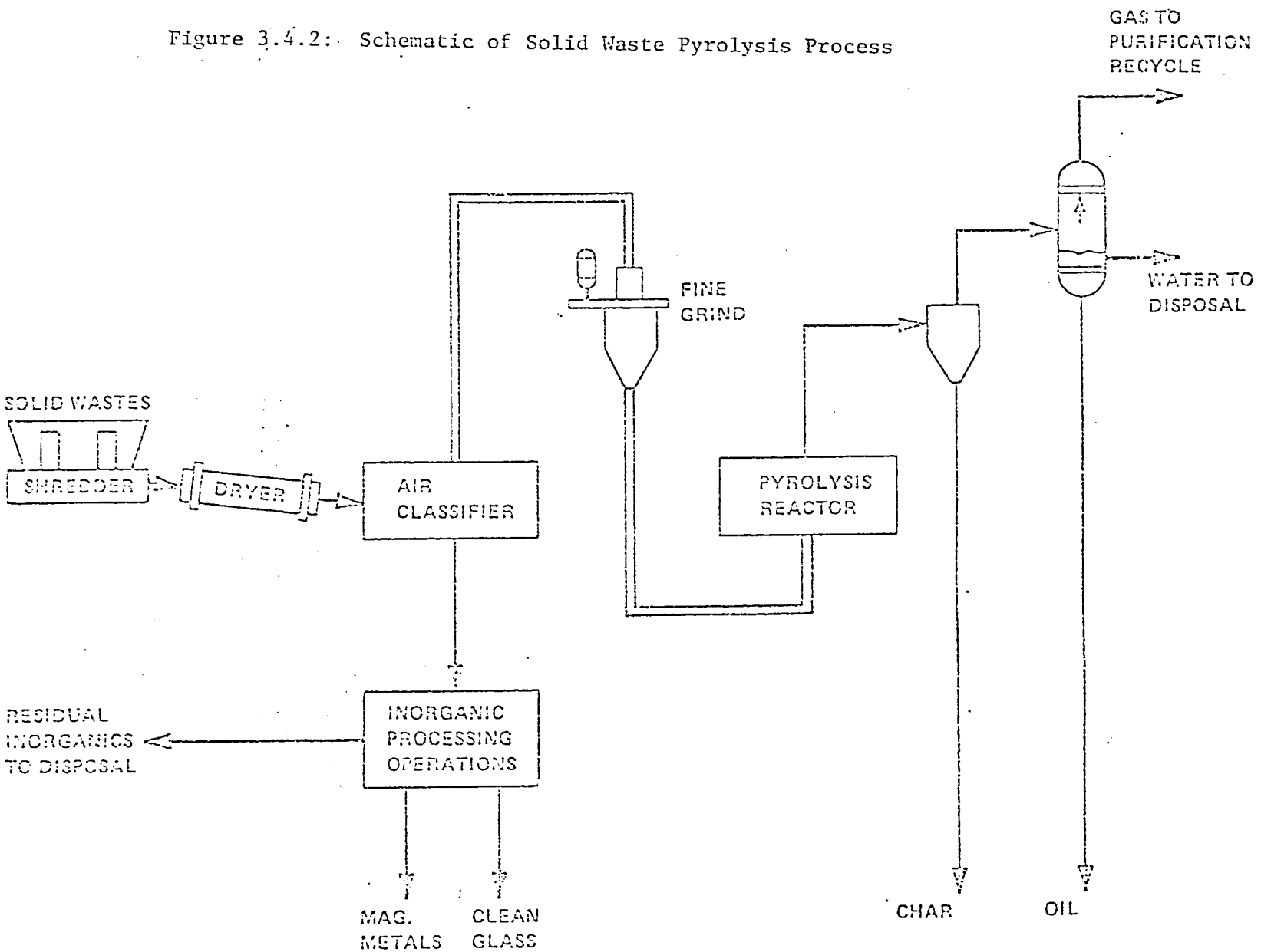
Charcoal	300 kg
Gas (inflammable - calorific value 2500 kcal/m^3	$140m^3$
Methanol	14 liters
Acetone	3 liters
Esters (methyl acetal, ethyl formate, etc.)	8 liters
Acetic acid	53 liters
Wood oils and light tar	76 liters
Creosote oil	12 liters
Pitch	30 kg

(Water of decomposition of the dry wood 25%)

Source: Charcoal Production in Papua New Guinea - An Assessment of Selected Sites, Technologies and Feedstocks by A.C. Harris

The figures shown above, however, vary widely depending upon the type of raw material and method and equipment used. The pyrolysis conversion of wood to produce charcoal has an efficiency of about 40% with modern kilns, whereas the efficiency is 20% with traditional earthern kilns. The charcoal making can be improved in various ways. Portable steel kilns in large masonry kilns could be

Figure 3.4.2: Schematic of Solid Waste Pyrolysis Process



Source: Solar Energy as a National Energy Resource NSF/NASA Solar Energy Panel, Dec. 1972.

used or an externally heated retort can be substituted for the internally heated kilns.

Charcoal is easier to transport and handle economically than an equivalent amount of wood. In many countries of the world, charcoal is most widely used as a household fuel in urban areas. Charcoal is also used in industries: iron industry and gun powder industry.

The iron industry generally prefers charcoal that has properties of high crushing strength and can be manufactured from various heavy hardwood species, whereas in the gun powder industry, softer charcoal derived from softwood species (willow and basswood) is preferred.*

The production of biomass-derived fuels by pyrolysis has the advantages that biomass contains low sulphur. However, the disadvantage of the pyrolytic conversion processes include high technical skills required in operation and the requirement of dry feedstock.

Gasification of wood differs from pyrolysis in the sense that gasification temperatures are sufficiently high to yield only gaseous fuels. Otherwise this process is very similar to that of the pyrolysis process. The low Btu gases produced from a gasifier can be burned in boilers and gas turbines.

3.4.4.2 Wet Processes

Another principal method of converting organic wastes into energy is by biological means, such as fermentation. Wet processes which involve micro-organisms differ in two ways from dry processes: First, an aqueous environment is necessary and, second, they are slow and depend on the nutrient conditions.

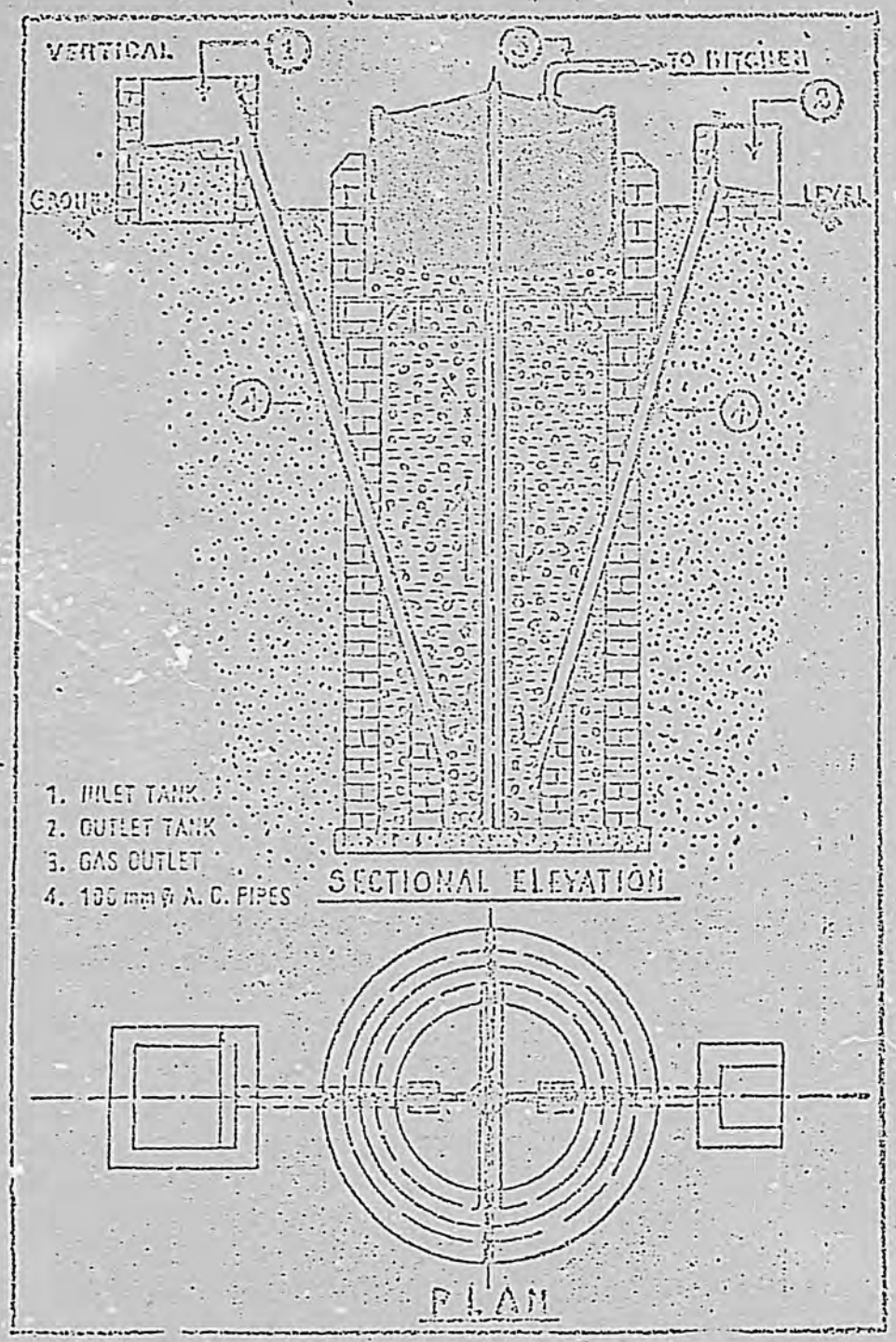
*Gas and liquid products of wood pyrolysis can be burned in boilers. This process is usually considered for existing gas or unfired boilers for which there is a need to convert to solid fuels. Retrofit of gas or oil boilers to direct wood firing is very expensive. The uses of gaseous and liquid fuels can, therefore, minimize the boiler retrofit requirements.

3.4.4.2 (i) Production of Methane: When organic matter is decomposed under oxygen free conditions, they produce a flammable gas known as methane. The raw materials used for production of methane by fermentation have been classified as waste materials, which include agricultural crop residues, animal wastes, and urban refuse. The anaerobic digestion of biomass producing methane, known as biogas, can be achieved with the help of a simple and cheap plant known as a biogas digester plant. This can be constructed by and large from raw materials available in rural areas. The biogas plant shown in Figure 3.4.3 is comprised of a digester of adequate size to ferment the cow dung, urine and night soil in an efficient manner. The gas holder covers this digester to collect and divert the gas produced through fermentation to the points of use, i.e. kitchen stoves, Gobargas lamps, and gas engines. Special gas appliances meant for Gobar gas such as stoves, gas lamps and engines have been developed and manufactured in India.

As a fuel, biogas is similar to natural gas which contains about 80% methane and has a calorific value of 8,660 kcal/m^3. The heat value of biogas can be further improved by reducing its carbon dioxide content. The size of a gas plant at any place will be determined by the actual number of animals or people. The small gas plant in India is of 2 m^3 size, which requires about 5 animals. This is enough to meet the energy needs for cooking and lighting for a family of 5 - 6 people. The amount of dung needed for this plant is 45 kg of wet dung or 9 kg of dry dung per day.

Following is the gas consumption for different applications, based on Indian experience:

For cooking	12 ft^3 (0.3428 m^3)	per day per person
For lighting	4.5 ft^3 (0.1285 m^3)	per hour per lamp of 100 candles
For motive power	15 ft^3 (0.4285 m^3)	per Hp per hour



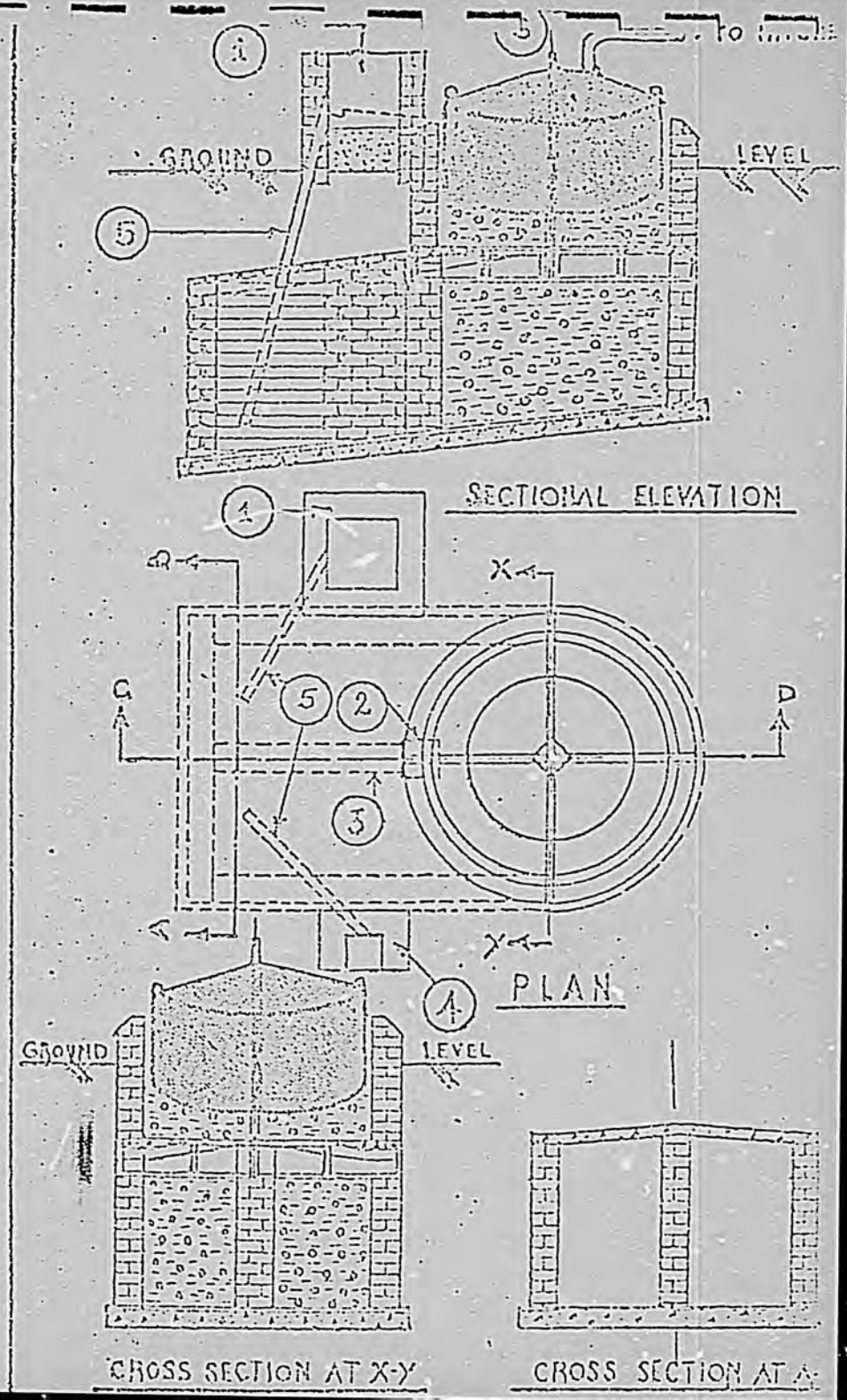


Figure 3.4.3: Biogas Plant (Indian type)

Table 3.4.4 shows the approximate number of animals required for different sizes of biogas plants.

Size of Plant m^3	(ft^3)	Approximate Number of Animals Required
2	(70)	2 - 3
3	(105)	3 - 4
4	(140)	4 - 6
6	(210)	6 - 10
8	(280)	12 - 15
10	(350)	16 - 20
15	(525)	25 - 30
20	(700)	35 - 40
25	(875)	40 - 45
35	(1,237)	45 - 55
45	(1,590)	60 - 70
60	(2,120)	85 - 100
85	(3,004)	110 - 140
140	(4,948)	400 - 450

Source: '"Gobar Gas: Why and How?" KVIC Newsletter (India), July 1974

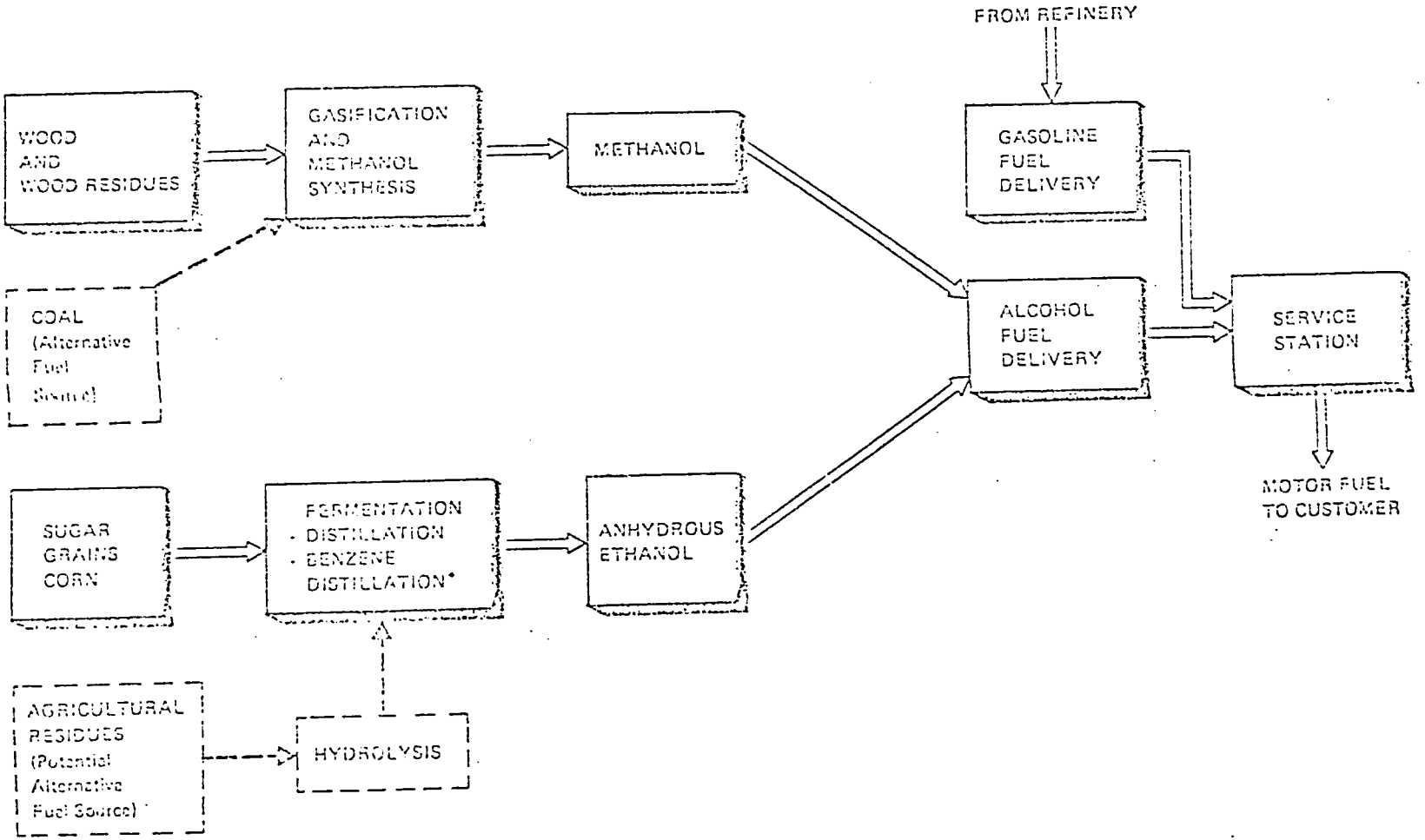
On an average, the daily drippings expected from a medium size cow, buffalo or bullock can be 10 kg (green weight). Very large buffaloes may give as much as 20 kg per day. Of course, this applies to animals which are stable. The quantity of dung available from different animal species is shown on page 6 of this report.

The digested organic waste becomes an odorless innocuous, incapable of attracting or breeding flies. It becomes a better organic manure than the conventional farm yard manure. The biogas produced can be used as a fuel for cooking, lighting, drying, thrashing and processing agricultural products, driving tractors and farm machinery and pumping water for drinking and micro-irrigation purposes. Biogas driven engine pumpsets can be introduced with little or no modification in the existing diesel pumpsets widely being used in India and many developing countries. This can be employed to meet the growing energy and irrigation needs of the rural villages of developing countries. India and China have already launched programs for installing biogas plants of various designs and sizes. Many other developing countries have also been trying to introduce biogas plant installations in a big way.

3.4.4.2 (ii) Production of Alcohol: There is a world-wide attention on the near-term possibility of blending biomass-derived alcohols with gasoline for transportation fuels. Alcohols produced from biomass are renewable fuels. The use of alcohols produced from biomass as an automotive fuel could be substituted for petroleum products, reducing the country's dependence on imported oil. In a later section, the production, utilization and environmental impacts associated with the use of alcohol (ethanol) will be discussed in detail, based on the Brazilian experience. This section, therefore, covers these aspects only briefly.

Alcohols can be produced from various biomass resources such as wood, sugar cane, grain, cassava, corn, sweet sorghum, sugarbeets and potatoes. The production of alcohols using biomass resources is a well established technology. Methanol and ethanol are the only alcohols which are currently being considered for extensive use as an automobile fuel. Figure 3.4.4 gives likely routes for

Figure 3.4.4: Biomass-Alcohol Fuel Routes



*ETHANOL DRYING PROCESS

Source: "Biomass-Based Alcohol Fuels
The Near-Term Potential For Use with Gasoline"
MITRE Technical Report (July 1978)

the production of alcohol from biomass resources. The upper route is for the production of methanol and the lower one for ethanol.

Production of methanol from biomass can be achieved in a two-step process. The first step is a high temperature gasification process which produces "synthetic gas", a mixture of hydrogen and carbon monoxide. The second step involves conversion of the synthetic gas into methanol. It is expected that because of its availability at relatively low cost, wood would continue to be the principal biomass feedstock for the production of methanol. However, the present efforts include using other biomass materials, as mentioned above, to produce methanol. The problems associated with them are their limited supplies and high costs for collection and transportation.

The lower route of Figure 3.4.4 shows the most likely routes for the production of ethanol from various biomass feedstocks. The fermentation process can accept any biomass feedstock whose carbohydrate content can be easily fermented. Other biomass resources like wood or agricultural crop residues can be used for the production of ethanol. Conversion of cellulosic materials to alcohol would, however, require an additional front-end stabilization step called hydrolysis. The cost of these processes still appear to be too high, according to a study made by DOE (USA).

Both methanol and ethanol could be used directly as substitute fuels in automobile engines. However, carburation systems that are in use presently would require some significant modifications to accommodate the use of these alcohols. An engine designed to run on gasoline would not run on pure alcohol fuel without the conversions described above.

Both methanol and ethanol can be mixed separately or together with gasoline in any desired proportions. As the percentage of alcohols in the fuel blend increases, reduction in driving performance occurs. Stalling and hesitation on

warm-up are the most common problems to be encountered. The extent of performance loss depends on the type of vehicle, its age and state of tuneup. It is estimated that these performance problems are usually not severe so far as the percentage of alcohol is less than about 15%.

Use of methanol was first demonstrated by the Vulcan Cincinnati Corporation (USA) in 1972. The test facility consisted of a commercial utility boiler with a capacity of 50 MW. The results showed that methanol provides not only a good stable flame and good burning efficiency, but also better performance than natural gas or fuel oil. In addition, methanol can also be used as a fuel for fuel oil. Another potential use of alcohols relate to transportation and processing of coal. Alcohols may have future use as replacements for natural gas in drying processes.

3.4.5 Limitation of Biomass

Large scale usage of biomass for energy production is likely to compete heavily with the primary demands for food and fiber. Traditionally, agriculturally suitable land has had grain production as a primary focus. The other problems are that biomass quantities are subject to variation with the weather. There are certain constraints which limit the use of three major biomass resources, namely, animal wastes, agricultural crop residues and forest residues. Supply constraints are one major limitation, which includes the potentially higher value use of wood bark for other purposes. Similarly, the residual value of agricultural crop residues is a source of plant nutrients and soil conditioner. The removal of manure from the soil also affects fertility of the soil. Other constraints relate to problems of potential users, i.e. public utilities, who are uncertain as to the reliability of long-term supply and the lack of demonstrated viability of existing biomass sources. The high cost of collection

and transportation of biomass resources also limits their use on a large scale.

3.4.6 Environmental Impacts

The environmental effect of a large scale biomass energy plantation may include alteration of the earth's heat balance, radical changes in natural vegetation, heavy water use, water contamination from soil and fertilizer run-off, and the deterioration of soil quality. Surface water impacts may arise from soil erosion, run-off and increases in water temperature and volume. Care should be taken so that roads that are sited properly, ditched and water-barred should minimize erosion hazards. Run-off volume problems may only be temporary and probably would be reduced once vegetation returns and the biomass begins to grow.

Run-off temperatures will increase during the site preparation phase. The surface water resources will be further affected by treated effluent from biomass conversion facility. However, there are a variety of chemical treatments which will remove non-biodegradable compounds.

Ground water resources may also be affected by various farm management activities, water tables may fall slightly, and fertilizer and pesticide contamination of ground water is possible.

Various impacts on the ecology may occur either from air and/or water or directly from farm activities. Adverse ecological consequences may include soil and aquatic biota shifts, changes in wetland areas, disruption of wildlife community disturbances.

Conversion and utilization of biomass as a fuel are not expected to cause any serious problems. Combustion of biomass may produce particulates, carbon monoxide and smaller amounts of SO_x, hydrocarbons and NO_x. However, control systems are adequate to mitigate the particulates and proper design and

operation can greatly reduce emission of CO, NO_x, and hydrocarbon levels. Since biomass contains very low sulphur, sulphur oxide levels will cause no significant impacts.

3.4.7 Prospects of Biomass as a Fuel in Developing Countries

Biomass as an energy source has a great potential for developing countries. The renewable nature of the biomass plantation offers potential for a sustained output of wood for fuel. In addition to direct burning, wood can be processed to produce gaseous or liquid fuels as well as charcoal. Charcoal technology is well established, involving wood distillation, pyrolysis and heating in the absence of air to produce, together with charcoal, gaseous and liquid by-products. Ethanol production through the bioconversion route also offers distinct possibilities. Although the technology is rapidly developing, a great deal of further research and development are still needed.

Biogas produced from anaerobic digestion of organic wastes, including animal wastes, holds considerable promise for the developing countries. There are many advantages to be drawn from the use of biogas, especially in rural areas. In many developing countries, dried cattle dung has been traditionally used as domestic fuel, robbing the soil of an important fertilizer, thus reducing soil fertility. The use of biogas units provides a sanitary and convenient way to produce fuel while retaining a large part of the feedstock in the form of sludge. This sludge can be used as an effective soil conditioner and fertilizer.

While many biogas plants are already in operation in China, India and a few other countries, experience to date shows that capital costs of a digester are still high and beyond the reach of the average rural poor in many developing countries. Further work in this field is required to arrive at the cost effective and best possible design of a digester that gives an optimum yield of

methane and requires low maintenance. Community size biogas plants seem to be more advantageous to the poorer sections of the rural population.

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3.5 GEOTHERMAL ENERGY

1. Introduction

Geothermal Energy is that energy derived from the internal heat of the earth. The interior of the earth consist of a molten fluid of extremely high temperatures called magma and heat is constantly being dissipated from the interior to the earth's surface and atmosphere. In some instances, due to geological faults in the earth's structure, the magma has pushed its way closer to the surface. The magma will then heat the layers above it, and vast quantities of energy may be stored in these layers relatively close to the earth's crust (surface).

This energy is geothermal energy, and sometines it may manifest itself naturally in the form of geysers, hot springs, fumaroles or boiling mud pools.

In the past, this energy form has been overlooked as a useable source of energy, but rising energy costs and new developments in the exploration technology enables resources to be identified and utilized very effectively, up to depths of 3 km from the earth's surface. Geothermal energy , however, is not a renewable resource; as each geothermal field has a lifetime, which will be dependent on the rate of explotation of the energy. It is by no means easy to predict the life of the field at full scale production, but certainly, while available geothermal energy is one of the cheapest sources of energy available. A field life of a minimum of 20 - 30 years should be considered if the resource is to be utilized.

3.5 2. Characteristics of Geothermal Energy

There are three principal types of geothermal energy: 1) Hot Dry Rock, 2) Geopressured, and 3) Hydrothermal

1) Hot Dry Rock: These are geologic formations at accessible depths with high heat content and little or no water. Thermal energy may be extracted by cir-

culating a heat transfer fluid (water) through deep wells connected by man-made factures in the rock.

2) Geopressured: These resources consist of water and dissolved methane at high pressures and at moderately high temperatures. Geopressured resources may provide a combination of three energy sources: fossil energy from the dissolved methane, mechanical energy from the high pressure fluid and thermal energy from the moderate temperature fluid.

Commercial use of geopressured and hot dry rock resources is not foreseen for 5 to 10 years as improvements in the technology are required before these resources can be tapped economically.

3) Hydrothermal: In hydrothermal systems, natural water circulation moves the heat from deep internal sources towards the earth's surface. There are three types of hydrothermal systems: (i) Semi-thermal fields which produce hot water at temperatures up to about 100°C and from depths of 1 to 2 km, (ii) Wet Hyper-thermal fields, producing pressurized water at temperatures above 100°C. When the fluid is brought to the surface and the pressure reduced, a portion may be flashed into unsaturated steam; (iii) Dry Hyper-thermal fields, producing dry saturated or superheated steam at pressures above atmospheric.

Hydrothermal energy is a fairly wide-spread resource, and this energy form has been the most developed. Dry hyper-thermal fields are the most desireable at present, as the steam may be used directly to run a turbine for power generation. This has been done in Italy, U.S.A. and Japan.

Wet hyper-thermal fields produce large quantities of water as well as steam. This water is separated before the steam is passed through the turbines,

and the water may be flashed into steam for use in low pressure turbines, or it may be used for other applications where heat is required. Wet fields are much more common than dry fields, and this resource is currently being utilized in many countries throughout the World.

The semi-thermal fields which produce hot water are usually utilized for heating of buildings and for the provision of low to moderate temperature process heat in agriculture and industry. This use has been applied on a large scale in Iceland and Hungary. Electricity may also be produced from these waters by utilizing a secondary fluid, in a closed cycle, the heat input being provided from the geothermal fluid via a heat exchanges.

3.5.3 Data Collection and Analysis

Exploration for geothermal energy has become very technical and complex, involving a variety of disciplines which incorporate geological, geophysical and geochemical studies of a region. The examination of surface irregularities by the geologist, and this is followed by the geophysical studies to obtain crustal structure information. The geochemical analysis is necessary to determine the nature of the fluid, and it serves to indicate the base temperature of the reservoir.

Figure 3.5.1 illustrates one possible amalysis procedure for a region, starting with a regional survey and culminating in a model of the hydrothermal system.

It should be noted that even with such an elaborate procedure, no drilling has taken place, A comprehensive analysis of the subsurface conditions should be carried out to indicate the best location for the initial boreholes, as drilling is a very costly operation and has no guarantee of success.

Many of the geothermal exploration techniques have been adapted from the experiences gained in oil explorations. Once surface conditions which indicate thermal activity are identified, some of the follwoing geophysical methods may be employed:

REGIONAL SURVEY

PETROLOGY	REFRACTION SEISMOLOGY
STRATIGRAPHY	GRAVITY SURVEY
TECTONIC STRUCTURE AND HYDROLOGY	MICROEARTHQUAKE SURVEY
HYDROTHERMAL ALTERATION	MAGNETIC SURVEY
HOT SPRINGS AND FUMAROLES	RESISTIVITY SURVEY
CHEMICAL ANALYSIS OF THERMAL WATERS	INFRA-RED SURVEY
DEUTERIUM AND TRITIUM	HEAT FLOW

PRIMARY RESULTS

GEOLOGICAL MAP	EXCESS HEAT STORED	CHEMISTRY OF THE THERMAL FLUID
CRUSTAL STRUCTURE	NATURAL HEAT LOSS	ORIGIN OF THE THERMAL FLUID

PRIMARY MODEL OF THE HYDROTHERMAL SYSTEM

Figure 3.5.1 Schematic for analysis of a geothermal reserve

3.5.3.1 Thermometry:

By embedding themometers of a suitable type at various depths (a least 1 and 2 meters) and at many points over a wide area, and by observint their readings, the geophysicist can deduce temperature gradients and heat flow rates may then be calculater, if soil conditions are known. These results can indicate more deeply seated hot spots in the subsoil. Temperatures over 1°C higher than the average for the formation, and those below an upper limit, say 50°C above the average, are detected.

3.5.3.2 Electrical Resistivity:

A hot water field will tend to produce a zone of low resisturity, dut to the dissolved salts, while a steam field will tend to be a high resistivity zone. The resistivity measurements are performed by injecting direct current into the ground through suitably spaced electrodes, and emasuring the voltages between these electrodes. More recently, induction electromagnetic methods have gegun to be used. These techniques can give very accurate details concerning the geothermal resource, without the need for exploratory drilling, provided that tne data is properly interpreted. The drawing of a resistivity map is recommended for better siting of the initial prospecting wells.

3.5.3.3 Gravimetric:

Gravimetric techniques may be used to measure changes in rock densities. A known standard is set at one location, and comparisons with the densities at other points in the region are made. The changes in densities reflect major and minor fault zones beneath the surface, and in the Imperial Valley, California, there is a definite correlation between high heat flows and density highs.

3.5.3.4 Infrared and Remote Sensing:

The intensity of the infrared radiation given off by a body increases with temperature rises. Aerial infrared surveys (or satellite surveys, if possible) can be used on high temperature regions to outline thermal surface patterns. The subsequent interpretation of these patterns can give insights to possible geological structures controlling the heat flow.

3.5.3.5 Seismic:

Measurements of the time seismic waves take to travel between two points can lead to identification of different densities and crystal structures. This data may be used to determine the best drilling sites and to clarify the subterranean picture. Another seismology technique is the ground-noise survey in which a seismograph is used to measure the intensity of the backgroune noise of the region. Areas of increased noise levels are usually associated

with geothermal reservoirs.

3.5.3.6 Magnetics:

The magnetic method of exploration of a geothermal field is dependent on the change in magnetic properties of magnetized minerals due to hydrothermal alteration and high temperatures. By use of a magnometer, magnetic anomolies can be located and magnetic contours of a region charted. This can help to determine rock type, hydrothermal alterations and possibly hot rock deposits.

All the above techniques have their advantages and disadvantages in assessing the geothermal potential of a region, but the two that offer good results at relatively low cost are the thermometry and electrical resistivity techniques. In addition to these methods, geochemistry affords one of the cheapest tools available to the geothermal exploier. Not only is geochemistry important in assessing the worth of a site, but it is very important to the engineer as geochemistry will indicate the nature of the geothermal fluid thus enabling adequate precautions against corrosion damage to be taken.

Geochemical analysis should include:

1. fundamental water chemistry
2. identification of chenical constituents relative to resorvoir temperatures.
3. dissolved gas content
4. indicators of various processes associated with high temperature reservoirs.

There is a direct relationship between a geothermal water's chemistry and it's original reservoir temperature. Hot waters containing various silica and/or magnesuim concentrations and soduim/potassuim ratios can provide accurate indicators of reservoir temperatures. Figure 3.5.2 shows the increase of silica

solubility with rise of temperature.

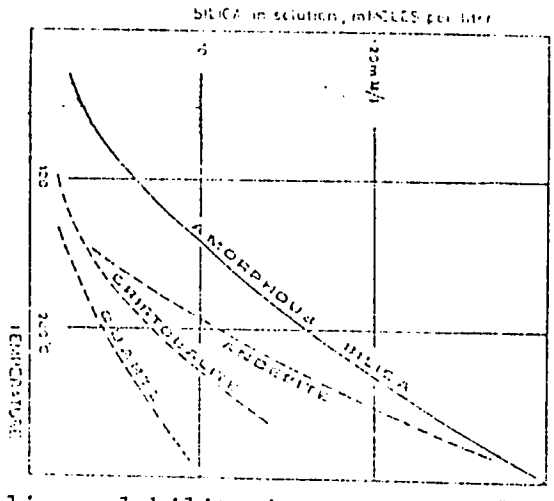


Figure 3.5.2: Silica solubility in water as a function of temperature

Source: Cherimisinoff and Morresi, Geothermal Energy Technology Development

3.5.3.7 Exploratory Drilling: Upon completion of the exploratory techniques and location of a favorable site, exploratory drilling is carried out. This is an important part of the resource assessment for the following reasons:

1. to confirm and revise the previous information,
2. to prove the technological and economical feasibility of a site,
3. to provide the information necessary for locating drill sites, and plant design and useful life.

Drilling for geothermal energy is not unlike drilling for oil and gas. The drilling rigs employed are usually of a medium-depth capacity, between 1000 and 1500 meters, as the geothermal resource is usually shallower than oil and gas. Figure 3.5.3 shows a typical layout for a typical drilling operation.

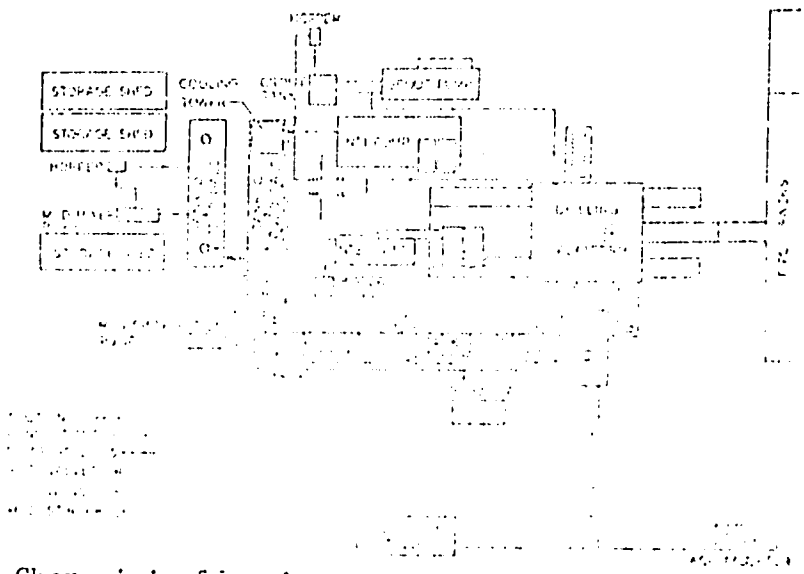


Figure 3.5.3: Schematic of equipment layout and flow lines for a drilling rig

- Source: Cheremisinoff and Morresi, Geothermal Energy Technooogy Assessment

Some indication of the drilling involved is given by Table 3.5.1 below, in which figures for some of the larger wells in production are given.

Table 3.5.1 Drilling Depth and Hole Diameters of some wells.

Locality	Dia. of Hole	Total Depth
Iceland (wet steam)	8 3/4/ins.	1500 m
Iceland (hot water)	8 3/4 ins.	2200 m
The geysers, U.S.A. (dry steam)	12 1/4 ins.	300 m
Wairabei, N.Z. (wet steam)	7 5/8 ins.	1000 m

Source: UN Conference on New Forms of Energy, Rome, 1961

The current limit for exploiting geothermal energy is approximately 3000 m; this figure is based on the current state of drilling technology and economic considerations.

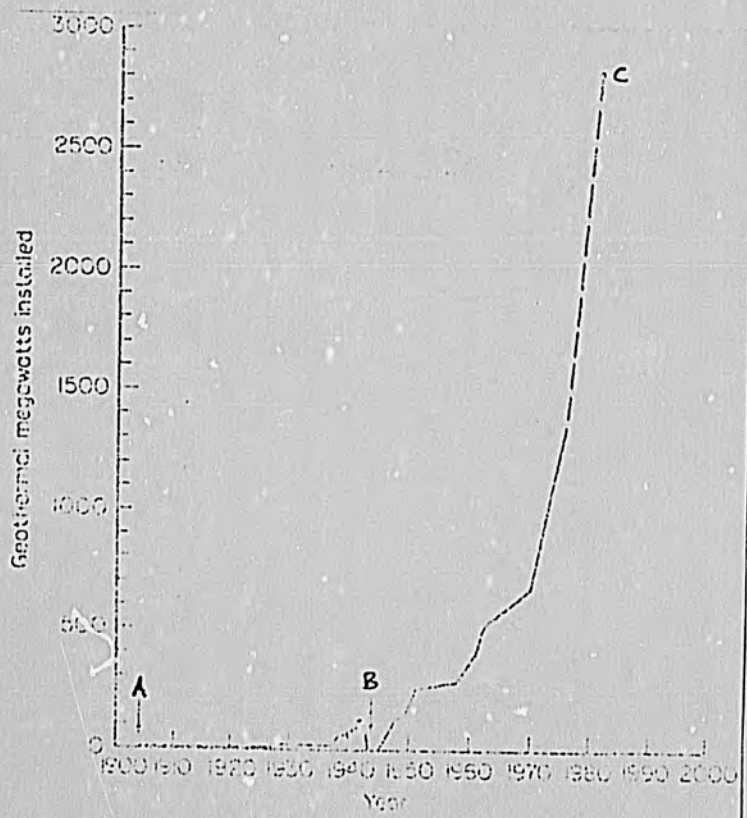
UTILIZATION OF GEOTHERMAL ENERGY

One of the major constraints of utilizing the geothermal resource is that of transporting the energy. Geothermal energy is heat in the form of steam and/or hot water, and long transmission pipelines from the source to the point of use result in large energy losses and significantly reduced overall efficiency. Thus, for high temperature resources (> 100°C), the current practice is to utilize the energy in the geothermal fluid to produce electricity, which can then be transported over relatively long distances. For low temperature resources (< 100°C) the optimal distance for transp ing the fluid is regarded as being about 10 km, and the fluid may then be used for a variety of moderate temperature applications, including space heating, hot water, industrial and agricultural process heat.

3.5.4.1 Electricity Generation

The use of geothermal energy for electricity generation was initiated in 1904 by Prince Piero Conti in Larderello, Italy. Since then, very little activity took place for another half century until New Zealand began to produce electricity at Wairabei in the 1950's. Figure 3.5.4 below gives a picture of the power plant development since 1900, while Table 3.5.3 summarizes the known installations up to 1976.

Table 3.5.3: Summary of Geothermal Power Installations (to 1976)



Country	Gross Capacities (MW) In service	Definitely planned	Contemplated
USA	522	1621	
Italy	420.6	44	60
New Zealand	202.2	165	
Mexico	75.5	325	
Japan	70	100	
El Salvador	60	30	
USSR	5.8		
Iceland	2.8	70	
Turkey	0.5	15.5	
Philippines		443	
Nicaragua		65	
Indonesia			30
Chile			15
Santa Lucia		1.5	
Kenya			30
Totals	1362.4	2877	135

In service 1362 MW
In service and definitely planned 4239 MW
In service, planned and contemplated 4374 MW

Figure 3.5.4: Growth of Geothermal Power Useage

Source: Geothermal Energy H.C.H Armstead

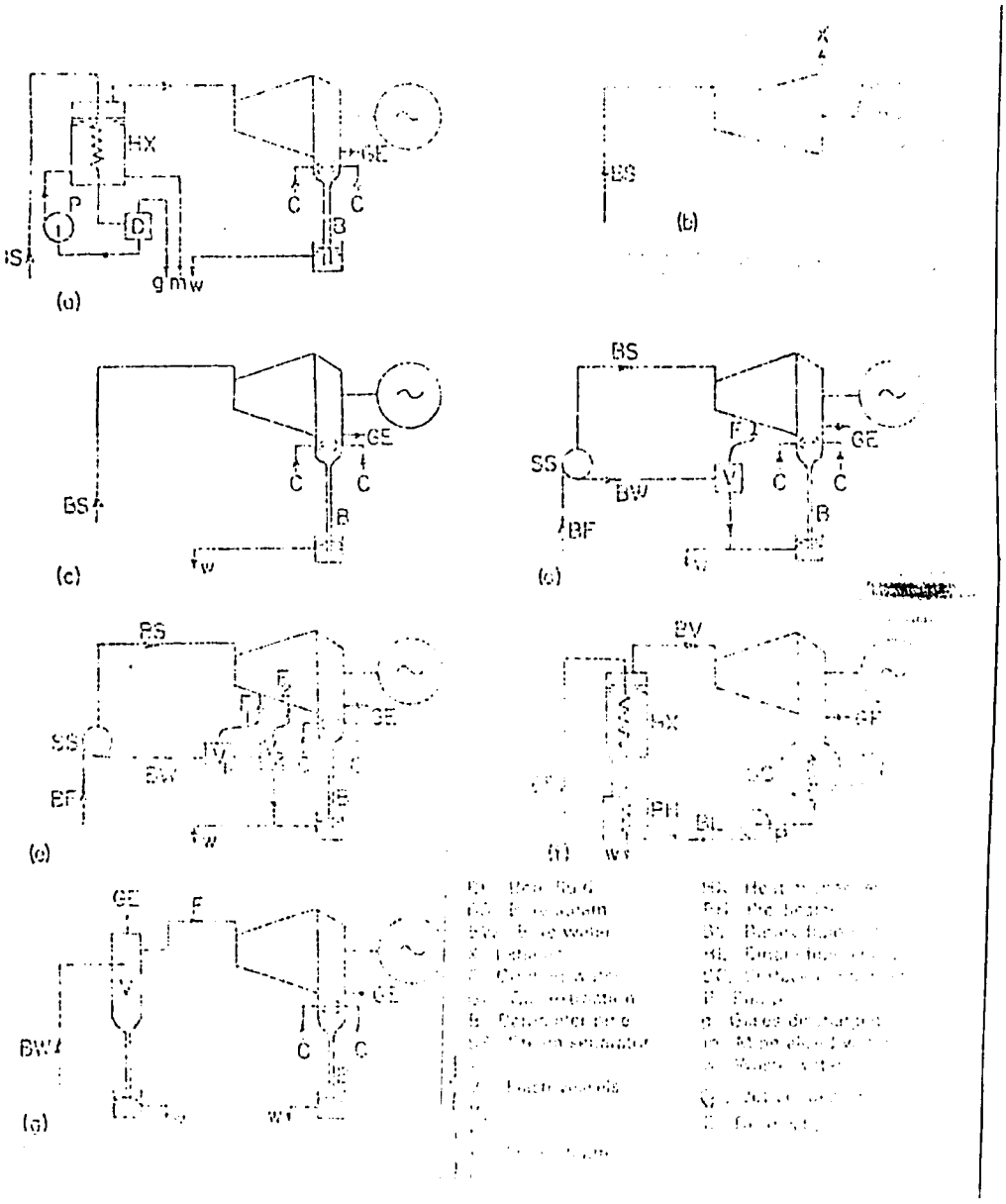


Figure 3.5.5: Geothermal power generation cycles
(a) Indirect condensing (b) Direct Non-Condensing
(c) Straight Condensing (d) Single Flash
(e) Double Flash (f) Binary Fluid

Generation of electricity from geothermal energy is an inherently inefficient process owing to inescapable thermodynamic constraints. Nevertheless, geothermal energy will continue to be utilized for power generation for some time, owing to the ease of using and transporting electricity, and the lack of development of other areas of the technology.

The various cycles used for geothermal power generation are shown schematically in Figure 3.5.5.

3.5.4.1 Indirect Condensing: This was the first system used at Larderello and involved the use of a heat exchanger to produce steam from water, due to the corrosive nature of the fluid. Since then advances in the metallurgy field have rendered such plants obsolete.

3.5.4.2 Direct Non-Condensing: This is the simplest and least costly of the cycles. Dry steam is passed through a turbine and exhausted to atmosphere, but usually twice as much steam is required as in a condensing plant. Such plants have application mainly as standby plants to meet peak loads, as they are very inefficient.

3.5.4.3 Straight Condensing: Direct contact jet condensers with barometric discharge pipes are used in place of surface condensers. Otherwise the plant is virtually the same as in conventional power plants.

3.5.4.4 Single Flash Cycle: In wet fields, supplementary heat may be extracted from the hot water by flashing the water to steam at reduced pressures. The flash steam is then passed through the lower pressure stages of the prime mover(s). Ideally, maximum efficiency is obtained if the flash vessel operates

at a temperature mid-way between that of the hot water and the condenser.

3.5.4.5 Double-Flash Cycle: Such a system was adopted for the Wairabei scheme. A second flashing operation is performed to extract more energy from the hot water, and at Wairabei about 30-32% of the power from the hot water is provided from the second flashing operation.

3.5.4.6 Binary Fluid Cycle: Refrigerant fluids, heated in heat exchangers by the geothermal fluid, can be used to drive turbines. The binary cycle has some advantages over the other cycles including: (i) the confining of chemical attack to the heat exchanger; (ii) higher vapor pressures may be used, thus allowing self-starting turbines; and (iii) fluids that would be too low for flashing operations may be used for power generation. Its main disadvantages include: (i) heat exchangers are costly and waste some energy; (ii) a feed pump which is costly and consumes power is needed; (iii) the binary fluids are volatile and must be carefully sealed; and (iv) development and plant costs will remain high until the technology is further developed.

The binary cycle has many enthusiasts, particularly in the U.S.A., and recently a 10 MW plant was opened in California and is operating without any major problems.

Some typical generating efficiency curves are shown in the following Figure 3.5.6.

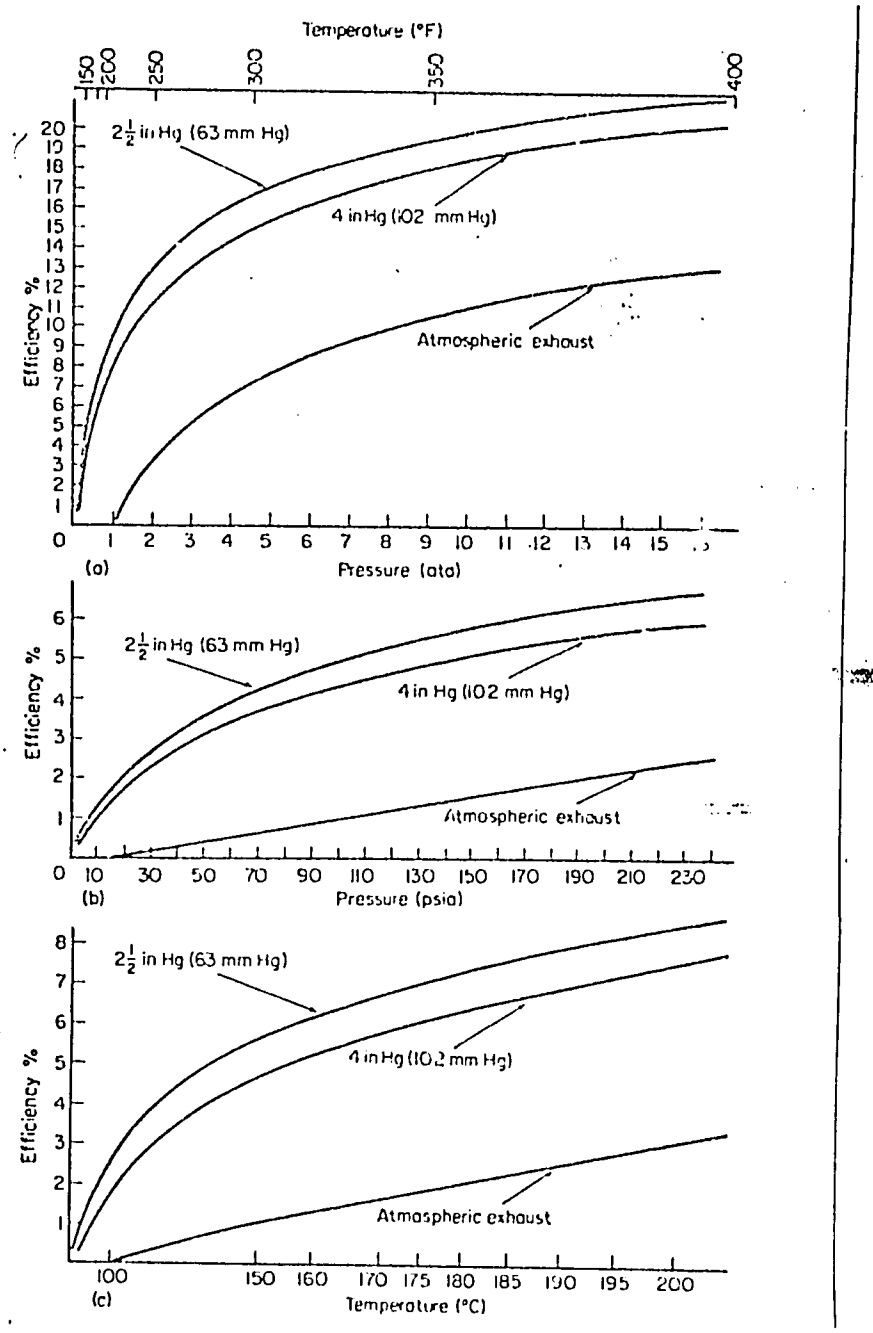


Figure 3.5.6: Typical geothermal generation efficiencies
(a) Dry saturated steam (b) Boiling water (single flash)
(c) Boiling water (double flash)

Notes: (i) Pressures and temperatures are at turbine entry
(ii) All horizontal scales apply to all three figures
(iii) No allowance is made for gas exhausters or other auxilliaries

3.5.5 "Other" Uses of Geothermal Energy

The use of geothermal energy to provide heat is an inherently more efficient process to the generation of electricity from geothermal sources. However, the losses encountered in pipelines limit the applicability for heating purposes in many cases. For this reason, most of the developments in geothermal energy were concentrated on power generation, but as the technology develops, more uses for geothermal heat in domestic, industrial and agricultural fields are foreseen.

3.5.5.1 Space Heating and Hot Water: Over half the population in Iceland is now served by geothermal energy for domestic heating requirements, and it is expected that within a decade nearly all the dwellings will be so served. In Hungary, 3500 homes were supplied with geothermal heat in 1975. Some quantitative data for these two countries is given in the following Table 3.5.4.

Table 3.5.4: Some quantitative data concerning domestic geothermal space heating and hot water supplies

Country	*Category*	*Heating demand (MW, thermal)*	*Approximate annual heat consumption (GWh, thermal)*	*Annual load factor*
Iceland [94]	In service in 1976	557	258.1*	
	Under construction or firmly planned before 1980	267	1237*	52.9%
	Tentatively planned beyond 1980	289	1339*	
	Totals, in service, planned and contemplated	1113	5157*	52.9%
Hungary [95]	In service 1975	57.5	262.8	52.2%
	Planned for completion by 1985	517.5	2365.2†	
	Totals, in service, and planned	575	2628	52.2%

* Estimated on the assumption of a constant annual load factor which, in 1975, has been deduced at 52.9% from the year's energy consumption in Iceland for space heating purposes of 2200 GWh(thermal) and demand of 474.7 MW(thermal) [7]. It is of interest to note that the annual load factor thus deduced is very nearly the same as that attained in Hungary in 1975.
† Estimated on the assumption that the known load factor of 52.2% in 1975 will be maintained in future years.

Field temperatures of 80°C are sufficient for domestic purposes, though in some cases temperatures as low as 50°C are used. The thermal efficiency of the building and the climate are the major factors in the use of this heat source. In many cases the geothermal fluid, preferably hot water, is piped directly into the house, although in some cases heat exchangers have to be used if the fluid is agressive.

3.5.5.2 Air Conditioning: Direct use of geothermal heat to provide the heat input to operate absorption air conditioning units is possible. One application for this purpose is known. The International Hotel at Rotorau, New Zealand is served by such a plant, which requires about 668 kW thermal heat input.

3.5.5.3 Industrial Applications: Many industries are heat intensive without requiring high-grade heat. The number of industries that could be served with geothermal heat is immense, but some are listed below:

(i) Chemical industry - extraction of salts, minerals, heavy water production, fermentation processes, etc.

(ii) Mining and upgrading of minerals - production of diatomaceous earth, boric acid, peat drying, alumina by the Bayer process.

(iii) Food processing - production of sugar, coffee, milk, canning, cattle meal from Bermuda grass, rice parboiling, freeze drying.

(iv) Various other industries - textiles, rayon manufacturing, pulp and paper, timber, cotton seed oil, brewing, refrigeration and gas liquefaction, plastics and other uses for process steam and heat.

3.5.5.4 Farming: This includes all forms of husbandry - agriculture, horticulture, livestock, etc. For these applications only low-grade heat is generally

required, and in temperate regions and elevated lands, geothermal heat offers great scope. Some possible applications are:

(i) Greenhouse and soil heating - currently practised in numerous countries, whereby tropical produce such as bananas have been grown successfully in Iceland.

(ii) Soil sterilization - the heating of soil to sterilize it against insects and pests is practised in Japan.

(iii) Crop and fish drying - low temperature (<80°C) drying is currently being practised in Iceland and the USSR.

(iv) Animal husbandry - heating of farm buildings in winter, particularly for poultry, can be easily accomplished with geothermal heat.

(v) Fish breeding - temperatures down to 20°C may be used for hatcheries when breeding trout, eels and other fish.

Other applications for geothermal energy that are of potential importance include distillation for the provision of potable water, and balneology and crenotherapy. In addition, geothermal areas offer scope for tourism, as many of the geothermal phenomena possess both scenic beauty and great curiosity value.

Geothermal energy will be utilized for many purposes in the future, particularly as exploration will reveal more semi-thermal fields which are more suited to thermal applications than electricity generation.

3.5.6 Environmental Factors

Geothermal energy connot be regarded as a totally non-polluting source of energy. In comparison to the combustion of fossil fuels, however, the environmental problems to be dealt with in utilizing geothermal energy are much less.

The major problem encountered with geothermal energy exploitation is that of the release of carbon dioxide (CO_2) to the atmosphere, along with the

vented steam. The "greenhouse effect" created by an excess of CO_2 in the atmosphere could serve to raise the temperature of the Earth and its atmosphere, with subsequent disastrous results. The possibility of extracting the CO_2 from the exhaust steam for commercial use is one method being studied to tackle the problem.

The release of hydrogen sulfide (H_2S) is another problem, but this may be regulated by either scrubbing the gas with ferrous oxide, or by oxidizing the H_2S to form sulphur dioxide, which may then be scrubbed with cooling tower water.

Dissolved toxic elements* in the fluid can lead to poisoning of the environment if the fluid is not disposed of properly. Reinjection of the fluid to an intermediate depth could alleviate this problem, and many scientists are now of the opinion that carefully controlled reinjection could lengthen the lifetime of a field.

Noise pollution is effectively dealt with by the use of mufflers, and is not regarded as a serious problem. Some noise is inevitable in the case of blowouts, maintenance, and early drilling of a field, but these effects are still relatively minor. Thermal pollution of viewers due to the cooling waters is regarded as a serious problem, particularly when small rivers are used to supply the cooling waters and the heated water is rejected back into the river. This problem is being studied closely at all geothermal power stations to determine the net effect over a period of time.

*(e.g. boron, arsenic)

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4. United Nations Conference on New Sources of Energy, Proceedings, Rome, 1961.

5. United Nations Geothermal Symposium, Proceedings, San Francisco, 1975.

3.6 OTHERS

3.6.1 HYDROGEN

Another energy source envisioned to be a potential alternative to fossil fuels is hydrogen. The lightest of all elements, is very chemically reactive and would normally be found combined with other elements as in water, fossil hydrocarbons, biological materials, and other minerals. Because of this nature, hydrogen cannot be regarded as a primary energy source obtainable from nature like petroleum and coal, but rather as an energy carrier or a medium of energy storage (requiring another energy source to produce it in its usable form).

In general, hydrogen posses some inherent properties that can make it an attractive fuel source, foremost of which is its high specific energy (energy content per unit mass) believed to be greater than most any other chemical fuels (Figure 3.6.1.1)

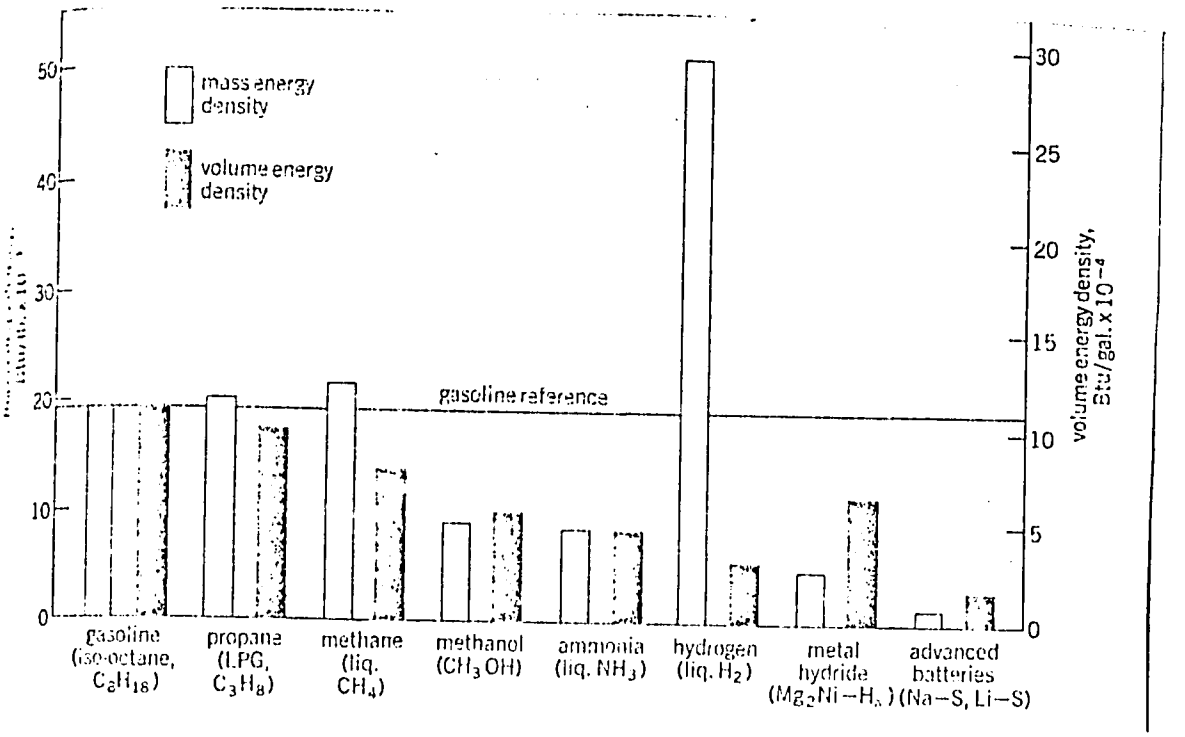


Figure 3.6.1.1. A graph comparing the energy density characteristics of a number of fuels.

1 Btu/lb = 2326 J/kg ; 1 Btu/gal = 279 J/liter

Upon combustion, hydrogen produce water as the only exhaust product, and does not give off carbon monoxide (CO) and carbon dioxide (CO_2) as by-products of reaction. Hydrogen therefore practically produce "clean air" and rids of air pollution problems which is one of man's primary concerns. Other properties of hydrogen would be that it is obtainable from water, it can be transmitted and consumed in gaseous forms, and it can replace hydrocarbons in most of its applications, most often even with increased combustion efficiency. Athough many of these characteristics make hydrogen seem an ideal fuel source, some qualifications may still have to be made to make hydrogen, in reality practical energy source. In view of the wide difference in the characteristics of our present energy forms from hydrogen, people may have yet to evaluate and determine the implications of a hydrogen energy economy through an assessment of the benefits, risks, and uncertainties involved therein.

Data Collection and Analysis

Apparently, the production of hydrogen would essentally require the knowledge of the availability of raw materials needed, the processes needed to produce hydrogen, as well as their technical and economical practicability and acceptability.

Raw Materials

At present, the most used raw materials for the production of hydrogen is water and methane (from natural gas and/or coal). Over 80% of the industrial hydrogen now in use is produced from the above hydrocarbon source and it is felt that this is likely to be so for another 20 to 25 years.

Obviously, water would appear to be most preferable as it comprises roughly 75% of the worlds total surface area. However, the decision would have to take into account the characteristics of the process that produce hydrogen from water, its complexities, and its viability. On the other hand, although methane (in the form of natural gas) provides an ideal hydrogen source, it seems that reserves are declining (due to continously increasing demands) and it may not be available for the large scale production of hydrogen. Coal, however, could warrant the previously mentioned 20 - 25 years production, considering the presently known resources avaliable.

Hydrogen Production Processes

In broad, hydrogen may be produced in one of several processes. However, only six (6) of these will be discussed, focussing mainly on those that use hydrocarbons (natural gas and coal) and water as raw materials.

A. Reformation of Methane

Among fossil hydrocarbons, methane (CH_4) seems to possess the most ideal hydrogen to carbon ratio (4:1) suitable for the production of hydrogen. Through a process termed "reforming", this hydrogen is obtained by decompostion of the substance, together with steam.

The reformation process essentially consists of chemical reactions involving water (in the form of steam) and methane, in the presence of a catalyst. At the same time, heat is supplied to the reaction. In effect, both the methane and water are stripped off of their hydrogen, with the reject carbon and oxygen discarded as carbon dioxide (CO_2). This series of reactions is given in Table 3.6.1.1 below. When all the energy inputs needed to achieve the complete reformation processes are considered, usual efficiencies come up to about 70%.

Table 3.6.1.1

Chemistry of Steam Reforming of methane	
Reforming reaction	$CH_4 + H_2O \longrightarrow CO + 3H_2$
Shift reaction	$CO + H_2O \longrightarrow CO_2 + H_2$
Net reaction	$CH_4 + {}_2H_2O + \text{Heat} \longrightarrow CO_2 + 4H_2$

B. Coal Gasification

Coal gasification has been employed for several years. Although emphasis was mainly given to the production of methane (as natural gas) from coal, proper modifications can produce hydrogen with a relatively simple process. If one is to consider the implementation of a hydrogen energy economy, coal gasification must be considered as it is expected to be the lowest cost large-scale hydrogen source for many years.

A typical gasification process felt most likely to be used for future systems has steam reacting with coal at high pressure and temperature (about 950°C). Carbon dioxide (CO_2), carbon monoxide (CO), and hydrogen are in turn produced, and the oxides are later separated in the reaction leaving essentially pure hydrogen as the final product (see figure 3.6.1.2).

Figure 3.6.1.2

Coal Gasification Process

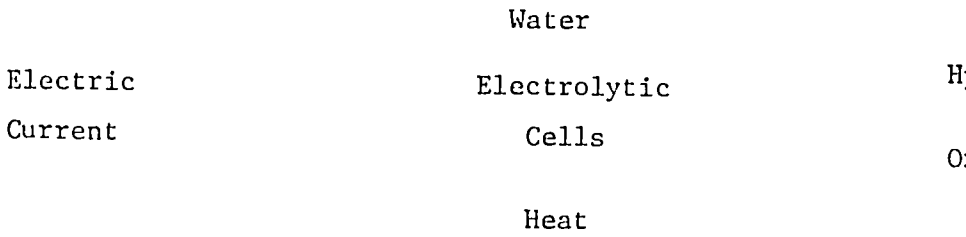
	Steam	Oxygen	Steam	Lime	
Coal	Gasification		Shift Reaction	Purification	Hydrogen
	Ash			Residue	

C. Electrolysis of Water

Essentially, the electrolysis of water resultings in the production of hydrogen is a technology well-known and demonstrated to make hydrogen, water is dissociated through the use of heat, supplied in the form of electricity (see

Figure 3.6.1.3). Although relatively simple, this process has not been commercially used to produce hydrogen mainly because of its cost and its overall low net efficiency (about 36%). One advantage of the system, however, is its versatility due to its flexibility in terms of the natural size of the practical electrolytic cell.

Figure 3.6.1.3 The Electrolysis of Water



D. Closed Cycle Thermochemical Decomposition of Water

By using thermal energy, the need for electricity to generate hydrogen may be eliminated. However this temperature required may be too high and the hydrogen produced may be too small. Through a series of chemical reaction steps, water can be broken into its hydrogen and oxygen constituents. For one or more of the steps in the cycle, very high temperatures would be required and this may be supplied by gas-cooled nuclear reactor and highly concentrated solar radiation.

This process sometimes appear to be more attractive than electrolysis due to its projected net efficiency of 55% being higher than for the former process.

E. Mixed Thermal / Electrolytic Process

Through a combination of thermal and electrolytic processes, the electricity needed to dissociate water may be reduced to two tenths ($^2/_{10}$) that of which would have been consumed in electrolysis. In a series of chemical reactions shown below, hydrogen is produced first through the use of electrolytic processes, and second, by thermochemical reaction.

Electrolysis	$2H_2O + SO_2 \longrightarrow H_2SO_4 + H_2$
Thermal	$2H_2SO_4 \longrightarrow 2H_2O + 2SO_2 + O_2$
Net Reaction	$2H_2O \longrightarrow 2H_2 + O_2$

F. Biophotolysis

Through processes of photosynthesis, it was discovered that hydrogen production was also possible. Solar radiation could provide energy that may excite electrons from a hydrogen donor such as water, and some of these may go to form hydrogen gas.

The mechanism by which this process works is that solar radiation is absorbed by pigments of plant materials, transmitted to an electron (hydrogen from water), and this electron, through physico-chemical conditions, combines with hydrogen protons to form the gas. This usually occurs at ambient temperatures, due to the presence of biological catalysts.

All the above processes inherently possess respective advantages over one another, and they could only influence ones decision to choose one process from the rest. A summary of these advantages/disadvantages is given in Table 3.6.1.2, and shows that electrolysis presents distinct advantages of being independent on fossil fuels (unlike coal gasification) and being able to operate at temperatures much lower than that of thermochemical cycles. Likewise, it could be intergrated with terrestial solar energy collection systems.

Table 3.6.1.2

Comparison of Hydrogen Production alternatives *

Process	Advantage	Disadvantage
Reformation of Methane	Presently the cheapest method	Scant long term potential

		as a source because of limitations on methane supply
Coal Gasification	Cheapest and most secure near-term alternative to methane reformation; abundant coal resources (in some parts of the world).	Ultimate limitation is exhaustion of the coal resource; requires large plant size.
Eletrolysis of Water	Proven reliable technology small unit plant size; need suited to all terrestial solar energy collection approaches; oxygen coproduct, easily separated for possible use and economic credit improves the economics; improvements in efficiency quite likely; can produce hydrogen at high pressures, thereby eliminating the need for costly compression to pipeline pressures.	High cost, lower net energy efficiency, possible resource limitations on catalysts.
Thermochemical decompositions	Potentially most efficient nonfossil processes; not tied to fossil-fuel resources; possibly compatible with high temperature, focused solar collectors.	Not a proven technology; materials problems in containment; complex large unit plant size expected; expected release of harmful chemicals.

Source: The Hydrogen Energy Economy

Storage/Transmission

There are essentially three methods by which hydrogen may be stored - as a compressed (high pressure) gas, as a liquid, or as a hydride (like metal hydrides).

Compressed hydrogen storage may be useful for small systems but may present problems for large scale utilization as it has a very low energy density. On the other hand, it may appear attractive for areas where suitable reservoirs such as depleted oil or gas wells, exist.

For liquid storage, vacuum or foam-insulated vessels would be needed in order to maintain a temperature below - 423°F. Although this storage system reduce the hydrogen storage volume by a factor of about 850, one should also be aware that large amounts of energy are necessary to liquify hydrogen.

Hydride storage involves combination of hydrogen with metals (or other suitable elements). This may be done by exposing metals or alloys to pressurized hydrogen. The metal hydride formed may then be disassociated through the use of heat energy, after which hydrogen may be liberated. This energy needed to start the decomposition is believed to be 10 - 75% that of the energy content of the hydrogen stored, depending on the metal hydride used. Compared to liquid some hydride systems hold as high density per unit volume.

As regards hydrogen transmission, the most attractive seems to be the use of gas pipelines. However, the volume of energy that could be transmitted would be less than that of natural gas. Hydrogen may also be transported in its liquid and hydride form, through trucks, rails, or freighters.

Applications

Of all hydrogen applications, the most appealing is that of as an air transport fuel. Hydrogen seem to be attractive because of its mass energy density (28, 641 Cal lg) which leads to lighter fuel loads and overall weight savings to aircrafts. With a few simple modifications, existing aircraft engines may be made to operate on hydrogen. Space aircrafts of today utilize hydrogen as one of its primary fuel sources.

In the case of liquid hydrogen it could find use as a convenient fuel for marine vessels. However, it would probably be best suited for shorter range domestic shipping as longer storage time would require much insulation to avoid boil-off.

Hydrogen may also be used for automobiles, trucks or buses, but the widespread use of the fuel is hindered by the on-board storage of hydrogen. It appears today impractical to carry storage tanks in vehicles, not to mention someof the hazards thus created.

Several other applications exist, most of them in areas where electricity is used. At present, however, one would tend to choose electricity from the standpoint of safety, cost and convenience. What is needed most is through research and development efforts that would make hydrogen a variable fuel source.

Environmental Aspects / Limitations / Safety

The first chief disadvantage of hydrogen is its extremely low boiling point (20°C) causing handling problems. When mixed with air, it forms a combustible mixture and at normal temperatures, hydrogen gas heats upon expansion, accom-

panied with the possibility of ignition. Fuel-air explosion at confined space is thereby possible. However, due to hydrogen's low energy content with respect to volume and its tendency to diffuse rapidly, its explosive potential in open areas is greatly reduced.

The use of hydrogen is expected to have minimal enviromental impacts. As earlier stated, its principal product of combustion is water, and thus creates no significant environmental imbalance. Although combustion may possibly produce nitrogen oxides at high temperatures it could be reduced to negligible levels and may be contained more earily than in hydrocarbon combustion systems.

One major impact of hydrogen utilization on the environment may be that which is associated with hydrogen production and manufacture of related equipment.

On summary, hydrogen may serve as a chemical common demoninator in the energy economy, mainly because hydrogen is derivable from water (a inexhaustible resource), and that it has a close relationship with electricity (as hydrogen is most readily obtained from water by electrolysis and hydrogen can be used to generate electricity). There would thus be a great interchangeability between the above two forms of energy, which may in turn offer quite many opportunities for economic, technological and social benefit.

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3.6.2 TIDAL / WAVE ENERGY

Another potential source of electricity and power may be that which could be derived from the ocean's tidal and wave motions.

Ocean tides refer to the periodic increases and decreases in the surface level of the oceans, which are principally caused by the gravitation exerted by the earth, sun, and moon. The difference between the high - tide levels and the low-tide levels (tidal range) produced may then be used to run turbines.

Waves on the other hand, are created when winds pass across the open waters of the ocean. This would involve the gravitational potential energy of elevated water and the kinetic energy from the forward motion of the waves. This energy that may be extracted from the waves are renewable as it could be rapidly replenished by wind and ocean-surface interaction.

Data Collection

In order to harness the tidal power potential of any ocean site, it is essential that a tidal range sufficient to warrant energy production exists. Tidal ranges may be measured as the difference in height or level between successive high and low waters at a given station. They vary in different locations and may have large values in areas where tidal oscillations are amplified by relatively shallow bays, inlets, or estrearies. The other parameters important in the evaluation of tidal energy potential is the surface area of the tidal basin, and the length of the barrage necessary to enclose the basin. In a tidal cycle, the maximum electrical energy which may be produced will be: $E_{max} = \rho g R^2 S$

Where ρ = sea density, g icm^3

g = gravitational acceleration, cm/sec^2

R = tidal range, cm

S = Surface area, cm^2

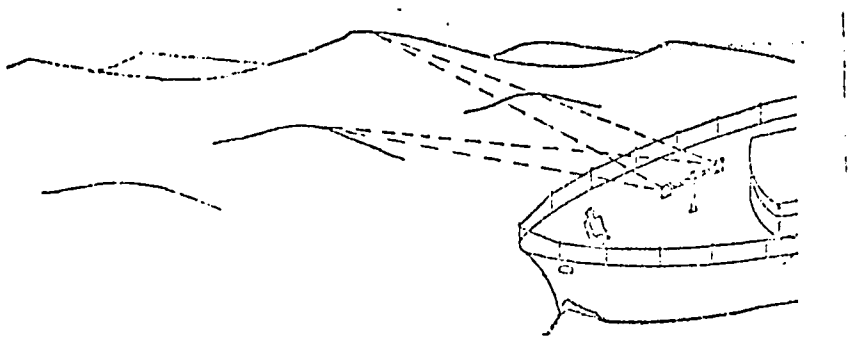
ϵ = tidal-to-electrical conversion efficiency

$$max = \frac{g - cm^2}{sec^2}$$

A suitable tidal power site would usually have a small length-of-barrage to energy-produced ratio.

In the case of wave energy potentials, wave measurements are usually taken. This may be possible through the use of several techniques and instruments, the most direct of which is stereo photogrammetry. This system would involve simultaneously taking stereoscopic photographs of the sea from two points about 5 meters apart (Figure 3.6.2.1).

Figure 3.6.2.1. Measurement by stereophotogrammetry

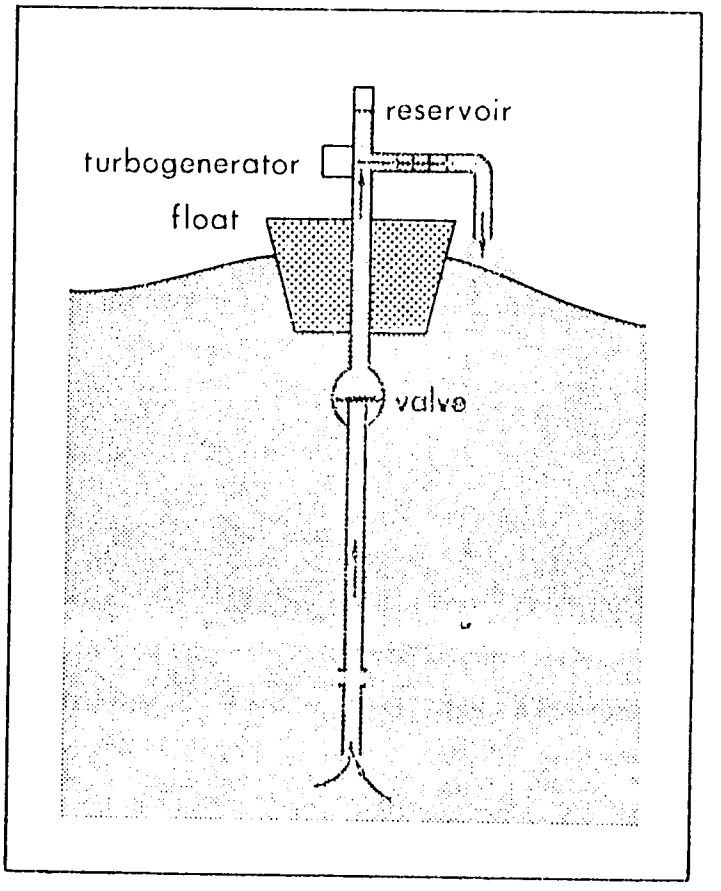


The positions of every part of the wave's surface is then measured from the two photographs through a process similar to that used for obtaining the contours of the ground from an aerial survey. This process however, has limited usefulness as it entails laborious mentlods of obtaining contours from the photographs, and includes only waves seen by the man inside the camera. Other devices which may be used continously measure the height of the water surface at one fixed point.

Another method which may be utilized is through the use of rivermills where no dam is required but only a vertical axis rotor which would be installed in the oceans in regions where strong tidal streams and currents exist.

Wave energy utilization, on the other hand, still needs further development. Although there are several possible schenes to convert wave motion to electricity, implementation is usually limited by the wide range of amplitudes and frequencies characterzing wave motion. A phototype wave energy extraction device (Scripp's Institution of Oceanography) is given in Figure 3.6.2.4. The system consists of a vertical riser tube, a buoyant float, and a flapper check valve. The buoyant float is made to respond to wave motions. At approximately one half of the wave cycle, the flapper check valve closes, and the water in the vertical riser tube follows the motion of the float. The check valve then opens when the float begins downward motion, and the inertical forces pump water to a greater height than that of the wave. With subsequent wave cycles, the water level of the reservoir is raised higher successively, until an energy head suitable for power generation is attained. This stored water may then be discharged through a turbine generator to produce electrical power.

Figure 3.6.2.4. Small Wave Power Generator



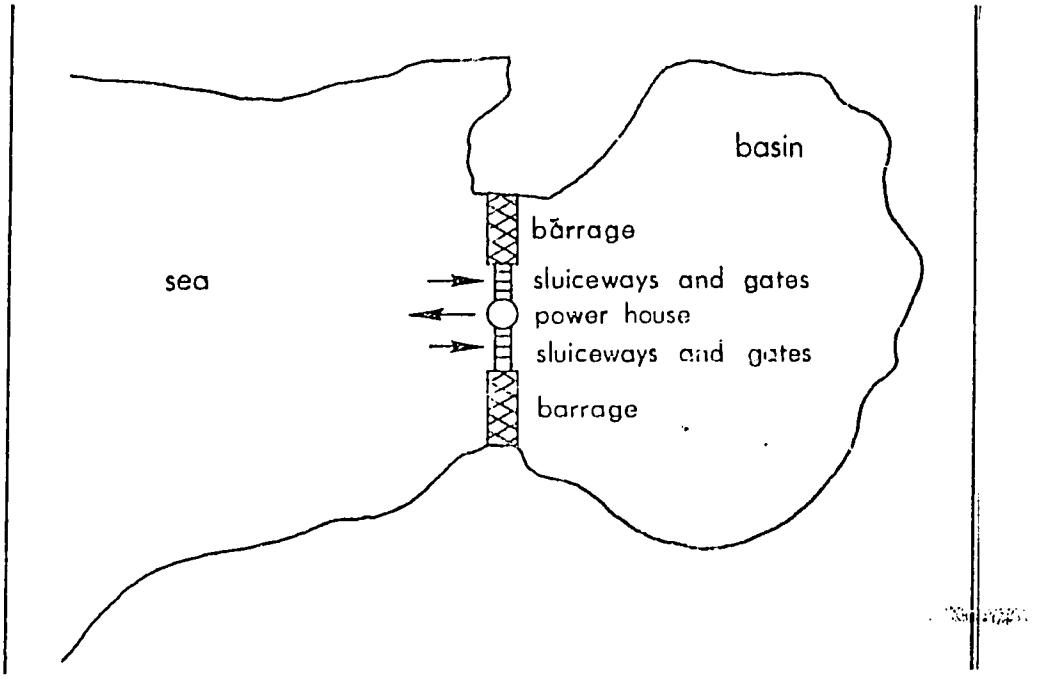
Such instruments may be connected to recorders and a permanent trace of the height of the water surface may be made on a time base.

The power developed from a wave cycle is taken to be the product of the potential energy change and the frequency of gravity waves.

Conversion Processes

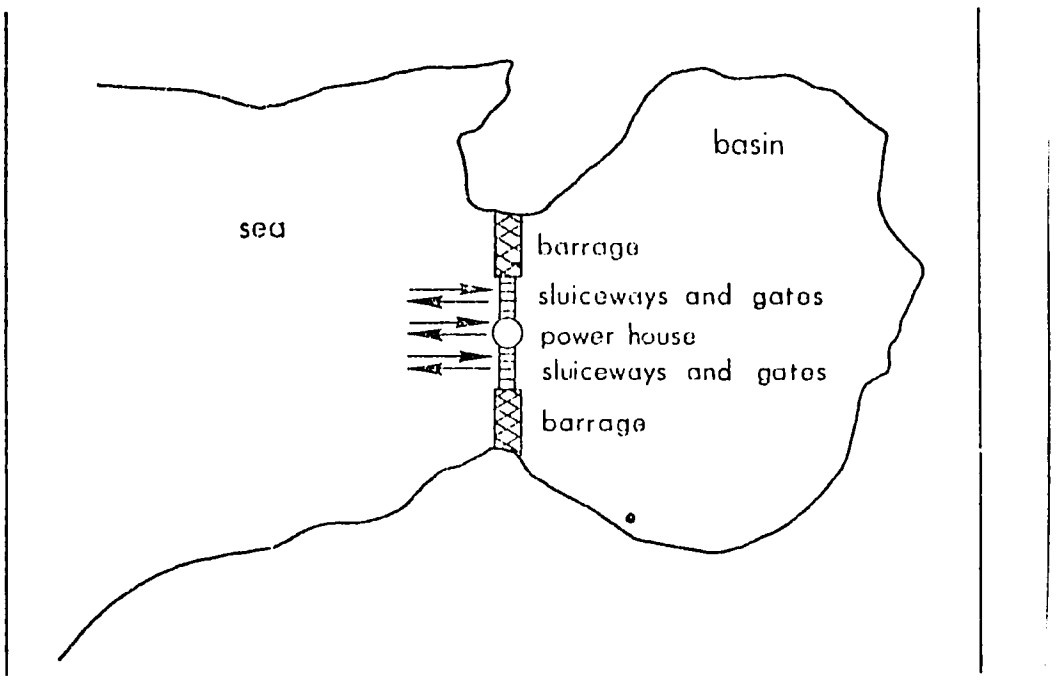
Tidal motions, to be converted to electricity, requires relatively simple principles similar to these applied to pumped-water hydroelectricity systems. Techniques usually involve the creation of a single basin made by the closing of the estuary or bay by a barrage (Figure 3.6.2.2). Water would fill the basin in times of rising tides and this would be released when the level of the sea becomes lower than that of the basin.

Figure 3.6.2.2. One-way, Single-basin Tidal Power Installation



Through this, electrical energy is derived from the potential energy of the enclosed water by placing a turbine generator in the power house. Several odifications of this process may be used as in two-way or multi-basin schemes (Figure 3.6.2.3).

Figure 3.6.2.3. Two-way, Single-basin Tidal Power Installation



Environmental Effects / Limitations

In general, the ultimate energy potential of both tidal and wave energy is limited by the small number of suitable locations. Good tidal range and wave heights do not occur frequently.

As regards environmental view points, tidal power plant stations do not produce noxious wastes, consume depletable energy, nor produce pollutants. Possible major effects, however, would be the physical and oceanographic changes in the surroundings that such plants could bring about. Flooding and erosion may also be a possibility as well as modifications in the local weather patterns. Marine ecology should thereby be a major factor to consider in future installations. Quite important also would be the effect on the fishing industries. Although this may well be difficult to assess, it should never-the-less be given serious thoughts.

Wave energy, does not seem to have severe environmental impacts. Although a minute cooling of ocean water may result, no chemical pollutants or heat would be added to the atmosphere as a result of the wave energy extraction. One other effect would be the hazard to marine transport that would be caused by wave convertors and possible coastal erosions.

The utilization of both tidal and wave energy generally appear potentially significant. However, a need for further research and developments may still be needed to make tidal and wave technology available for feasible use.

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Kendall, Henry and Steven J. Nadis. 1980, Energy Strategies: Toward a Solar Future. A Report of the Union of Concerned Scientists. Cambridge Massachusetts: Ballinger Publishing Co.

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3.6.3 OTEC

Approximately 100 years ago, a French physicist-engineer Jacques d'Arsonval first proposed a system for generating electricity from the sea. The system, termed Ocean Thermal Energy Conversion (OTEC) would utilize the temperature difference between warm surface and cold deep ocean waters to drive a closed-cycle heat engine similar to those used in electricity generating plants. The process is a low efficiency one due to the low temperature difference involved (approximately 20°C), but it could be economical because the fuel is free--the solar energy collected by the ocean.

Following d'Arsonval's work, the most significant developments in OTEC to date have been the construction of a small plant off the coast of Cuba in 1929 by Georges Claude. This plant did produce electricity for a short time, but failed when the iron cold water pipe was destroyed. Since then France, U.S.A. and Sweden have recently stepped up their development programs, and the first pilot plants (approx. 40 MW) should be built by 1985.

3.6.3.1 Characteristics of OTEC

Every year approximately 1707 X 10^{21} joules of energy from the sun heat the surface layers of the tropical seas. This represents an enormous solar collector that, if tapped, could produce large quantities of electricity. The two basic concepts for OTEC are the open-cycle and the closed- cycle systems, both of which operate on the Rankine cycle. On the open- cycle system, the warm surface waters are flashed into steam at reduced pressures and the steam is used to drive a turbine, while in the closed- cycle system, the warm waters are passed through heat exchangers to vaporize a secondary working fluid, which is then used to drive the turbine. The cold sea-water is used as the coolant in the condenser in

both cases. A schematic of a Rankine cycle is shown in Figure 3.6.3.1.

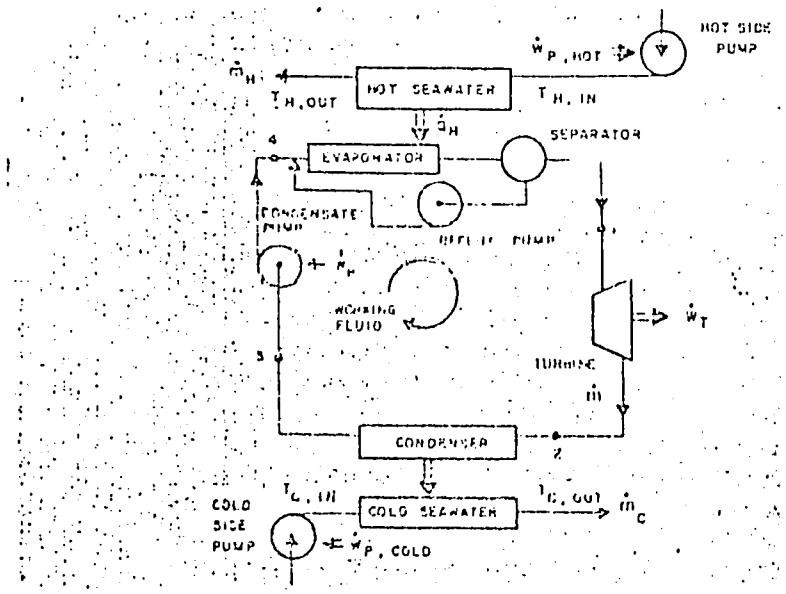

Figure 3.6.3.1: Schematic of Rankine cycle

Due to the low temperature differences (ΔT) involved, the efficiency of generation is severely limited by the maximum carnot efficiency. This is illustrated in Figure 3.6.3.2, where the maximum efficiency possible in tropical seas with a ΔT of 20°C, would only be about 6%. This is very low, and the net efficiency could be as low as 3%, but the vast resource represented by the tropical seas could still result in very low generating costs.

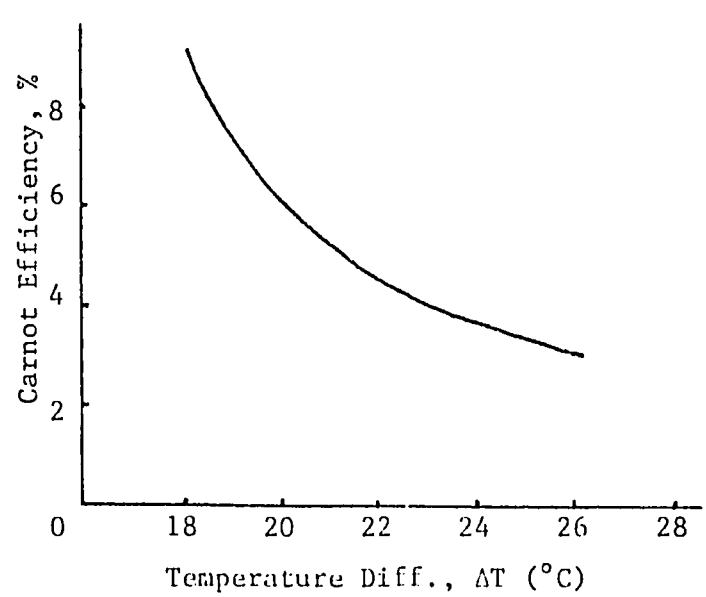

Figure 3.6.3.2: Effect of temperature difference on carnot efficiency

Those aspects of the OTEC that require development are mainly the long cold water inlet pipe, the heat exchangers and the transportation of the energy produced. At present, the effects of the ocean's currents on a pipe some 300 to 1000 meters long are unknown; the heat exchangers required for an OTEC plant will have to be very large due to the low temperature differences involved, but research is currently being done in this area. The problem of the transportation of the energy also has to be addressed, as long underwater power cables of the size required for Megawatt sized plants have not been utilized before. Two options proposed for the usage of the energy produced by an OTEC plant are (i) to utilize the energy on the plant, e.g. in the production of aluminum offshore; or (ii) to produce hydrogen from desalinated sea-water and transport the hydrogen by barges for other applications. At present, however, the main problems center around the heat exchangers and the cold water pipe.

3.6.3.2 Data Collection and Analysis

With an OTEC plant, some important data to be considered include the following:

(i) Temperature gradients

(ii) Speed and direction of ocean currents

(iii) Wind velocities

(iv) Wave heights

(v) Distance from shore to proposed site

To obtain this data, standard marine engineering practices may be followed. However, in analyzing the data for a proposed plant design, agencies familiar with operating in salt-water and oceanic conditions should be consulted. The effects of corrosion of the system components due to the aggressive nature of the sea-water can be very severe, and particular attention should be paid to the choice of materials.

Fishing agencies should be contacted to determine the possible effects on marine life as a result of pumping relatively large quantities of cold ocean water into the warm surface regions. Local shipping lanes could also be affected and the relevant marine agency should be consulted.

The analysis of the local ocean currents is critical for the design of the long cold water pipe. Strong currents could destroy a long pipeline in a short time, and this was the reason for failure of Claude's plant in 1929.

3.6.3.3 Power Generation by OTEC

OTEC systems use the ocean's natural thermal gradients to produce useful energy. In the closed cycle system, a working fluid such as ammonia is cycled through a mechanical system that exposes it in sequence to warm and then cold waters. The warm surface waters vaporize the fluid which is then pressurized and expanded through a turbine to produce electricity. This vapor is then condensed using water brought to the system through a long pipe reaching into the cold waters of the ocean. This liquid is pumped back to the surface and the cycle repeated. In an open cycle, the sea-water itself is the working fluid, eliminating the need for heat exchangers and providing the possibility for fresh water production as well. A schematic of one design is shown below in Figure 3.6.3.3.

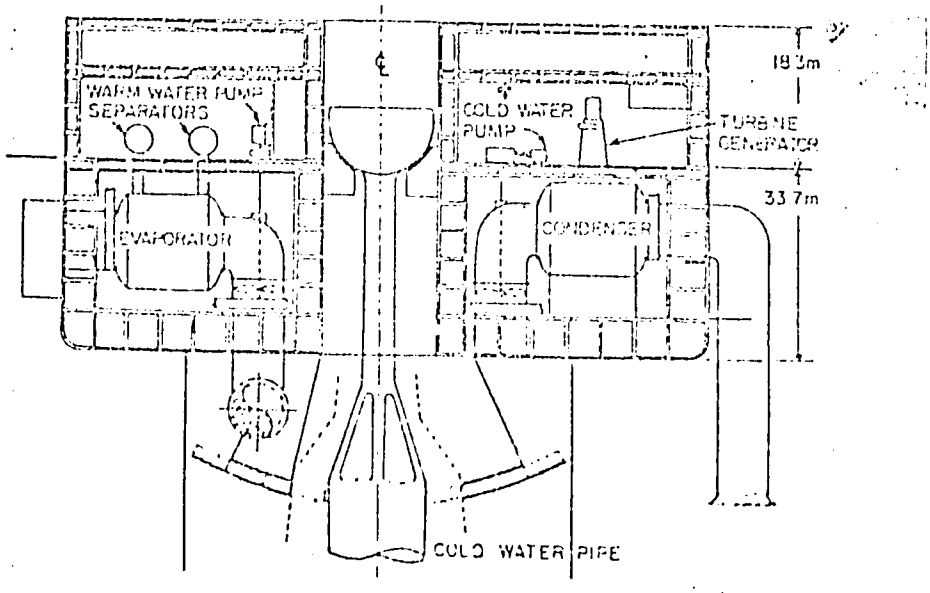

Figure 3.6.3.3: TRW OTEC power plant

The main components of an OTEC plant are the following:

(i) Evaporators

(ii) Condensers

(iii) Turbine/generators

(iv) Heat exchangers (closed cycle) or flashing vessel (open-cycle)

(v) Cold water pipe

(vi) Hull

(vii) Mooring system

The evaporators, condensers and turbine/generators which make up a power module, operate on standard design principles in use today on low temperature geothermal plants. The hull design and mooring system may be adapted from off-shore oil drilling technology, but as mentioned before the cold-water pipe and heat exchangers still require development. The OTEC platform itself may be a semi-submerged or fully submerged arrangement, and an artist's impression of one design by Lockheed is shown in Figure 3.6.3.4. The actual size of an OTEC plant of about 100 MW capacity would be smaller than many current off-shore oil rigs.

Tropical seas which have a temperature differential of about 20°C per 600 meters depth offer the best sites for OTEC. Table 3.6.3.1 shows a comparison of different thermal cycles proposed by five design teams. Note that all of these cycles operate on a closed-cycle. From these theoretical analyses it appears that OTEC could generate electricity at competitive costs, but the technical problems that exist still remain to be solved.

TABLE 3.6.3.1: COMPARISON OF DIFFERENT THERMAL CYCLE PARAMETERS

PARAMETER	SSPI	U MASS	CMU	TRW	LOCKHEED
Net Power Output (MW)	100	400	100	100	160
Gross Power Output (MW)	125	480	140	125	240
Working fluid	R-12/41	Propane	Ammonia	Ammonia	Ammonia
Working fluid flow rate (bg/sec/MW net)	234	116	34.5	32.6	38.4
Site T (^{o}C)	20.0	17.8	22.2	21.8	18.5
Net Cycle Efficiency	2.3	2.4	2.3	2.4	2.1
Length of cold water pipe (m)	610	340	610	1220	490
Cold Water flow (m^3/sec)	330	1470	430	370	1800
Hot water flow (m^3/sec)	620	4520	515	440	1370

SOURCE: McGOWAN, J.G.; SOLAR ENERGY, VOL. 18, 1976 pp. 81-92

3.6.3.4. ENVIRONMENTAL IMPACTS

Most of the analyses done on OTEC to date has been concerned mostly with the effect of the environment on the OTEC plant and not vice-versa. This is mainly due to the fear of bio-fouling that can occur in the fluid passages of the plant.

Anticipated environmental consequences of an OTEC plant appear to be relatively few; however, one benefit that could result from OTEC is the growth of a fishing industry in the vicinity of the plant, due to the nutrients contained in the cold water pumped to the surface.

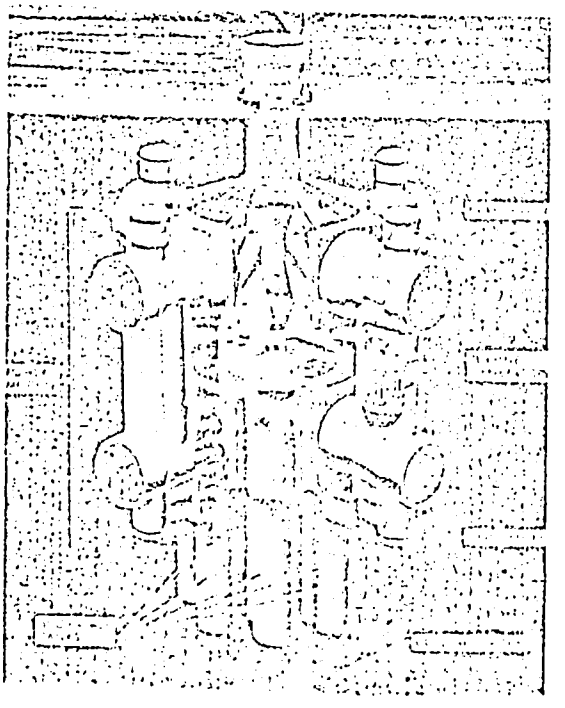

Figure 3.6.3.4: Lockheed OTEC system

4 Liquid Fuels From Biomass

4.1 Ethyl Alcohol

Almost all the material of this section comes from a World Bank's paper, from September 1980, titled "Alcohol Production from Biomass in the Developing Countries". [1] Additional information was taken from a report of the Brazilian Council of Research and Development (CNPq), from December 1978 titled "Technological Assessment of the Ethyl Alcohol" [2], and a report of the Company of Industrial Technology, from August 1980 titled "Alcohol From Cassava" [3] (only the Portuguese version is available for the last two reports).

4.1.1 Introduction

Alcohol production from biomass has been undertaken by man for at least 2,000 years. At the time of introduction of automobiles on a commercial scale, alcohol was initially considered as an obvious fuel. Alcohol from biomass was also a key raw material source for chemical industry well into this century. However the discoveries of petroleum and the decline of the prices of petroleum products until the last decade, displaced biomass alcohol in the market, except in particular periods and conditions (shortage of petroleum caused by wars, etc.).

The great increase of petroleum prices during the last decade and the increasing concerns about the adequacy of future petroleum supplies have resulted in renewed interest in alcohol production from biomass sources. This renewed interest is based both on economic and strategic reasons.

Biomass based alcohol is the major renewable energy source that offers immediate prospects of substituting a premium petroleum byproduct (gasoline) liquid fuel. In fact this is already a reality in Brazil. The basic technology for production of alcohol is well known and can be transferred easily

to most countries. This report will not cover the utilization of biomass alcohol for chemical uses, as an alternative of some petrochemical branches. Those interested in this matter may refer to the CNPq report.

Two different types of alcohol are of main interest, ethyl alcohol (ethanol) and methyl alcohol (methanol). Both can be produced either from hydrocarbon (petroleum/gas) products or from biomass. Ethanol can be produced from a wide variety of biomass materials (sugars, starches and celluloses); its production from sugars and starches is proven, widely available and simple (the production from cellulosic materials will be discussed later). Because this report is primarily interested in the use of alcohol from biomass for substitution of gasoline (totally or partially) in automobiles, and considering that ethanol is a more suitable substitute than methanol (presents less technical and environmental problems), methanol production (from wood or gasification from other biomass materials) will not be discussed here.

4.1.2 Characteristics of Ethanol

The main physical and chemical properties of ethanol are compared with gasoline and diesel in Table 4.1.1. Ethanol is completely soluble in gasoline and diesel oil, provided no water is present in the system. If water is added, the alcohol preferentially absorbs the water and separates into two phases, which makes the mixture useless as an automotive fuel.

The properties affecting combustion efficiency are substantially different for ethanol compared to hydrocarbon fuels, as can be seen in Table 4.1.1. At this point it is important to remark that combustion efficiency is a function not only of the heat of combustion of the fuel but also of the efficiency of the combustion system.

Table 4.1.1: Main Physical/Chemical Characteristics of Ethanol and Hydrocarbon Fuels

Property	Ethanol	Gasoline	Diesel oil
Formula	CH_3CH_2OH	Hydrocarbons C_4 to C_{12}	Hydrocarbons C_{14} to C_{19}
Molecular weight	46.1	100 - 105 avg.	240 avg.
Composition (wt %)			
Carbon	52.2	85 - 88	85 - 88
Hydrogen	13.1	12 - 15	12 - 15
Oxygen	34.7	---	---
Specific gravity	0.79	0.72 - 0.78	0.83 - 0.88
Boiling temperature, °C	78	27 - 225	240 - 360
Flash Point, °C	13	-43	38
Flammability limits (volume %)			
Lower	4.3	1.4	---
Higher	19.0	7.6	---
Octane number			
Research	106 - 111	79 - 98	---
Motor	89 - 100	71 - 90	---
Cetane number	0 - 5	5 - 10	45 - 55
Heat of Combustion			
kcal/kg	6,390	10,500	10,280
kcal/l	5,048	7,700	8, 738
Solubility in water	infinite	0	0

The economic value of a fuel is a function of (i) heat of combustion of that fuel (ii) efficiency of the combustion system and (iii) various other properties such as ease of use, environmental impacts that vary with application. The influence of these factors on ethanol economic value as a fuel is different for different applications and will be discussed in the next section.

4.1.3 Uses of Ethanol as a Fuel

As a petroleum substitute, biomass based ethanol has three possible main applications: (a) boiler fuel to substitute for fuel oil or other fuels (b) gasoline substitute and (c) diesel substitute.

a. Ethanol Use as a Boiler Fuel

Ethanol, in a direct combustion use such as boiler fuel, would substitute for fuel oil (the heat of combustion of fuel oil No. 6 is 9.560 kcal/kg or 8,795 kcal/l) in a direct ratio of their heats of combustion. This application does not take advantage of its other chemical/physical characteristics. Thus, ethanol's energy value as a boiler fuel is about 66% of the fuel oil value by weight or 57% by volume.

b. Ethanol Use as a Gasoline Substitute

The use of ethanol as a gasoline blend* (gasohol), in an internal combustion engine (otto cycle), takes advantage of some of ethanol's physical/chemical characteristics, improving combustion efficiency, octane rating and results in other engine performance characteristics such as starting, carburation and emissions. Existing internal combustion engines do not require any modifications to run on gasohol of up to 20% ethanol blend. Tests

*As was pointed out earlier, when used as a gasoline blend, ethanol must be anhydrous (99.8% ethanol) to avoid the formation of two liquid phases.

Table 4.1.2: Ethanol Yields of Main Biomass Raw Materials

Raw Material	Ethanol Yield liters/ton	Raw Material Yield* tons/ha	Ethanol Yield liters/ha/yr
Sugarcane	70	50	3,500
Molasses	280	NA	NA
Cassava	180	12.0 (20.0)**	2,160 (3,600)**
Sweet Sorghum	86	35.0***	3,000***
Sweet Potatoes	125	15.0	1,870
Babassu	80	2.5	200
Corn	370	6.0	2,200
Wood	160	20.0	3,200

*Based on average yields in Brazil, except for corn which is based on the average in the US.

**Potential with improved production technology.

***Tons of stalks/hectare/crop. Two crops per year may be possible in some locations.

satisfactory solution and additional technical development is necessary to arrive at an optimum disposal technique in each case to minimize environmental problems.

4.1.6 Energy Balance For Ethanol Production

The principal rationale for ethanol from biomass is to use it as a substitute for imported petroleum. Thus the type, cost and amount of energy inputs to produce the alcohol are critical to fuel ethanol's economic viability. In some cases, where energy balances are either marginal or even negative, it may be totally acceptable if a relatively low cost (non imported) form of energy input is converted into a premium energy form.

In the Brazilian agricultural system, sugarcane (or sweet sorghum) shows a net positive energy balance, generating 3 - 8 times as much energy as it consumes. Cassava has a modest positive energy balance but can be increased about eight times if a wood plantation is included in the agricultural system (in these calculations only the priced energy inputs or outputs are considered; thus solar energy to produce crops is excluded). Data from the US shows that ethanol from corn has a negative energy balance even if an "energy conservation" design is employed.

4.1.7 Capital Costs of Alcohol Plants

The Brazilian alcohol industry, which has built more than 300 distilleries, is the only country with actual experience with the construction of a large number of plants of different sizes and at different locations. The data presented in Table 4.1.3 shows capital costs for sugarcane based alcohol distilleries in Brazil for a capacity range of 20,000 to 240,000 liters/day. The Brazilian industry is very competitive with European and US suppliers.

Table 4.1.3: Capital Costs of Alcohol Plants

(Brazilian data 1979 prices, in 1,000 US$)

	Capacity, 1,000 liters/day		
	20	120	240
Engineering	135	400	680
Process equipment	950	3,950	6,800
Utilities	220	925	1,620
Freight	60	225	300
Civil works and land	270	750	1,250
Erection	135	400	500
Contingency	230	950	1,350
Installed cost	2,000	7,600	12,500

However, only a few developing countries with well developed, efficient domestic manufacturing sectors are likely to build plants at the cost level achieved in Brazil. Most other developing countries, without the benefit of Brazil's extensive experience, could expect costs of 25 - 100% higher than those in Table 4.1.3. It is estimated that capital costs of molasses based plants are at least 20% less than sugarcane based plants. On the other side, cassava/corn based plants are estimated 10 - 20% more. Table 4.1.3 shows significant economies of scale in the range 20,000 - 240,000 liters/day. Additional Brazilian data indicates that the economies of scale diminish rapidly above 300,000 liters/day.

However, in some circumstances, small scale plants (less than 20,000 liters/day) may be viable. When compared with plants of higher capacity, the small scale plants for production of alcohol from cassava show many

xi) Climate information, in particular the rainfall in the region

xii) Availability of wood, charcoal, vegetable wastes, etc. to be used as fuel.

4.1.9 Final Comments

The economics of ethanol production will not be discussed here because this kind of analysis depends on many assumptions that must be taken into consideration in each particular country. Also, most of the petroleum import countries consider the substitution of imported petroleum by domestic resources of substantial strategic value.

In the Brazilian case, with the present petroleum prices the ethanol economics is favorable. Those interested in an example of ethanol economics calculations may refer to the World Bank paper.

The general economic prospects for alcohol production from biomass are, in principle, favorable to those countries that are net agricultural exporters and petroleum importers (like Brazil, Thailand, Philippines, Sudan and others). However, successful alcohol projects will involve a close association of agricultural systems, alcohol plants and assured markets in the energy sector linked by a reliable raw material collection and alcohol distribution network. Alcohol plants cannot be viewed in isolation and must be designed and appraised as a part of an integrated system, or in other words, as a national alcohol program. The Brazilian pioneer experience, with its positive and negative results is an experience to be studied by other developing countries.

4.2 Vegetable Oils As A Substitute For Diesel Oils

4.2.1 Introduction

Vegetable oils, together with alcohol from biomass are the only fuels from the renewable resources that may be substituted on a large scale and in a relatively short period, (5 -10 years) the fractions of petroleum used in internal combustion engines for automotive transport. Alcohol is suitable for substitution of the lighter fractions (gasoline) used in otto cycle engines, while vegetable oils are suitable for substitution of the medium fractions (diesel) used in diesel cycle engines.

The technical feasibility of utilizing straight (i.e. without any chemical additives) vegetable oils as a fuel for diesel engines has been a subject of controversy since the beginning of this century, when Rudolph Diesel, inventor the diesel engine, experimented with peanut oil in his motors. In his preface to Chalkey's "Thermodynamics", 1911, he predicted that the use of vegetable oils in diesel motors will have great importance in the future, helping considerably in the development of agriculture in those countries where it will be used.

Until the end of the forties, many experiences on the use of vegetable oils had been reported in the technical literature. A recent review by H.L. Filho, et. al. [4] shows the variety of conclusions achieved by different researchers in many parts of the world. They found many contradictions that can be attributed, in part, to the variety of vegetable oils used and the different stages of development of the motors.

On the other hand, it is well documented that during World War II, the Chinese developed industrial batch-cracking processes to produce motor fuels from tung oil that could not be exported. The average commercial yield of crude oil was 70% by volume of the original tung oil. One ton of this crude

oil produced about 0.73 tons of equivalent diesel oil, plus other useful liquid fuels. [5]

During the fifties and sixties, experiments on the use of vegetable oil for use in diesel engines had practically stopped due to the low cost of petroleum. The oil crisis in the seventies has renewed interest in the use of vegetable oils for fuel, and development is now taking place in a few countries, in particular Brazil, Philippines and U.S.A.

4.2.2 Some Physical Characteristics of Vegetable Oils and Their Performance in Diesel Engines

Diesel engines are the most advanced commercially available internal combustion engines for automotive use today. Figure 4.2.1 shows a comparison of the relative efficiencies of the otto and diesel cycle motors. Diesels are appreciated not only because of their higher efficiency, but also their strength and durability. Therefore it is desirable that any possible substitute for diesel oil will not affect the characteristics of the engine.

Figure 4.2.1: Influence of Compression Ratio on Efficiency of Otto and Diesel Cycle Motors

Table 4.2.1 shows some physical characteristics of vegetable oils, diesel oils, and "vegetable diesel oil". The expression "vegetable diesel oil" means an oil obtained by chemical transformation of vegetable oils, that has properties similar to those of diesel oil. The table shows that vegetable oils have a lower cetane number, higher viscosity, higher carbon residue and higher flash point.

Experiments conducted by Mercedes Benz do Brasil show that vegetable oils, straight or mixed with diesel, are potential fuels for diesel motors. However, their use decreases the efficiency of the motor and increases the maintenance schedule to remove the residue formed inside the engine. [4] These drawbacks can be attributed to the differences in physical characteristics shown in Table 4.2.1.

In order to use vegetable oils efficiently in diesel engines, it would thus be necessary to (i) increase the cetane number (ii) reduce the viscosity (iii) reduce the carbon residue and (iv) reduce the flash point. By doing these improvements chemically, "vegetable diesel oil" was formed.

4.2.3 Chemical Treatment to Obtain "Vegetable Diesel Oil" From Vegetable Oils

Many vegetable oils, such as peanut, tung, soya, cotton, sunflower, palm, colza, avocado and coconut oils are a mixture of fatty acid glycerides which can be represented by the formula:

Table 4.2.1: Some Physical Characteristics of Vegetable Oil, Diesel Oil and "Vegetable Diesel"

Characteristic	Diesel Oil*	Peanut Oil	Soya Oil	Cotton Oil	Sunflower Oil	"Vegetable Diesel"
Lower Caloric Power, kcal/l	8,400	7,900	7,850	8,050	7,950	
Distillation Temperature, °C (85% recovered)	370 (max)	359	348	369	338	318
Cetane Number	45 (min)	33	36	40	39	52
Viscosity, cst at 37.8°C	1.6 to 6	38	32	37	37	1.62
Carbon Residue on 10%, wt %	0.3 (max)	0.42	0.45	0.42	0.42	0.28
Flash Point, °C	38 (min)	314	322	326	324	23

* Brazilian specification

where R', R'' and R''' are hydrocarbon radicals of the type C_nH_m with the number of carbon atoms in the range of diesel oils. A theoretical process to separate these hydrocarbon radicals is illustrated in Figure 4.2.2.

A practical method to obtain "vegetable diesel oils" is composed of three steps:

(i) Thermal decomposition of the glycides by steam injection to produce dilute glycerol and fatty acids. The glycerol (which must be further concentrated) is a valuable chemical product.

(ii) The fatty acids have a lower viscosity than the original vegetable oils, but because of their chemical aggresivity they must be neutralized. This may be done by descarboxilation of the fatty acids by a soap-cracking process.

(iii) Distillation and refining the oil to separate the lighter and heavier fractions.

A schematic diagram of this process is shown in Figure 4.2.3. This is the process used in China during World War II. Today, many of the more recent engineering concepts could be applied to improve the efficiency of the process. In Brazil, a small private company claims to have developed a variation of this process, to make it commercially viable.

4.2.4 Sources of Vegetable Oil

Almost all the vegetable oils produced in the world are for human consumption. In 1979 their price in the international market varied from $500 to $1,000 per ton. This indicates that these oils are not competitive with petroleum for the production of diesel substitutes at present. However, it must be considered that the research and development of varieties, until recently, was directed to comestible oils and not the more toxic varieties

Figure 4.2.2: A Theoretical Process to Obtain Equivalent Diesel Oil From Vegetable Oil

Figure 4.2.3: Production of "Vegetable Diesel Oil" from Vegetable Oils

Source: Simplified from the paper of C.C. Chang and S.W. Wah, [5]

which had greater productivity. Also, only a small proportion of the oil producing plants are commercially exploited. It is well known that the prices of vegetable oils in the international market is not rising with the price of petroleum, so it is possible that at some point it will be more convenient to use these oils for fuel. This is particularly the case in countries which are both vegetable oil exporters and oil importers.

Table 4.2.2 shows the current productivity of some oil producing plants. For a more rapid start in a program of utilization of vegetable oils for fuel, plants like peanuts, soya, sunflower and colza are most favorable due to their shorter times to production of oil. However, the palm, avocado and coconut are more productive plants.

One of the most promising plants for oil production is the palm (Elaeis Guineensis L.). [The following data is taken from a report by Group V of the Brazilian Energy Commission]. In favorable conditions, the palm (over 25 years) will produce 3 to 5 tons of oil per hectare, and 0.6 to 1.0 tons of almond oil per hectare. The conditions necessary for such production are (i) intense sunlight (ii) temperatures between 24 - 28°C and (iii) good rainfall, well distributed throughout the year.

The costs for a palm oil agroindustry (1977 prices) are as follows:

1. Capital for agroindustrial complex - $5,000/ha.
2. Production and maintenance - $150 - 200 per ton of oil produced.

With regular rainfall the plant will produce oil all year round, which means production may be on a continuous basis. Table 4.2.3 shows the production of oil as a function of the age of the palm (percentages by weight).

Table 4.2.2: Characteristics of Some Oleaginous Plants That Can Be Used For Substitution of Diesel Oil

Plant	Source of the Oil	Oil Production kg/ha year	Time to Start Production days/years
Peanut	Seed	800	120
Soya	Seed	600	150
Cotton	Seed	200	
Sunflower	Seed	600	130
Colza	Seed	800	150
Babacu	Almond	130	7 years
Palm	Fruit	4,000	8 years
Avocado	Fruit	5,000	5 years
Coconut	Fruit	1,200	7 years

Table 4.2.3: Oil Production From The Palm Plant As A Function of Age

Age of the Plant (Years)	% of Total Oil Produced	% of Oil as Almond Oil
5	17.0	3.4
6	19.0	3.8
7	20.0	4.0
8 - 25	20.0	4.0

4.2.5 Final Comments

As was stated at the beginning, alcohol and vegetable oils are the only fuels from the renewable resources that can be substituted for gasoline and diesel respectively for automotive use. The alcohol and vegetable oil producing plants also have comparable productivities; for instance sugar cane and palm show similar yields of ethanol and "vegetable diesel oil" respectively.

While the partial substitution of gasoline with alcohol is already a reality in Brazil and the U.S.A., there are no reported significant substitutions of diesel oil by vegetable oil. If one considers that alcohol can only be substituted for gasoline, the lack of an alternative for diesel may (and in the case of Brazil is so doing) result in an unbalance of the refining of the petroleum products, with an excess of gasoline produced. Consequently, those countries interested in petroleum substitution from biomass sources should consider the use of vegetable oils for fuel, not only because they are the natural complement to alcohol, but because vegetable oils are more versatile than alcohol in the sense that both equivalent gasoline and equivalent diesel may be obtained from vegetable oils (note: in this paper, coal/charcoal is considered as an alternative to the heavy oils).

Finally, it seems that the utilization of vegetable oils as a fuel is only a matter of time, as was predicted by Rudolph Diesel.

5 Socio-Economic Aspects

5.1 The Energy Problems of the Developing Countries

The consequences of the 1973-74 increases in the price of petroleum have raised energy to a priority issue around the world. Within a short time the costs of energy and the enhanced awareness of the depletability of fossil fuels, have become an immediate and pressing concern. While OPEC oil revenues increased from $33 billion in 1973 to $108 billion in 1974, the rise in oil prices directly added an estimated $10 billion to the import costs of the oil importing developing countries (OIDCs) in 1974, which created greater adverse impacts on the economies of these countries than the industrial countries.

5.1.1 The new round of oil price increases in 1979 added approximately $9 billion to the annual import costs of the OIDCs, even if there was no change in their oil imports: the current account deficit of the OIDCs was estimated to increase from $32 billion in 1978 to $43 billion in 1979 and probably exceeded $50 billion in 1980. Most developing countries continue to experience pressing economic problems in accomodating their economies to this situation. Taken together with the rapidly growing populations, growing urbanization, high unemployment rates, and recurrent food inadequacies, the OIDCs are incurring increasing difficulties resulting from increased payments for imported energy. In addition, the economic and social progress in most countries stagnated, and in some cases reversed. Higher priced fuels needed for industrial development have been purchased at the expense of economic growth, and food production has decreased because of the lack of energy intensive fertilizers and fuels to operate irrigation systems.

5.1.3 For the oil importing developing countries, the new level of petroleum prices has three fundamental implications:

(a) In the short run (5 years), given their very limited ability to conserve oil or to substitute other energy sources for petroleum, they must continue to borrow foreign funds required to finance oil imports or else reduce their rate of economic growth;

(b) In the long term, most have the opportunity to develop alternative indigenous energy sources. At the present crude oil prices it is now economic to develop domestic sources of petroleum that were regarded as uneconomic at pre-1973 prices, and to endeavor to expand their known reserves. At the same time, efforts to expand the provision of energy from alternative sources to substitute for petroleum-based energy supplies should be encouraged.

(c) In most of these countries, the socio-economic objective of ameliorating the welfare of the majority of the rural population will be frustrated from the energy viewpoint by the serious depletion of the noncommercial (i.e. wood and agricultural wastes) energy sources, causing major environmental damage and social hardships, which can only increase with higher prices of kerosene.

5.1.4 A few examples provide some indication of the impacts of the increasing petroleum prices.

Table 1 Energy Imports as % of Merchandise Exports

Low Income Countries	1973	1977
Ethiopia	11	27
Mali	13	25
Pakistan	16	43
Tanzania	17	33

Middle Income Countries	1973	1977
Thailand	12	29
Philippines	9	33
Morocco	9	28
Turkey	16	79
Portugal	17	36
Brazil	21	37

Source: World Bank

5.1.5 For most countries, the cost of imported energy has been increasing despite strong conservation efforts (Mali from 25% of merchandise exports in 1977 to 49% in 1980; Brazil from 37% to 50%). The burden of petroleum imports bill and the general expectation for its livelihood to increase in the real terms in the future are the pricipal rationale for energy-deficit developing countries to look into biomass energy as a substitute for petroleum; and assess other indigenous forms of energy.

5.2 Energy Demand and its Management

Developing oil importing countries consumed in 1980 a small share (12%) of the world's commercial energy.[1] As their economies are growing faster than those of the industrialized countries, their demand for commercial energy is expected to increase rapidly with the higher rate of urbanization, industrialization, motorized transportation and other applications in energy-intensive developments.

5.2.1 The current international energy situation and the bleak outlook for the future have increased awareness in developing countries of the need for better efficiency of energy utilization and for some measure of energy demand management at the national level. Energy demand management becomes most important in those countries which endeavor to develop indigenous fuel resources to substitute for imported petroleum. This, in the first instance, requires a thorough knowledge of the demand in a country. Analysis of energy demand is, therefore, an essential tool for energy planning and a starting point in national resources assessment. Energy conservation is the counterpart to increasing energy production in that a barrel of oil saved is worth a barrel of oil imported or produced. Energy pricing is an important policy instrument and an essential factor in energy demand management.

5.2.2 Energy Demand Analysis

Energy demand analysis can be made at the aggregate national level by computing the gross statistics of imports and domestic production, less

1 The term "commercial energy" refers to those energy forms in which there is a large international and domestic market, and which supply the requirements of a modern industrial economy, i.e. petroleum fuels, hydro, natural gas, coal and electricity. "Non-commercial energy" comprises all those fuels used in the traditional sector of the economy, such as wood, charcoal, crop residues and animal dung.

exports if any. Useful energy demand analysis is made on the basis of sectoral consumption, of different energy types and quantities in sectors such as agriculture, industry, transportation, domestic and other services. The sectoral consumption data can be disaggregated into end-uses, broadly categorized as the personal and freight transportation, end-uses inside buildings (i.e. space conditioning, water heating, cooking and electrical appliances) and material processing (metal refining, food processing, etc.) Figure 1. Further disaggregation of data entails more detailed information collection and some form of data processing.

5.2.3 In the demand analysis, the energy consumption of traditional fuels in the rural areas, where the majority of the people live in developing countries, and, by the poor urban dwellers should be included. While traditional fuels rarely enter into commerce, and almost always are unrecorded, in most developing countries they represent a substantial proportion of the total energy consumption. The depletion of forests in many developing countries has been characterized as a "second energy crisis". The rural energy crisis stems from the fact that the rate of fuel wood consumption outstrips that of reforestation with serious environmental, economic and human consequences. Deforestation, especially on steep hillsides, contributes to soil erosion, reduction of water catchment areas, and increased siltation of reservoirs, irrigation canals and river beds, increasing the damages of floods. As fuel wood supplies diminish, people turn to burning dung and agricultural residues, depriving the soil of valuable nutrients and organic conditioning material. Some estimates indicate that the current use of dung for fuel "costs" about 20 million tons of foregone food grain production annually.

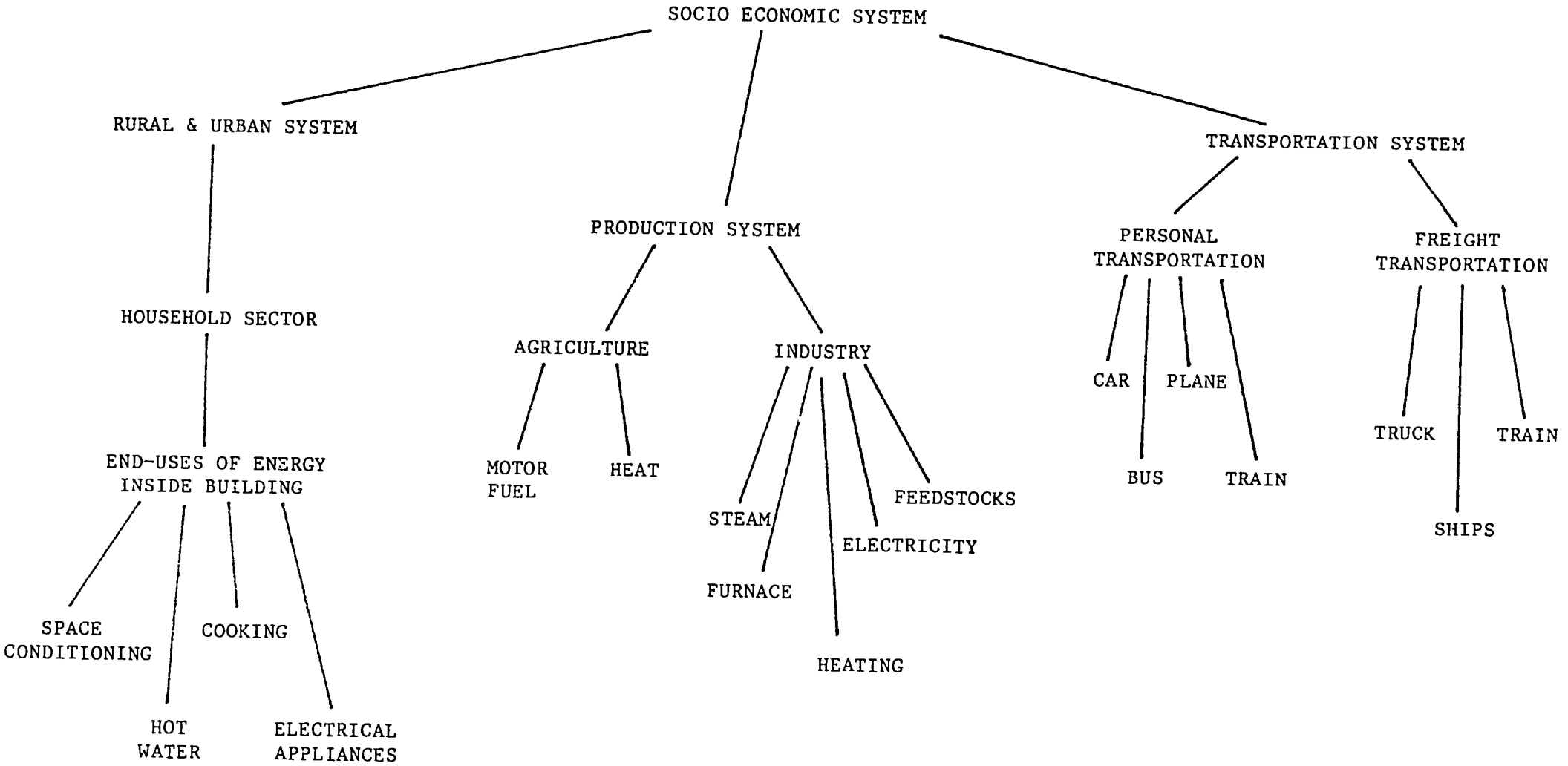

Figure 1

Source: Energy System Analysis, p.333

5.2.4 Africa is the most dependent on traditional renewable resources, Asia somewhat less and Latin America is the least dependent on these resources. The human cost of the rural energy crisis is high, both in terms of the immediate impacts on the lives of the poor, and on the long term prospects of improving the quality of the rural population. The fuel wood shortage has exerted heavy burdens on the labor and cash flows of low income groups. In some parts of Tanzania, for instance, 250-300 work days are required for fuel wood collection to meet the family needs. A recent World Bank survey found poor families in Bujunbura, the Capital of Burundi, to be spending more than 30% of their income on fuel, mainly charcoal.

5.2.5 Energy Resources Data

The major problem of energy demand analysis in developing countries is the unavailability of energy consumption data. This is attributable to many factors which are outlined below:

(a) lack of a statistical reporting system;

(b) low to non- response to questionaires which might be due to ignorance, indifference or suspicion that the questionaires will be used for income tax purposes, and the resultant misunderstandings which may lead to distorted information;

(c) Since most of the surveys conducted entail high costs and the returns from these surveys are not readily tangible as compared with other productive investments, government officials tend to be very reluctant to allocate sufficient funds for such surveys.

(d) Most of the staff carrying these surveys lack proper training.

(e) Large seasonal variations, transportation bottlenecks, and shortages entail that current consumption fails to reflect effective demand and,

consequently, forecasting demand on trend analysis becomes difficult.

5.2.6 Some of the problems outlined above can be overcome by an intensive propaganda and explanation of the energy problem and its impact on the economy. The introduction of energy topics in the educational system could increase the understanding of energy economics.

5.2.7 In countries where a full coverage demand survey cannot be undertaken due to the high cost, it is recommendable that random sampling procedure be adopted. The reliability of the estimates depends on the size of the sample; a large sample size means greater degree of confidence on the estimate but also a greater cost. A balance between cost and the desirable degree of accuracy ought to be established. Since detailed information requires substantial funds and staff to collect and analyze the data, for developing countries it is essential that the level of data collection and analysis satisfies their needs within the financial and personnel constraints. Only after establishing a system that ensures a flow of reliable data, can developing countries proceed to detailed information collection and analysis, especially in energy intensive sectors.

5.2.8 Energy Demand Management

Improving the efficiency of energy use means using each source of energy in such a way as to increase the value of energy output from a given volume of resources, and reducing waste in each energy using activity. In most developing countries, per capita consumption of energy is relatively small, still proper demand management policies can shift consumption from lower to higher value uses, reduce the energy cost of output, encourage a

switch from more to less costly sources of supply, and promote the development of indigenous energy resources. At the national level this entails setting priorities among the principal uses of energy; for instance, industrial versus commercial or household activities, public versus private transport, energy-intensive versus non-energy-intensive, planning industrial growth in accordance with the availability of indigenous energy resources or assured supplies of the foreign sources. Appropriate implementation of demand management policies can reduce the overall energy cost to the economy and promote economic growth.

5.2.9 An essential tool in most countries for increasing energy efficiency is a pricing policy which ensures that the price of energy in various uses reflects its real economic cost. For most energy products this means the highest price for which they could be traded either within the country or with other countries. It is only when the product cannot be traded, or cannot substitute for another energy product which is traded, that its economic price is its cost of production or replacement.

5.2.10 A government can levy a tax on some or all energy products to encourage energy conservation or interfuel substitution. Where political and strategic factors, particularly for land-locked countries, suggest that there may be uncertainties in obtaining energy supplies from abroad, a government may also allow a premium over economic prices in assessing the viability of developing indigenous energy resources. Government can also employ a variety of nonprice controls, such as import restrictions, quantity rationing or quotas, for selective short-term intervention in the market for certain energy and energy-related products while fundamental price

adjustments are under implementation. Finally, it may be necessary to impose on government agencies, which are often insensitive to or insulated from market forces, various forms of budgeting or rationing to ensure that the energy consumed in public projects and services also reflect its real cost. Administrative and pricing policies need to be supported by the educational programs for the general public and for particular kinds of consumers, to help overcome the socio-political inertia to realistic energy prices, and to disseminate information on the available appropriate technologies. Training in efficient energy practices should be encouraged for all who operate equipment that produces or consumes energy.

5.2.11 The energy problem varies widely among developing countries and so universal prescription for a program of energy demand management exists. In the poorer developing countries most of the commercial energy is used by the affluent city dwellers, and in industrial and transport activities related to their needs. Consumption patterns in these areas, and in the middle income countries, resemble those in high income countries. Studies carried out in urban areas of developing countries indicate that the top 20% of income recipients, because of their greater use of modern appliances, use up to 60% of the commercial energy consumed by households, against only 5% by the poorest group. In the rural areas and amoung the urban poor, kerosene is used for cooking and lighting. The majority of the rural population relies heavily on wood for cooking, usually on open fires or in stoves with heat efficiency of less than 10%.

5.2.12 The subsequent sections discuss measures for energy demand management in agriculture and the main energy using sectors - private households,

transport, industry and electric power, with great emphasis on renewable energy resources.

A. Agriculture

5.2.13 In most developing countries, agricultural production accounts for approximately 5% of the commercial energy consumption. Since this is relatively a small proportion, management of demand is less likely to reduce substantially the total energy consumption. However, rising prices will adversely affect the costs of production which depend on improved seed varieties, assured irrigation and the application of petroleum-based chemicals such as fertilizer and herbicides. In many rice production systems, costs of fertilizers comprise 50% of the cash outlay.

5.2.14 High petroleum prices will also raise the costs of tubewells and other forms of irrigation that rely on pumpsets driven by diesel fuel and increase the total cost of agricultural mechanization.

5.2.15 The best yield-increasing technology is the improved seed-water-fertilizer approach adopted under the Green Revolution in most Asiatic countries. Through improved seed varieties, proper irrigation methods and efficient fertilizer application, high yield increases of basic staples can be achieved.

5.2.16 First, the energy economic policies should encourage the domestic production of fertilizers to substitute for imported petroleum-based fertilizers. Countries endowed with substantial quantities of hydro-power and limestone can manufacture ammonium nitrate and calcium nitrate fertilizers

by an electrolysis process. The economics of such projects ought to be carefully examined.

5.2.17 A second approach is to ensure better use of energy by improving farm practices. It is estimated that only 30% of the plant nutrient in chemical fertilizers applied in developing countries is used by the plants and the rest is wasted. In rice production, root zone placement of fertilizers can improve the efficiency 50% over the traditional spray methods. Crop residues and other organic by-products can be used as a partial substitute for chemical fertilizers.

5.2.18 Diesel pump irrigation systems should, where the topography permits, be replaced by gravity irrigation. If research can improve their cost effectiveness, solar pumps hold good potential for irrigation.

5.2.19 On the other hand, the windmill technology for pumping water has been in existence for a long time and is cost competitive with conventionally powered pumps. The cost of harnessing wind energy is estimated at US 20¢/ kwh assuming a 5.5 hour/day operation with winds of 11 mph. Windmill- powered pumping is generally more competitive for relatively shallow water sources that require small pumping capacity.

5.2.20 High energy costs affect agricultural marketing and processing. These issues are discussed in the transport and industry sections.

Liquid Fuels From Biomass

5.2.21 The production of alcohol, especially ethanol, from sugar cane is a commercially well established technology. Alcohol in the form of methanol can also be produced from wood, but the methanol-gasoline blends are much

more difficult to use as vehicle fuels.

5.2.22 Following the Brazilian experience, many developing countries are in the process of commencing ethanol production. The economics of alcohol production greatly depends on the cost of raw materials (sugar cane, cassava, etc.) which varies depending on land availability, agricultural productivity, labor costs and other inputs. Capital costs also vary significantly, depending on plant capacity.

The techniques for producing ethanol from feedstocks such as cassava, wood and sorghum that smallholders can grow efficiently on marginal land can lessen the potential land use conflict between food and fuel, widen the scope for ethanol production in the developing countries and increase the employment benefits of producing energy domestically. The other important considerations are that domestically produced ethanol is free from foreign interference and can lead to improved balance of payments.

5.2.23 On the other hand, ethanol production has some adverse limitations. Like all agricultural based industries, it is subject to the vagaries of nature. A year of bad weather with destructive floods or persistent drought or an outbreak of disease could destroy sugar cane and any other feedstocks, and this could have serious impacts on the economy.

5.2.24 On the overall, ethanol production from sugar cane is very competitive with other forms of energy such as gasoline as shown in the Table 2 below.

Table 2: DEVELOPING COUNTRIES: COMPARATIVE COSTS OF ENERGY FROM DIFFERENT SOURCES
(Notional delivered cost to OIDC consumers in coastal locations, in 1980 US dollars per barrel of crude oil equivalent)

	f.o.b. Export Cost a/	Transport/Processing Distribution Cost	Total Delivered Cost
I. Imported Fuels			
Crude Oil			
(Arabian Light ex Ras Tanura 6/1/80)	28.00 /b	2.75 /c	30.75
Products from above (Refined) at Point of Consumption)			
Gasoline (90R)		)	35.50
Household Kerosene		4.00)	42.60
Diesel 53/57		)	35.50
Heavy Fuel Oil		)	27.20
Refined Products			
Gasoline (90R)	39.35	4.15 /c	43.50
Household Kerosene	41.50	4.38 /c	45.88
Diesel (53/57)	39.50	4.63 /c	44.13
Heavy Fuel Oil	24.20	3.25 /c	27.45
Liquefied Petroleum Gases			42.50
Liquefied Natural Gas			27.00
Steam Coal	6.00-8.00	3.00-6.00	9.00-14.00
II. Domestic Production			
Crude Oil - Low Cost	5.00	1.00	6.00
- High Cost	12.00	1.00-3.00	13.00-15.00
Natural Gas - Low Cost	0.30	1.95	2.25 /d
- High Cost	2.20	8.80	11.00 /d
Coal - Low Cost	2.00	2.50	4.50
- High Cost	5.00-10.00	10.00	15.00
Refined Petroleum Products (from Domestic Crude Comparable to Arabian Light)			
Gasoline (90R)		)	9.40-21.00
Household Kerosene		2.50)	11.30-25.40
Diesel (53/57)		)	9.40-21.00
Heavy Fuel Oil		)	7.20-17.50
Liquefied Petroleum Gases			10.00-25.00
Synthetic Fuels e/			
Gasoline, Diesel Fuel from Cracked Fuel Oil f/			11.00-21.00
Gasoline, Diesel Fuel from Coal			40.00-60.00
Ethanol from Sugar Cane			25.00-45.00
Methanol from Natural Gas /g			25.00-45.00
Gasoline from Methanol			40.00-60.00
Shale Oil h/			25.00-35.00
Renewable Energy e/			
Firewood			8.00-20.00
Charcoal			30.00-80.00
Dung Cakes (India)			5.00-10.00
Solar Heat			50.00-90.00
Geothermal Heat			9.00-11.00
Electric power (at 2.4¢ to 10¢ per kWh) /i			40.00-166.00

a/ For domestically produced fuels, wellhead or mined cost is used.
b/ Posted prices from Platts Oilgram, June 6, 1980.
c/ Freight rates computed on basis of 60,000 ton tanker on Persian Gulf-Far East route, from Platts Oilgram June 9, 1980. White products (diesel and gasoline): clean tanker rate. Crude oil and heavy fuel oil: dirty tanker rate.
d/ Natural gas price range derived from information on Bank projects and studies in Bangladesh, Pakistan and Thailand.
e/ Cost delivered to consumers near point of production.
f/ Assumes production from fuel oil produced in local refinery from indigenous crude oil.
g/ Based on a gas price range of US$0.40-$1.50 per Mcf equivalent to US$2.25-$8.30 per boe.
h/ Based on Shell Group and Bechtel Corp. estimates with adjustment for inflation.
i/ Cost of electricity used in an electric heating device such as a cooking stove.
Source: World Bank staff estimates except where noted.

B. Household Use of Energy

5.2.25 In developing countries, households account for about 45% of the total energy consumption, and of this only 10 - 20% is commercial energy. Much of the noncommercial energy (charcoal, dung, etc.) has limited marketability. Households in developing countries use energy mainly for cooking, while space heating and cooling attains significance in the upper income levels.

5.2.26 In many rural areas, firewood, charcoal, crop residues and animal dung represent all the energy used and this amounts to 25% of the energy consumption in developing countries. About 75% of the population of the developing countries or approximately 2 billion people use traditional fuels for cooking.

5.2.27 While most of these people have access to firewood, approximately 0.5 - 1 billion use agricultural and animal waste for fuel. As noted above, the rapid depletion without matched afforestation programs has adverse environmental, social and economic consequences.

5.2.28 From the socio-economic viewpoint, it is important for government to promote the use of efficient stoves. Two types of stoves have been developed for quite sometime. The first is referred to as a "sand" stove which is made from a mixture of sand and clay or bricks with a chimney. This type of stove is built where it is to be used and the technique of constructing one can be taught to local artisans. The estimated cost is US$10 - 20 including labor, which is within the affordable range of the majority of the poor.

5.2.29 The success in introducing the extensive usage of these stoves depends on the feedback from the users to the designers, who should incorporate suggested features, and the entire system should be based on artisans with a direct interest in selling service as stove builders.

5.2.30 Another area where efficiency can be improved is in the production of charcoal. Modern equipment can achieve 40% efficiency in the conversion of wood to charcoal in contradistinction with traditional kilns which achieve only 20%.

5.2.31 Both in India and China large-scale biogas programs have been undertaken. The estimated cost of the Indian family-size biogas digester is US$240 - 360, which is greater than the average rural income per capita. To be effective, the Indian program has shifted emphasis from family-size plants to community-size plants to achieve equitable socio-economic goals. Tanzania has also adopted the community-size plants approach.

5.2.32 Biogas production from cow dung, pig manure and human waste is, in many cultures, unacceptable.

5.2.33 Since most developing countries are in the tropics, the amount of solar radiation is abundant and can be utilized for cooking and water heating. Flat-plate solar cookers are estimated to cost US$50, and domestic flat-plate water heaters cost approximately US$55 per square foot in the United States. In a considerable number of developing countries flat-plate collectors are being manufactured to meet commercial needs such as hotels, hospitals and other institutions to attain low to medium temperatures up to 180°F.

5.2.34 The financial and economic viability of the flat-plate collector is questionable. In the United States of America the industry thrives largely because of federal and state subsidies which could be as high as 70% of the investment cost to the homeowner. For the developing countries that are non-producers of copper, steel, glass and aluminum, it will take a considerable time for solar systems to be competitive with commercial energy such as hydro.

5.2.35 Finally, in analyzing energy consumption in the domestic sector, the following data is required:

(a) the number of persons in the household;

(b) the amount of disposable income;

(c) monthly electricity and fuel consumption by energy types, end-use, quantity and cost;

(d) inventory of energy-consuming appliances in the household.

5.2.36 This information is useful in computing the total domestic energy consumption and the effects of energy price changes to the household income. In some developing countries, the urban poor spend up to 30% of the household income on cooking and lighting fuels; consequently price increases have severe socio-economic impacts.

C. Transport

5.2.37 In most developing countries, the modern part of the transport sector shares the largest proportion of the fossil fuels and is almost completely dependent on petroleum products, primarily used in internal combustion engines which constitutes one of the most efficient forms of mobility. The high demand for petroleum based energy in this sector is illustrated in Table 3 below for a selected number of countries:

PERCENTAGE SHARES OF TRANSPORT IN TOTAL PETROLEUM PRODUCT DEMAND IN SELECTED DEVELOPING COUNTRIES

Country/Year	1970	1975
Brazil	60	61
India	49	59
Columbia	54	57
Mexico	--	61

Table 3

Source: World Bank

5.2.38 Typically, more than 50% of the total petroleum is consumed in the transport sector, and it is quite conceivable that this percentage will increase as developing countries experience accelerated economic growth. Furthermore, the share of gasoline, largely used in the private transport, in the demand for petroleum products is substantial. The sectoral consumption by various modes of transportation is shown in Table 4 below. The road transport (cars, buses, trucks) accounts for the largest proportion of energy consumed.

Developing Countries: Consumption By Mode of Transport

Trucks	35 - 45 %
Buses	8 - 12 %
Private Cars	25 - 35 %
Shipping	5 - 10 %
Air	5 - 10 %
Rail	2 - 5 %

Table 4

5.2.39 Energy for transport poses onerous policy and planning problems for governments of developing countries. In analyzing the impact of energy policies on transport, several criteria should be applied and these include energy efficiency, economic efficiency, fuel pricing, taxation and interfuel substitution.

5.2.40 Simple comparisons of the amount of energy consumed by different transport modes demonstrate wide variances in their energy efficiencies and care must be taken in interpreting such results. For instance, large proportions of the travel by trucks, barges and rail cars occurs when the vehicles are empty. Therefore, tons shipped is the most effective measure of fuel efficiency when shipping densities are alike. For fuel efficiency comparisons, ton-miles-per-gallon values are useful when commodities of similar densities are invovled; however, load size, vehicle type or mode and distance may vary.

5.2.41 The energy demand of various transport modes in the USA is given below. Since the transport technology is similar worldwide, this data should be reasonably representative for developing countries.

ENERGY INTENSIVENESS OF VARIOUS TRANSPORT MODES

MODE	LOAD FACTOR	ENERGY INTENSIVENESS
		(Btu/ton-mile)
Rail (diesel)	94 %	750
Inland waterway	85 %	500
Truck (diesel)	59 %	2,400
Air cargo	65 %	63,000
		(Btu/passenger-mile)
Small (U.S.) car	2.2*	2,582
Standard (U.S.) car	2.2*	4,323
Urban bus	30 %	2,308
Air	50 %	6,300

*Passengers per trip

5.2.42 Inland waterway (including coastal) shipping and rail systems are several times more efficient than road transport when used as heavy load carriers. A major policy option for countries with coastal and inland waterways should increase these modes of transport.

For passenger transport, improvement of the public transport services would be instrumental in diverting part of the traffic from private cars to more efficient bus and rail services, and car pooling should be encouraged. Electrification of rail or trolley bus services can increase usage of the indigenous resources used to generate power. The type of indigenous resource used, whether hydro, geothermal, etc. depends on the availability of these resources.

Government can promote fuel efficiency by import restrictions on high

fuel consumption vehicles, by high import duties on gas guzzlers, and by encouraging imports of only fuel efficient automotives. A combination of these measures with appropriate pricing and conservation policies could lead to savings in the order of 20 - 25% in the transport sector.

An important transport energy policy issue that needs to be addressed is the utilization of ethanol (ethyl alcohol) as a fuel in the transport sector as a partial substitute for gasoline and diesel oil. Ethanol-gasoline fuel mixtures can be used in motor vehicles without any engine modifications for ethanol admixtures up to 20% by volume. At higher percentages of ethanol (up to 100%) engine modifications are necessary. Several net oil importing developing countries have large sugar industries and ethanol can be produced either from molasses or directly from sugar cane juice. Production of ethanol from cassava, grain or any crop containing appreciable quantities of starch or sugar, is also technically possible as discussed in detail in earlier parts of this report. The economics of ethanol production must be examined on a case-by-case basis in each developing country, particularly as it involves optimal use of agricultural land.

Often the animate mode of transport, which has been around from time immemorial, is ignored in the transport sectoral analysis. This animate mode of transport uses animate energy to distribute goods and services, using animals of burden such as camels and yaks or animal drawn carts and above all, man's own muscle power. These modes of transport are inefficient and time consuming. Improvements are essential both in the animate and modern transport subsectors.

D. Industry

Industry is loosely classified into "heavy" and "light" segments. In general, the heavy industries are very energy intensive, particularly those involved in metal smelting. Industry is a major user of commercial energy in the developing world. In countries for which data are available, the industrial sector accounts for approximately 35% of the total energy consumption, and this percentage is expected to increase as these countries achieve higher levels of industrialization.

Table 5 gives representative energy requirements for producing a number of basic industrial raw materials. Some of these are of low intrinsic value, such as lime, cement and brick; it is usually more economic for a developing country to buy the fuel and use the imported fuel to process local raw materials into products of this nature. In general, it is difficult, on economic grounds, to justify the establishment of the more energy-intensive industries in developing countries if both energy and low materials are to be imported.

The analysis of energy demand in the industrial sector should be made by types of energy input and the nature of the energy form required as follows:

Fuel Type	Output
Fuel oil	Low pressure steam (0 - 60 psi)
Natural gas	High pressure steam (250+ psi)
Coal	Low temperature heat (up to 150°C)
Lignite	High temperature heat (150°C)
Electricity	Processing
	Motive power
	Space conditioning

Table 5 ENERGY REQUIREMENTS FOR HIGH PRIORITY PRIMARY PRODUCTS

Primary Product	Energy Required per net ton (short ton of product in millions of BTU)
Aluminum ingot	244
Quick lime	8.5
Portland cement	7.6
Common brick	3.5
Gaseous chlorine	18.0
Liquid chlorine	20.7
Cement copper	87.0
Refined copper	112.0
Glass containers	17.4
Steel slabs	24.0
Gray iron castings	34.0
Carbon steel castings	42.0
Refined lead	27.0
Gaseous nitrogen	2.9
Liquid nitrogen	8.1
Ammonia	39.0
Elemental phosphorus	172.0
Phosphoric acid	10.8
Basic brick	27.0
Fireclay brick, including ladle brick	4.2
Sulphuric acid (Frasch sulphur)	0.83
Sulphuric acid (weighted average for all raw materials)	0.04
Elemental zinc	65.0

Source: "Energy Use Patterns in Metallurgical & Non-metallic Mineral Processing - Phase 4 Energy Data and Flow Sheets, High Priority Commodities", by Battelle Columbus Laboratories, 1975. Report No. PB-245759.

This type of information is essential for implementing energy substitution by developing indigenous resources.

Large plants should be encouraged to carry out their own energy audits. The purpose of these audits is to study energy flows in the plant and to minimize losses. Small industrial plants will probably be unable to carry out their own energy audits. However, the aggregate energy savings can be substantial. This justifies the setting up of an energy audit group within the energy planning organization to train energy auditors.

5.3 Energy Pricing Policy

Energy pricing is a fundamental tool for controlling demand and planning. The major energy pricing policy objectives are:

(a) to reduce the consumption and improve the efficiency of energy use;

(b) to set prices that reflect the true foreign exchange and opportunity costs of fuels;

(c) to accelerate exploration for and development of indigenous primary energy resources, both renewable and non-renewable.

These objectives are not readily attainable in practice and they generate a series of related issues which do not lend themselves to a single solution. Some of the issues worth considering are:

(a) What should be the relationship between the prices of the primary energy fuels such as coal, crude oil and natural gas charged to power utilities? Furthermore, what relationship should these prices bear to those charged to the producers?

(b) What should the relationship be between the prices of petroleum products (liquid petroleum gas, gasolines, kerosenes, diesel and fuel oils) at the ex-refinery price level and at the retail price level?

(c) What should the relationship be between the prices of competing fuels at the end-point of consumption; for instance between charcoal, liquid petroleum gas (LPG), kerosene, natural gas and electricity for domestic cooking; between gasoline, diesel oil and LPG as fuels for transort; between coal, fuel oil and natural gas for thermal power generation?

(d) At what rate should indigenous non-renewable energy resources in developing countries be depleted and does the price applied to any given resource satisfy the depletion rate objectives?

(e) Should energy prices be used as a mechanism to achieve income distribution objectives in a society? If so, how?

These pricing policy issues can only be answered on a country to country basis within a large framework of energy policies and economic growth targets. The energy planners should ensure that domestic price increases do not create adverse effects on the economy and that the burden of such increases is not completely shouldered by the consumers.

Some recent studies in Sudan and Malawi indicate that the demand for diesel is relatively price inelastic in the short term which means that substantial and massive price increases are necessary to have any marked effect on demand. The diesel price increase is passed onto the consumer without a noticeable decline in fuel demand.

Although pricing issues can best be analyzed on a country specific setting basis, general guidelines can be used to delineate appropriate prices of primary renewable and non-renewable fuel resources, such as hydro, wind, coal, crude oil, natural gas, etc. Some of the guidelines are outlined below.

(a) The delivered price should not be higher than the economic cost of the next best alternative fuels. For instance, domestically produced

ethanol should be set at import parity with imported gasoline.

(b) The delivered price of the fuel should not be less than its full marginal economic cost of supply.

(c) The revenues derived from the sales of fuel should be adequate to cover the producing entity's full accounting costs, including depreciation, and a sufficient return on capital to keep energy producing entities financially viable, including the need to carry on exploration for new resources.

Since 1973 some of the developing countries have taken positive steps to achieve the pricing policy objective of adjusting national liquid fuel prices to international levels. Table 6 illustrates the differences in retail gasoline and Bunker C fuel prices in a selected 11 developing countries. What this table highlights is a widening gap in petroleum product prices in these countries dependent of their petroleum resource endowment and internal economic policies. The pricing policies of Brazil, India and Kenya have moved international parity.

Table 6 RETAIL PRICES OF GASOLINE AND RESIDUAL FUEL OIL IN SELECTED DEVELOPING COUNTRIES*

Country	Retail Prices of Regular Gasoline US cents/US gallon		Retail Prices of Residual Fuel Oil US$/Barrel	
	July 1976	July 1977	July 1976	July 1977
Brazil	150.7	151.2	7.31	13.51
Colombia	21.1	27.4	6.05	15.69
India	142.4	142.4	11.32	12.83
Indonesia	63.8	63.8	8.42	8.42
Iran	32.2	45.6	10.91**	2.69***
Kenya	109.0	125.0	11.76	N.A.
Mexico	65.0	46.0	9.70	N.A.
Philippines	71.0	84.8	16.38	16.95
Saudi Arabia	11.8	11.3	2.52	2.60
Thailand	76.8	73.3	13.52	12.61
Venezuela	13.8	13.2	0.67	3.18

* Source: IBRD
** Price to international vessels
*** Price to domestic users

N.A. not available

A comparative analysis of retail prices of regular and premium gasoline, kerosene, diesel oil and residual oil in July 1973 and July 1977 for 30 developing countries is presented in Table 7. The annual rate of increase of individual petroleum product prices between 1973 - 1977 varied tremendously among products and countries. Generally, products for direct consumption, such as gasoline, are taxed more heavily than those for intermediate uses, such as fuel oil. In the case of petroleum products, such as kerosene, which are mostly consumed by low income rural (for lighting) and urban (for cooking and lighting) households, the level of taxes usually applied to such products is either very low, or subsidized by government.

Table 8 shows the taxes on regular and premium gasoline, kerosene, diesel and residual fuel oils in July 1973 and July 1977 for 30 developing

Table 7: TAXES ON PETROLEUM PRODUCTS PRIOR TO AND POST 1973 OIL EMBARGO

DEVELOPING COUNTRIES

(in USc/gallon, except residual fuel oil in USc/42-gallon barrel)

Countries	Regular Gasoline			Premium Gasoline			Household Kerosene			Diesel Fuel Oil			Residual Fuel Oil		
	1973, July	1977, July	% Growth 1973-77	1973, July	1977, July	% Growth 1973-77	1973, July	1977, July	% Growth 1973-77	1973, July	1977, July	% Growth 1973-77	1973, July	1977, July	% Growth 1973-77
Argentina, Buenos Aires	44.7	65.2	9.9	53.1	80.9	11.1	14.2	21.0	10.3	20.9	17.3	-4.3	65.5	191.3	30.7
Bolivia, La Paz	4.0	2.8	-9.3	5.0	6.4	6.4	0.0	0.6	178.3	0.0	2.4	293.6	0.0	84.8	859.6
Brazil, Rio de Janeiro	9.7	37.8	40.5	1.1	52.9	163.3	3.9	7.6	18.2	11.8	11.3	-1.1		0.0	
Burma, Rangoon	24.2	2.5	-76.4	24.2	25.9	1.7	0.8	1.7	20.7	4.3	1.7	-26.1	8.8	70.0	67.9
Chile, Santiago	23.6	37.8	12.5	63.2	52.9	-4.5	3.1	5.3	14.3	0.6	22.7	148.0	92.0	476.3	50.8
Colombia, Bogota	4.2	6.2	10.2	5.2	15.3	31.0	0.2	0.1	-18.9	4.0	0.0	-347.2	0.4	42.0	220.1
Dominican Rep., S. Domingo	18.7	0.0	-557.6	18.7	40.3	21.2	14.7	14.7	0.0	6.0	5.5	-2.2	390.6	389.8	-0.1
El Salvador, S. Salvador	25.7	54.1	20.5	25.7	54.1	20.5	0.0	0.1	77.8	3.2	2.6	-5.3	29.4	30.7	1.1
Ethiopia, Addis Ababa	43.8	22.7	-17.9	43.8	28.4	-11.4	34.9	12.9	-28.3	37.5	15.1	-25.5		0.0	
Ghana, Accra	28.8	25.1	-3.5	28.8	63.0	21.6	1.2	13.1	81.8	9.4	15.7	13.7	470.6	608.7	6.6
India, New Delhi	49.3	92.8	17.1	49.5	93.2	17.1	12.2	18.9	11.6	23.0	19.7	-3.9	49.3	57.7	4.0
Jamaica, Kingston	13.6	110.7	68.9	16.6	115.1	62.3	0.0	0.0	-	0.0	0.0	-	0.0	0.0	-
Kenya, Nairobi	31.3	55.0	15.1	31.3	55.0	15.1	7.2	6.0	-4.7		23.0		0.0		
Lebanon, Beirut	31.0	25.1	-5.4	31.0	25.1	-5.4	14.0	11.2	-5.7		2.0			56.3	
Mexico, Mexico City	4.5	15.0	35.1	5.4	22.0	42.1	1.6	0.0	-255.7		0.0		33.6	0.0	-661.4
Morocco, Rabat	53.0	103.5	18.2	52.2	114.7	21.8	20.0	24.9	5.6		24.6		99.7	198.0	18.7
Pakistan, Islamabad	37.5	61.0	12.9	37.5	46.0	5.2	5.0	23.0	46.5	11.4	39.0	36.0	87.5	558.6	59.0
Panama Rep., Panama	13.7	43.2	33.3	13.9	50.5	38.1	15.3	1.7	-73.2	0.0	2.0	276.1		1512.0	
Paraguay, Asuncion	20.0	24.0	4.7	25.0	28.0	2.9	9.0	7.0	-6.5	7.0	5.0	-8.8	210.0	168.0	-5.7
Peru, Lima	8.0	31.0	40.3	16.0	43.0	28.0	0.2	0.6	31.6		1.0			29.4	
Philippines, Manila	5.2	25.5	48.8	5.2	28.1	52.5	2.1	3.6	14.4	0.0	8.9	446.2	30.2	96.6	33.7
Portugal, Lisbon	59.7	118.8	18.8	71.0	142.3	19.0	5.7	22.9	41.6		8.1		144.1	259.5	15.8
Singapore, Singapore	56.0	112.6	19.1	56.0	108.2	17.9	8.0	3.8	-20.5	2.8	0.0	-309.1	93.1	189.8	19.5
Spain, Madrid	39.3	34.0	-3.7	42.5	38.0	-2.8	9.1	6.0	-11.0		6.0		4.5	0.0	-360.6
Sri Lanka, Colombo	31.0	26.4	-4.1	33.5	27.5	-5.1	5.0	3.2	-11.8		4.9		0.0	144.6	996.6
Thailand, Bangkok	16.1	26.8	13.6	16.3	27.0	13.4	7.5	6.2	-4.9	3.1	6.2	18.9	50.0	0.8	-181.2
Tunisia, Tunis	73.7	238.1	34.1	77.3	251.0	34.2	18.8	27.4	9.9		47.2		0.0		
Turkey, Ankara	25.3	22.9	-2.5	36.4	31.7	-3.5	17.2	16.6	-0.9		18.8		202.0	209.0	0.9
Uruguay, Montevideo	42.0	64.0	11.1	57.0	87.0	11.2	4.0	11.0	28.8	6.1	13.5	22.0	168.0	168.0	0.0
Yugoslavia, Belgrade	42.0	91.0	21.3	47.0	94.0	18.9	22.0	22.0	0.0		37.0		0.0	676.0	1512.5

Table 8: RETAIL PRICES OF PETROLEUM PRODUCTS PRIOR TO AND POST 1973 OIL EMBARGO - DEVELOPING COUNTRIES

(in USc/gallon, except residual fuel oil in USc/42-gallon barrel)

Countries	Regular Gasoline/1				Premium Gasoline				Household Kerosene				Diesel Fuel Oil				Residual Fuel Oil			
	1973, July	1977, July	% Growth 1973-77	1977 World Price as % of 1977 Domestic Price	1973, July	1977, July	% Growth 1973-77	1977 World Price as % of 1977 Domestic Price	1973, July	1977, July	% Growth 1973-77	1977 World Price as % of 1977 Domestic Price	1973,/1 July	1977, July	% Growth 1973-77	1977 World Price as % of 1977 Domestic Price	1973, July	1977, July	% Growth 1973-77	1977 World Price as % of 1977 Domestic Price
Argentina, Buenos Aires	60.4	82.6	8.1	47	71.8	100.9	8.9	43	34.0	45.9	7.8	83	45.9	39.0	-4.2	97	390.4	728.8	16.9	165*
Bolivia, La Paz	17.0	27.8	13.1	140*	30.0	64.9	25.7	67	6.0	5.6	-1.7	684*	10.0	24.1	24.6	155*	336.0	856.8	26.4	140*
Brazil, Rio de Janeiro	29.2	151.2	50.8	26	37.8	185.2	48.8	23	27.2	83.2	32.2	46	39.6	83.2	27.9	46	235.1	1351.4	54.8	89
Burma, Rangoon	43.3	40.8	-1.5	103*	48.4	175.0	37.9	27	20.8	29.2	8.9	142*	20.7	29.2	9.0	133*	398.8	540.0	20.5	148*
Chile, Santiago	56.7	90.7	12.5	43	170.1	117.2	-9.8	37	37.8	52.9	8.8	72	4.0	75.6	108.5	50	920.2	2540.2	28.9	47
Colombia, Bogota	14.3	27.4	17.7	142*	19.3	36.9	17.6	118*	12.6	26.1	20.0	147*	12.0	50.0	42.9	76	399.0	1596.0	41.4	75
Dominican Rep., S. Domingo	47.0	0.0	-728.0	388*	61.0	99.0	12.9	44	36.0	75.6	20.4	51	32.0	52.8	13.3	72	961.8	1959.3	19.5	81
El Salvador, S. Salvador	52.0	97.6	17.0	40	55.6	103.2	16.7	42	18.0	64.0	37.3	60	24.0	44.0	16.4	86	403.2	1438.5	37.4	84
Ethiopia, Addis Ababa	89.5	121.3	7.9	34	96.6	142.1	10.1	32	68.8	82.0	4.5	49	65.3	82.0	5.9	44	354.4	1302.0	38.4	88
Ghana, Accra	54.2	101.5	17.0	41	58.8	145.0	25.3	31	29.2	72.5	25.5	56	25.4	72.5	30.0	49	1084.0	2375.1	21.7	43
India, New Delhi	71.2	142.4	18.9	29	73.7	149.1	19.3	30	30.7	54.6	15.5	74	43.4	56.3	6.7	64	413.3	1282.9	32.7	89
Jamaica, Kingston	37.6	171.7	46.2	23	45.5	180.8	41.2	24	14.7	32.0	21.5	120*	16.0	48.0	31.6	79	453.6	1270.0	29.4	95
Kenya, Nairobi	59.0	125.0	20.6	33	63.9	130.0	19.4	35	33.3	69.0	20.0	59	28.5	89.0	32.9	40	806.2			
Lebanon, Beirut	47.0	73.0	11.6	57	54.0	85.2	12.1	53	29.0	54.8	17.2	74		36.5		98		1022.3		112*
Mexico, Mexico City	24.2	46.0	17.4	80	33.3	66.0	18.7	59	10.3	9.0	-3.4	394*		10.0		380*	300.0			
Morocco, Rabat	89.3	160.0	15.7	26	93.2	180.0	17.9	25	43.7	65.0	10.4	62		65.0		55	590.8	1000.8	14.1	115*
Pakistan, Islamabad	50.8	108.0	20.8	38	55.0	116.0	20.5	39	16.7	31.0	16.7	131*	25.3	54.0	20.9	66	423.5	895.6	20.6	128*
Panama Rep., Panama	46.8	100.0	20.9	39	50.3	110.0	21.6	40	22.0	50.1	22.8	76	21.0	50.0	24.2	76		1621.0		74
Paraguay, Asuncion	57.0	150.0	27.4	26	81.0	180.0	22.1	24	42.0	78.0	16.7	49	35.0	78.0	19.7	49	1008.0	2268.0	22.5	53
Peru, Lima	21.0	93.0	45.1	42	35.0	136.0	40.4	32	4.0	12.0	31.6	319*	15.0	21.0	8.8	181*	470.0	504.0	1.8	238*
Philippines, Manila	18.0	84.8	47.3	50	22.0	92.5	43.2	51	16.0	57.2	37.5	73	15.0	61.8	42.5	63	420.0	1694.7	41.7	73
Portugal, Lisbon	84.6	177.6	20.4	20	99.5	207.2	20.1	19	30.4	45.4	10.5	87		59.2		65	405.3	905.1	22.2	133*
Singapore, Singapore	88.0	107.0	5.0	39	94.0	119.8	6.3	39	91.0	52.2	-14.9	80	20.0	41.6	20.1	94	581.0	1508.2	26.9	82
Spain, Madrid	78.3	139.0	15.4	26	98.7	179.0	16.0	22	34.0	72.0	20.6	55		52.0		74	446.0	1112.0	25.7	108*
Sri Lanka, Colombo	71.7	146.7	19.6	28	77.5	152.5	18.4	30	17.5	40.0	23.0	101*		60.3		59	371.6	2111.6	54.4	54
Thailand, Bangkok	39.0	73.3	17.1	57	43.0	78.7	16.3	60	36.0	50.0	8.6	83	19.9	49.2	25.4	79	504.0	1260.8	25.8	98
Tunisia, Tunis	161.0	155.5	-0.9	27	168.3	164.7	-0.5	27	65.9	36.6	-15.8	111*		85.4		42	405.4	2252.3	53.5	51
Turkey, Ankara	41.7	58.0	8.6	71	55.0	71.8	6.9	63	36.2	52.4	9.7	77		51.9		69	770.0	1118.0	9.8	103*
Uruguay, Montevideo	85.0	157.0	16.6	25	108.0	199.0	16.5	22	30.0	84.0	29.4	49	25.0	72.5	30.5	52	588.0	1554.0	27.5	77
Yugoslavia, Belgrade	72.0	140.0	18.1	26	78.0	146.0	17.0	26	36.0	59.0	13.1	67		88.0		44	252.0	1201.0	47.8	100*

* Implicitly, this petroleum product is subsidized since it is priced below the world price.

countries. Since this difference in taxation gives rise to wide price differentials, it inevitably stimulates substitution of expansive fuels by cheaper ones at the consumer level. One result has been a disproportionate rise in kerosene consumption in many countries.

Direct subsidies applied to specific liquid fuels, although socially justifiable, introduce severe distortions in energy demand patterns, and give rise to abuses as well as interfuel substitution, since many items of energy consuming equipment can easily switch fuels, especially if the financial incentive to do so is high. For instance, with slight modifications a gasoline/kerosene admixture can be used in motor cars. When retail prices of kerosene and gasoline differ by as much as 300 - 400%, it is inevitable that kerosene can be diverted to other uses than the one originally intended to be subsidized.

Energy pricing can play a significant role in accelerating exploration for and development of primary renewable and nonrenewable resources.

5.4 Energy Conservation Measures

Energy conservation measures are essential instruments in the national energy demand management. Possible measures of energy conservation are:

(a) Governments of the OIDCs should encourage efficient usage of automatives and should penalize, through fiscal means, usages of inefficient systems.

(b) The prices of all energy supplies to the end user should at least be equal to world market prices. Subsidized prices fail to reflect the real economic cost of energy to the economy.

(c) Significant energy taxes should be levied on certain fuels to reinforce the effects of market prices. For instance, kerosene

can be used to adulterate gasoline fuel and if the price differential between these fuels is very substantial, the consumers will purchase more kerosene and governments will incur financial losses.

(d) Conservation measures need to be undertaken to increase the use of waste heat from electricity generation and utilization of combustible waste from industrial processing. Industries should be encouraged, if not mandated, to conduct energy audits in order to determine areas of energy losses and implement energy saving measures.

(e) Lighting and thermal efficiency standards should be introduced in commercial, residential, and public buildings. Building insulation is important in hot climates to reduce air conditioning loads, and new buildings need to be designed with energy efficiency in mind.

(f) In the transport sector energy can be conserved by improving the public transportation system, enforcing the national maximum speed limit, encouraging the importation of fuel efficient automatives, and reducing the number of government vehicles.

(g) Financial incentives should be established for use of indigenous energy resources.

(h) A comprehensive public education program on the essence of energy conservation should be launched by government.

(i) A full-time government energy conservation department should be established to monitor and coordinate a national energy conservation program. The duties of this department should include training of specialized personnel such as energy auditors.

Energy conservation measures can be achieved within a relatively short time and without substantial investments, so long as government is willing to play a leading role through financial incentives to affect conservation.

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