SOLAR ENERGY IN THE 80s

Edited by
COSTIS STAMBOLIS

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INTRODUCTION

As our social and economic infrastructures tend to become closely related to the planet's energy equation the need for the development and application, on a large scale, of peaceful and renewable energy sources is becoming more apparent. In a world which is threatened with the non-availability of fuel oil supplies and the menace of nuclear war, one is bound to look into the future energy prospects with considerable scepticism. On the other hand, the role of renewable energy sources, such as solar energy, has not yet been fully appreciated, nor explored, by most of the world's governments and major industrial organisations.

Taking a global energy view, we feel that solar energy is one of the most promising alternative energy sources because of its diffuse nature and worldwide availability. It is true that some countries enjoy greater amounts of solar radiation than others and this is why different types of systems and components are required in each case. Unfortunately, solar energy is not yet seen, by the majority of nations, as a national energy source. There is still a lot of mystique attached to the words 'solar energy', let alone its applications. It is also true that during the passed decade interest and funding on solar energy increased manyfold, and that phenomenal progress was achieved in a considerably short time. However, a lot more needs to be done if solar energy is to make a world impact as a major energy source.

Looking ahead into the 80s and beyond, we see that the major challenges will be the development of economic solar technologies. Until the time comes when economic interpretation of life becomes more human, the problem for solar energy will always be the competition with conventional energy sources. But already there are many places in the world today where cost-effectiveness is irrelevant simply because no other energy sources exist.

This volume contains papers that were presented in the 'Solar Energy in the 80s' conference which took place in London at the very beginning of the new decade. The great majority of the work reported at the conference was based on many years practical experience with the result that the ensuing discussions concentrated on the actual current and potential problems of solar energy applications. It may seem unconventional for a non-academic group such as Heliotechnic Associates International to have convened a conference of this kind but it was precisely because of the practical orientation of and focusing on working installations that H.A.I. took the initiative to organise this event. The conference which received wide support and publicity was sponsored by four diverse organisations, a fact clearly indicating the type of support that solar energy activities have at long last started to receive. The four sponsoring organisations were: UNESCO, one of the oldest UN bodies which started supporting solar energy activities more than 25 years ago; the Atmospheric Sciences Research Center of the State University of New York at Albany, a leading US research centre on solar energy; the Williams & Glyn's Bank Ltd, a major British financial institution; and the Atelier, an established engineering consulting organisation in St. Albans, Hertfordshire.

In many respects the conference proved to be an eye-opener, as indeed most conferences are supposed to be, with a fair amount of work reported here for the first time. Harry Tabor, one of the pioneers in the field of solar energy, announced an important breakthrough in solar power generation: the use of a non-convecting solar pond to operate a 150 kW thermal power station which makes use of a low temperature, organic-vapour, Rankine turbine as the power plant. (See pages 189-196). The design, installation and operation of such a pilot plant will certainly stand as a milestone in the history or harnessing the sun, heralding the development of much larger units in the 5MW range, which can find application in many parts of the world, especially in developing countries. On the electricity generation side the rapid progress and immense potential prospects of photovoltaic cells was reported by Yves Chevalier, at COMES, the French official Government Agency on Solar Energy (see pp 197-202). With a total of 2 MW worldwide installed photovoltaic capacity at present and a predicted 100 MW by 1985 and prices dropping in real value, solar cells may well prove to be one of the most economic ways of producing electricity in many remote areas and used for equipment with low power requirements.

Several new solar buildings were presented and perhaps the most exciting one was the police barracks at Bagnol-sur-Ceze in the south of France (see pp 93-106) Architect George Chouleur has used the entire south facing vertical wall of the building to integrate 155 m^2 of collector surface. Thus the quite awkesome problem of accommodating the collectors has been overcome. Solar architects Sham Jauhri, Dominic Michaelis and Philip Tabb described many new solar housing schemes, most of them having been realised over the last year. In the papers presented by Ron Stewart (see pp 23-62) and Don Forrest (see pp 63-68) several successful ways were shown of combining and integrating solar energy components to overall energy conservation schemes in residential and industrial buildings. Such a novel approach could well pave the way for energy savings on a big scale in urban areas where many restrictions exist for the location of solar collector areas. Klaus Speidel of Dornier System, announced for the first time the development of a new solar powered water pump (see pp 157-188) and solar cooling and desalination projects which have taken place in the Middle East. Such developments highlighted the tremendous potential for applying solar energy systems in developing countries which usually enjoy high annual solar radiation values but often lack the necessary economic and industrial resources.

Professor David Hall discussed the importance of biomass in a global context and critically evaluated the different methods which are currently used for producing useful fuel such as methane, ethanol and alcohols (see pp 5-20). He also stressed the fact that the total world wood-fuel consumption is grossly underestimated in officially published statistics and could be as large as three times more than is usually acknowledged. It is surprising that approximately ½ of the world's total energy use is biomass. However, there are imminent dangers from the excessive use of wood in many countries which are afflicted from desertification. It is now estimated that half of all the trees that are cut down are used for cooking or heating. Perhaps one of the most practical ways of utilising solar energy is through the photosynthetic process and although efficiencies are usually very small, the potential for increased wood-fuel production is enormous because of the great versatility of plant growth.

The social and economic implications of solar energy utilisation and the impact of growing solar markets were expertly debated by Dr. Charles Levinson (see pp 233-234). In his presentation Dr. Levinson emphasised the role of controls in matters of energy policy and how these are held by the large multi-national energy corporations and financial institutions. Therefore it is not surprising that research into softer technologies, particularly of solar energy, has been stunted and diverted towards the development of centralised collection and generating systems. The democratic power generation opportunities which are now presented by solar energy utilisation are likely to be threatened by efforts to dominate and monopolise this field by a few large companies.

The decision making aspects in the field of solar energy are perhaps far more crucial than most people who are involved in the broad energy field can appreciate. With new processes, materials and techniques being announced almost every day the need is becoming apparent for a critical evaluation of this rapidly evolving technology. For decisions to be taken as to the type of equipment or process that are worth developing, the type and size of investment required, and where to market and locate manufacturing facilities, require a sound understanding of the long term implications. In view of the fast increasing demand for the use of solar systems there is a need for authoritative information on systems' performance and an examination as of the various choices and constraints which are inherent in solar energy utilisation. A range of these choices are analysed in the various papers contained in this publication. Although the technological choices are wide it must be pointed out that, at least at this stage, these are important economic and social constraints.

Clearly, decisions are taken by different people serving under different capacities, and the following is an outline of the main levels involved:

Consumer - house owner, developer, farmers, local government authorities, industry, engineering and building contractors;

Industrial - manufacturers of equipment (e.g. collectors) and producers of prime materials (e.g. copper);

Corporate - financial corporations, banks, investment advisors;

Government - legal, economic and policy making officials.

The decisions which usually need to be taken and where information is required are of the following kind: (a) type of system, (b) type and size of equipment, (c) level of investment, sales policy, (d) operational conditions and service, (e) legal and social aspects, (f) economic subsidies.

The papers presented at this conference which was purposely subtitled 'A decision maker's conference', outline, and some of them in great detail, the technological options that are currently available and others that are being developed. Options do exist and it is up to the 'decision makers' to evaluate the solution that they offer. A good example of the kind of decisions that will need to be taken is given by Professor John Page in his paper on 'Solar Prospects for the UK and the EEC (see pp 21-22). Prof. Page raises the question of scale, in solar systems, and the need to concentrate on medium scale applications. He says: "Small may be beautiful, but medium size is likely to prove substantially better".

It appears that the most critical period in the development of solar energy utilisation is going to be the decade of the 80s. The question immediately arises as to the directions that we should follow so as to lead solar technologies to a position where they can make substantial contribution to world energy needs. What has become clear over the last five years is that too much money has been spent in re-inventing the wheel and in improving component efficiency at the expense of economics. As Tabor rightly observed (see pp 1) "The place for sophistication is in the thinking, not in the hardware". The directions that solar technologies should then follow in their further development should be towards improving simplification, reliability and economic viability. Compared to other modern technologies solar energy has a long way to go but the foundations have already been laid. What solar enthusiasts should be arguing about is not how many percentage points solar technologies can score before the year 2000, but how fast they can become a leading force in electricity supply, domestic and industrial heating/cooling, cooking and agricultural applications for the millions of needy people in the Third World.

Looking ahead into the 80s we can confidently say:

> Use small scale solar energy now, intensify large scale solar research and have faith in the eventual use of the sun as major energy source.

Costis Stambolis
London, June 1980

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PAST, PRESENT AND FUTURE DEVELOPMENTS IN SOLAR ENERGY—A PERSONAL VIEW

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If Peter Glaser, whom we had expected to participate,(1) had been here, he would - if my memory serves me correctly - have been the third of the present participants who attended the First World Symposium on Solar Energy, held in Arizona in 1955, the other two being our session chairman, John Page and myself. We were, of course, younger then than we are now and naively enthusiastic. I presume to be speaking for my two colleagues when I say that we are still solar enthusiasts but our enthusiasm is somewhat tempered by a better understanding of the issues involved, some of which I shall touch on in these remarks.

We can divide the 25 years that have elapsed since the Arizona meeting into two periods: the first twenty i.e. up to 1974 and the fuel-oil crisis - and the five years since then.

In the first period, there was a small amount of activity, solid and basic: it was, in effect, an extension of the excellent work started at M.I.T. by Prof. Hottel and his colleagues in the forties. There was almost no government sponsorship in countries such as the U.S., UK, Germany, Japan, etc. and indeed most other countries. There was some governmental support in France - largely because of the group of heliotechnicians who had been working in Algeria and returned to France when Algeria became independent - and also because of the personality of Prof. Felix Trombe. There was some government support in Australia - within the CSIRO - again mainly due to the persistence of one man - Roger Morse - who was head of the Mechanical Engineering Division of CSIRO. There were government-sponsored projects in some other countries but all on a rather small scale: the Soviet Union also reported on solar R & D. In Israel, the work of my own group came directly under the prime-minister, Mr. Ben Gurion, who, if I am not mistaken, was the only prime-minister or president in the world to actively promote solar research - and this was in the 50's! In the U.S., UK and other countries, there were small university groups - with even smaller funds - such as the Wisconsin University group inspired by the late Prof. Farrington Daniels. A solar conference, in this period might bring together fifty scientists and engineers. The work reported was mostly of good scientific standard but relatively unsophisticated in the technical sense.

In the second period, all this changed: in 1975, at the Los Angeles ISES meeting, 4000 people turned up: the cynics implied that the large attendance was prompted by the possible availability of large R & D funds rather than by a compelling desire to solve the energy crisis, but be that as it may, a large number of individuals and groups rapidly became involved in solar work.

This second period has been characterised by an increasing degree of sophistication, some of which may be good but much of which is harmful. Thus new computational techniques

(1) This lecture was added to the programme when it became known that Dr. Glaser would not be able to attend.

have been developed to determine rapidly the expected yield of a solar installation - and this is good, but can go too far: the last ISES meeting in 1979 revealed a very large amount of intellectual effort being applied to refining such methods far beyond what is reasonable, seeing that the original methods were only statistical and the sunshine itself exhibits wide variations from year to year, and to making the systems more sophisticated. This may have been - at least at some stage - due to the influence of space scientists and the aero-space companies entering the solar field and it is my personal view that they missed the point.

In 1977, I had been given figures for a total installed cost of \$40 per ft^2 of collector for a house heating installation (this being incremental to the cost without solar) and whilst the figure has been contested by some, it has been confirmed by others. Yet the annual useful heat yield of the collectors was as low as 60,000 BTU/ft^2 in a monitored Canadian installation to about 200,000 BTU/ft^2 under better conditions. At \$5/million BTU - the cost of heat from oil at that time - the value of the solar yield was 30 cents per ft^2 per year in the bad case, to \$1 per ft^2 per year in the good case. The capital cost of \$40/ft^2 appears indeed as a very poor investment. What the sophisticates forgot was that we are dealing with an energy source of very low unit value i.e. under \$1 per square foot of delivered solar energy - to use the example given: to invest \$10/ft^2 for the collector (a current target price) is borderline economically, but to let this rise to \$40/ft^2 for the installed system is rendering many solar energy applications totally unviable economically, converting them to playthings in an affluent society(2).

The place for sophistication is in the thinking, not in the hardware. Thus, who is important is the bio-chemist, photo-chemist or physicist who builds a highly sophisticated model of how a photon-converter works, this possibly leading to simple hardware, with a chance for low cost. A recent example is in photo-electro-chemical cells where good science at the Weizmann Institute has raised the efficiency of conversion from 2-3% to 8%. The photobiologists, when they fully understand photosynthesis and plant growth may devise efficient converters (plants) of extremely low cost. Yet another example - that I will describe in another session of this conference - is the solar pond, which is extremely sophisticated in conception but which leads to the lowest-cost thermal solar collector yet developed.

On the whole, most solar devices are not really viable, even against the present high cost of fuel. The exceptions are almost the same as they were 25 years ago, e.g. the simple thermosyphon solar hot-water heater which has no pump, controllers or maintenance costs. (As soon as an attempt is made to upscale this simple water heater - for example to heat a house - the extra sophistication eats away the economic viability). Passive buildings - where the building is designed to exploit solar radiation for heating and - perhaps - nocturnal radiation for cooling, is another exception (provided the enthusiasts don't go too far: many passive buildings are now costing too much!) What we - to our shame - unfairly call "primitive" societies knew remarkably well how to build livable structures centuries ago: we are just having to relearn much of that primitive "technology"!

Earlier, I referred to Prof. Trombe in France. His work is widely recognised (he was awarded the Farrington Daniels Award of the International Solar Energy Society last year). His two main areas have been passive houses and solar furnaces: the latter had nothing to

(2) Affluent in money, not in primary energy sources!

do with the energy crisis. Trombe, a high-temperature chemist, needed a clean source of high-temperature heat, so he built solar furnaces including a large one involving a field of articulated mirrors concentrating solar radiation to a focal point on a high platform. Later, the aerospace people, possibly fascinated by the beauty and structural engineering of Trombe's furnace, proposed building such systems to generate power(3). The concept will work but economic and operational viability appear - at least to me - very remote.

To look to the future, we note the two basic characteristics of solar energy that are the cause of most of the difficulties to date:

(i) The intensity is low, so that very large devices are required to collect significant amounts of energy.

(ii) Solar radiation is intermittent.

These two characteristics provide the clue as to where we have to concentrate our efforts i.e.

(a) materials technology - in the widest sense;

(b) energy storage.

Just as man in the western world insists on his private car - so as not to feel enslaved by a railway timetable - so he demands energy on tap when he wants it, not when the sun shines. Thus, low-cost energy storage (accent on low-cost) is an a priori condition for solar energy utilisation on any significant scale, most particularly long-term storage. This is one of the basic motivations of the very good work being done on bio-conversion as a major long-term contribution for solar energy utilisation. Bio-conversion is also a special case of materials technology - how to get large areas of "collector" for a small capital outlay. The use of phase-change materials for heat-storage is again a question of materials technology: not only must they have desirable reversible properties, but ultra low-cost materials have to be identified - especially if long-term storage is considered. Other aspects of materials technology are in the materials of construction of solar devices. Examples: new semi-conductors for low-cost direct photo-conversion. Note that here again, the problem of energy storage is an inhibiting factor to viable direct conversion: we do not have, today, an effective and cheap method of storing electricity on a large scale. A further example is new plastics, that need to be resistant to the temperatures and ultra-violet radiation associated with thermal solar collectors.

I will conclude with a philosophical comment: there are no magical solutions to the energy shortage problem: in any area the energy needs will be met - in whole or in part - by a mix of energy sources - and any contribution by solar - even if not ideal - is to be welcome and exploited to the full.

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(3) A form of "central receiver" had been proposed by the Russians in the forties, but the major inspiration for current U.S. activity would appear to have been the work of Prof. Francia in Italy who demonstrated small-scale, power-tower generators in the sixties.

ENERGY FROM BIOMASS—SOLAR ENERGY THROUGH BIOLOGY

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ABSTRACT

The current worldwide government sponsored research and development of solar energy in 1980 approaches $2½billion. More than four-fifths of this is allocated to expenditures in the Americas (Brazil, USA and Canada) where important biomass programmes have been implemented over the last five years - the result of the realisation that biomass can provide liquid and gaseous fuels, besides solid fuel and chemicals, at a cost and with socio-economic benefits that look surprisingly favourable even at these early days of implementation studies and pilot plants. Biomass for energy programmes are currently being implemented and are under assessment in many countries of the world.

KEYWORDS

Biomass, energy, solar energy, fuels, resources, conversion, energy ratios, economics, national programmes.

INTRODUCTION (refs. 1-17; 21-25; 41-45)

Hardly a day goes by without there being a news item warning us of the impending shortage of oil and what it is going to cost us - if we can get it! This belated realisation that non-renewable liquid fuels are going to increase in price, and possibly even be rationed, is one of the main reasons why biomass is being looked at so seriously by so many of the developed countries. Possibly even more important, for the developing countries of the world, is the so-called 'woodfuel crisis' which may be even more serious since the problems of deforestation have such long-term detrimental agricultural, social and economic consequences.

The oil/energy problem of the last five years has had three clear effects on biomass energy use and development. Firstly, in the developing countries there has been an accelerating use of biomass as oil products have become too expensive and/or unavailable. Secondly, in a number of developed countries large research and development programmes have been instituted which have sought to establish the potential and costs of energy from biomass. Estimated current expenditure is approaching $100 million per annum in North America and Europe. The work is still at the early stages but results look far more promising than was thought even two years ago. Demonstration projects and small-scale commercialisation are being rapidly implemented. Thirdly, in at least one country, viz. Brazil (which currently spends over a half of its foreign currency on oil imports), large scale biomass energy schemes are being implemented as rapidly as possible - the current investment is over half-billion dollars per annum.

There is no doubt that the majority of the people in the world live by growing plants and processing their products. The main issue in developing countries is that of scarcity and the problem of trying to maintain, or possibly even to increase, the present level of use without harming agricultural or forestry and ecological systems. More efficient use of existing biomass and possible substitutes for biomass use, e.g., solar and wind based technology, should be considered and implemented as quickly as possible to reverse the trend of excessive biomass use, as is already occuring in many countries. In the developed world the expertise exists and is already being used to implement biomass energy programmes from the point of view of potential technology and economics. Biomass can provide a source of energy now and in the future; just how much it can contribute to the overall provision of energy will very much depend on existing local and national circumstances and thus it is imperative that each country establish its energy use patterns and the potential of biomass energy. This is not very easy to accomplish quickly, but needs to be done as soon as possible.

Not many people need reminding that our fossil carbon reserves, whether for fuel or chemicals, are all products of past photosynthesis. However, what most people do not realise is the magnitude of present photosynthesis - it produces an amount of stored energy in the form of biomass which is about ten times the world's annual use of energy. Table 1 also shows that the total amount of proven fuel reserves below the earth is only equal to the present standing biomass (mostly trees) on the earth's surface while the fossil fuel resources are probably only ten times this amount. This massive-scale capture of solar energy and conversion into a stored product occurs with only a low overall efficiency of about 0.1% on a worldwide basis but because of the adaptability of plants it takes place and can be used over most of the earth.

It is not widely appreciated that one-seventh of the world's annual fuel supplies are biomass (equivalent to 20 million barrels of oil a day - the same as the USA consumption rate) and that about half of all the trees cut down are used for cooking and heating. Because this use is mostly confined to developing countries it has until recently been sadly neglected and the effects of overuse of biomass are having serious and long term consequences. In the non-OPEC developing countries, which contain over 40% of the world's population, non-commercial fuel often comprises up to 90% of their total energy use. This non-commercial fuel includes wood, dung and agricultural waste and because of its nature is seldom thoroughly considered. Total wood-fuel consumption is probably three times that usually shown in statistics, and about half of the world's population relies mainly on wood for their cooking (four-fifths of total household energy use) and heating. Furthermore, supply statistics of non-commercial energy can be out by factors of 10 or even 100.

In my estimation a rural person in the developing countries uses on average about 15 GJ of biomass-derived energy every year. This is the equivalent to 1 tonne or 1.4 m^3 of air-dry wood. Local and regional differences in annual use abound, as do the relative proportions of wood, dung and agricultural wastes. The developing countries have a population of about 3 billion of which about 70% are rural. Biomass energy in rural areas usually supplies more than 85% of the energy - and this is mostly used in the household for cooking. There is also an urgent need to supply more local energy for agriculture and small industry. We calculate an annual worldwide rural biomass energy use of about 3.2×10^{10} GJ. In Africa about 65% of the total energy consumed is biomass-derived, in Latin America the figure is about 45%, while in India and the Far East about 50% is biomass energy. Including the urban population of developing countries, who often use large quantities of biomass-derived energy (say, an average of 8 GJ/year), and the use of biofuels by small scale industries, we come up with a total biomass energy use in developing countries of about 4 x 10^{10} GJ; this is about one-seventh of the world's total energy use - equivalent to about 20 million barrels of oil per day.

In this paper I would like to present some evidence that fuels produced by solar energy conversion are a very important source of energy now and will continue to be so for the foreseeable future - probably even to an increasing extent. We should re-examine and if possible, re-employ the previous systems; but, with today's increased population and standard of living, we cannot revert to old technology, but must develop new means of utilising present-day photosynthetic systems more efficiently. Solar biological systems could be realised to varying degrees over the short and long term. Some, such as the use of wood, biological and agricultural wastes, and energy farming, could be put into practice immediately, whereas others may never become practicable. Photobiological systems can be tailored to suit an individual country taking into consideration total available energy, local food and fibre production, ecological aspects, climate and land use. In all cases the total energy input (other than sunlight) into any biological system should be compared with the energy output and also with the energy consumed in the construction and operation of any other competing energy producing system.

Solar energy is a very attractive source of energy for the future but it does have disadvantages. It is diffuse and intermittent on a daily and seasonal basis, thus collection and storage costs can be high. However, plants are designed to capture diffuse radiation and store it for future use. Hence the serious thought (and money) being given to ideas of using biomass as a source of energy - especially for liquid fuels, but also for power generation and other end uses (Table 2). I am aware of biomass programmes in the UK, Ireland, France, Germany, Denmark, Sweden, USA, Canada, Mexico, Brazil, Sudan, Kenya, Australia, New Zealand, India, Philippines, Thailand, Israel, South Korea and China. The biggest difficulty with implementing them seems to be the simplicity of the idea - the solution is too simple for such a complex problem! Fortunately for us, plants are very adaptable and exist in great diversity - they could thus continue indefinitely to supply us with renewable quantities of food, fibre, fuel and chemicals. If the serious liquid fuel problem which is predicted within the next 10 to 15 years comes about, we may turn to plant products sooner than we expect. Let us be prepared!

What I am definitely not proposing is that any one country will ever be able to derive all its energy requirements from biomass - this is highly unlikely except in especially favourable circumstances. What each country (or even region) should do is to look closely at the advantages and problems with biomass energy systems - summarized in Table 3. The long term advantages are considerable but implementation of significant programmes will take time and require important economic and political commitments. The programmes will vary in their emphasis and thus most of the research and development should be done locally. Such R & D is an ideal opportunity to encourage local scientists, engineers and administrators in one field of energy supply. One should always be fully aware of the assumptions involved in any energy cost projections (especially if they are more than 6 to 12 months out of date!) before extrapolating or drawing firm conclusions. Even if biomass systems do not become significant suppliers of energy in a specific country in the future, the spin off in terms of benefits to agriculture, forestry, land use patterns and bioconversion technology are, I think, significant.

FACTORS FOR IMPLEMENTATION

The main factors which will determine whether a biomass scheme can be implemented in a given country are (a) the biomass resource, (b) the available technology and infrastructure for conversion, distribution and marketing, and (c) the political will combined with social acceptance and economic viability. These points are now considered in turn. (ref. 1)

(a) The resource base

The total annual production of biomass, (net primary production), the amount of wood produced (including natural forest and managed plantations), and the harvested weight of the major starch and sugar crops are shown in Table 4. In addition there is a worldwide availability of crop residues and other organic wastes. Although the amount of such wastes have been calculated in some detail for the USA, Canada and some European countries where they have been identified as the major short term biomass-resource, such figures are not generally available for the developing countries. Such data that is available is often questionable and cannot, at present, form a basis for any energy planning discussions. In addition to established sources of wood and food a wide range of other land and aquatic cultivation systems have been proposed for the future.

(b) Technology for conversion

Biomass as it stands in the field or collected as wastes is often an unsuitable fuel since it has a high moisture content, a low physical and energy density and is incompatible with present demands for a fuel to be used in internal combustion engines - the main power source for transport and agriculture in most countries. Established conversion technology can be divided into the biological and the thermal (Table 2). The great versatility of biomass energy systems is one of their most attractive features - there are a range of conversion technologies already available (and being improved) yielding a diversity of products, especially liquid fuels to which the world seems to be addicted and on which most world economies have recently been based.

Plant materials may be degraded biologically by anaerobic digestion processes or by fermentation, the useful products being methane, ethanol and possibly other alcohols, acids and esters. At present the established technologies are the anaerobic digestion of cellulosic wastes to form methane or the fermentation of simple sugars to form ethanol. The most suitable feedstocks for anaerobic digestion are manures, sewage, food wastes, water plants and algae.

The most suitable materials for thermal conversion are those with a low water content and high in lignocellulose, for example wood chips, straw, husks, shells of nuts, etc. The most likely processes to be adopted will use part of the material as fuel for the production of the required mixture of carbon monoxide and hydrogen (synthesis gas) for the subsequent catalytic formation of alcohols and hydrocarbons. During gasification oxygen or steam may be introduced in order to enhance the degree of conversion to synthesis gas and to increase its purity.

Two basic routes of catalytic conversion, of synthesis gas to further products can be recognised. The gas may be converted directly to hydrocarbons via the Fisher-Tropsch synthesis, or may be used for the formation of methanol. Both routes are well established in connection with use of gas produced from coal with plants operating in countries such as South Africa and Germany. Some plants using sorted domestic rubbish are operating and considerable research is being carried out on