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Report

drawn up on behalf of the Committee on Energy and Research

on the need for a Community policy on the use of solar energy

Rapporteur: Mr L. NOE'

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PE 47.793/fin.

By letter of 21 July 1976 the Committee on Energy and Research requested authorization to draw up a report on the need for a Community policy on the use of solar energy.

Authorization was given by the President of the European Parliament in his letter of 15 September 1976.

On 10 September 1976 the Committee on Energy and Research appointed Mr Luigi NOÉ rapporteur.

It considered the draft report at its meetings of 28 January 1977, 15 March 1977 and 17 May 1977 and at the last meeting unanimously adopted the motion for a resolution and the explanatory statement

Present: Mrs Walz, chairman; Mr Veronesi, vice-chairman;
Mr Noé rapporteur; Lord Bessborough, Mr Dalyell, Mr Edwards, Mr Ellis,
Mr Fuchs, Mr Leonardi and Mr Ripamonti.

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The Committee on Energy and Research hereby submits to the European Parliament the following motion for a resolution, together with explanatory statement:

MOTION FOR A RESOLUTION

on the need for a Community policy on the use of solar energy.

The European Parliament,

- having regard to the report from the Committee on Energy and Research (Doc. 120/77),

1. Believes that the correct strategy for seeking substitutes for oil is to consider all the alternative sources which together may make substantial contributions;
2. Recommends that the close coordination between Community actions and national programmes in this sector be maintained;
3. Believes that efforts should be made in the member countries to collect the data on solar radiation and meteorological conditions necessary to determine the feasibility of solar energy applications, and to compare the data on more closely observed meteorological conditions with the data on solar radiation over the same period;
4. Believes that all research into the use of solar energy for the heating of buildings should be accompanied by research and programmes to discover the best methods of drawing economic advantage from improved insulation and from investments in solar energy;
5. Notes that on the basis of existing knowledge and experience it is possible to obtain hot water for domestic use at competitive prices by means of equipment for the collection of solar energy; calls upon the Commission and the Member countries to encourage this application;
6. Hopes that studies on the storage of heat produced, both for short and long periods, will be intensified;
7. Recommends that, with the aim in this sector too of ascertaining what practical applications are possible and until acceptable storage methods have been developed, close attention be paid to current experiments in various climatic conditions in the Community on ambient heating by solar collectors, using additional heat sources;

8. Stresses that solar energy applications in agriculture, through the use of simple and robust apparatus, should be carefully studied by the Community, in view of their advantages, especially for the developing countries;
9. Stresses the importance of providing the manufacturers of solar collectors with sufficiently extensive production programmes to bring about a reasonable reduction of their costs;
10. Believes that although the production of electrical energy using solar radiation appears for the time being distinctly more expensive than other existing possibilities experiments should be continued both on the process utilising the concentration of rays by means of mirrors, and with the photovoltaic method;
11. Points out that if solar energy is to be effective, it will have to make a breakthrough at various levels, through technology, through harmonization of standards and through a policy of tax concessions;
12. Believes that solar energy could be usefully applied by Member States in the construction of public buildings;
13. Hopes that every Member country will participate actively in the EEC programme;
14. Believes that cooperation between industrialized countries and developing countries on the use of solar energy is essential;
15. Holds the view, nevertheless, that neither the development of this alternative source of energy, nor that of others, can, in the short or medium terms, replace the vital contribution of energy from nuclear fission;
16. Instructs its President to forward this resolution and the report of its committee to the Council and Commission of the European Communities.

EXPLANATORY STATEMENT. Introduction

1. Research on the development of solar energy applications is at present being conducted in five parallel directions, with various degrees of priority and at different stages of development:
 - A. Use of solar radiation to heat water for use either, most simply, to meet domestic hot water needs, or to heat buildings in winter and cool them in summer.
 - B. The use of solar radiation to generate electricity by means of special cells, known for this reason as photovoltaic cells: direct conversion; or by heating a liquid thermal vector: indirect conversion. In the latter case two systems are under study: the concentration system, based on the use of mirrors which concentrate the solar radiation on a boiler; the distributive system in which the liquid is heated in a large number of containers laid out on the ground.
 - C. The use of solar energy to obtain fresh water from brine or sea water, by the use of evaporation tanks or solar heating plants.
 - D. The cultivation of special fast-growing plant species, which can make energy producing substances available to man in considerably greater quantities; this method has always been used, but present research efforts are aimed at obtaining a quantitative leap in available resources.
 - E. Construction and operation of furnaces using concentrated solar rays for conducting high temperature processes (above 3,000 degrees) for metallurgical and thermochemical applications.
2. It should be noted at the outset that in the view of almost all the experts consulted, the main application which can and should be extended as quickly as possible is the heating of water for domestic use. This method can be applied ideally in individual dwellings, but is not limited to these, and can be extended without difficulty to schools, hospitals, swimming pools, camp sites, animal-raising farms, etc.
3. The method of heating water for ambient heating purposes requires a solution to the storage problem and further study and development, because, as the costs of this kind of installation have to be recouped over a limited number of months in the year, it is not yet competitive. Air conditioning in summer, using the same energy source may improve economic viability of installations of this type. Desalination and high temperature applications have as yet little effect on the overall energy balance, although they appear feasible with a modest development outlay.

4. Much work still remains to be done before electrical energy can be produced by both the above systems, and it is by no means certain that within the next few decades large-scale applications will be possible, especially in the geographical area with which the European Community is concerned. It should be noted that the high latitudes of most of the Community territory mean that solar rays arrive at less than optimum angles while the number of hours of sunshine per day is also unfavourable. Weather conditions in winter, especially in the northern part of our territory, are not usually favourable either, with the result that considerable fluctuations are likely to occur in the output of electrical energy produced by this means.

5. Moreover, Mr Hirsch, vice-president of ERDA, responsible for the development of replacement energy sources, including solar energy, expressed great doubts about the feasibility of obtaining, within the foreseeable future, appreciable quantities of electrical energy through the use of solar radiation and, in a summary graph describing the satisfaction of future electrical energy requirements, he gave first place after the period in which the present generation of reactors will have given due service, to the contribution from fast breeder reactors; next, a more substantial contribution from electrical energy produced by nuclear fusion, and finally, a fairly limited and doubtful contribution from solar energy.

6. This has to be made clear from the start since, although we believe that politicians should make every possible effort to apply those techniques which have already been developed as soon as possible, we nevertheless consider that it is equally important to prevent the press or other information media from spreading dangerous illusions among the public about the possibility of solar energy solving all our problems in the field of electrical energy production in the foreseeable future.

7. This certainly does not imply that research into electrical energy production of this kind should be abandoned. As we will see later in more detail, we take the opposite view, without, however, placing blind trust in the success of these efforts.

8. The cost of the mirror surfaces to receive radiation and the large areas of land which would have to be used for such mirrors are at the root of the high costs, as we will see in more detail later.

II. CONVERSION OF SOLAR ENERGY INTO HEAT

LOW TEMPERATURE APPLICATIONS

HABITAT

9. Solar energy should be considered against the background of the prospects for energy savings through the partial replacement of fossil and nuclear fuels, which are needed for industry, in the heating of homes, together with other solutions such as the improvement of thermal insulation of walls, double glazing, etc.

10. By the year 2000, it could contribute about 3% of total energy supplies, if vigorous programmes are implemented.

Present situation

11. There are three main uses in dwellings: domestic hot water, home heating, and cooling.

12. The first application is already economically viable in areas of Europe with plenty of sunshine and almost viable in areas with an average amount of sunshine. Heating can be achieved with simple and robust solar collectors, which are easy to mass produce. Indeed, collectors for this purpose are already produced by more than 30 companies in the Community.

Although some experts predict a life of 20 years, no detailed information is available on the ageing of these collectors, under the influence of thermal cycles, ultra-violet radiation, climatic conditions, etc.

13. As regards home heating, a number of demonstration solar houses have been built (TROMBE and EDF houses in France, PHILIPS houses in Germany, ZERO ENERGY HOUSE in Denmark, etc.).

14. Although these houses are interesting from a technological point of view they are not economically viable. Present solutions are still very expensive since there is no mass production and because the crucial problem of energy storage has not yet been solved. Large initial investments are therefore needed since the solar systems have to be linked with conventional heating systems. Moreover, as pointed out above, the cost of the installations would have to be recovered over a limited period of operation. At the Ispra Research Centre, too, numerous studies are in progress to improve the heat-storing capacity of water-filled storage tanks by the use of chemical additives. Evidently, in research on solar houses, special attention must be paid to the window/wall surface ratio and to insulation questions.

15. The third point concerns cooling. In the main, absorption cycles will be used, such as lithium bromide or ammonia. These cycles perform satisfactorily with heat sources of around 100° which can be provided by some of the collectors already developed. The joint use of heating and cooling, spreading the period of recovery of the costs of the collectors over a broader time span, makes these installations more advantageous.

However, much remains to be done as regards the standardization, the determination of the lifespan and the technological improvement of the apparatus involved.

Development prospects

16. If solar energy is to make an effective breakthrough it will have to do so on several levels:

A. technology

- reduction of the costs of solar collectors, and extension of their lifespan;
- research into energy storage systems using, for example, the latent fusion heat of certain eutectic salts, parafins, etc.
- development of simple regulating systems;
- development of collectors operating at temperatures around or above 100°, with sufficiently high performance for use in cooling, as well as other fields such as desalination, distillation, etc.;
- in general, demonstration of the reliability of solar components and their maintenance costs.

B. standardization

The large-scale marketing of solar systems presupposes manufacturing and operational standards, and guarantees of performance and duration similar to those existing for conventional installations.

C. dissemination of information on solar technology

Even for applications which are already viable economically and whose components are commercially available, there is a great lack of information among the potential users: architects, town planners, builders etc.

Objectives can be set for solar energy just as for nuclear energy, but they are limited to the overall results which can be obtained indirectly, since this is primarily a public market, through the mobilization of public opinion via the mass media.

DISTILLATION

17. Apart from the heating and cooling of houses and buildings requiring low temperatures (100°C) solar heat is used in the food and agricultural industry (e.g. drying), the distillation of ethanol, and for the distillation of sea water.

18. An American study is now assessing the possibilities of using solar energy in the food and agricultural industry and in the distillation of chemical compounds. In developed countries the energy used in this sector could represent a considerable proportion of the total primary energy consumption.

Distillation of sea water

Basin Stills

19. Solar energy has been used in sea water desalination up till now only with simple basin stills, consisting of a container with a black bottom and a glass cover through which solar radiation enters, vapourizing the sea water.

20. These basin stills have no economy of scale; they have a modular construction and initial investment costs are high. Costs, however, are based on currently available technology.

21. Within the 50 to 500 m³/hr range, fresh water can be produced at a cost of from 1 to 1.7 dollars per m³, with a saving of the order of 5% over oil-fired distillation plants. Even assuming that the price of conventional fuels remains constant (0.1 \$/kg, or 12 \$/bl), solar desalination has the decisive added advantage that the extra costs would be more than fully recovered after ten years' operation.

22. As materials will be mostly locally available and maintenance can be carried out by unskilled labour, basin stills are suitable for developing countries. A plant producing 50 m³/hr would meet the needs of a relatively small community (6,000 inhabitants).

Industrial sea water desalination

23. Desalination of sea water on a large scale is normally done in large industrial installations (multiflash). These units consist of 10 to 15 compartments in which sea water is successively exposed to temperatures of around 80°C at which it is made to boil at reduced pressure. The main feature of these installations is the fact that they recover 90% of the heat needed.

Similar systems using solar energy in which the collectors act as boilers would require only 10% of the collector surface of basin stills required in the simple evaporation method to produce the same amount of water.

24. The optimum operating temperature is 80°C ; these installations are therefore very suitable for solar energy using currently available technology. The start-up and shut-down of these installations takes several hours; for this reason they will have to run continuously and heat during the night should be provided by oil burners or solar energy stored at constant temperature.

25. The cost of water production with these installations run on solar energy and oil is approximately the same ($\pm 1 \text{ \$/m}^3$ for installations with a capacity of 800 m^3).

Conventional technology and advanced technology

26. Generally speaking, desalination can be carried out in two different ways: with basin stills, which require relatively simple material and unskilled labour, and with advanced technology systems, which require further development, careful design and materials studies.

27. Whereas basin stills have achieved a certain stability in costs and are unlikely to undergo major technological changes, high technology systems are still developing.

28. It should also be pointed out, however, that the two approaches will co-exist, since they can be used over two different ranges of application. All development efforts should be directed towards the second approach which has the better cost/benefit ratio.

Economic trends

29. The estimated medium- and long-term economic trends in solar desalination should take account of the projected costs of fossil fuels and the technological improvement of solar collectors and of conventional desalination plants.

30. For fossil fuels, it has been calculated that demand will double every ten years. As regards solar collectors, however, by maintaining the same efficiency and by standardizing production, costs could be reduced from an average of $\$60 \text{ per m}^2$ to approximately $\$25\text{-}30 \text{ per m}^2$. At present it appears that the cost of water will fall by 3% for every 10% reduction in the cost of the collector.

HIGH TEMPERATURE APPLICATIONS

PRODUCTION OF HYDROGEN FROM WATER USING SOLAR ENERGY

31. The use of solar energy, because of its intermittent nature, requires an energy storage system. Hydrogen is well suited as an energy vector for this purpose.

Hydrogen can be produced from water using solar energy, either by direct high-temperature thermal dissociation, or thermochemically, at temperatures which vary according to the chemical reaction used.

Direct thermal dissociation of water

32. A high degree of dissociation of water is obtained at temperatures above 3,000^o K.

33. Various methods have been proposed for separating hydrogen from the gaseous mixture: separation by centrifugal force, porous ceramic membranes, magnetic separation, etc.

34. The method has a high degree of efficiency but requires considerable research and development (high temperature materials, separation techniques, solar receiver design).

35. No large scale experiments appear to be under way along these lines.

Thermochemical production of hydrogen

36. In this process heat must be supplied continuously for the endothermic reactions of the cycle. In view of the intermittent nature of the solar energy source, heat must be supplied to the reagents through a thermal vector which accumulates primary energy.

A solar receiver (a cylindrical heater of the hollow black body type, or fluidized-bed reactor) stores primary solar energy concentrated by a series of mirrors in an intermediate thermal vector.

37. The chemical reactions which can be used include the following:

- reactions using oxygen as a reagent;
- reactions using hydrates and hydroxides;
- reactions using carbon dioxide or sulphur dioxide.

Heat from the back reaction is thus supplied continuously to the endothermic reactions of the thermochemical cycle.

38. This solution can be considered as an alternative to the direct production of hydrogen by electrolysis using electrical energy generated by a solar power station. Since both projects are in their early stages, no comparative economic data is available.

III. DIRECT CONVERSION OF SOLAR RADIATION INTO ELECTRICITY

PHOTOVOLTAIC PROCESS

39. Solar energy can be efficiently converted into electricity.

Under the effect of a ray of light, a potential difference develops at the surface of a slab of semiconductive material (silicon, gallium arsenide, cadmium sulphide, etc.). Light is thus converted into electrical energy.

40. The most advanced process for achieving this is by means of solar cells made from silicon semiconductor material. Most space technology applications would have been impossible without these cells. However, if one considers the use of solar cells in terrestrial applications it becomes apparent that whereas in space it is the weight versus energy ratio which is most important, on earth the essential factor is cost versus energy, at least if we consider the impact this source might have in applications for larger scale energy production.

41. Many other systems have been investigated, using different types of materials, but at present only silicon cells are produced on a relatively large commercial scale. Recently, at the University of Stuttgart synthetic materials of a different nature have been tested, which reduce the unit cost of the electrical energy produced, but require an even larger surface of exposure.

42. This relatively small market value explains why most cells are produced by fairly small companies and automatic mass production techniques needing high investments are still at a rudimentary stage. The market is of course small since the price of the KW generated in this way is still high, even though it has been already reduced compared to the price of space cells by one order of magnitude.

43. In 1976 in the United States prices between 14 and 30 \$/peak watt have been quoted¹. This corresponds to 1-2 c/kWh and is thus below the price of the energy in dry cell batteries (20-100 c/kWh), but still one order of magnitude above that for energy obtained from diesel or gasoline engines driving electrical generators (5-30 c/kWh). It is two orders of magnitude above electricity costs from central generating stations.

44. An important feature of electricity production by direct or indirect conversion is the large areas required. The energy density of solar radiation is low, about 1 kW/m² at maximum and around 200 W/m² on average.

¹Peak watt is the value reached when sunlight is at its maximum.

45. Thus either large convertor areas are needed to produce a substantial amount of energy or else solar cells are used only for applications where reliability, unattended use, use in remote locations etc., and not the amount of energy as such are the decisive factors.

46. Since in contrast with the transistor industry the cost of semiconductor material will be the ultimate limiting factor, strong research efforts are being made to save materials, e.g. by the development of single crystal silicon ribbons, thus avoiding cutting losses.

47. Another trend is to turn to other materials which, because of the physical processes involved could work efficiently also in the form of thin films: gallium arsenide cells, cadmium sulphide cells.

48. Because of the large areas needed, clearly not all regions of the Community are suitable for this kind of application. Moreover, since solar energy conversion systems are so capital intensive, lifespan is a decisive factor. Both are no problem for silicon, but they definitely exclude other types of materials.

49. Another way to manage the cost problem has been not only to reduce cell costs (possible by one order of magnitude but difficult for two orders), but also to decrease the area of cells needed to produce a given amount of energy. This may be done by increasing the density of the energy incident on the cell through optical concentration, but this procedure clearly increases the unit cost of the apparatus, assuming that mirrors or Fresnel lenses can be produced on a lower \$/m² value than semiconductor cells.

50. One drawback of this method is the fact that it works only on direct radiation, whereas solar cells as such work on any kind of light input, even diffused light, although with poorer performance, leading thus to certain limitations. Nevertheless, cost estimates indicate 1.5\$/peak watt using this method, a value which could lead to an increase in annual demand by 2 orders of magnitude.

51. This increase in demand will be very important since without it no essential permanent reduction can be expected: in this sense, also government guaranteed markets (public or military applications) would be an important factor in promoting this technology.

52. What are the prospects; Within 5 to 8 years a reduction of costs to 2-5 \$/W_p at a production rate of 10 MW/year is realistic (ERDA estimates are 5 \$/W_p in 1978/80); within 15 years costs of below 0.5 \$/W_p (ERDA: 0.5 \$/W_p in 1986) leading to a sales volume of 500 to 1,000 MW/year are possible. The first phase will thus see the use of photovoltaic systems in the range of smaller power sets, say in the 5-100 kW range; in the longer

term 1 - 10 MW stations could be constructed. Thus the first phase will not make an impact on energy supplies as a whole, but may very well suit local needs, and the needs of developing nations.

Finally, by the year 2000, solar electricity produced by solar cells in Europe could amount to about 10,000 MW, or 0.5 - 1% of the total electric generation capacity at that time.



IV. INDIRECT CONVERSION OF SOLAR ENERGY INTO ELECTRICITY

SOLAR POWER PLANTS

Present situation

53. A number of experimental plants using solar energy concentrated by means of mirrors to produce steam and hence mechanical energy have been established in a power range from 1 to 100 thermic KW. More ambitious projects cover the range from 500 KW to 1 MW and beyond.

54. The largest existing installation in Europe is sited at St. Ilario near Nervi (100 KW_{th}), and has been designed and directed by Professor Francia of Genoa University who already in the 1950s began experiments on the use of mirrors for the solar heating of a boiler; he continued with mirrors of increasing diameter (the latest are approx. 80 cm) and recently ERDA (USA) ordered from an Italian firm an experimental installation based on the principles worked out by Professor Francia.

55. The European Community is planning a 1 MW demonstration power plant; the work has been contracted to Italy (ENEL + Ansaldo) and a site will be chosen shortly.

56. In France the CNRS is studying three prototype power plants in the 100 KW to 10 MW range. The CNRS has extensive experience, beginning in 1946 of the production of high temperatures (up to 3800°C) by concentration of solar radiation by means of lenses, from its work at Odeillo in the Pyrenees. On the basis of these studies it was possible to construct in 1970 a solar furnace of 1000 KW power using parabolic mirrors.

Principles

57. The various projects can be grouped according to three basic principles:

- in the lower power range (less than 1 KW) flat plate solar collectors will be used, operating at low temperatures and with low performance. These plants can be very useful in isolated regions, where the possibility of providing even a limited amount of power can be a very valuable advance.

- in the medium power range (around 100 KW), distributed collectors concentrating solar energy to some extent could be used (around 10 m² of collector surface are needed per thermic KW produced). These plants could be useful in developing countries.
- for power stations (some projects extend to 10 MW), the principle used is that of a series of mirrors focusing solar energy on a tower-mounted boiler (approximately 7 m² of mirror surface per thermic KW produced are needed).

This type of power station could be advantageous in both developing countries and industrialized countries.

58. One major limitation, at least in densely populated areas, is the large surfaces which have to be used in constructing these plants: approximately three hectares per installed MW.

59. As in all processes where the primary energy source is free, the economic benefits are linked to the reduction of capital investment and the achievement of a high rate of use; this implies simple and cheap technology and easy maintenance and at the same time continuous operation.

60. In view of the intermittent nature of solar energy, one of the key problems is energy storage.

61. Although the technology for collectors, mirrors and boilers is more or less available, storage technology requires much further development; thermal storage to provide a few hours operation in the absence of sunlight is not enough. In some cases the electricity grid can absorb the daily variations in energy production but in isolated areas continuous operation poses serious problems.

In Switzerland preliminary studies have been carried out on a programme for the installation by the year 2000 of 40 solar mirror power stations at high altitudes, to avoid the winter fogs which form in the Alpine valleys, with the aim of producing considerable quantities of day-time electric power, which would be particularly valuable in winter. Thanks to the large storage capacity of hydroelectric reservoirs available in Switzerland, the electricity produced by solar means can become complementary to hydroelectric power. Hydroelectric power stations would operate on cloudy days, while on clear days important savings of the reservoir rates could be made.

V. CHEMICAL CONVERSION

BIOCONVERSION

62. Research on bioconversion can be divided into two sections:

- (a) production of biomass (wood, algae, etc.) by natural photosynthetic processes;
- (b) production of hydrogen by modified photosynthetic processes.

Biomass

63. Wood has been and is still used for energy production. Using fast-growing hybrid poplars, an efficiency of 0.6% could be obtained. (Efficiency is defined as the energy content of the product per hectare per year, divided by the yearly solar energy radiated on this surface). With an efficiency of 0.6%, 300 km² of forest would be required to fire a 1,000 MW power station.

64. Other promising biomass species for energy production are algae and water weeds. Under favourable conditions (warm water, organic waste as a nutrient) large quantities of biomass can be produced. Figures of 60 tonnes to 200 tonnes of dry matter per hectare and per year are quoted for algae and for water hyacinth respectively.

65. By harvesting, chopping and fermenting this biomass, synthetic natural gas (SNG) can be produced. The efficiency of conversion of solar light into synthetic natural gas would be about 1% and 4% for algae and water hyacinths respectively.

66. Energy costs for harvesting, chopping and fermenting are not included and are estimated to be about 10% of the energy produced. The cost of synthetic natural gas production from sea algae is estimated at around 0.15 \$/m³ (energy content of 1 m³ SNG is 7,000 K cal). Cost estimates for SNG production from water hyacinths are not yet available, but will be of the same order of magnitude.

67. Algae and water weeds both have a high protein content and can be used as food for cattle, poultry and fish. They are also very efficient in purifying waste water (heavy metals, organic waste, etc.).

A major drawback in the use of these bioconversion methods is the large surfaces required in order to provide only a few per cent of the primary energy consumption in developed countries, although the impact might be important in developing countries with low per capita energy consumption and low energy production.

Hydrogen by bioconversion

68. Certain algae and bacteria are able to produce hydrogen under special conditions. They contain an enzyme, hydrogenase, which modifies the photosynthetic process in that it produces hydrogen.

69. This process has been demonstrated in laboratory conditions using compounds extracted from leaves and bacteria. It is believed that energy conversion efficiencies of 10 to 15% are possible. However, energy production by this method is still a long way off.

70. Many years of research will be required to understand the complicated photosynthetic processes involved. Problems such as the degradation of hydrogenase and chloroplast in artificial surroundings, and the fixing of chloroplast will have to be solved.

PHOTOCHEMICAL AND PHOTOELECTROCHEMICAL CONVERSION

71. Physicists consider solar energy as a high quality energy source in the form of energy particles at a very high equivalent temperature; in principle this means that it is possible to convert 95% of its energy into useful work. For this reason, some believe that it is unprofitable to degrade this energy for use in low temperature collectors. It is possible to envisage direct conversion of solar energy by copying certain natural processes like the photosynthesis of chlorophyll.

72. Photochemical conversion uses a substance with a strong degree of absorption of solar energy which stores this energy and then releases it, converting itself into a second substance which in turn should have a low degree of absorption.

73. So far no pair of substances has been found to be truly satisfactory. The second substance must react back to the primary state to reactivate the conversion cycle: it seems that it might be possible to control this return to the initial state electrically, thus opening new prospects for research.

74. Photogalvanic conversion uses a photochemical reaction in an electrolyte which initiates a charge transfer process between two inert electrodes. This would produce an electric accumulator similar to conventional accumulators except that charging would be done by solar radiation. So far no combination of reaction products has been found which is stable for more than a few seconds. However, photogalvanic conversions have already been achieved with a small output.

75. Photovoltaic energy conversion in electrolytic cells is carried out by means of a photosensitive electrode in an electrolyte; the counter electrode is used for transmitting the electric charge. The photosensitive electrode is a semiconductor with a very high absorption of solar energy which is analogous to conventional photo-electric cells; the only difference is the existence of the electrolyte between the electrodes.

This system has a number of advantages in energy conversion including heat production and the production of electricity through hydrogen.

76. There have been very few studies in this field (only about 20 papers published), but they are interesting. In 1976 for the first time a chemically stable cell was developed with an energy conversion efficiency of 6%. If such techniques can be developed, there are prospects for the development of large-scale low-cost cells. The Joint Research Centre is carrying out such studies.

77. The principle underlying photocatalytic conversion is that photons with a wave length of 1 micron have sufficient energy to split a molecule of water into its constituents, hydrogen and oxygen. Unfortunately this system is not possible because water is transparent. One would have to find a material to absorb light energy and transfer it in turn to the water molecule. However, such a catalyst was discovered recently and produced a conversion efficiency of 10%.

78. Finally, some of the above methods appear promising, but it is still impossible to forecast the time-scale and the efforts necessary to achieve energy production or to determine when it will become economically viable.

VI. COMMUNITY SOLAR ENERGY PROGRAMME

79. The Commission has initiated a major research programme on solar energy, in two parts:

- direct action by the JRC
- indirect action carried out by contract.

The Joint Consultative Committee has responsibility for overall coordination of the Community's work on solar energy as regards direct and indirect action.

Solar Energy Programme of the Joint Research Centre (direct action)

A. JRC 'direct action' programme

80. Work on solar energy was begun at the Joint Research Centre within the framework of the multiannual programme 1973-1976. This programme has employed 14 research staff per year and an amount of 3.05 Mua has been spent over the four-year period.

81. Under the new JRC multiannual programme 1977-1980 work in this area will continue; in fact, it will be considerably stepped up, as the staff involved directly in the research goes up to 35 per year and the appropriations reach 14.53 Mua for the new four-year period.

82. The technical content of the programme has developed over the years; a description of these developments is given below. It should be noted that this programme, during both its preparatory and its practical phases, is closely coordinated with the indirect action programme in the same field.

Multiannual programme 1973-1976

83. During this period, studies have been carried out in the following areas:

- (a) Applications of solar energy in housing;
- (b) Development of materials for solar collectors;
- (c) Photovoltaic conversion of concentrated solar radiation;
- (d) Electrochemical solar cells;
- (e) Chemical storage of solar energy.

84. Areas (a) and (b) are closely linked and constitute the most important part of the programme. They aim at designing high performance flat plate collectors and developing measurement procedures for determining their thermal efficiency. It became apparent during the programme that it is very important to improve the drawing up and standardization of measurement procedures for solar collectors, as the views of industry in this area

differ widely. This is essential for the proper evaluation and optimization of integrated heating, cooling and storage systems. Several test installations have therefore been built for performance testing under various conditions: loops with water or glycol (for temperatures above 100°C) for the simultaneous testing of up to five collectors; a special mechanical device for sun tracking; a solar simulator in which collectors can be tested with an extended light source simulating solar radiation and a comprehensive field test facility for investigations on combined heating/cooling systems for habitat.

85. Since the selective surfaces play an important part in achieving high performance from collectors, several new surfaces have been produced and are undergoing endurance tests. These surfaces are made of double layers on copper base, nickel black on stainless steel, and resins with suitable optical and mechanical properties.

86. On the basis of the acquired expertise and of the results obtained in the areas (a) and (b), the JRC has progressively formed a focal point for the testing and calibration of industrially produced solar collectors.

87. Area (c) is based on the principle that for a given incident radiation the use of concentrators reduces the necessary semiconductor surface and therefore decreases the cost of the corresponding photovoltaic convertors. Technical assessments of various types of concentrators (parabolic trough, Fresnel lenses, etc.) have been performed and test installations have been built for the evaluation of photoelectric conversion of concentrated solar radiation.

88. Areas (d) and (e) are more speculative and concern fundamental research on photoelectrochemistry (quantum conversion) and photo-induced chemical reactions. The photovoltaic effect generated at semiconductor (TiO_2) - electrolyte interface has been studied extensively and the possibility of photo-catalytic water decomposition has been investigated.

Multiannual programme 1977-1980

89. In preparing this new programme, action has been taken along two lines: firstly, as mentioned above, the research effort devoted to solar energy has been considerably increased, secondly, on the basis of the results obtained, efforts have been concentrated on a fewer number of topics assembled into three well-defined projects:

Project I - Thermal conversion of solar energy for housing and for distillation (seawater distillation, ethanol distillation).

Project II - Construction and operation of a large indoor solar irradiation facility - called Helio-Climatron - which provides for the testing of solar energy conversion systems (photovoltaic or thermal) under very diverse climatic conditions.

Project III - Advanced studies of a more exploratory character on bio-conversion of solar energy and electrochemical solar cells.

Emphasis will be placed on the two first projects, which by their nature are closely interrelated.

B. Community 'indirect action' programme

90. The advantages of solar energy are widely recognized; this is clear from appropriations in this sector and their growth over the years.

In August 1975 the Council approved a large-scale joint indirect action programme with an endowment of 17.5 million u.a. for a four-year period (approximately 4.5 million u.a. per year).

The Community 'indirect action' programme consists of 6 projects:

91. Project A: solar heat collectors and their application to dwellings.

- Action 1. - Low temperature use of solar energy for heating and cooling buildings;
2. - study of plane surface collectors;
 3. - pilot applications to dwellings for domestic use.

Prototypes constructed in various countries have already shown the technical feasibility of this type of application. However, improvement of design and development of economic methods of production are necessary if solar energy is to be used to heat buildings.

92. Project B: Self-contained generating sets for the production of mechanical and/or electrical power.

- Action 1. - the use in medium and high temperature areas of solar heat to produce mechanical and/or electrical power;
2. - improvement of low power groups (1 + 10 kw);
 3. - pilot installations of 1 MW .

The first part of this project deals with increasing performances and reducing production costs of the existing small power sets.

The second part deals with electricity generation by thermodynamic cycle. This process presents major problems because of the concentration devices necessary and the rather high temperatures. There is, however, already a demonstration plant (near Genoa, Italy) producing steam at more than 550^o C and 150 atmospheres, with a thermal conversion efficiency of at least 65%. This has been operating for 7 years on a laboratory scale.

This project is for the time being coped with by a series of studies aiming at preparing specifications for the development of components and at determining the technical feasibility of the 1 MW plant.

93. Project C: Photovoltaic conversion

- Action 1. - development of alternative cells and improvement of existing cells;
2. - feasibility study on new concepts;
 3. - new methods of preparing semi-conductor materials;
 4. - silicon thin film;
 5. - automation of panel production;
 6. - new or improved encapsulating materials;
 7. - data collation.

This project covers a large spectrum of research activities dealing mainly with the development and performance testing of photovoltaic cells of various type and composition. In September 1977 the results of this project will be presented at a European Symposium on terrestrial photovoltaics (Luxembourg).

94. Project D: Photochemical, photoelectrochemical and photobiological processes.

- Action 1 - fundamental studies of the most appropriate energy systems for the different regions of Europe.

It is essential to carry out basic photoelectrochemical and photobiological research so as to promote the development of new methods of producing chemical substances.

Research activities so far have concentrated on hydrogen production from plants and on studying the related mechanisms.

95. Project E: Photosynthetic production of organic matter

- Action 1. - Choice and development of the most suitable energy crops for the different regions of Europe.

The aim of this project is to promote selection and improvement work on plant species with the sole aim of increasing specific production for the different types of geographic areas and local climates.

96. Project F: Data network relating to solar radiation

- Action 1. - Collection, standardization and distribution of comprehensive data on number of hours of sunshine throughout the Community;
2. - Definition of the implications of the large-scale use of solar energy.

In the framework of this project a special working group is at present defining which practical work must be done by the EEC and which work underway elsewhere (IEA, WMO, NATO, CCMS) can be used in order to set up the collection of meteorological and other data required by users and research workers.

C. NATIONAL PROGRAMMES

97. The attached tables refer to research carried out in the Member States in the field of solar energy. The main themes of national action largely overlap those of the Community programme, in particular: low temperature applications for dwellings; high temperature conversion for the production of electrical and/or mechanical energy; photovoltaic conversion; photobiological conversion and the gathering of data on insulation.

E N E R G Y R & D P O L I C Y

PROGRAMME ACTIVITIES COMPARISON

SECTOR: 8. NEW ENERGY SOURCES

SUBSECTOR: III. Solar Energy

Annex I

B	D	DK	F	IRL	I	NL	UK
.Insolation data collection in Belgium			.Collection of solar data	.Analysis of solar radiation data	.Data survey	.Collection of solar data	. Insolation data collected
.Technological studies on low temperature heat production and habitat application		.Low temperature heat production and habitat applications	.Utilization for domestic heating .High efficiency collectors	.Passive solar walls for domestic space heating - Feasibility study of solar space and water heating - component performance - design construction and monitoring of solar test buildings - techno-economic analysis	.Heating and conditioning of dwellings .Thermal utilization of solar energy: -radiators		.Solar energy heated houses . Thermal utilization of solar energy

SOURCES: CREST/51/76

Department of Energy, Press Notice No. 63 of 17.2.77

B	D	DK	F	IRL	I	NL	UK
	.Possibility of using solar desalination installation for domestic heating			.Standardization of test and evaluation of solar components and thermal performance of buildings			
	.Construction of demo-solar houses with:		-demo-installations in individual and block dwellings	.Demo-programme of solar buildings	-demo-units	.Installation and evaluation of collector heating system in dwellings & buildings	
.solar collectors for heat production	-solar collectors heating -improved thermal insulation	(flat collectors)	-supporting research: +collectors		-collectors	.Flat plate collectors	. Collectors for heat production
.Storage of solar energy	-H ₂ O storage		+storage systems		-storage systems		
	.Investigation of the technico-economical aspects of smaller independent solar power units (thermal conversion)		.Thermodynamical cycle conversion .Improved systems for pumping -feasibility studies for power plants up to 25 MWe or equivalent (collectors, thermodynamic cycles, storage,...)		.Steam generation plant of St. Ilario .Design of 1 MWe power plant .Solar energy conversion into mechanical energy .Small electric units		

B	D	DK	F	IRL	I	NL	UK
<p>.Photovoltaic conversion -thin film technology -Si, CdS, InS cells</p>	<p>.Further development of Si technology and of photoelectric conversion</p>		<p>.Photovoltaic conversion: -Si technology; +single crystals +polycrystals +ribbon -CdS - CdTe</p>		<p>.Photovoltaic conversion</p>	<p>.Photovoltaic conversion -solar cells materials</p>	<p>. Photovoltaic conversion</p>
<p>.Bioconversion and natural photosynthesis .Photochemical processes .Artificial photosynthesis .Photoelectrolysis</p>	<p>.Construction of a solar heated outdoor swimming pool</p>		<p>.Photobiological conversion: -photosynthesis -biomass conversion (see also under 1.V) .Solar glass-houses (see also under 1.V)</p>	<p>.Feasibility study on biomass production and conversion: -ecological and genetic study of energy crops -small scale field trials -econ., social and environm. analysis -large scale field experiments -development of harvesting equipment and of a pilot conversion plant</p>	<p>.Photobiological processes .Photochemical processes</p>	<p>.Conversion into fuels: biochemical, chemical, electrochemical and agricultural aspects</p>	<p>. Photobiology conversion. Production of liquid or gaseous fuels using two biological systems.</p>

SOURCES: CREST/51/76
Department of Energy, Press Notice No. 63 of 17.2.77

B	D	DK	F	IRL	I	NL	UK
.Econ.study on the potential utilization of solar energy in B							Assessment studies . Studies on possible utilization of solar energy.

SOURCES: CREST/51/76
 Department of Energy, Press Notice No. 63 of 17.2.77

VII. CONCLUSIONS

98. Since the sun is our greatest unexploited source of energy, we believe that it could represent a valuable and inexhaustible resource to replace the non-renewable energy resources which are gradually being depleted. In the future the use of solar energy could make a definite, though limited contribution to solving the major world energy problems.

99. It should however be pointed out that the use of solar energy will be determined both by changes in the price of the fuels which will gradually be replaced by solar energy and especially by advances in the technology of the use and application of solar energy.

100. It should also be pointed out that the economic aspects of solar energy production are greatly influenced by estimates of the lifespan of collectors and the increase in price of other fuels.

101. We believe that the problem of correctly estimating the efficiency not only of the collectors but of the whole system will determine the feasibility of large-scale applications of solar energy, for many reasons, especially from the point of view of the consumer.

102. As regards the construction industry, it is vital for the components of solar energy systems to have a similar lifespan to other construction materials. At present our knowledge of the lifetime of these components and their deterioration is very limited. We have very little information for example on damage caused by variations in temperature, ultraviolet radiation, etc. Moreover, public opinion must be informed as accurately as possible of the contribution that solar heating can make, something which is not being done at present.

103. However, we are convinced that to be viable solar energy must necessarily be developed on a large scale and since for numerous applications the technology is already available, immediate results could be achieved.

104. The Committee on Energy and Research suggests that the Governments of the Member States and the national industries, taking account of the aid which will be provided by the EEC, should take an interest in the research and development of solar energy. According to our information, in the United States, France, West Germany, the United Kingdom and Japan there has been a clear political commitment to research and development of solar energy, with clearly defined responsibilities. It would also appear that these countries are allocating considerable sums for research into solar energy.

105. The European Parliament and its Committee on Energy and Research welcome the EEC's efforts, which are concentrated on the application of solar energy for domestic heating, on high efficiency plate collectors and joint heating and cooling systems. These studies will of course make it possible to draw up economic, thermic and technical models, which can be compared with experimental data. It is clear that the development of solar energy, with its long-term nature, is at present a priority sector for close collaboration within the present joint research programme.

106. In conclusion we believe it is extremely important to encourage public debate on solar energy and as research expands the systematic collection and diffusion of information on the development of solar energy on a world-wide scale will become increasingly valuable.

ANNEX CONCERNING THE USE OF SOLAR ENERGY TO HEAT WATER FOR DOMESTIC USE

Solar heat is trapped by means of solar collectors.

A solar collector consists essentially of a metal plate, blackened with special types of glaze, which absorbs light energy and converts it into thermal energy. To prevent the loss of solar heat to the surrounding atmosphere, the plate is first insulated with one or more sheets of a transparent material and then with an insulation blanket.

The thermal energy thus generated is drawn off from the absorbent plate by means of a fluid circulating in pipes connected to the plate itself and transferred to the point of utilization, e.g. the hot water tank.

The heat-conducting liquid may be a mixture of water, a monoethylene glycol anti-freeze solution and an anti-corrosive agent.

A collector installation should not be constructed with a size sufficient to be capable of providing the necessary thermal energy at all times of the year, because, by virtue of the wide seasonal variations in the intensity of solar energy, it would be too large, and therefore superfluous, throughout the summer period.

A double collector with a usable area of approximately 3 m² is adequate to meet an average family's daily domestic hot water requirements, estimated at 180 litres of water at 40°C. Any shortages during the winter period can be made up by conventional methods, e.g. the use of electrical heater elements.

Collector installations are also equipped with a simple control device. In view of the techniques and materials currently employed, installations of this kind cannot replace conventional energy sources; they can, however, provide a useful additional source, provided that they are made fully cost-effective.

The efficiency of such installations is dependent on two factors: latitude and meteorological conditions. Taking these into account, solar energy might be expected to meet 59% of domestic hot water requirements in Milan, 80% in Rome and 67% in Messina.

These figures would imply that, within certain limits, meteorological conditions are a more important factor than latitude.

Two types of apparatus are used for determining solar radiation values: pyranometers, which measure total radiation (direct and diffuse), and pyrhemometers, which measure the values of direct radiation only.

Since figures are not available for all regions of the Community, it will be necessary, for some years at least, to compile the available meteorological data (cloud cover, temperature and humidity levels, wind velocity, etc.) so as to obtain, by comparing the amount of solar energy received, the radiation values required.