The larger of the two water tunnels has a jet diameter of 30 in. and the speed is continuously variable up to 60 ft./sec. (35 knots). In both tunnels the pressure at the model can be varied between 2 lb. per sq. in. and 45 lb. per sq. in. absolute. Powered models cannot be made much less than about 8 in. in diameter, and much thought was therefore given to the design of a suitable working section. This resulted in the concept of a slotted-wall working section partially open and partially closed. The philosophy behind this idea is that the wall corrections of an open jet are very much less and of opposite sign to those of a closed jet, and by enclosing the open jet by a cage of bars one can in fact get the virtues of an open jet tunnel and a very much longer working section.

A considerable amount of development was done on the optimum layout of such a working section, and as a result of this it has been found possible to double the effective size of the working section, at any rate so far as tests on bodies of revolution are concerned. Hence powered models some 10 in. in diameter and up to 12 ft. long containing 100 h.p. can be tested in the 30-in. tunnel. These models are fitted internally with a five-component balance and also means of measuring the torque and thrust.

In addition to the novel working section, this tunnel is also fitted with a 'resorber'. This takes the form of four 11-ft. diameter passes up and down a 60-ft. deep pit, and by the combination of pressure and time re-absorbs any cavitation or gas bubbles that may have been formed in the working section during the course of the experiments.

Model Water Entry Tank

To assist in the study of the air-to-water entry behaviour of weapons, a new glass-sided tank 29 ft. long, 9 ft. deep and 5 ft. wide has recently been erected. This tank has been designed to examine the behaviour on entering water of 2-in. diameter models which are fired from a slotted cylinder catapult with entry speeds of up to 300 ft./sec., which on Froude scaling corresponds to about 1,000 ft./sec. full scale.

The virtue of this type of catapult is that it enables the models to enter into the tank with varying amount of pitch and yaw, which are vital parameters in these investigations. The models can be fired into the tank at any angle between horizontal and vertical, and high-speed photography is used to examine their behaviour.

USE OF SOLAR ENERGY

The World Symposium on Applied Solar Energy and the Conference on Solar Energy, which were held recently in Arizona, have received considerable publicity. These conferences were sponsored by the Association for Applied Solar Energy, the Stanford Research Institute and the University of Arizona, with Mr. Lewis W. Douglas as the general chairman. That more than a thousand scientific workers, representing many nations, travelled to Arizona to discuss problems concerned in the application of solar energy, indicates the interest in a subject that was first exploited forty to seventy years ago and which has been intensively studied during the past ten years. Press reports from the conferences on the future of solar energy have varied from unqualified optimism to salutary pessimism. At the concluding session, the vice-chairman, Mr. Merritt L. Kastens, who was responsible for the organization on behalf of the Stanford Research Institute, said that he had been asked : "Were the conferences successful ?" He said that he would be able to answer this question in ten years time ; this was the only reply that could be given, for it is difficult at the moment to see in correct perspective the precise applications of solar energy that are economic, and the path of future developments.

Whatever may be the outcome of the conferences, there can be no question that never before have all the existing facts concerning the present position of research in the various applications of solar energy been presented simultaneously and freely discussed by scientists, engineers and industrialists, and the conferences mark a turning-point in progress. It was indeed this consensus of opinions from workers in many fields that gave unique importance to the meetings, for the problem of utilizing solar energy must be considered on a global scale and cannot be limited to the specific requirements of any one country.

The two meetings, held consecutively, were independent but complementary. The conference, which was held first in the University of Arizona, was for the purpose of discussing among scientific workers the basic problems that must be solved before solar energy can be successfully applied, with a detailed description of researches at present in progress for this purpose. The symposium, held in Phoenix, was intended to summarize the general position of solar-energy utilization and especially to acquaint industrialists with the problems involved, since successful development depends ultimately upon co-operation between science and industry.

Conference on Solar Energy

A total of nearly a hundred papers was presented at the Conference on Solar Energy, and this necessarily involved sub-division into a number of separate sessions. The opening session, of a general nature, dealt with the characteristics of solar radiation as emitted from the surface of the Sun and as received at the surface of the Earth, these studies being an essential preliminary to the study of utilization. Prof. Farrington Daniels also gave a general paper outlining the methods of utilization.

The remaining sessions, held concurrently, were as follows. Section *A* : Thermal processes comprising flat-plate collector design and the principles of selective radiation ; solar furnaces for the production of high temperatures ; solar energy for house and water heating, for cooking and water distillation ; solar power machines. Section *B* : Photochemical processes comprising large-scale algal culture ; algal physiology ; photochemistry in higher plants and in non-biological systems. Section *C* : Electrical processes for the direct conversion of radiation to electricity, including thermoelectric generators, photovoltaic cells and $p-n$ junctions and photogalvanic cells. There was also a session devoted to a discussion of the measurement of solar radiation. The technical implications of these papers are discussed later.

World Symposium on Applied Solar Energy

The general scope of the technical papers at the World Symposium was similar to that of the papers presented at the preceding conference, but they were intended for an audience possessing a wider range of interests. Each author was a recognized authority on his subject, and presented this in the form of a comprehensive survey.

The opening remarks were given by Mr. Lewis W. Douglas, and were followed by an invocation delivered by the Right Rev. Arthur B. Kinsolving, Bishop of Arizona. Prof. Farrington Daniels, of the University of Wisconsin, who is doing so much to promote research on solar energy, and Dr. J. E. Hobson, director of the Stanford Research Institute, presented papers covering in a comprehensive manner the utilization and economics of the applications of solar energy. The principal speaker at the welcoming luncheon was Sir Edward Bullard, director of the National Physical Laboratory, who outlined the benefits that could accrue from solar energy, but also emphasized the difficulties involved in such developments. It was generally considered that his realistic speech counteracted the excessive optimism of those who were unaware of the true magnitude of the problem. At the banquet, Mr. John Jay Hopkins, chairman and president of General Dynamics Corporation, gave an inspiring address on the possibility of creating a World Energy Community by united governments to organize correlation of all energy resources. He emphasized the need to adapt our thinking to changing times and conditions in considering the relationship between the forces of atomic fission, fusion and applied solar energy.

An exhibition of solar appliances was arranged at Phoenix in conjunction with the symposium. Comparison was facilitated of the various schemes for house and water heating, for water distillation and for solar cookers. In this latter connexion efforts are being made by the research group at the University of Wisconsin to reduce costs by constructing the reflectors from aluminium-coated plastic instead of sheet aluminium. The largest single exhibit was an engine of Italian design, operated by sulphur dioxide vapour and used to drive a water pump. The National Physical Laboratory of India showed a small-scale model to illustrate its system of movable panels of mirrors which can be used to provide concentrated radiation for steam generation or other heating processes. Examples of solar furnaces were demonstrated and also some ingenious pumping devices operated directly by the action of vapour and liquid.

The particular value of the exhibition was that it enabled industrialists to see the present state of progress, and to compare directly designs from different countries. Though extremely instructive, many of the inventions shown clearly require much more development before becoming anything like economic possibilities.

Summary of the Technical Papers

It is impossible to describe in full detail the contents of such a large number of papers, but a brief indication is given below of the scope and present state of development in those fields where solar energy could be applied.

House heating. Much can be done by the suitable design of houses to reduce the artificial heat load required, by double-glazed windows and effective heat installation. Additional heat can be provided by collectors of the flat-plate type fixed on the roof with a sufficient hot-water storage to last over two or three days. Several solar-heated houses have been operated in the United States for a number of years, and a newly designed house will shortly be constructed at the Massachusetts Institute of Technology, which should be capable of supplying 80 per cent of the heating requirements throughout the year at Cambridge, Massachusetts.

Water heating. The heating of domestic hot water by solar radiation is a relatively simple process in suitable locations ; the problem is to reduce the cost by mass production. Many designs of heater were described, and a large number of simple appliances are in operation in Japan, which has an acute fuel shortage, though the solar radiation conditions are far from ideal. The cheap supply of natural gas in the United States seems to have curtailed the development of solar heaters, even in areas having high solar radiation.

The efficiency of the flat-plate type of collector may be improved by coating the absorbing surface with a thin metallic oxide film which is a good absorber of visible radiation, but a poor emitter of the longer heat waves re-radiated from the collector surface. The researches in this field, described by Dr. H. Tabor, director of the National Physical Laboratory of Israel, created considerable interest at the conference and may have far-reaching consequences by raising the operating temperature of the flat-plate heat collector and extending its use to steam generation.

Water distillation. A simple design of water still for the conversion of brackish to potable water would be a great benefit to isolated farms in arid areas. Considerable development has taken place in the design of such stills in Algiers, Morocco, Australia and California. Here again the essential problem is to produce a design which will be cheap and yet robust. Experiments are being made with the substitution of plastic for glass condensing surfaces. The average rate of distillation is about 0·8 lb. of water per day per square foot of surface area.

Mechanical power. Small power units for irrigation pumping could replace the very inefficient devices, using human or animal power, which are still employed in some parts of the world. Present developments include the Italian design of engine using sulphur dioxide vapour as a working fluid which costs about a thousand dollars per horse-power output. Other possibilities are steam or hot-air cycles, and development of these is proceeding in India, the U.S.S.R. and Israel. Several ingenious designs were described in which the direct action of volatile fluid is used to operate water pumps, but the efficiency of all such devices is necessarily low because of the small temperature difference utilized.

Electrical power. Solar radiation may be converted to electricity by thermo-couples in which heat is an intermediate form of energy and which, therefore, are subject to the toll of the Carnot efficiency. Higher efficiencies are attained by photoelectric devices, and the Bell silicon cell which is now in commercial production attains a conversion efficiency of 11 per cent. The high cost of the cell (25 dollars a square inch) means, however, that at present such applications are very limited ; but a battery of such cells is being used to charge accumulators on telephone systems, and to operate portable radio transmitters and receivers.

Photogalvanic effects. Certain chemical processes are affected by the action of light with a change in the equilibrium. This change may be used to create an electric potential which may be discharged when the products revert to their original state. At the moment such processes are inefficient, but there is the possibility of remarkable developments which may extend the scope of the applications of solar energy. It is possible in a similar manner to produce hydrogen which could be stored and used at any convenient time as a fuel.

Solar furnaces. A number of solar furnaces for the production of very high temperatures have been constructed; the largest at present in use is the well-known 40-ft. diameter mirror at Mt. Louis in the Pyrennees. This was designed by M. Felix Trombe, who announced that construction has now been commenced of a new furnace which will have a capacity of 1,000 kW. There are also large solar furnaces in operation in Algiers, the U.S.S.R. and the United States. At the moment these furnaces are used for research on the properties of materials up to temperatures of 3,000° C.; but they could also be developed for production purposes in suitable localities.

Algae cultivation. Intensive production of algae can be stimulated by the application of solar energy, though the general opinion was expressed that this would only be economically feasible for food production. A suspension of the algae in water, with the addition of nutrients and enrichment of carbon dioxide, is circulated in a suitably designed pond or tank. Although the efficiency of conversion based on the light quanta absorbed for the liberation of one oxygen molecule may approach 30 per cent, the overall efficiency does not exceed 5 per cent in these special cultivation tanks, compared with a figure of well below 1 per cent for the normal growth of crops on land. *Chlorella* is normally used, and there are many biological problems, such as the development of strains which will grow rapidly at temperatures up to 40° C. and will resist diseases or contamination. Considerable development work is in progress in the United States, Japan, the Netherlands and Germany.

Air conditioning, refrigeration and heat pumps. This is a field which is particularly apt for the utilization of solar energy and yet is one where little research work has been described. The problem is to adapt present well-known cycles, such as the absorption process, to operate at the low temperatures attainable by flat-plate collectors. Concentration by mirrors would enable existing cycles to be utilized, but it is generally considered that the expense of such systems would not enable them to compete with fuels as an energy source. Solar heat collectors could be used in temperate climates to improve the performance of heat pumps, if a suitable means of storing the low-temperature heat were available.

Conclusions

Solar radiation is almost the only source of energy that remains unexploited. The total amount of energy available is ample for the world's requirements, and the difficulty lies principally in its relatively low intensity and variability due to the changing position of the Sun and atmospheric effects. The normal energy sources, apart from nuclear energy, are naturally concentrated forms of solar energy—either as fuels which are a concentration in time, or water power which is a concentration in space. So long as these are available, there is little scope for the application of solar energy, mainly because of the high initial cost and the difficulties of energy storage. But there are many places where fuels are expensive or in some cases non-existent, and in such areas there are potential fields of application for solar energy. For example, electrical power could probably be developed from solar energy at a cost of about a shilling a kWh., which would be unacceptable for large communities but would be welcomed if no other source were available.

Artificial collectors of solar energy, namely, all processes except the natural photosynthesis by living plants, comprise essentially the flat-plate type of collector, or concentrating systems with mirrors, or devices which collect photon energy directly. The first method degrades the radiant energy to heat at a low temperature-level; the second system operates at a high temperature-level which can attain half the temperature of the Sun's surface, but is necessarily more complex and needs a guiding system. These systems are satisfactory if the energy is to be used in the form of heat, but in the production of power the inevitable toll of the Carnot cycle results in a low efficiency of operation. If the objective is electrical power, then devices that convert the photons directly into electricity by photovoltaic methods have higher efficiencies and are therefore more promising if the present cost can be reduced by a factor of ten or a hundred. It is along such lines that major developments in the future must inevitably proceed, though, in the meantime, the conventional heat-cycles of low efficiency may bridge the gap.

Applications of solar energy should not be considered as substitutes for existing energy sources but rather as complementary, and the various energy sources should be combined according to the requirements and the resources of the location. Solar energy cannot replace many of the existing uses of concentrated energy, either thermal or nuclear, but can supplement these, especially for the production of heat at relatively low temperature-levels, that is, below the normal boiling point of water. At the moment, solar energy is essentially for nations that 'have not' rather than for those that 'have'; it may enable many of the benefits of industrial civilizations to be attained by those living in isolated and undeveloped areas, by increasing the comfort of life and improving the amenities. In time to come, as fuel reserves are depleted, applications will be extended, and in the future solar energy may contribute greatly to the supply of energy. Considered from these aspects—that is, as an immediate policy for undeveloped areas and as a future policy for other areas—the continuation of research on the utilization of solar energy fulfils an important function in global development.

The Arizona conferences cannot do other than stimulate all these developments; but in addition two definite proposals have emerged from them. The first is the creation of a journal for the publication of solar energy research, and the second is the formation of an applied solar energy research laboratory, possibly in Arizona. Finally, the delegates from outside the United States, numbering more than a hundred, who attended through the generosity of American foundations, will have returned to their own countries with inspiration renewed from these memorable conferences. HAROLD HEYWOOD