It is a rich and rewarding experience to come to the part of the world having the greatest energy treasury known on earth and to talk seriously about adding to that resource the priceless and timeless energy from the sun. After 35 years of personal involvement in the development of this supplement to our present and future needs, I think you can understand with what deep feelings of satisfaction I view the commitment to solar energy use here in the Middle East. I sincerely appreciate this opportunity to share with you some thoughts on what I believe will become man's most important effort to assure his future on earth. Historians will someday note the start of the solar age of man as these closing decades of the twentieth century. It is exciting and challenging to be part of that history.

Before proceeding, let me slightly modify the title of these remarks. I would like to divide the solar applications into three main groups, so perhaps a more suitable title would be, "Solar Energy - Today, Tomorrow and Next Week". In other words, I would like to divide the whole topic into the present uses of solar energy, applications which should become important within the next few years, and finally, solar technologies which may become important some time in the future.

I have taken my task to be a brief survey of the major, but certainly not all, solar applications, and to group them into some sort of a time scale for use. I shall also try to present brief explanations of the technology involved in these applications so that this diverse audience of specialists, planners, decision makers, and interested on-lookers can have a good perspective of the field.
SOLAR ENERGY - TODAY AND TOMORROW

by

George O.G. Løf

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It is of course impossible to cover all the solar applications -- solar energy can be used for everything for which oil is used -- so if I do not include someone's favorite concept, only time limitations have prevented. Moreover, the speakers to follow me on this excellent program will cover the details of the topics I can only broadly mention.

So, in this introduction to the present status and future prospects of solar energy, I shall provide primarily some facts, and to some extent, opinions. The facts have to do with the technology and the opinions are on the prospects and timing for new applications of these technologies.

PRESENT APPLICATIONS -- "SOLAR TODAY"

Other than solar use in agriculture and salt production, the heating of domestic hot water, the supply of heat to buildings, and the heating of swimming pools are the most important uses of solar energy today. In the colder climates of the world, the heating of swimming pools by use of transparent plastic covers floating on the water is the most cost-effective use of solar energy we now have. Recovery of investment in the simple solar cover can be made in a few months by the saving of fuel. Domestic hot water is the next most cost-effective application in most areas, and is widely used in Australia, Japan, and many other countries. Manufacturers of well-designed equipment are marketing these systems in continually increasing volume, probably approaching a million units per year.

Solar water heating technology is relatively simple. Water or some heat transfer fluid is circulated through passages in a black metal plate, usually covered by at least one sheet of glass, into an insulated storage tank. Natural circulation or pumping may be used. Typical family-sized installations involve three to six square meters of solar collectors and 100 to 300 liters of storage. Most of the family hot water requirements can be met by such
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units in sunny climates. Larger systems for apartment houses, schools, and other commercial and institutional buildings are also in common use.

Although not yet widely used, hot water for manufacturing processes is an attractive solar application. A great deal of water at temperatures below 100°C is required for many industrial purposes, and where fuels are expensive, solar energy may be an economical alternative, even today. Demonstrations of process heating with solar energy are being made in the United States, and as fuel prices move upward, these applications can be expected to increase.

In the heavily populated areas of Europe and North America, the heating of buildings requires enormous amounts of energy. In the United States, for example, about 20 percent of the national energy consumption is for the heating of buildings. Substitution of solar energy for a substantial part of these requirements is technically possible and is approaching economic competitiveness. Several thousand residences and commercial buildings are now being solar heated in the United States, with systems supplying typically 40 percent to 80 percent of the annual heating requirements. Although the cost of solar heating is greater than heating with natural gas and oil, measured by comparing interest and depreciation on invested capital versus the value of the fuel saved, solar heating is becoming competitive with electric resistance heating where electricity prices are approaching or exceeding about 7 U.S. cents per kilowatt-hour.

The two principal systems for space heating with solar energy are the liquid type, similar to solar water heaters but of larger size, and the air type. The oldest, continuously solar heated building in the world is my residence in Colorado employing an air system constructed 20 years ago. This installation has demonstrated the long-term, trouble-free effectiveness of such a system. Modern counterparts are being commercially installed, with excellent results. Buildings of various architectural style, including
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the flat roofed structures used in many parts of the world, can be provided with solar heating facilities.

An exceptionally important program of solar heating development and evaluation is in progress at Colorado State University. Here, three identical residential-type buildings are being solar heated, and cooled, by different types of solar systems. Liquid systems are involved in two of the structures, an air system in the third. A fourth, smaller building, is being used in an evaluation of combined residential and greenhouse solar heating. In addition to the continuous, long-term measurement of system performance with flat-plate solar collectors, three types of evacuated tube solar collectors are being investigated and the performance compared with flat-plate types. One of these projects involves an international cooperative effort with groups in West Germany. Results of these investigations are providing important information on the performance, cost, and operating requirements of these systems.

The flat-plate liquid system in one building involves a solar collector in which an aqueous solution of antifreeze is heated, heat exchange to water in a storage tank, supply of the heated water to a transfer coil for heating air circulating through the house, hot water supply to a lithium bromide absorption air conditioner, and heat exchange to the domestic hot water supply. An auxiliary gas-fired hot water boiler is used for supplementary heating and cooling as needed. The performance of this system during the past three years has shown good results for space heating and water heating, but lower effectiveness than expected for cooling. Gradual improvement in the cooling operation has taken place, but reliability and competitiveness with conventional cooling have not yet been established.

The air system in the second house supplies heated air from the collector to the rooms, when required, and to a bin of small rocks for heat storage. Hot water is also furnished by heat exchange. Heat is delivered from storage
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to the rooms when the sun is not shining by circulation through the pebble-bed in the reverse direction.

A moderate amount of cooling is also available in this system when used in a climate where night temperatures are substantially lower than during the day. The pebble-bed is cooled at night by circulating outdoor air through the pebbles, assisted by evaporative cooling of the supply air. During the day, house air is circulated through the cool pebbles usually at temperatures near 15°C. In desert-type climates, where night temperatures are low, this system may have considerable practical value.

Solar collectors comprising evacuated glass tubes in which selective absorbing surfaces are located have been applied in two of the solar heated buildings at Colorado State University. One of the systems has involved numerous operating problems and is not considered practical at the present time. Excellent results were secured with a second evacuated tubular collector, in association with the solar heating and cooling system first employed with a flat-plate collector. In the near future, a third evacuated tube collector will be used in this system. These high efficiency (but at present costly) collectors have attractive potential for heating and cooling use. Temperatures well above 100°C can be regularly obtained at solar collection efficiencies above 50 percent. With manufacturing economies expected possible in large volume production, units of this type may challenge flat-plate collectors in heating and cooling applications.

Comparison of the performance of the various systems previously described shows, as expected, good performance of an evacuated tubular collector system for heating and cooling, good performance and acceptable cost for with the air system for space heating and water heating, and somewhat lower effectiveness of the flat-plate liquid system. It is evident that flat-plate systems of both liquid and air types can be effectively and economically used in space heating applications and for domestic hot water supply in sunny climates and
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NEAR-TERM APPLICATIONS - "SOLAR TOMORROW"

Desalting of seawater and brackish water with solar energy is a very old process. The first solar still was built in Chile over 100 years ago. Solar stills of the same general design of improved materials are providing fresh water in about a dozen locations mostly in the Mediterranean region. Water deliveries of over 5,000 liters per day are being made from each of these plants. It is the very limited use of solar distillation of salt water which justifies the placement of this application in the "near future" category, because costs appear to limit current use to small applications in remote areas.

A solar still consists of a simple glass-covered shallow basin in which salt water is slowly evaporated by the sun, the vapor condensing on the sloping glass covers. Troughs for condensate collection and openings for brine overflow and discharge constitute the solar still. Three to five liters of water can be produced from each square meter on a sunny day. Quantities up to a few thousand liters per day can probably be produced by this method at lower cost than any other desalination technique. Drinking water for small communities and for livestock in remote areas can be provided by these simple systems. The Middle East may be one of the most attractive regions for this application in the near future.

Although solar drying of crops has been practiced for centuries simply by spreading the crops on the ground or on racks, exposed to the wind and sun, improved solar drying by use of enclosures supplied with solar heated air are more recent developments. As fuel costs increase, substantial growth of these applications can be expected. The heating of ambient air to temperatures suitable for drying many types of materials, lumber, grains, vegetables
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and fruits, and manufactured products can be accomplished at high efficiency and moderate cost. Demonstration projects in Australia and the U.S.A. are providing useful data for near-term application on a steadily increasing basis.

Although discussed briefly above, evacuated tube collectors might also be put in the "tomorrow" category. The reason for such placement is the current high cost of these units. It appears, however, that in sizable volume of manufacture, the costs can be substantially reduced. The advantages in higher efficiency, particularly at temperatures exceeding 100°C, appear to justify substantial effort in the development of this technology. The generation of low pressure steam, operation of cooling equipment, and other intermediate temperature applications appear to match very well the capabilities of these efficient collectors. Requiring no sun tracking and capable of using diffuse radiation, evacuated tubular collectors can be expected to become increasingly important as costs decline. Typically, involving current investment of three times that of flat-plate collectors, evacuated tubes should become economically competitive when their cost reaches levels perhaps 50 percent above those of flat-plates, on an equal area basis.

Tomorrow's solar application probably of greatest interest and value in the Middle East is for the cooling of buildings. Numerous solar cooling systems are in experimental use, mainly in the United States. Nearly all are based on the supply of solar heated water to lithium bromide absorption cooling machines. The first such system was put into operation about four years ago, at Colorado State University, so the technology is in its early stages of development. Performance of this and other systems has not been as good as has been desired, and improvements are being made as the work progresses. The systems are not yet practical for general use.

In addition to technical limitations, high cost is a deterrent to use. Economies of scale are substantial in this system, so it appears that solar
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Other methods of solar cooling are possible. The use of a desiccant to dehumidify the air, with regeneration of the desiccant by solar heat, coupled with heat exchange and evaporative cooling, is being investigated in several laboratories. Another process of possible special usefulness in the Middle East is a new, open-cycle absorption cooling system involving reconcentration of the absorbing solution by its direct evaporation from a nearly flat roof across which it is slowly flowing. Modification of this process by use of solar heated air in a packed evaporating column is being investigated.

Small-scale generation of mechanical power or electricity may be coupled with the use of the power to drive conventional compression air conditioning equipment. Small turbines operating in a Rankine cycle at vapor supply temperatures of 100 to 150°C have been demonstrated. These temperatures are well within the range of evacuated tube collectors, and for the cooling of large buildings, this system may come into substantial use.

As suggested immediately above, solar cooling by all the possible processes involves equipment that is much more expensive than conventional cooling machinery. There are economies of scale, however, and it appears that the prospects for economical application of solar cooling in large buildings are considerably better than in single-family houses. Development work is clearly needed for establishing the viability of any of the potential systems, particularly under the severe conditions encountered in the Middle East.

Another possible cooling application is for refrigeration of foods. Small refrigerators have been operated experimentally by the use of solar collectors as generators of refrigerant in ammonia absorption cycles.
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FUTURE SOLAR ENERGY USES - "SOLAR NEXT WEEK"

Solar energy has been experimentally used for production of mechanical power or electricity for nearly a century. A focusing system was built in Egypt in 1913 which developed nearly 50 kilowatts of power for pumping, and numerous small units have been designed and tested since that time. All have proved to be prohibitively expensive and most have demonstrated poor performance.

Recent work in the Soviet Union, the U.S.A., Italy, France, Japan, and a few other countries has led to numerous small-sized (up to a few kilowatts) solar electric generators employing heat engines of various types. Steam and other working fluids have been used, and a few experimental installations have employed flat-plate collectors and low pressure engines rather than concentrators of various types with engine supply temperatures of several hundred degrees C.

Applications for these small solar power plants have usually been projected to be for electricity supply on a small scale in remote areas where electric grids are impractical and where fuel transport costs for diesel-electric generators are extremely high. For such applications, the costly solar power installations might not be far greater, after further development, than the alternatives. An objective view of the economics of such systems places the cost of electricity deliverable from such units at $0.25 to $0.50 per kilowatt-hour produced, assuming location in a very sunny climate and a moderate amount of electric battery storage. In remote areas, where small diesel-electric generators are operated, total costs may not be far less than these estimates. Further development of such systems therefore appears important.
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Another method for generating electricity by a solar thermal process involves a large field of flat mirrors reflecting solar energy to a boiler-receiver on a tower in the mirror array. The heliostats, similar to those used in the one megawatt (thermal) solar furnace installation in France, track the sun, and provide highly concentrated radiant energy to the steam generator. The testing of a ten megawatt (thermal) facility of this type is soon to commence in the U.S.A., and the construction of a ten megawatt (electric) generating facility in California is expected to start later this year. At construction costs in the vicinity of $2,000 U.S. per peak kilowatt, the generation of 1500 to 2000 kilowatt-hours per year is estimated to provide electricity at 10 cents to 20 cents per kilowatt-hour. These estimates are several times the current costs of electricity generation in central stations, so appreciable application should not be expected for several decades. At some such time, comparison of the economics of this system with assemblies of interconnected steam generators of the concentrating collector type, as well as with other methods for electric power generation with solar energy can then show if this central receiver concept can be competitive with the alternatives.

Photovoltaic electric generation by use of single crystal silicon cells is extensively used on space craft and to an increasing extent for small electric applications involve communication and navigation systems. The present cost of about $10,000 per peak kilowatt of capacity is far above the cost of alternatives for substantial supplies of electric power. A great deal of commercial activity in many companies and several countries is resulting in cost reductions, and the combination of volume production and innovations is expected to result in major cost reductions. Cost predictions of $1,000 per peak kilowatt by 1985 are frequently made, and a goal of $500 per kilowatt by 1985 has been set in the U.S.

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CONCLUSIONS

It has not been possible in the limited time available to cover all of the solar applications and methods of conversion. Let me simply mention the generation of electricity by use of temperature differences in the ocean, by use of the wind, and by the conversion of agricultural products and waste materials not only to electricity but to other fuels such as alcohol and methane. Electricity from the wind has an early potential for use, but the other possibilities are more speculative either for technical or for economic reasons.

To close these remarks, let me summarize and classify again the applications mentioned.

(1) Solar Energy - Today

Present uses of solar energy are for domestic water heating, for space heating, and to a more limited extent for industrial process heat. On more limited scale, the production of fresh water from salt water and the drying of various materials are used under special circumstances, and the potential for growth appears substantial.
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Present uses of solar energy are for domestic water heating, for space heating, and to a more limited extent for industrial process heat. On more limited scale, the production of fresh water from salt water and the drying of various materials are used under special circumstances, and the potential for growth appears substantial.
(2) Solar Energy - Tomorrow

The development of evacuated tube collectors for more efficient solar collection at "intermediate" temperatures of 100 to 150°C offers major potential for heating applications, particularly in industrial processes and for cooling. The cooling application itself, by use of such collectors and by development of improved cooling cycles appears a near-term prospect. Refrigeration for food preservation in commercial operations also appeals to early use particularly in developing economies.

(3) Solar Energy - Next Week

Electric power generation, possibly by thermal processes, but with some major manufacturing economies, more likely with photovoltaic methods, appears to have very large potential for establishment toward the end of this century, with massive introduction in the early decades of the next century.

These developments are not only of great value to the energy users of the world, but they also represent major opportunities for business activity in all aspects of supply of equipment and materials for these new technologies. Manufacture, marketing, servicing, import/export, and financial investment all offer attractive returns to the bold, but careful, participant. I mention caution, because there are many pitfalls that must be avoided. I view with dismay, and a growing fear, that lack of experience and understanding may be a serious deterrent to widespread solar energy use. Failures are already occurring at an alarming rate. Overoptimism and illusion, with respect to equipment durability, performance, and cost could lead to public rejection. The construction of a sizable solar thermal electric power generator, for example, could demonstrate only that solar electricity is too
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impractical and expensive for serious consideration. We must not allow solar energy to resemble a small child that in its eagerness to rush across the playground can't make its feet move fast enough to avoid falling.

If these problems can be avoided, solar energy is sure to become one of the biggest businesses of the twentieth century. I am sure that firms and nations represented here will share in the rewards of such developments. And in particular reference to the Middle East, let me share with you an interesting observation of an Indian journalist to whom I talked after I addressed the recent world conference in New Delhi. He said, "I would conclude from your remarks that the leading countries of the next centuries will be those having the greatest sources of solar energy, and that other nations will be dependent on them for much of their goods and services." This may well become true, and certainly this area of the world will then continue to be an energy treasury.
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