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BOOK REVIEWS

SHORT PAPER

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Book Reviews

Sun Power: An Introduction to the Applications of Solar Energy, by J.O. McVeigh. Pergamon Press: Pergamon International Library of Science, Technology, Engineering and Social Studies: 1977, 208 pp., 250 × 176 mm. *Reviewed by Magdi M.H. Ragheb, Department of Nuclear Engineering and Thomas J. Higgins, Department of Electrical and Computer Engineering, University of Wisconsin, Madison, Wisconsin 53706.*

This book is a critical review of the intriguing newly-reborn field of "Sun Power." The theoretical treatment is kept to a minimum; it includes an extensive bibliography updated to 1976. In nine chapters, diverse subjects relating to solar energy research are overviewed: these range from heating applications, solar-powered engines and photovoltaic cells to biological conversion systems and wind power. SI units are used. Overall, this text can be considered, somewhat, an updated British counterpart of the earlier-published (1974) USA text by Duffie and Beckmann[1].

As petroleum and other fossil-fuel world supplies dwindle, many energy planners believe that the "twin" sources of solar energy and thermonuclear fusion may become the world's main source of energy. The reviewers rather tend to a belief, which was enforced on reading the book, that the future energy source of the world will be "optimized integrated energy systems": all energy-producing options (solar, nuclear, fossil, geothermal, wind, hydroelectric, etc.) are optionally conjoined to enable satisfaction of worldwide hunger for better living qualities, through providing a plentiful supply of energy.

A polarization towards one or two options and elimination of the others will not be successful. A new breed of "energy engineers and scientists" is needed: to lead energy research towards implementing such integration in the future, recognizing energy options seem not to be competitive but rather complementive. Our thought, after reading the book, is that solar power can indeed supply a substantial share of humanity's need for energy: but that it will always need to be supplemented by the other energy-production methods.

In such thought this book seems a very worthwhile acquisition for engineers and scientists, in all energy fields, who desire to acquire an interdisciplinary insight relative to solar energy and to understand both the potentialities and the limitations of it.

At the Miami International Conference on Alternative Energy Sources[2] in December 1977, attended by nearly 1000 energy experts from 40 countries, it was reported: ". . .it would be possible to have solar hot water in nearly 2.5 million new homes by 1985 under the National Energy Plan. . .". Under this, Carter's administration plan, federal tax credits of up to $2000 would be allowed for a solar energy system costing $6400. The House increased this to $2150, and the Senate broadened it to include businesses [3]. It was also reported: ". . .if federal price controls were ended on oil and gas, solar economic parity for water heating is achieved today in all states but Washington, where there is inexpensive hydroelectric power." However [2], ". . .solar space heating in 1985 would continue to cost more than oil or gas heat, even if prices were deregulated." Whereas $450 million are being spent on magnetic, laser, and electron beam nuclear fusion research this year, $58 million will be spent on photovoltaic research alone[4]. Unlike silicon crystals that must be arduously grown and cut, amorphous silicon which can be sprayed over a surface like paint is being developed at RCA's research center in Princeton, N.J., and promises low cost for mass production. Gallium arsenide, with its higher conversion efficiency and high temperature operation, is being developed at IBM's research center in Yorktown Heights, N.Y. "Instead of setting 1000 costly solar cells under the sun, researchers at Sandia Laboratories in Albuquerque, N.M. are working to focus sunlight concentrated 1000-fold onto a single gallium arsenide cell"[4]. Solar energy research seems to be moving at quite a fast pace. . .!

The author dedicates his book to ". . .those who are striving to conserve rather than consume, to develop a simpler non-violent lifestyle and to obtain power without pollution through the use of renewable natural energy resources", and states in his preface: "It is now widely accepted that the growth in energy consumption which has been experienced for many years cannot continue indefinitely as there is a limit to our reserves of fossil fuel. Solar energy is by far the most attractive alternative energy source for the future, for apart from its non-polluting qualities the amount of energy which is available for conversion is several orders of magnitude greater than all present world requirements." The author unfortunately fell into the trap of emotional persuasion of the reader. As regards "non-violence", solar produced electricity can operate gaseous diffusion, centrifugation or laser separation plants for production of nuclear weapons: nuclear reactors are not needed for that purpose. Violence can be attributed to the minds of people using a certain technology, not to the technology itself. In any case, abundant energy in the world, whether it is solar, fossil, or nuclear, is the best deterrent to violence: strong economies preclude social troubles; and plentiful resources preclude international conflicts for their control.

As regards pollution, what can be more "polluting" than wars, social troubles, famines and epidemics? One must also remember than any energy production method entails some form of pollution. Even solar energy entails pollution in two forms: the first is thermal pollution caused by the low conversion efficiencies involved, and the second is pollution in the industrial processes of manufacturing the energy collecting devices. The latter have relatively large volumes, due to the low energy-densities involved. The merit of a technology regarding pollution depends on how its particular waste products affect the environment or can be isolated from it. Such needs careful assessments, and cannot be based on general arguments. The social responsibility of scientists requires them to convey objective unemotional information to the public. Their failure to do so may have catastrophic consequences in the future: economic collapse, social troubles and wars. . .

In the first chapter the history of solar applications is reviewed, including the attack of Archimedes upon the Roman fleet at Syracuse (214 B.C.), and the Ericson air cycle and his concern about the energy crises in 1876 (history repeats itself). Ericson predicted that the coal fields would eventually be exhausted and that this would cause great changes in international relations in favor of countries with continuous sun power (both the oil and nuclear genies were hiding in their Aladdin lamps by then), and commented: "Upper Egypt for instance, will, in the course of time, derive signal advantage and attain a high political position on account of her perpetual sunshine, and the consequent command of unlimited motive force. The time will come when Europe must stop her mills for the want of coal. Upper Egypt, then, with her never-ceasing sunpower, will invite the European manufacturer to remove his machinery and erect his mills on the firm ground along the sides of the alluvial plain of the Nile where sufficient power can be obtained to enable him to run more spindles than 100 such cities as Manchester". Other applications are reviewed, such as the world's largest solar distillation system in Las Salinas, Chile, and the most spectacular solar engine development of the century (1913); the Shuman-Boys Sun-Heat Absorber at Meadi in Egypt, which included a solar tracking system for a solar collector of 1277m² area, with a maximum recorded pumping horsepower of 19.1 hp.

The growing international interest in solar energy research and development is reviewed, as well as major conferences such as the July 1975 UCLA Conference. This interest is exemplified by the USA program growth which expanded from an expenditure of $1.2 million in 1971 to $300 million in 1977. The author concludes: "Conventional fossil fuel reserves can only last perhaps a hundred years at the most, and there are very considerable technical and environmental reservations about nuclear energy. Solar-energy, which is non-polluting and inexhaustible, is already economically viable for certain applications in almost every country of the world". We previously commented on the usefulness of such general statements. As regards the economically viability, we report this statement by Lof[6]: "In my view, it is likely that genuine economic competitiveness of solar electricity with conventional sources can be achieved the next century, but, it is my expectation that before that time, solar electricity will be generated in demonstration plants, on a subsidized basis, primarily in the course of a long-term program for developing and demonstrating this source of electricity and for solving many of the design and operating problems encountered in any new technology", and further: "Although somewhat more expensive than conventional fuels at today's prices, solar heating is now a commercial reality. Land developers, builders, and the general public are not yet convinced that solar heating is practical and economical. The financial community is uncertain about the future of solar heating, local officials are apprehensive about conformance with zoning and building code requirements, so *demonstrations* of the practicality and economy of solar heating is absolutely essential".

The second chapter is a classical treatment of Solar Radiation, including topics such as the measurement of the solar constant (1.35 kw/m²), the relationship between global, direct and diffuse radiation, the spectral distribution and alteration of direct solar radiation by scattering and absorption in the atmosphere, the radiation measuring instruments and the International Pyrheliometric Scale of 1956. Approaches for gathering data from a radiation measurement network for design purposes are discussed. The author concedes:

"More than half the solar radiation received in the British Isles is diffuse and this puts limitations on any applications which involve focusing." and further: "The comparatively low radiation levels in the winter period are combined with an increased proporation of diffuse-radiation, which greatly reduces the effectiveness of many solar space and water-heating systems."

In Chapter 3 the water and air heating applications of solar radiation are discussed. In South Florida, USA, during the late 1930's, solar energy was the main method for providing hot water services to single-family residences, blocks of flats and other small commercial buildings. However: "One of the drawbacks in high latitude countries, such as the UK is that there are many days in the winter months when the total radiation received will be too small to make any useful contribution." An analysis of the flat-plate collector based upon the Hottel-Whillier-Bliss equation is exposed: as well as its physical design characteristics with exploration of the greenhouse effect and the use of selective surfaces and surface treatment and choices of collector materials and corrosion. Developments in collector design are surveyed: for low temperature-rise application (e.g., swimming pool heating) the emphasis is on designs which can be shown to have very short payback periods (the capital cost of the system divided by the current annual value of the fuel saved) in the order of five years or less, the thermal trap collector, honeycomb systems, structurally-integrated collectors (where the collector is also the roof of the building), negative-pressure distributed-flow collectors, the compound parabolic concentrator, the spiral or sea-shell collector, the trapezoidal moderately-concentrating collector, the stationary reflecting/tracking absorber, the evacuated tubular collector, the heat-pipe collector, the floating deck heater and the cylindrical heater/storage system. Air heaters for crop drying and space heating and their integration into a heating and cooling system are also surveyed. The chapter is concluded by a brief comparison of the performance of various collectors, the establishment of standards, the use of a solar simulator and a disappointingly short section on thermal storage materials and methods.

Chapter 4 treats the space heating applications. Storage months of up to several months seem to have been achieved in some solar houses and considerable reductions in the total volume of the storage area may be possible by the use of chemical storage methods. The term "solar houses" first became familiar in the USA during the 1930's, when architects began to use large south-facing windows to let the lower slanting rays of the winter sun penetrate into the back of the room. In an experiment, unfortunately, a solar house required 16% more heat than the orthodox house during the December-January test period because of heat losses at night from the large windows. Various houses and buildings in the USA, UK and other countries are described to illustrate the historical development of solar heating: from the MIT house number I (1939), which was considered as very uneconomic and was demolished in 1941, to more recent designs such as the University of Delaware's Solar One (1973), the Copper Development Association Decade 80 House, Tucson (1975), and the UK Building Research Establishment Houses. The French and German programs are briefly reviewed. The author concludes the chapter by reporting: . . ."the variety of designs described will fascinate the reader and thoroughly confuse the earnest seeker after the optimum design.", and: "It has been shown that solar space heating in buildings saves energy. Investment in a solar energy system is always subject to interference by Government as fuel prices are raised or lowered, but if at is considered to be socially desirable to have buildings at least partially heated by solar energy, it is a function of Government to see that it is economically attractive."

The thermal power and other thermal applications are treated in Chapter 5. For solar-powered heat engines, the higher the source temperature becomes, the greater the Carnot cycle efficiency for any fixed sink temperature. When the characteristics of solar collectors are considered, it can be seen that there is a conflict: as any increase in collector temperature results in a corresponding decrease in overall collector efficiency. Maximum ideal solar collector efficiencies are reported in the range of 5-12% for different collectors (Fig. 5.1). Some practical engines (closed-cycle hot-air engine, open-cycle hot-air engines, and vapour engines) are briefly discussed. With focusing collectors, engine efficiencies are reported as just under 20%; with flat collectors, it is just 3.5%. Concepts of large-scale power generation are surveyd; the central "power tower" system (estimated cost in 1975 for a 300 MW plant was $930/kw), the distributed-collector system (solar farm), the ocean thermal energy (overall cycle efficiency ranging from 2.1 to 2.4%), satellite solar power stations, and heliohydroelectric power generation. Cookers and furnaces applications using Fresnel lenses are very briefly outlines. Refrigeration and cooling is also treated. The great advantage here is that the maximum amount of solar energy is available at the point of maximum demand: cooling of buildings and food preservation. Four methods are considered: 1) The compression refrigeration cycle in which the refrigeration side is driven by solar-powered engines, 2) Absorption systems, 3) Evaporative cooling systems, and 4) Radiative cooling systems. Other applications with heat pumps, solar ponds, sea-water distillation, process heat for food processing, and solar-electric cars are also briefly reviewed. This area is surely an inventor's paradise.

Chapter 6 is devoted to a brief discussion of the methods of economic analysis. The Southern California Edison Company seems to have concluded that there were ways of combining solar heating and cooling concepts such that the use of solar energy with electrical energy was more economical, both for the company and the consumer, than the use of either alone. Conventional discounted-cash flow concepts, including the effect of inflation, are used to establish the present value of future savings and can be used to determine if it is economically justifiable to invest in a solar heating system, and calculational examples are given. "Investment in solar equipment is essentially a long-term investment, as capital repayment factors smaller than 0.1 can only be achieved with a ten-year period if the inflation rate is greater than the interest rate." Marginal Analysis is used to help decide which collector should be used in a given system, or whether a selective surface or double-layer glazing is worthwhile. Two other topics related to collectors are briefly treated: the optimization of the collector area, and the effect of variable interest and inflation rates and the deterioration of the collector system and its need for maintenance.

Chapter 7 combines the subjects of photovoltaic cells, biological conversion systems and photochemistry. Conversion efficiencies of up to 16% for silicon cells and over 20% for certain gallium arsenide cells have been reported under laboratory conditions. The use of solar cells in space applications is well known; their advantages being that they have no moving parts to wear out and that they need little or no maintenance. However, a Japanese estimate considered that a 10 MW generating station made with the technology available in 1974 would require the entire world production of silicon: about 1000 tons. Fortunately, silicon is a very common element. The National Science Foundation in the USA estimated that by 1990 there should be 5000 MW at peak output manufactured annually in solar arrays, and 20,000 MW at peak output manufactured by 2000 (which would be approximately 2% of the projected total electrical demand). The types of solar cells (silicon, cadmium sulphide, gallium arsenide and indium phosphide) and their use in automatic weather stations and other remote instruments are treated. Other related subjects are mentioned: electrical storage by the sodium-sulphur battery, super-flywheel concepts, eutectic mixtures of metal fluorides, as well as water electrolysis to produce hydrogen. "One of the major objections to solar cells has been the high energy input necessary in some manufacturing processes, particularly with silicon cells. This could be overcome by using a solar furnace to manufacture silicon from silica." Luckily, there exists a solar solution for that problem too. In photosynthesis, the maximum theoretical conversion efficiency is about 27%; but under normal agricultural conditions, very low efficiencies are achieved, usually less than 1%. By careful genetic selection and intensive cultivation, the conversion efficiency is expected to reach 3% under normal conditions. Trees are suggested to be used as an energy crop: "I should rather go for a stroll in an acre of forest than in an acre of solar cells," as well as the ocean cultivation of giant kelp seaweed and marine micro-organisms. Even the conversion of solid organic materials to fuels is considered: with aerobic fermentation, materials containing simple sugars and starches can be used to produce ethyl alcohol or ethanol, and methane can be generated from domestic sewage. A section is devoted to photochemistry: such as the photosensitized decomposition of water to hydrogen and oxygen.

On the premise that "Energy from the Wind is derived from solar energy," Chapter 8 is devoted to Wind Power, even though that subject deserves a book itself. The historical development of wind-generated electricity in Denmark, UK, USSR and the USA, some recent developments, as well as some large scale wind energy programs, are reviewed. The author discusses the wind energy potential and the wind annual statistical energy distribution and its dependence on shape of local landscape, height of windmill above ground level and the climatic cycle. The chapter is concluded by a discussion of the complementary nature of wind and solar energy.

Chapter 9 considers some practical heating applications in some detail. For swimming pool and other low-temperature applications the "enclosed" collector design details are considered, including a list of materials and brief construction details. A domestic solar water heater collector plate design is also exposed. The integration of solar water heating into the Domestic Hot Water System by the thermosyphon or the forced circulation, or pumped system is explained. The author warns the readers against the claims of commercial brochures: ". . .many misleading statements have been published. Typical examples are: 'solar heat can provide nearly all your domestic hot water requirements free', and: 'the panels will heat all the domestic water needed by an average family in the summer and 80% of the required water in the winter'. This is not necessarily untrue but it could only happen if people were prepared to alter their way of life quite radically and face the prospect of storing dirty dishes, cups and saucers, dirty clothes, etc. for weeks on end during the winter months while waiting for a few sunny days". The author draws attention that National Standards for solar heating systems are needed. We appreciate the author's scientific integrity when he comments about energy-saving methods: "Although the provision of adequate loft insulation and trying to eliminate draughts by sealing round the edges of windows and doors will not be as interesting or exciting as building a solar water or space heating system, these measures will be far more cost effective at present." The author reports results of an analysis carried out in the UK in 1974 and compares it to those of solar heating over a five-year period. Basic roof insulation (50 mm) has an installation cost of £30 and the estimated value of saved fuel in 5 years is £110, draught prevention costs £10 and saves £50, whereas a practical 6 m² solar heating would cost £180, a commerical 6 m² system would cost £500, and both would save £200 over 5 years (with no inflation). The conclusion is clear: one should start by thinking "insulation", then "solar heating" later.

In assessing the viability of solar systems, the author used the payback period criterion, defined as the capital cost of the system divided by the current annual value of the fuel saved. Other more realistic criteria could be suggested; the energy gain of the system: defined as the amount of energy generated by the system during its lifetime, divided by the amount of energy required to manufacture, operate and maintain it during its lifetime; or the energy payback time: defined as the time required for the system to generate sufficient energy to equal the amount of energy expended in manufacturing, as well as operating and maintaining it during its energy payback period. The US energy consumption is about 2500 billion KHW per year: 19% of it is used for heating and cooling of buildings, 25% for industrial process heat, 24% for transportation, 25% for electricity production, 5% for petrochemicals and 2% for exported energy products. The sources of this energy are oil (40%), natural gas (33%), hydropower (4%), coal (20%), nuclear (2%), and synthetic fuel, oil shale, geothermal, wind, and solar energy (1%). The solar contribution will indeed increase but can contribute only to the 19% heating and cooling of buildings sector, unless a major scientific breakthrough is attained in photoelectric cells research. With the supply of oil and natural gas dwindling, coal and nuclear energy have to come into the picture to fill the gap. It seems unrealistic to assume that solar energy alone can satisfy the largest share of energy demand in the near future.

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Reactor Core Fuel Management, by P. Silvennoiem. Pergamon International Library of Science, Technology, Engineering and Social Studies: Oxford, England: Pergamon Press, Ltd., 1976, 257 pages. *Reviewed by Magdi M.H. Ragheb, Department of Nuclear Engineering and Thomas J. Higgins, Department of Electrical and Computer Engineering, The University of Wisconsin, Madison, WI 53706, USA.*

This compactly-written book by P. Silvennoiem, of the Technical Research Centre of Finland in Helsinki, is divided into three parts. The first part comprises elementary concepts of reactor physics, neutron diffusion, reactor-core heat transfer and reactivity, and reactor operation. The second part, titled "Core analysis," defines the variables of core management, reviews the methods of core analysis and the associated computer code modules and epitomizes different reactor concepts. These two parts have, respectively, lengths of 98 and 124 pages. The third part, concerned with methods of optimization and system integration, comprises a very compact 21 pages. The book contains an index; and each chapter entails a pertinent bibliography, updated to 1975.

Reactor-core fuel management, as defined by the author, encompasses: "Determination of the nuclear properties associated with fuel and fuel assemblies whether fresh or burnt.

"Specification of the fuel loaded in the core and strategies used in loading and discharging as well as the patterns of internal shuffling during irradiation.

"Control procedures during operation which are related and parallel to the objectives specified on fuel.

"Consideration of the constraints brought about by other units of the power generation system, by power demand, or by safety.

"Optimization of fuel and control strategies and sequencing the decisions for the purposes of fuel procurement."

These physics, engineering and economical aspects are all aimed at the optimal utilization of the nuclear fuel within the design limits imposed on the reactor core. Even though of great importance for reactor designers and reactor operation personnel, the subject has been treated only superficially in previous Nuclear Engineering texts [1, 2, 3, 4].

The optimal utilization of nuclear fuel is a subject of prime importance for the world energy supply and economy. An over-supply of uranium and national stockpiling at low prices resulted in depression of uranium prices to less than $5 per pound ($U_3O_8$) by 1971. Prices remained low until the October 1973 war, the U.S. arms resupply for Israel, and the ensuing Arab Oil Embargo, with the subsequent rise in oil, coal and uranium prices: the last to $40 per pound in 1976. The future demand for uranium fuel is expected to reach a cumulative total of 2 to 3 million tons of uranium by the year 2000. In the next quarter-century the uranium-producing industry must grow at an unprecedented rate of 12-15% per year, and spend 10 to 20 thousand million dollars to supply an energy-hungry world with a cumulative total of two to four million tons of uranium: knowing that the lead time to bring a uranium deposit into production is about 10 years [5]. This supply problem is accentuated by the unreliability and hazardousness of a coal-based economy: The carcinogens (e.g., benzpyrene), sulphur, and nitrogen oxides that are released in the burning of a fossil fuel pose a formidable environmental problem, strip mining is particularly messy, and the increase of the carbon dixode in the atmosphere at the current rate of one third of one percent per year—which suggests the concentration will double by the middle of next century. The last factor alone has led to scare scenarios of a series of climatic catastrophes: such as the melting of the ice caps that might drown coastal areas of the world [6].

In his article about the "Carbon Dioxide Question," G. Woodwell [8] reports: "The potential hazards associated with a steady increase in the carbon dioxide content of the atmosphere will loom large in the coming decades and will doubtless bear heavily on such decisions as whether to accelerate the development of power plants based on nuclear fuel instead of those base on coal and whether to preserve forest areas instead of encroaching on them (and, if the forests are to be preserved, how to provide the new lands that are almost certain to be needed for agriculture). There is almost no aspect of national and international policy that can remain unaffected by the prospect of global climatic change. Carbon dioxide, until now an apparently innocuous trace gas in the atmosphere, may be moving rapidly toward a central role as a major threat to the present world order." The USA Carter Administration in its National Energy Plan proposes to double domestic coal production in the next decade or so: from 665 million tons in 1976 to 1.2 billion tons by 1985. However, according to a report to Congress prepared by the General Accounting Office (GAO), the prospects are not good. The GAO study entitled "U.S. Coal Development—Promises, Uncertainties," concludes that, "in fact, it will be very difficult to achieve one billion tons annually by 1985" [9]. Over the longer term (beyond the year 2000) it appears to the GAO analyses that coal will be both supply-constrained (particularly with regard to low-sulphur and metallurgical coal) and demand-constrained (in the sense that utility and industrial users are not going to buy coal if they cannot use it). The very-long-term prospects for increased coal demand, "ride on the hope of coal gases and liquids becoming environmentally safe and economical." There is no question, according to the GAO report, that "coal will supply a large part of the nation's energy future." The required "trade-offs" will be costly, however, "particularly in terms of human life and disease." If in the final analysis it is decided that the costs of coal use beyond a certain level are too high, and increased oil importation is not a tenable alternative, then, the report states, the U.S. has only two major alternatives open to it between now and the year 2000: (1) to accelerate the expansion of conventional nuclear power so that nuclear-generated electricity substitutes for oil and gas wherever possible, or (2) to improve energy conservation, through both increased efficiency and decreased consumption. [9].

The situation is made more critical by the U.S. Administration policy of stopping the reprocessing of spent fuel involving plutonium and delaying the introduction of commercial fast breeder reactors. This creates the problem of storing plutonium which is a valuable fuel and should be burned for its energy. At the Iran Conference on Transfer of Nuclear Technology, some of the 109 nations which signed the global nonproliferation treaty said they might withdraw as a consequence of the U.S. nuclear control policy: because they could no longer benefit from the accord, which is designed to prevent the spread of nuclear weaponry around the world, and promote the peaceful uses of nuclear energy [7].

There have been estimates that under the present Light Water Reactors