(First Rough Draft)

SOLAR ENERGY CONVERSION AND THE FEDERAL REPUBLIC OF GERMANY--SOME SYSTEMS CONSIDERATIONS

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Introduction

During the coming fifty years or so the industrialized nations will have to carry out the transition from the present major dependence on the fossil fuels to dependence on some mix of long-term energy options. These options are geothermal energy, the fission and fusion sources, and solar energy. The potential new role of coal is a special one and will require careful consideration during this transition period. Since in the industrialized world especially we do not use the primary sources directly, but rather use secondary forms such as refined fuels, electricity and to some extent heated water, the interface between the primary sources and the secondary energy infrastructures will also be an important issue.

One crucial aspect of the energy problem is that it will require three to five decades to make such a transition. Given the requirements for technological development lead times, the enormous amounts of capital required, and the dynamics of market penetration for large-scale new technologies, I see no way in which this transition period can be significantly compressed.

An additional consideration is the need for "resilience" in our energy strategies for the future. The parallel development of a diversity of options constitutes an insurance policy against an uncertain future. If, for example, after the two decades of lead time required to bring a major new technological option to commercial readiness, we encounter serious difficulties, we could use other options also brought to commercial readiness <u>during the same time period</u>. <u>This would permit us to "buy time"</u> to correct the problems associated with the first option (or even abandon it for the time being) and still continue with the business of society. Unavailability of alternatives forces us to suffer the consequences of decreased growth in energy production or the consequences of using the option which has turned out to be in some ways a serious problem.

At IIASA we are concerned with trying to better understand the various energy systems options which will be available on a long-term basis, and to understand the dynamics and ramifications of carrying out various strategies for the large-scale use of these various options. Each of the four major classes of long-term options has its problems. In particular, when new technologies are deployed on a very large scale (i.e., approaching the terawatt regime) many systems problems arise which were not perceived during the initial period of scientific and technological development.

In the field of nuclear energy, for example, we have seen a world-wide development of concern over the large-scale deployment of power reactors at the very time when such technologies could be having a significant impact on energy problems. At IIASA we have been concerned among our various energy-related studies with such issues as reactor safety, public perception of risk, and strategies for isolating the nuclear fuel cycle from the "sociosphere" as well as the ecosphere as we approach the terawatt domain with fission technologies. This work has been extensively discussed elsewhere(1-5).

Because of our concern with the overall question of energy and its large-scale use, we recently began to examine the solar option as part of our research activities (6,7).

During the past few years there has been an enormous rise in both public and political interest in the potential use of solar energy for production of mechanical energy, heat, electricity and synthetic fuels. As an energy source it has the advantages of being non-depletable and accessible in the same form forever. It is very widely distributed and not subject to embargo, and is of very high thermodynamic quality. (With attainable concentration techniques heat can be generated at temperatures close to the surface temperature of the sun.) Moreover its use would appear to bypass some of the problems associated with the combustion of fossil fuels and the use of nuclear fuels.

However, solar energy as a large-scale primary energy source also has some negative aspects. It is a low-density source, never exceeding a power level of approximately one kilowatt per square meter at sea level. It is subject to the diurnal and seasonal cycles and to weather conditions, and it is not storable. Because of its low density, very considerable surface areas will be required for solar conversion machinery to provide really significant amounts of energy to mankind. To provide half of the average primary energy requirements of the world today would require covering 130,000 square kilometers of sunny land with machinery with an average of twenty percent solar conversion efficiency. This represents about 0.1 percent of the land area of the world and is equivalent in area to roughly one percent of all of the land which is arable or under crops. To provide half of the primary energy requirements of a world of ten billion people using an average of 5 kw(th) would require slightly over four million square kilometers of sunny land (average of kwh per sq. meter-day), an area equal to almost three percent of the land surface of the earth or equivalent to about one-third of the total arable and cultivated land of the world today.

If the solar option is to be a real, long-term, global primary energy source for the activities of man, the potential structure and impact of systems with an aggregate size *in the million square kilometer range* will have to be seriously examined.

In this paper I will briefly explore some of the issues which may arise when considering the potential role of solar energy conversion options for central Europe in general, and for the Federal Republic of Germany in particular. My remarks here are a prelude to the work which we anticipate carrying out over the coming 12 months and are therefore preliminary rather than representative of a completed study.

A Systems Perspective of the Solar Option

Solar energy can be converted into various useful forms of energy such as shaft horsepower, heat over a very wide temperature range, electricity and synthetic fuels. The technologies for providing low temperature heat for buildings have been discussed in detail in this workshop and will not be discussed here. Rather, in later sections, I will consider some of the economic and institutional aspects of these solar-thermal systems options.

In addition to conversion of sunlight to heat, there are various possibilities for production of electricity. The solar-thermal electric conversion technology under development by MBB in the Federal Republic, by CNRS and Electricite de France in France, and by a number of government sponsored industrial teams in the U.S., may eventually be able to compete with the production of electricity by combustion of oil at the present world market prices, even in central Europe (8). Prototype systems in the range of 1.0 to 100 megawatts electric will be operational early in the next decade. The French are planning a 25 Mwe French central receiver solar thermal electric plant for the early 1980's. Present U.S. plans call for construction of a 5 Mw(th) solar test facility by 1978, a 10 Mw(e) central receiver pilot plant by 1979 and a 10 Mw(e) distributed solar-thermal-electric system by 1981. In addition, the current plans (9) call for a 100 Mw(e) solar- thermal electric plant by 1985. Facilities in the 100 Mwe range could be commercally available well before the end the century; perhaps as soon as the late 1980's. Although photovoltaic processes have been generally regarded as far too expensive for terrestrial applications on a large scale, recent work by the Mobil-Tyco Solar Energy Corporation (10) in the growth of single-crystal ribbon silicon is among the possibilities which could lead to commercially interesting terrestrial photovoltaic modules becoming available within the coming ten to fifteen years. The direct conversion of solar-generated heat to hydrogen by combined electrical and thermal processes or direct thermal dissociation of water is an additional major option for the long-term, although considerable technical and engineering work remains to be accomplished to determine the feasibility of such an approach.

In order to make use of solar energy conversion in an industrialized society, we have to concern ourselves with the nature of the enormous, complex, integrated energy systems which mobilize the primary energy resources and produce and distribute the secondary forms. These systems are made up of four basic components or subsystems - energy conversion, storage, transport and power conditioning. The power conditioning subsystem includes both the hardware and the software, or organizational processes, for operation of the system.

An important concern for the systems analyst interested in solar energy conversion is the behavior of such energy systems when solar conversion elements are embedded in them. For example, a building can be considered as an energy system - fairly simple for the case of single-family dwellings and quite complicated for very large building complexes. If solar conversion elements (collectors) are embedded in a building , how will the performance (technical and economic) of that building system be modified? In addition, since buildings are embedded in the much larger electric utility and fuel systems of a region or country, how will the embedding of large numbers of solar heated buildings affect the operation of the fuel and electrical systems? This latter issue is not trivial. Economic considerations dictate that solar heated buildings have a supplementary supply of energy (electricity, gas,oil, district steam or hot water, etc.) as a backup for periods of cloudy weather or unusally high demand. Since these buildings will be embedded in a larger energy distribution system, they will possibly aggravate the peak demand problems for the distribution system. Such issues are currently under study at the Southern California Gas Company (11), the Southern California Edison Company (12), the Electric Power Research Institute (13) and elsewhere. In the event that the presence of solar heated buildings in large numbers requires the gas or electrical utilities to install additional generation or supply capacity to serve the peak demand, this will have to be reflected in the rate structure and may result in some direct penalties to solar heated buildings. On the other hand, the requirement for on-site storage could provide a mechanism for utility load leveling. Such techniques have been used by electric utilities to level loads using off-peak electricity for water heating and to some extent this has been applied to space heating through electric heating of concrete blocks (thermal storage) in homes in Europe. These techniques are certainly well-known in the Federal Republic and experience with such techniques (and associated issues of related rate structures) could serve as the basis for extending the analysis to solar heated buildings.

If we embed solar-electric conversion elements in an integrated modern electrical utility system, we will have to determine the impact of this embedding on system behavior and reliability. How much short-term and long-term storage will be required in order to make optimal use of the solar electric generation units? How much additional generating capacity will be required to insure meeting the standard utility system reliability criterion of not more than one day in ten years when peak demand exceeds system supply capability? (This important issue of margin analysis has been examined by the Aerospace Corporation (1), Minneapolis- Honeywell(15) and is under consideration at EPRI(16) currently.) What kinds of strategies are required for solar facility siting? How will the economic constraints on the solar generating units change as the solar-derived percentage of total generating capacity increases? What will be the spatial and temporal environmental impacts of deployment of large numbers of solar electric units and the associated requirements for storage and distribution? I feel that these are some of the systems issues which must be examined carefully in conjunction with electric utilities in Europe before the solar electric option can be ruled out as a potentially significant future electricity option.

In the case of conversion of solar energy to synthetic fuels (e.g. hydrogen, perhaps by a combined electrolytic and thermal dissociation process) we will need to know how this hydrogen can be used and what it will be worth, in part to determine investment thresholds for solar fuel production facilities. How does producing hydrogen from sunlight in central Europe compare with, for example, production in North Africa or the Middle East and shipment by pipeline, or with production in Australia and shipment by cryogenic tanker to Europe? I would like to propose that this latter possibility - that of creating a synthetic equivalent of a (non-depletable) giant oil field - also deserves serious consideration. Hydrogen is a secondary energy form suitable for global transport. High efficiency conversion of sunlight and water to hydrogen in intensly sunny, remote regions with abundant non-productive land might ultimately compete with the use of on-site solar-thermal systems on buildings in Europe. In addition, it is the one solar energy conversion process which can in principle provide all of Europe's total energy needs. The possibility of storage of hydrogen in depleted oil and gas fields in Europe would provide reserves of several years total demand. This permits both buffering between the output of the remote, continuous production systems and transportation infrastructure against the variable demand, and some insurance against potential embargo problems. Furthermore, the diversity of potential sites for such synthetic fuel fields is far greater than the diversity of sites of giant oil fields. This diversity would also permit a more resilient energy strategy in terms of unanticipated political events. I recognize that this proposal may have, to some, the air of science fiction about it. Nevertheless, I believe all of the technological problems can be solved. The major issue would be the cost of constructing and operating such a system and to date I have not seen a detailed cost estimate for this approach. It is an area which we intend to explore further at IIASA.

Finally, for each of these options, what would the systems look like in detail? What would be their requirements for capital, energy, water, land and materials?

Each of these questions must be examined if the entire menu of potential large-scale solar energy options is to be seriously and carefully explored.

In the case of central Europe, two immediate issues come to mind - the adequacy of available sunlight and land. I believe the general impression of many people is that there is neither sufficient sunlight nor sufficient land to permit solar energy conversion - in any technological format - to become a really interesting option for this part of the world. The results of our preliminary study of the potential use of solar thermal electric power generation in Austria (7) suggest that such technology can, with reasonable interest rates (8 - 12 %), amortization times (15 - 30 years) and the current estimated costs for such systems (DM 75 to DM 175 per square meter of heliostat), be competitive with combustion of oil for electric power generation. Similar results may also apply to Germany. The land area constraints are discussed in a later section of this paper.

The remainder of this paper is devoted primarily to issues relevant to the use of solar-thermal systems for water and space heating in buildings. In particular, I have tried to indicate some of the present range of cost estimates, and some of the institutional issues which may be of importance as the solar-thermal technologies become commercialized in the Federal Republic.

Energy Conserving Design of Buildings and Communities and the Potential Role of Solar Energy Conversion

Energy conservation has been a general concern in Europe for considerably longer than in the United States due to the much longer history of high energy prices. However, the emerging availability of commercial solar-thermal hardware for building applications may be an incentive to re-examine the question of energy conservation in building design and operation in all parts of the world where cost and availability of energy is an important issue.

A substantial literature from Europe and the U.S., based on both research and actual experience, has emerged in the area of energy conservation in buildings over the past several years (17). My purpose here is only to highlight some of the more important aspects of this work as it relates to the potential use of solar-thermal systems for buildings.

Energy use for space conditioning of a building is determined by a number of factors, including the characteristics of the "skin" of the building, the design of the internal heating, ventilating, and air-conditioning (HVAC) system, and the operating cycle and maintanence schedule of the building energy system. In addition, of course, is the external environment to which the building as an energy system must adapt to provide acceptable levels of interior comfort.

Virtually all residential structures, from individual houses to high-rise apartment buildings, have heating and cooling requirements which are dominated by the skin response of the stucture. The conduction of heat through the skin and the solar load on the structure (especially by transmission through glazing) are far more important than the internal generation of heat in determining the heating and cooling requirements. By contrast, large commercial structures, such as office buildings, have energy requirements which depend primarily on internally generated loads from people, lighting and machinary, as well as on requirements for bringing in outside air and controlling internal humidity. This is why such buildings have energy demand profiles which exhibit little difference between summer and winter, even in extreme climates. They are essentially being air-conditioned all year.

In the case of residential structures, modifications in the shell of the building, through the use of such measures as insulation, weather stripping, double glazing, and shading devices to control solar heat gain, can decrease overall space heating requirements by a factor of two to three over those associated with the type of residential structures commonly built in the United States. (Although the current trend is towards energy conservation). The difference between conventional and "energy conserving" housing in Germany may be considerably smaller since energy use has been of far greater concern in Europe than in the U.S. until very recently. In any case, approaches to energy conservation for residential structures in the U.S. through establishment of prescriptive standards affecting the building shell appear likely to be effective (18). In the U.S., such standards have been developed by a number of different bodies (19) and adapted in many regions at the state and local level, as well as by the Federal Government for homes with mortgage insurance provided by the Federal Housing Administration.

In the case of the HVAC systems, there is relatively less which can be done beyond requiring high efficiency fuel conversion units or perhaps heat pumps instead of straight resistive heating.

Large commercial buildings are far more complex, and relatively more expensive. The HVAC systems can be responsible for as much as forty percent of the cost of the entire building. In this case computer modeling of the response of the building as an energy system to a combination of external weather, sun, and building operation requirements, is invariably required to design highly efficient buildings. In the U.S. the traditional concern of builders to build at minimum first cost has resulted in large buildings with energy requirements as much as four or five times greater than would be required for slightly more expensive buildings designed to be energy conserving. It has been demonstrated that no single factor can account for this difference, but rather through a combination of architectural design, energy system design, building system operation and careful maintanenence such large reductions in energy requirements can be achieved. These measures can and generally will be cost-effective over the lifetime of the building at present prices for electricity and fuels.

The complexity of such buildings precludes, however, any simple prescriptive approach to energy conservation as is possible in residential buildings. Rather, a set of performance standards which specify the overall energy performance of the building independent of architectural design, HVAC system desgn, and building operation and maintanenence, are required. In the U.S., the state of California has spent almost two years in the development and imposition of such performance standards on the construction design of new non-residential structures. (20) Although the use of performance standards requires considerably more work on the part of the architect, engineer and building plan inspection agencies than prescriptive measures, this performance approach permits a highly flexible and individual approach to energy performance optimization for each building. The eventual effectiveness of this performance-oriented approach to energy conservation in buildings is as yet not known, although analogous performance-oriented approaches have been effective in such areas as earthquake-resistive structural design of schools and hospitals in California. It is my contention that performance standards are the appropriate context for the encouragement of the use of solar-thermal systems in buildings.

Solar collectors can be considered one of a large number of architectural and engineering elements with which the design professionals can reduce energy requirements in a building. As such they will have to compete with all of the other energy conserving elements within a total life-cycle cost environment. In the case of domestic hot water systems, relatively little in the way of energy conservation can be employed to reduce the demand for hot water. Insulation of long, uninsulated piping runs and possible use of thermal exchange between used hot water and incoming cold water are among the few options. Beyond this, however, solar water heating will be required to effect a dramatic reduction in other energy required for hot water. Typically 70% of the hot water requirements for a family of four can be met using a solar water heating system of only 8 to 12 square meters, with the balance supplied by a supplementary source.

In the case of space heating (and cooling, where this is required), measures such as heavy insulation, double glazing and weather stripping are considerably more cost effective than solar components in the first stage of energy consumption reduction. However, beyond a certain point (perhaps 40% of original energy demand) such measures are no longer so effective. At this point, for residential structures, solar collectors combined with appropriate storage, heat exchange, transport and controls, can provide significant additional savings. For residential buildings and more complex commercial buildings as well, the importance of the solar components is realized as the second stage of an integrated two-step design process in which the first step is energy conservation.

In the case of complex buildings, the solar energy components are clearly elements in a total architectural-engineering-building operation strategy, and the ultimate issue will be the life-cycle cost of operation of the buildng system as a function of total energy requirements.

Solar District Heating Systems

District heating for smaller communities outside densely populated regions may be an interesting alternative to on-site solar heating. In the village of Mejannes-le-Clap in France, a solar district heating system incorporating 4,000 square meters of collectors is nearing completion. This system will provide domestic hot water and space heating to 100 dwelling units and a public swimming pool. The project is under the direction of the Societe d'Economie Mixte d'Amenagement du Gard. Similar approaches are being used in a condominium "village" in Vermont, U.S.A. and on several large commercial buildings in the U.S.

This form of energy production may place fewer constraints on urban settlement form and more easily permit retrofitting of existing structures by displacement of fuel in district heating systems for a portion of the heating requirements. In particular, the constraints associated with surface area to enclosed volume ratio requirements, orientation and size of roofs, etc. to permit on-site solar heating would be minimized. Expensive hand labor on individual buildings would be minimized and mass installation techniques could be used for fields of solar collectors and associated plumbing and storage. Economies of scale in production of standardized components could be more easily realized for the district heating approach, since this would not be so dependent on regional or local architectural, zoning or construction preferences or traditions. Also, integration with a central fossil fuel or total energy system would be simplified. It is an option which should be explored for Germany.

Economics of Solar Heating and Cooling of Buildings

Solar heating and cooling of buildings and solar water heating requires a capital investment in excess of that required for most non-solar systems. From an economic point of view, the important trade-off is between the amortization of the increased capital investment and the rate of operational cost savings due to displacement of electricity or fuel.

This is not true just of solar energy systems, but of a wide range of other energy-conserving architectural and engineering approaches. In a market environment in which the lowest first-cost of a building is more important than its operating costs, energy conserving techniques will not be widely employed. Therefore, if there is widespread use of solar-thermal systems in buildings over the coming forty or fifty years, it will be due to a market environment which requires minimization of the life-cycle costs of the structure. (In the United States the construction market has been almost exclusively first-cost oriented, with a few exceptions when the clients have been, on occasion, school districts, hospital boards, insurance companies, and others, which were concerned with long-term operation and maintanence costs of their buildings. This remains largely true in spite of the growing impact of market forces and legislative initiatives encouraging or requiring energy conservation measures in new and existing buildings.)

Given a life-cycle cost environment, we would like to know under what conditions solar-thermal systems can be competitive or life-cycle cost-effective. Ultimately such determinations will have to be made on a building-by-building basis, since the relative annualized costs of ownership and operation of buildings with and without solar equipped systems will depend on the amortization period and interest rate applied to the building, the installed cost of the solar HVAC system, the rate structure for the supplementary energy (gas, oil or electricity), the thermal demand profile of the building, and the local patterns of sunlight availability. In addition, the calculations will require estimates of the rate of escalation of local fuel and electricity costs. Each of these factors will vary widely, due to the enormous diversity in the building market. The solar systems will have to be compared on the life-cycle cost basis with non-solar options for the same building.

I hope this will be an easier process to generalize in West Germany than it has been in the United States. We (21) attempted to carry out such a calculation by comparing estimated costs of solar-assisted gas water heating with actual installed costs of non-solar gas hydronic (hot water energy transport) heating systems. Although it is very difficult to obtain detailed breakdowns in a contractor's aggregate bid (they often don't have the detailed breakdown themselves), we were able to find the installed costs per apartment unit in a number of recently built apartment buildings in Southern California. The cost per apartment unit of the installed non-solar (completely conventional) domestic water heating system varied by a factor of <u>more than two</u> due to variations in local costs of labor and materials, and in skill of the contractors. In all cases the apartment buildings were of similar size and construction. One would expect even greater variations with different geographic locales and building types.

My conclusion from this and similar experiences by others in the solar energy field is that one cannot make hard and fast rules about the relative costs of solar and non-solar systems for buildings, even when the solar components become widely accepted and used.

This does not mean that solar HVAC systems will not be able to compete with non-solar systems on a large scale. Several design professionals (22) have claimed that actual solar building projects they have designed and which are in advanced stages of construction will be life-cycle cost-effective when compared with oil heating or electric heating and air conditioning. A detailed comparison of the capital and life-cycle costs of a number of installed solar thermal systems in U.S. buildings will be published next Spring (1976) at which time I hope to be able to provide a detailed picture of the realities of the commercial solar energy activities in the U.S.

The factory cost of the solar collector is of course only a component in the total installed cost of the complete solar system. The system will include storage elements, controls, pumps, and perhaps other elements (heat exchangers and heat pumps) as well as plumbing components and structural elements to provide integration with the building. It is my experience that most researchers have been somewhat optimistic about the costs of such systems for buildings in the U.S.

In the summer, 1974, I made a survey (23) of those U.S.

companies which had entered or were preparing to enter the market with solar collectors. At that time the factory price of collectors ranged between DM 125 and DM 25 per square meter. These prices did not, of course, include the distributors' markup nor costs of transportation to site. One could purchase, for example, in summer, 197 the Miromit* solar collector (24) manufactured in Israel, with single glazing and selective absorber (1 mm galvanized steel) for DM 175 per square meter, FOB Los Angeles.

Similar costs for an assembled but unglazed collector were being quoted by Revere (25) at the time. PPG Industries (26) was quoting a single-glazed collector incorporating an aluminum Rollbond* absorber plate with integral insulation housing for the same price, and only ten percent more for double glazing. A collector incorporating a copper Rollbond* absorber plate was available for DM 300 per square meter. Sunworks (27) was offering a double-glazed collector with a selective surface on copper tube and sheet absorbers in the range of DM 175 to DM 250 per square meter. Although a comprehensive review of solar collector prices is underway at IIASA, these results will not be complete until the end of the year, since the survey was only recently initiated. However, I believe that, in the U.S. at least, we will have to expect the delivered-to-site costs of solar collectors to be at least DM 250 per square meter.

The actual costs of the installed systems (capital and operating) are what we really need to know. Some cost figures based on careful estimates and on actual experience are now becoming available. I will mention a few of them here. Professor

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* Trademark

J. Duffy (28) has carried out a detailed set of calculations on the cost and performance of solar heated and heated/cooled (cooling of course not a major issue for the FRG) buildings for various regions of the United States. He has developed a computer program to carry out these calculations for a fairly simple solar water and space heating system for single residences. Assuming an installed cost of DM 200 per square meters for collectors, and additional system costs of roughly DM 3000 for storage, controls, pumps, etc. (for 60 square meters of collector area) he concludes that such a system would be competitive in Madison, Wisconsin (with an extremely severe Winter heating requirement) when fuel costs exeed DM 15 per million kilojoules. An annual charge of 12% was assumed for the capital investment. Roughly 60% to 70% of the total annual heating requirement was provided in this calculation by solar energy, with the balance supplied by auxiliary fuel converted at 60% efficiency. The specific three bedroom single-family house used by Duffy as an example of the calculational procedure had a space heating load characterized by 1360 kJ per hour pr deg. C temperature difference (inside to outside), and a water heating load of 300 liters per day, heated from an average of 11 deg. C water main temperature to at least 60 deg. c.

Duffy's results indicate that heating oil must cost at least DM 90 per barrel before the solar system can become competitive in life-cycle terms. If the installed costs of the collectors are twice as high - DM 00 per square meter - then the cost of heating oil would have to be roughly DM 180 per barrel before life-cycle economic competitiveness were reached. It is clear for residential applications that the primary target in the development of commercial solar-thermal systems must be reduction in the installed costs of solar collectors.

Heating oil in the U.S. is approaching the DM 75 per barrel range (and is now at that level in Austria) which means that if solar collectors can indeed be purchased, transported to site, and installed for total costs of under DM 250 per square meter, there is some hope that in cold climates typical of the northern U.S. and of much of Germany that such systems would be life-cycle cost competitive.

The Westinghouse Electric Corporation commissioned a detailed study of the performance and costs of various solar thermal systems for six types of buildings in five regions of the United States. This study was carried out by the architectural firm of Burt Hill and Associates (Butler, Pennsylvania), as part of the larger Westinghouse "Phase Zero" solar heating and cooling of buildings study commissioned by the National Science Foundation (29). The building types were single and multiple family dwellings, mobile homes, schools, office buildings and stores. The regions (characterized by a single year of weather and insolation data) included Atlanta, Georgia (1956), Mobile, Alabama (1963), Santa Maria, California (1957), Wilmington, Delaware (1956) and Madison, Wisconsin (1956).

A variety of solar systems was carefully studied. For example, in single family dwellings, systems including solar heating and absorption air conditioning, solar heating only (with electric compression air conditioning), and solar- assisted heat pumps were examined.

The detailed results are available in the Westinghouse report (30) and will not be repeated here. The main points are that the approximate cost of the energy (heat) provided by the solar heating systems for the various building types and locations ranged from roughly DM 7.5 per million kJ for solar heated schools in Wisconsin (50% solar load) to DM 17 per million kJ for a solar heat pump system in a single family dwelling in Santa Maria, California. (80% of load carried by solar.) In most cases the installed costs of the collectors alone could not exceed between DM 50 and DM 150 per square meter to compete with heating oil (or equivalent) at DM 50 per barrel. The authors of this study felt that the development of procedures to integrate collector arrays into buildings to replace sections of roof would permit taking credit for a portion of the roof structure, and that the installed costs could be lowered to equal the costs of the collectors themselves. Again, the potential for life-cycle cost effectiveness in regions similar to central Europe was implied as a possibility as long as the competition is with expensive heating oil or electricity.

Estimates of the installed costs of solar heating and cooling systems in schools, offices and multifamily dwellings were made. Excluding the installed costs of the collectors, the remainder of the system (installation, plumbing materials, storage tank, plumbing markup, absorption air conditioner, supplemental heat system and associated ductwork) was in the range of DM 125 per square meter of collector area. The assumption that mass-produced collectors could be available at prices of forty dollars per square meter raised the estimated costs of the entire installed systems to between DM 250 and DM 375 per square meter, depending on building type.

The authors of the study are somewhat optimistic, and they base this in part on the assumption that energy costs will rise faster than the labor and materials components of solar collectors and that we can expect the "learning curve" effects of solar collector production technique evolution to bring the costs of the collectors in present dollars, to lower levels.

My final example is a cost breakdown for a large solar heated and cooled facility currently under construction at Los Alamos

Scientific Laboratory in New Mexico. (Fig. 1) I present this example because, as the solar consultant to the consulting engineering firm responsible for the building design, I was able to obtain the details of the contractor's bid breakdown. The details of this breakdown will be discussed in a separate paper on the Los Alamos building, (31) and I will only summarize the results here. I must emphasize that these are the costs quoted by a low bidder for a building in which all components are "off the shelf" with the exception of the solar collectors.

The National Security and Resources Study Center at Los Alamos is a three story, 6100 square meter structure that will serve as a technical library and conference center. The building was designed by Charles Luckman Associates (architects, Los Angeles) and Ayres and Hayakawa Energy Management (consulting engineers, Los Angeles). A major consideration in the design of this building was the incorporation of energy-saving measures including deep over-hangs with vertical fins for solar control, additional insulation glazing at windows, reduced lighting levels, hot and chilled water storage tanks for off-hour energy usage, outside air economizer cycles, and heat recovery units. The solar-augmented mechanical system with a 740 square meter south facing, 35 degree elevation solar collector, supported by roof trusses from the lower level mechanical equipment room to the third floor, will provide 87 percent of the annual heating and cooling requirements of the building. A study by the consulting engineers used computers to determine peak loads and predict the anual energy consumption for alternative HVAC systems employing solar collectors and thermal storage.

SOLAR ENERGY SYSTEM COST BREAKDOWN

National Security and Resources Study
Center - Los Alamos Scientific Laboratory

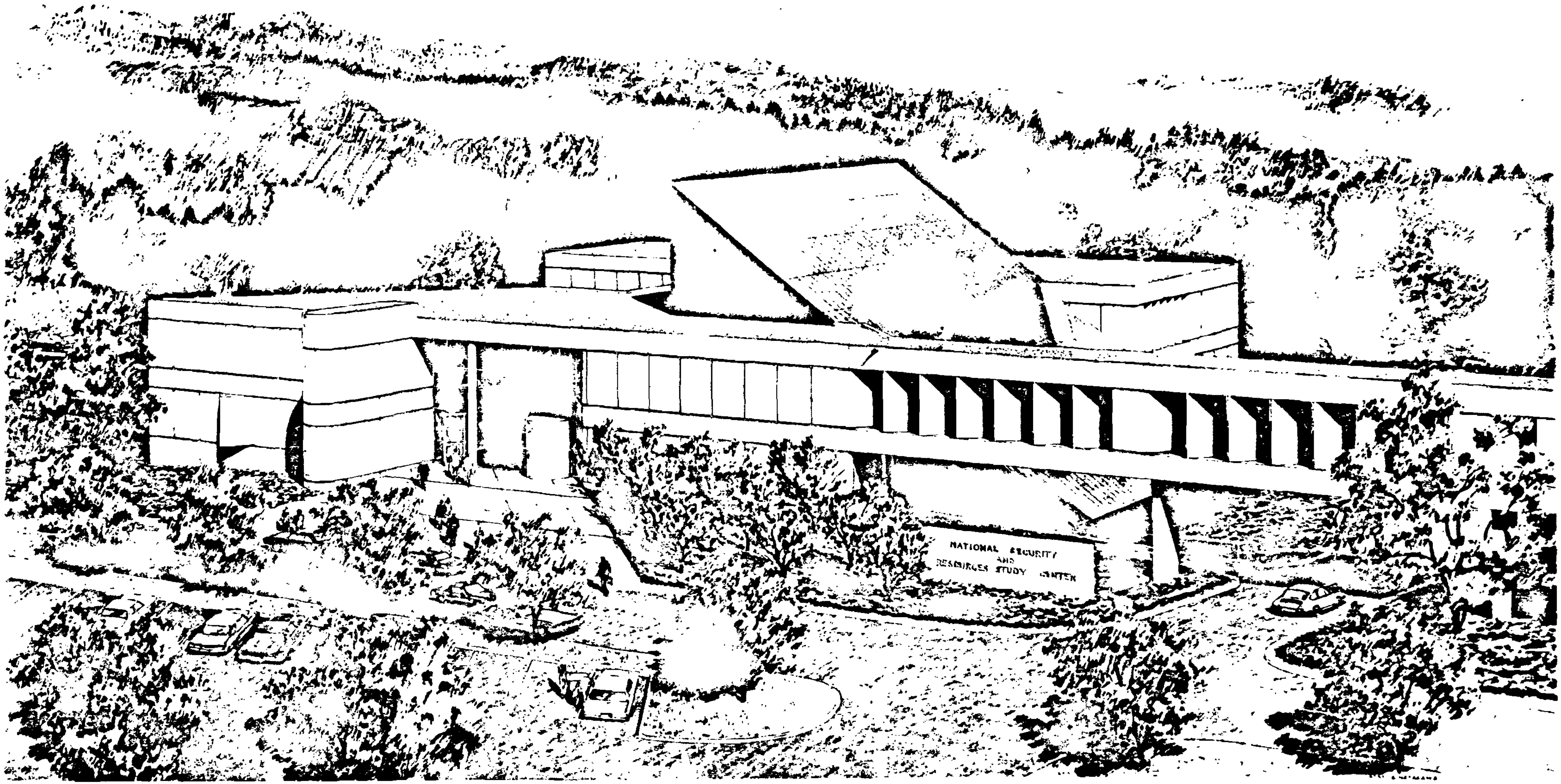
I.	Architect and Engineer (fee)	$	56,000
II.	Construction Costs		
	A. Structural		135,000
	B. Mechanical		118,000
	C. Electrical		7,760
	D. Energy Conservation Measures		132,075
	E. Instrumentation		195,000
	F. Architect markup		110,005
III.	Solar Panels ($ 150/m^2)		125,000
	TOTAL COST	$	878,840

Total collector area = 800 m^2

System cost per square meter =	$ 1100.	=	DM 2750
System cost without instrumentation, energy conservation	$ 690.	=	DM 1700
System cost without instrumentation, energy conservation or solar collector costs	$ 540.	=	DM 1350

NOTE: These cost estimates are taken from the bid breakdown from the contractor awarded the construction contract. The costs DO NOT include the non-solar components of the HVAC system such as normal duct work, absorption chiller unit, and so forth. These are the SOLAR SPECIFIC costs for the system.

Table 1.



'IONAL SECURITY & RESOURCES STUDY CENTER

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The total costs for the solar-specific portion of the building are shown in Table 1. Including all fees, parts, installation and markup, the total cost was 878,840 dollars for the system. This translates to roughly 1100 dollars per square meter (DM 2750 per square meter) for the system. Excluding the collectors, energy conservation features or instrumentation, we are still left with an installed cost of 540 dollars per square meter (DM 1350 per square meter). The solar panels were developed by Los Alamos Scientific Laboratory under a grant from ERDA and were charged against the project at DM 425 per square meter. It remains to be seen if this particular building represents an exceptionally expensive, early example of a careful and detailed engineering and architectural effort, or is fairly typical.

I conclude this section with a few observations on the development of commercial solar heating systems in the Federal Republic of Germany. It is clear that a combination of increased performance per unit area and decreased total installed cost per unit area of collector is the critical component of acceptable solar thermal system cost goals. Because of the potential for integrating solar considerations into buildings via the system building approach, I would like to repeat a few observations made earlier by Schoen and myself (32).

The integration of solar HVAC systems and building design and production could have a number of advantages over the usual process. Institutional constraints virtually rule out such an approach at this time in the U.S. but it may be possible in parts of Europe, including Germany, Scandinavia and France. Some potential advantages of the integrated approach might be that special preparation of conventional buildings (to accept the solar hardware) would not be necessary and the high cost of on-site installation of solar and related components could be decreased through factory integration. Aesthetic considerations may be easier to handle through integrated design. Predictable levels of thermal insulation and other properly integrated energy- conserving design techniques in systems-built structures could perhaps provide the appropriate environment for minimizing the entire costs of an installed solar HVAC system. Finally, the level of technolgy and systems orientation required for effective integration of solar hardware into mechanical and structural systems would be more characteristic of systems building than conventional building. Engineers and designers would work together, and this is crucial with the use of solar equipment whose performance, and costs are directly related to building form and structure. Ultimately we could expect to see the development and emergence of a "solar architecture".

Of course, there will also be some possible liabilities to such an approach. Solar heating will place new constraints on the design and orientation of buildings. Also, the systems builder looks to aggregate markets. However, solar systems must be designed to reflect various climatic environments. The combined system must somehow be sufficiently flexible to permit the cost savings available through sustained industrial production of the building units while being able to adjust to a range of climatic requirements.

Institutional Considerations in the Introduction and Diffusion of Solar-thermal Technologies for Buildings

The development, introduction and widespread commercial diffusion of a new technology is a highly complex process which is only partly technical in nature. Studies by Rogers (33) and others have shown that the diffusion of innovation involves many cultural determinants which interact to constrain the rate and scale of acceptance. In the case of commercial innovations, these cultural and institutional factors are especially important in determining if and when the innovative product or process can reach the market penetration thresholds required to more or less insure an eventual large share of the potential market. (I'll have more to say on the issue of market penetration dynamics later in this paper).

Although it may seem "irrational" to many of us, it is nevertheless true that in the building industries of the Western nations, many technical innovations which appear technically sound and economically attractive often fail to achieve widespread acceptance. This is perhaps especially true of the U.S. building industry, although the European building industries, considerably more rationalized by the necessity of rebuilding after 1945, will also experience such institutional and "cultural" constraints. Such institutional factors must be taken into account early in the process of commercial development of solar-thermal products if we are seeking the maximum likelihood of widespread commercial success. This is important because although the removal or absence of institutional constraints cannot force an uneconomic innovation into the market on a large scale, the presence of such constraints can severly erode the chances for success even when the innovation is economic.

In 1972 I organized an interdisciplinary team (34) at the California Institute of Technology to examine the potential for the use of solar-thermal technologies for buildings in Southern California. The disciplines represented included engineering, architecture, physics, economics, sociology, anthropology, and law.

In exploring the potential use of solar thermal technologies for water and space heating in Southern California, we were lead by the architect and social scientists to consider the problem of introduction and diffusion of solar-thermal technologies as <u>a problem of innovation within an innovation-resistant culture</u> (the building industry). Although it was clear that significant technical and economic work was necessary on the solar systems themselves, the technology might never be used (or even appropriately designed) if the larger institutional nature of the eventual marketplace was not well understood. In the U.S. many very large firms have suffered enormous losses in attempting to enter the building industry with various products which appeared economic and also technically satisfactory. This has been documented by Schoen , Hirshberg and myself in a number of papers and a recent book (37) concerned with the institutional aspects of development, introduction and diffusion of new energy technologies (particularly solar) into the U.S. building industry.

Because the institutional factors can be the eventual determinants of the rate and scale of acceptance and use of new technologies within the building industries of the Western countries, I have included a brief description of the U.S. building industry from an institutional perspective. (35)

The U.S. construction industry is, in the aggregate, one of the largest components of the American economy. It accounts for a total annual investment in new construction in excess of one hundred billion dollars, with some forty billion dollars invested each year in new residential construction alone. In spite of its primary position in the economy, this industry is first-cost oriented, unable to generate significant capital internally, and is extremely sensitive to national economic cycles.

The industry remains craft-based rather than technology-based, and sustains relatively little in-house research and development activities when compared with other major U.S. industries. It operates within a powerful and changing labor environment, a myriad of local code jurisdictions, and is exposed to the effects of multiple decision point and project approval cycles. It is understandable that *introduction of any innovative product or process which might create additional difficulties or expensive delays in construction is strongly resisted*.

The industry is dynamically conservative. That is, it tends to respond to attempted innovations or change, in ways which preserve its established operating modes, in order to avoid still greater risk and uncertainty. This is a natural consequence of its structure and the manner in which it must do business.

In any building project, a large number of individuals must interact at various stages of the project. The introduction of an innovative product or process frequently must involve acceptance by a large subset of these industry participants, such as the developer, the architect, engineer, contractor and subcontractors, building department officials involved in plan-check and approval, building inspectors, labor unions, lending institutions, and others.

The process of obtaining acceptance from each of these industry actors is time consuming, raises issues of performance uncertainty, and almost invariably increases the perceived risk of each participant. It should therefore be no surprise that under these circumstances few individuals embedded in a building project will push for an innovative approach when an accepted and familiar one will also work. This is especially true in the building industry, since few innovations can offer really substantial economic advantages to the project as a whole when the cost of a building project is distributed over many hundreds of individual components.

A partial list of institutional factors which can inhibit the development or diffusion of an innovation in the U.S. building industry would have to include the following:

Building codes (mechanical, electrical, structural, fire safety, plumbing, etc.)

Regulations and laws of local, state and Federal agencies including regulatory bodies

Tax laws

Local zoning ordinances (sometimes including local art juries which can constrain architectural form and appearance.

Industry and professional practises which determine the manner in which the various professions and trades work together.

Contractual relationships and laws which establish obligations and determine liabilities for architects, engineers, contractors and others.

Local labor practises.

Laws governing the operation of lending and insuring institutions.

Local "practise" and "rules of thumb" of lending institutions in determining qualifications for construction loans and long-term mortgages.

Local building department approval processes.

Traditional practises of local zoning and planning officials.

Availability and rate structure for electricity, gas, oil, district heat, etc.

Attitudes of local utilities towards energy-related products and building practises, and relationship of utility services to these.

Practises and rules of thumb of national mortgage insuring institutions such as the Federal Housing Administration, the Veterans' Administration, etc.

Availability of capital and prevailing interest rates.

Environmental concerns and movements as industry market forces

Weather and climate.

Prevailing trends and attitudes of producers and consumers towards architectural design.

The thousands of local code jurisdictions (often with mutually incompatible requirements even in adjacent locales).

Skilled trade union practises and jurisdictional arrangements.

Lack of an established legal body of urban sun rights and three-dimensional zoning practises,

and so forth.

Consideration of these institutional factors lead us to examine a variety of strategies by which solar technologies for buildings might be introduced and successfully diffused in the commercial U.S. building marketplace. Project SAGE, discussed below, was our attempt to learn more about this process by attempting to catalyze a real-world commercialization project for solar-thermal technologies.

I should add, with emphasis, that the point of this discussion is not to demonstrate that solar technologies cannot be used. On the contrary, I believe that a thorough understanding of the industry factors which can operate as constraints on solar technologies will make it possible to design more effective research, development and business strategies and increase the chances that this option can really make a significant long-term contribution to our energy needs.

Project SAGE - A Utility Based Business Scenario for Commercial Introduction of Solar-Thermal Technologies

In Southern California, domestic water heating and space heating account for six percent and nine percent respectively of total primary energy demand for all sectors. This market has been completely dominated by natural gas for the past several decades, with over 95% market penetration. In principle this large fraction of primary energy going towards production of low-grade thermal energy would appear to be a potentially significant area for application of solar water and space heating technologies. We realized that no technology - solar or otherwise - could compete with the artificially low prices for natural gas in this region, but anticipated both curtailments and dramatic price rises within the period 1972 to 1985. The curtailments have come faster than either we or the Southern Calif. Gas Co. expected, but the price rise has been slow due in large measure to political opposition to price deregulation of natural gas. Nevertheless, the costs of new gas from either coal gasification or imported LNG will be far higher than costs of domestically produced natural gas and will require massive capital investments in the associated infrastructures. For example, the present market for natural gas in the Southern California area is 70 million cubic meters per day. In order to increase the present supply capability by ten percent by LNG import from Indonesia or Australia, an investment in the LNG infrastructure would require some two billion dollars. This exceeds the capital worth of the entire local gas company which is, in turn, the world's largest gas utility.

Preliminary calculations indicated that heat from solar water and space heating systems might be competitive with such additional gas, provided the rate structure was appropriately designed. In addition, the investment required for a utility to get into the solar heating area would be on the order of millions of dollars, rather than billions, as is the case with either coal gasification or LNG imports. Furthermore, the solar market can be explored incrementally. By contrast, the first gas from LNG imports or coal does not become available until after a massive capital investment has been made.

Mr. E. Davis, one of the Jet Propulsion laboratory engineers working with us at Caltech developed the proposal for a utility-based business plan for marketing, installation and service within its service territory. The utility would bill for the total heat provided by a mix of sunlight and gas or sunlight and electricity, and amortize the procedure over the rate base. Subsequent analysis indicated that mutlifamily dwelling gas-supplemented solar water heating would be the earliest important point of market entry in the Southern California region.

After a year of exploratory cooperative studies between the Calif. Institute of Technology's Environmental Quality Laboratory and Jet Propulsion Laboratory, and the Southern California Gas Company Research Division, a gas Co. lead program has emerged, with partial support by ERDA. This project, called Project SAGE (Solar Assisted Gas Energy) has included detailed economic, technical, and institutional studies in parallel. On the technical side, a three story 32 unit apartment building in Southern California has ben retrofitted with a commercial solar water heating system supplemented by gas, to further explore the detailed technical and economic characteristics of such systems, including maintanence requirements and costs. In addition, the Gas Co. has been exploring various possible marketing strategies and the potential significance of the various regulatory and other legal constraints within which they must operate. Although it is too early to determine the extent to which these gas-supplemented systems will actually penetrate the residential water and space heating markets in Southern California, this project is paving the way for rapid market introduction once the appropriate conditions arise. Since such systems CAN compete today, on a life cycle cost basis, with all electric water heating, the possible curtailment of natural gas in the form of denial of new hookups could create an important point of market entry in the next few years for this technology.

The advantage of the utility-based scenario is that the manufacturers of solar equipment would see an aggregated market, builders would not have to incur first- cost penalties in the installation of solar hardware since this would be owned by the Gas Co., and building owners would not have to worry about maintenance. In addition, both gas and electric utilities have considerable experience in overcoming the resistance of builders to the incorporation of various types of eqipment, including the possibility of various types of subsidies. This is something no manufacturer could afford.

During this program the Gas Co. is exploring specific institutional constraints including legal questions related to broadening the means by which they provide basic energy services, subsidy of early non-economic installations (do the rate-payers or the stockholders pay for this), and the definition of responsibilities in providing energy service during construction. Regulatory constraints requiring detailed clarification include the billing rate and method appropriate to the mixed gas/solar systems, method for inclusion of the cost of early market installations in the rate base, return on investment in new systems, and inclusion of solar system maintenance with other utility maintenance expenses rather than in a separate account. Code factors include the definition of action required to establish necessary approvals for installation. Labor considerations include defining the required level of labor force and degree of training required, possible jurisdictional disputes among installation and servicing personnel, and licensing requirements for installation and maintanenence personnel. Insurance factors include the effects on insurance rates of the location of the collectors, safety requirements and overall effect on building owner's rates. Urban sun right questions include definition of legal rights of owners of solar equipment (in this case the utility).

The Southern California Gas Company has not yet decided to proceed with a major gas company-based solar energy operation in Southern California. However, Project SAGE appears to have laid the groundwork for this possibility if the market environment in the near future is conducive, and during this preparation period the major institutional and regulatory issues will have been worked out in advance. Further information on this program is available from several sources (36).

Conclusions

Solar heating systems may become economically competitive with alternatives once commercial solar systems are available. The design of systems which can be life-cycle cost competitive with heating oil and electricity will require considerable effort and skill, in a cooperative effort of government, industry, utilities, universities and others. The present effort in the Federal Republic appears to be a solid start in this direction. However, the experience in the U.S. indicates that meeting the required cost goals may be difficult.

Institutional constraints in the Federal Republic may be an important aspect of commercial success or failure of solar heating systems and should be addressed early in the technical development process. Although I must plead a lack of detailed knowledge of the German building industry, it is my impression that the institutional factors which I discussed for the U.S. building industry will have their counterparts in the Federal Republic. However, the European tradition of systems building and the more rationalized building industries (relative to the U.S.) may permit greater ease and economies in integration of solar heating systems into buildings.

In addition to the solar heating systems, I feel that other solar options, including electricity production and synthetic fuel production should be explored seriously before any final judgement as to their potential as long range options is made. In all three cases (heat, electricity and synthetic fuels) there will be important systems aspects which will have to be investigated early to optimize the technical development effort. A few of those issues have been mentioned in this paper.

I welcome comments, criticism and information which can lead to more detailed and improved versions of this paper and wish to thank the Bundesministerium für Forschung and Technologie for their interest and cooperation.

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