SOLAR OPTIONS IN CENTRAL EUROPE
A Synthesis of Solar Technology Assessment and Contemporary Criteria in 1978–1979

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SUMMARY

The contemporary (1978–1979) state of the art of solar energy conversion technology offers merely a limited view of the long-term potential of solar options in Central Europe. Nevertheless, the principal criteria are well enough understood to allow identification of the prerequisites for an accelerated use of solar systems for supplying thermal energy, as well as for electric power generation.

The global insolation (direct and diffuse solar radiation) for Central Europe ranges from about 1,000 kWh(t)/m^2/yr near latitude 50° N, to nearly 1,300 kWh(t)/m^2/yr near latitude 45° N. Considerable climatic fluctuations, pollution caused by urban and industrial concentration, and topographic influences contribute to the wide variety of uncertainties about solar energy inputs. Typical values are identified for comparative analyses. The potentially viable solar options have been analyzed in four categories:

1. Residential space and water heating systems (low-temperature options, $<100\ ^\circ\mathrm{C}$), using a variety of nonconcentrating, fixed flat plate collectors with heating oil substitution capacity of about 30 to 50 liters/m^2/yr (depending upon the economically justifiable working fluid storage capacity). The average (1978–1979) cost of such retrofits ranges from \$200/m^2 to 600/m^2 of installed systems (depending upon performance, quality, and installation difficulties of the hardware). Well-coordinated programs, leading to the integration of solar systems with other energy-saving measures, can significantly reduce their cost, while improving their performance.

2. Agricultural and moderate-temperature industrial process-heat-generating systems could use a variety of collectors ranging from nonconcentrating (fixed) to concentrating sun-tracking collectors. This choice of equipment depends upon the temperature requirements (>100 to 300 °C). Such area of application has a large potential but requires a systematic survey of many industries, which was beyond the scope of the work reported here.
3. *S*olar–*t*hermal–*e*lectric *c*oncepts (STEC) (high-temperature options, >400 °C) for generating electric power, and possibly hydrogen, in regions with favorable insolation, using high concentration by sun-tracking collectors (heliostats). System cost estimates for the 1990s for mass-produced hardware range between $1,700 and $2,200/kW(e) (1978 US$), without energy storage. This high-technology category is especially suitable for developing export and compensation trading.
4. Photovoltaic systems (fixed-angle arrays) for generating electric power, capable of converting direct and diffuse solar radiation, may become competitive with thermal systems after 1990, if the technology progresses at the same pace as in 1978–1979. System cost estimates for the 1990s (in favorable insolation regions) are between $1,500 and $2,400/kW(e) (1978 US$), excluding energy storage. For example, hydrogen could become the needed storage medium.

Parametric data and trade-off possibilities are offered to provide foundations for preliminary estimates of quantitative criteria, leading to the future contribution potential of solar options, both in the European region and in areas of higher solar insolation, where the proposed compensation trading concept (import/export) could be instituted.

The future, integrated versions of solar options could support the delineation of long-term energy policies, ultimately leading to the disengagement of energy demand from economic growth. This would be attainable by the next generation of industrial equipment and residential buildings, which will maximize the use of regenerative energy sources, subsequently decreasing the consumption of conventional energy carriers. It would include the intensified recycling of most materials, and, in particular, of those used to construct solar systems, thus drastically reducing the energy investment in the materials of intensive solar hardware. A variety of interrelated standardization and energy management measures for improving the overall cost effectiveness of solar options is considered as a prerequisite for solar options in Central Europe.

A conceptual evolution of a single-family house is shown in this report as a reference case for integrated solar energy systems, both active and passive, together with the use of heat-pumps and heat recovery from waste water, as well as from ventilated air.

A series of recommendations include the need for hardware standardization; the use of mass production methods; the need for development of more competitive energy storage; the structuring of national familiarization programs, and a formulation of a broad variety of incentives.

The synthesis of all these measures ought to serve as a stimulus to further systematic development of solar options.

PREFACE

Evaluation of solar energy as a potential substitute for fossil fuels and identification of the time phase in which solar technology may become a significant part of the energy supply mix are constrained by the characteristic uncertainties of solar energy inputs, the developmental status of solar technology, and the evolution of other energy supply alternatives. The numerous variables within the spectrum of attainable solar energy conversion performance allow a variety of approaches to the assessment of its utility. This interim effort identified the options that are now (1978–1979) most viable for solar energy exploitation in Central Europe, and the economic, as well as technical parameters of these options. In spite of the large number of contemporary concepts for the use of solar energy, a correlation with prototype data was made wherever possible to maximize the usefulness of the results. Nevertheless, the rapidly advancing research and development in solar technology, and the possibilities of significant breakthroughs in energy conversion and storage, necessitate the qualification "interim study" as an overall descriptor for this work.

The known history of engineering and industrial progress manifests the real potential of mass production, where there is objective and competent management, as well as favorable markets. The diffusion of solar technology will require a much more careful, well-coordinated effort from research, development, industrial, and governmental institutions, because it is unlikely to win a strong marketshare on its own. If left to the "forces of the free market," it may not attain the timely level of diffusion envisioned as a prerequisite for its becoming a significant element of the future energy supply mix. The fact is that the attainable performance of solar energy may be marginal in some geographic areas and locations, unless the collection, conversion, and storage are optimized in terms of durable efficiency, performance, and economic effectiveness. Even a superficial review of the collector area requirements for providing a modest solar energy diffusion shows the need for a well-coordinated, continuing overall optimization effort.

Regrettably, a large volume of research work in the energy field lacks critical review in terms of technical or economic feasibility in the given time phases and with regard to the regional characteristics. The limited resources for the effort reported here did not permit a systematic validation of the data – their selection is based on availability, years of engineering experience, and the judgment of the author.

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INTRODUCTION

The critical aspects of solar technology are still in the developmental process, the outcome of which is uncertain because of the large number of technical and economic variables affecting the application of solar options. Nevertheless, it is useful to evaluate what the justifiable rate of application of solar policy options is, which causes solar to be a growing contribution to the future energy supply mix. This is especially true when there is concern with an orderly long-term transition from nonrenewable, and often polluting, energy sources to a renewable, and cleaner, energy era.

The intermittent nature and the relatively low density of solar energy requires the use of large collector areas, which necessitates capital- and material-intensive collection, conversion, and storage systems. Unless a careful optimization of the design, orientation, and selection of a suitable solar system for a given requirement and location is made, its performance will be, at best, disappointing. A premature large-scale application of solar technology can be just as undesirable as a late implementation. For a highly industrialized region, such as Central Europe, a premature large-scale application of solar technology means using retrofit solar installations which are not likely to attain the performance and cost effectiveness of well-integrated solar installations in the next generation of buildings and industrial facilities.

A successful timing for an intensified use of solar options depends on further progress in the applicable research and development areas, and on the attainability of a competitive status with other energy supply alternatives in the future. While the desired technology assessment is currently constrained by the developmental status of solar technology, as well as by the uncertainty of the availability of petroleum and its future price, the contemporary criteria have been evaluated to provide a view of the potential of solar options in Central Europe.

SOLAR ENERGY AS A RESOURCE IN CENTRAL EUROPE

Existing meteorological data in Central Europe are merely a broad indication of solar energy as an applicable resource. Only a few meteorological stations have made measurements that can be directly applied for identification of the actual usable components of solar insolation.* The available global insolation data, direct and diffuse, must be adjusted to the local weather patterns, altitude, proximity to mountains or large bodies of water, air quality, shadowing effects (losses of illumination during early and late hours), as well as wind and humidity effects. The values vary by day and by location. In specific assessments for a given site, a stipulation of 20 degrees minimum elevation of the sun, to reduce shadowing effects, may significantly decrease the annual number of useful sunshine hours (i.e., to less than 1,100 h/yr near the Alpine regions, or to below 900 h/yr in the northern regions). This means that the annual capacity factor of a solar energy conversion system using (sunshine) concentrating collectors (to obtain higher temperatures) is less than 0.12 near the Alpine regions and 0.10 in the north, compared to fossil fuel systems, which can attain 0.70 or more.

To illustrate some typical insolation values for the Central European area, Table 1 offers averages of global insolation for latitudes 40° N and 50° N, both inland locations, arranged by seasons. It is rather obvious that most of the available solar energy is in the summer months, when less is needed except for industry and agriculture.

A review of insolation averages for the Federal Republic of Germany (FRG) revealed an average of 1,000 kWh(t)/m^2/yr and 1,650 hours of sunshine per year of which only 1,000 h/yr may be useful for conversion to a higher-temperature process heat (i.e., 150–300 °C). Furthermore, the typical specific heat demand for existing single-family houses ranges from about 150 kWh(t)/m^2/yr for a terraced house (about 100 m^2), to nearly 400 kWh(t)/m^2/yr for a separate standing house (about 120 m^2) exposed to the elements of the weather. Most of the heating is required for the winter months, and some is required during the transitional months, calling altogether for about 1,700 h/yr. Comparison of these values with insolation data for the winter and transitional months (Table 1) points to the importance of energy storage (hot water storage); the energy demand is highest when the solar energy inputs are the lowest.

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*Since 1976, an effort has been in progress to improve this situation.

TABLE 1 Sample values of insolation on horizontal surface in European areas.

Latitudes	Time of year Four winter months: Nov., Dec., Jan., Feb. (= 120 days)	Four transitional months: Mar., Apr., Sept., Oct. (= 122 days)	Four summer months: May, June, July, Aug. (= 123 days)	Annual totals (= 365 days)
50°N				
kWh(t)/m^2	130	360	600	1,090
%-year	12	33	55	100
Sunshine h/yr	230	580	780	1,590
%-year	14	36	50	100
40°N				
kWh(t)/m^2	280	520	880	1,680
%-year	17	31	52	100
Sunshine h/yr	490	770	1,000	2,260
%-year	22	34	44	100

It is characteristic in Central Europe that about a half of the insolation is diffuse. Evaluation of solar energy as a resource must therefore include a representative range of solar insolation for the various cloud covers. Table 2 provides an overview of such estimates.

Low-temperature solar systems and photovoltaic systems use both direct and diffuse radiation which make them potentially suitable for application in Central Europe. Solar energy conversion systems for moderate and high temperatures require concentrating collectors that function only during direct sunshine.

A correlation of Tables 1 and 2 together with realistic conversion efficiencies (see Table 3) provides a foundation for estimating the attainable performance of solar energy as a resource in Central Europe.

OVERVIEW OF THE SELECTED SOLAR ENERGY CONVERSION OPTIONS

An analysis of the 1978–1979 state of the art of solar technology yielded numerous concepts, representative samples of which were used as theoretical reference systems for the evaluation of the potentially suitable solar

TABLE 2 Range of typical solar insolation densities for various cloud covers.

Weather conditions	Daylight insolation densities ($\sim$kW(t)/m^2 on horizontal surface)
Heavy clouds, no sunshine, all radiation diffuse	0.10–0.25
Light clouds, no sunshine, most radiation diffuse	0.25–0.45
Hazy sunshine, most radiation direct	0.45–0.75
Clear sunshine, all radiation direct	0.75–0.90

options in Central Europe. Four categories of solar options were selected for interim technology assessment:

1. *Low-temperature options* for water and space heating (operating temperatures below 100 °C) in residential, commercial, and public buildings.
2. *Moderate-temperature options* for production of industrial or agricultural process heat (operating temperatures between 100 and 300 °C), or for the absorption type of air conditioning.
3. *High-temperature options* (operating temperatures in excess of 400 °C) as solar-thermal-electric-concepts (STEC); and possibly for hydrogen production.
4. *Photovoltaic options* for direct production of electricity and possibly for hydrogen or synthetic fuel production.

Categories 1, 2, and 4 were evaluated for application in Central Europe; and categories 2, 3, and 4 for development as potential export items and instruments for future compensation trade.

Solar technology is in various stages of development and with the exception of category 1, the existing hardware is essentially experimental, or in some cases first generation prototypes at best. This means that most performance and cost information is subject to further improvements. A composite of *projected performance and cost estimates* was used, selecting concepts of promising characteristics supported by theoretical and empirical information, to produce an overview of the reference systems. Table 3 features a comparative assessment of the selected options for the insolation regions of Central Europe, and for favorable insolation regions that are representative in some of the developing countries. The range of estimates illustrates uncertainties in design features, selection of materials, and other variables. Neither large scale energy storage nor hardware and labor transportation were included because of the associated complexities and uncertainties (particularly for remote sites in desert and mountain regions)..

In order to project a reasonably realistic capital cost structure, mass-production methods used in the automotive industry were considered representative of the lower limit of learning curves. Approximations with automotive products (European economy-class automobiles) showed a production cost average of \$3.50/kg hardware, or in terms of retail cost about \$6/kg hardware. These relate to the production of about 1.4 million complete automobiles per year (Volkswagen production is about 9,000 units per day, or 2.5 million complete units per year). It is estimated that nearly 20 years would be required to attain the desired target cost, without causing major capital and materials availability diversions, if ~85 percent learning curves are assumed.

Examining Table 3, with due consideration of the uncertainties, the overview indicates that the energy payback time favors mainly the low-temperature options and, to a lesser degree, the photovoltaic options for the insolation levels of Central Europe. If the recycling of materials is properly organized, the energy payback time can be drastically reduced. The photovoltaic options are still speculative when considering cost reduction feasibility. The capital payback time could become relatively favorable in most cases, except for STEC, in the low-insolation regions. This is primarily due to the limited amount of useful sunshine hours in Central Europe.

The low-temperature options can be installed as retrofits in existing buildings, or as integrated systems with heat-pumps and heat recovery equipment in the low-energy-demand houses of the future, the latter being decisively a superior alternative.

A future design of *a low-energy demand, single-family house* may incorporate a number of features separate from solar systems in contrast to conventional building practices, as summarized in Table 4. Although the attainable energy savings must be evaluated separately for each case and location, an integrated design of a low-energy-demand house may reduce the energy demand to less than 25 percent of that for a conventional building, i.e., one constructed prior to 1978. In favorable locations, this may eliminate conventional backup heating systems and allow the use of simple electric heaters in hot water storage tanks. This would facilitate optimized energy management in urban areas and reduce the sources of air pollution.

Further delineation of the criteria is contained in the description of each option.

TABLE 3 Overview of the estimated characteristics of selected solar options.[a]

	Solar energy conversion systems					
	Global insolation ~1,000 kWh(t)/m^2/yr Rated insolation ~0.48 kW(t)/m^2			Global insolation ~2,300 kWh(t)/m^2/yr Rated insolation ~0.76 kW(t)/m^2		
Estimated parameters	Low-temperature retrofits	High-temperature daylight STEC	Photovoltaic daylight arrays	Low-temperature retrofits	High-temperature daylight STEC	Photovoltaic daylight arrays
Energy storage	~6 m^3 hot water	~4 h storage	without storage	~6 m^3 hot water	~4 h storage	without storage
Collector area (~m^2/kW)	6	21	16	3	8	13
Overall system efficiency (annual)	0.35	0.10	0.13	0.45	0.17	0.10[b]
Use	Space and water heating	Electricity and synthetic fuels		Space and water heating	Electricity and synthetic fuels	

Direct system cost (~$/kW (1978 US$))[c]	1,200 to 3,600	4,500 to 5,800	1,850 to 2,950	600 to 1,800	1,700 to 2,200	1,500 to 2,400
Energy investment (~MWh(t)/kW)	7.3 to 12.0	21.00 to 52.00	18.50 to 24.60	3.6 to 6.0	8.0 to 20.0	15.0 to 20.0
Attainable primary energy substitution (~tce/kW/yr)	0.15 to 0.24	0.36 to 0.42	0.20 to 0.26	0.30 to 0.40	0.96 to 1.20	0.30 to 0.38
Energy payback time (~years)[d]	3.7 to 10.0	19.00 to 55.00	8.6 to 14.7	1.1 to 2.4	2.4 to 8.0	4.8 to 8.3
Operational availability (~year)	1979	1995	1995	1979	1995	1995

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[a] Configurations based on average insolation ratings for the given regions and on realistic load factors (i.e., ~1,700 h/yr for the low-temperature retrofits). Selected reference systems dimensioning was used.

[b] Decreased efficiency due to higher operating temperatures.

[c] Estimates for the year of operational availability.

[d] Prior to recycling (all subject to choice of materials). Not including site preparation, transportation to site, labor accommodation and other indirect energy investments, depending upon the location.

TABLE 4 Attainable energy savings for single family houses of modified design, as compared to conventional houses.

Energy-saving features	Examples of attainable energy savings[a] (percent)	Typical energy payback time[b] (years)
Optimized house insulation	35–45	0.3–0.5
Passive solar system	25–35	undetermined[c]
Solar water heating (including storage)	8–12	2.0–5.0
Solar space heating (including storage)	40–60	4.0–8.0
Heat-pump application	25–30	0.6–1.5
Heat recovery from exhaust air and waste water	15–30	undetermined[c]

[a] Not cumulative.
[b] Subject to choice of materials.
[c] Subject to building design and use.

LOW-TEMPERATURE SOLAR OPTIONS

Low-temperature solar-thermal systems are the closest to accelerated, large-scale commercialization. To aid the diffusion process in Central Europe, unified standardization and quality control regulations are needed to secure the availability of fitting spare components, such as collectors and hot water storage tanks.

Two reference systems were formulated for the interim assessment of the rate of possible application of such options:

1. A solar water heating system (retrofit), with 8-m^2 collector surface, for a single-family house. Such a system can substitute for oil heating of the water in the order of about 1,000 liters oil/yr, because of the otherwise marginal efficiencies of oil heating systems during the summer and transitional months.
2. A solar space and water heating system (retrofit), with 35-m^2 collector surface, for a single-family house. Such a system can substitute for oil heating in the order of about 1,540 liters oil/yr.

Using statistical information from the FRG, a representative assessment of both single- and two-family houses was made to estimate the number of solar systems that could be installed. About *3.2 million* of such buildings in the FRG could be adapted for a *solar system by the year 2010*. The primary energy savings attained annually by such a measure would be about 11 million tce*, or about *1.5 percent of the estimated primary energy* at that time period. A substantial amount of the installed solar systems would have to be retrofits, because the projected growth rates of suitable new buildings are not high enough to concentrate only on the advanced, integrated low-energy-demand buildings. However, such new building designs would eventually foster optimum savings of fossil fuels, and optimum benefits from environmental considerations.

Figure 1 conceptualizes a version of the transition from fossil fuels to the maximum use of solar energy and electric power in the FRG. Nearly four million residential units would be involved during an estimated 75-year period. This would contribute to the reduction of pollution, while facilitating the use of synthetic fuels in central power plants. It ought to be realized that between 25 and 40 million m^2 of collector surface are required in Central Europe to substitute (collectors) for 1 million tce of primary energy, depending upon the selected design features and economic trade-offs. The direct (solar systems) cost for 1 million tce is estimated to be between \$5 and 24 X 10^9 (maximum rate \$2 to 6 X 10^9 per year) depending upon the chosen trade-offs. The indirect cost for the integrated systems may be absorbed in the building cost. A program of such magnitude becomes interesting as petroleum prices increase and as economic losses, due to pollution, are fully recognized and quantified.

An assessment of the contemporary technical and economic criteria is necessary to identify the evolution potential of solar options from retrofit installations to the fully-integrated versions. Table 5 shows examples of prices of solar-specific hardware, such as would be used in the selected reference systems, as offered on the FRG market in the 1978–1979 time period.

An installed retrofit representative reference system for *solar water heating* (8-m^2 collectors) was priced in 1978 at \$3,800; with the long-term cost reduction projected to be \$2,400, when large-scale mass production prevails. A lower cost will be realizable for fully integrated systems included in the design of new buildings.

An installed retrofit representative reference system for *solar space and water heating* (35-m^2 collectors), was priced in 1978 at \$21,000, but some integrated versions of the same system were offered in 1979 for \$12,000; the long-term cost reduction was projected to be \$7,000, when large-scale mass production and full design integration prevail.

The long-term cost reduction projections correlate reasonably well

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*tce = tons of coal equivalent (1 tce = 8140 kWh(t)) ≈ 4.8 bbl (crude oil).

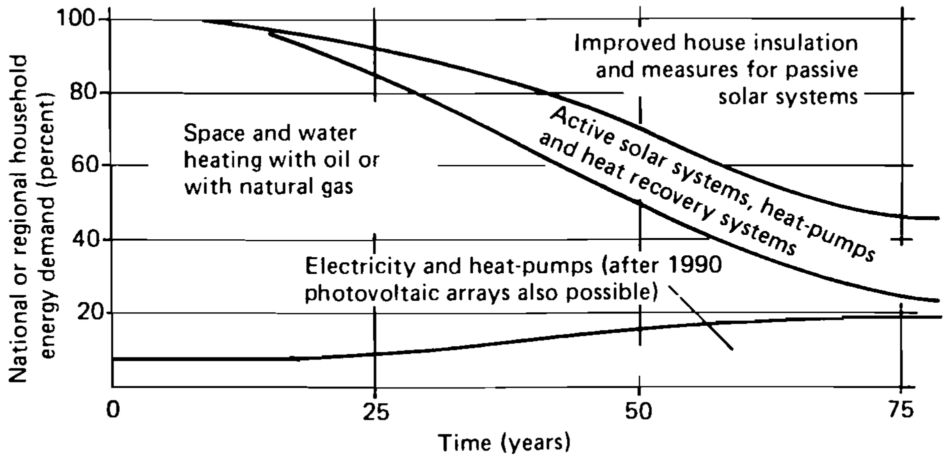

FIGURE 1 Possible evolution of low-temperature solar applications for residential buildings.

with the cost of automotive hardware. The prices of solar specific components represent nearly 50 percent of a typical retrofit space and water heating system installation; about 25 percent is for "off-the-shelf" hardware, and the remaining 25 percent for transportation, assembly, installation, and retrofit design. In the integrated systems of the future, the collectors will be a part of the roof, forming a part of the insulation, and many of their features will be standardized, proving to be more cost effective as indirect costs will be absorbed in the building costs. Furthermore, material recycling will also contribute to the reduction of energy investment and possibly to cost reduction.

Figure 2 illustrates the performance of various solar energy collector designs when traded off against costs of the reference systems for space and water heating. The designs without a selective absorber surface do not generally give a satisfactory performance when diffuse solar energy prevails. The principal constraining factors are the conversion of diffuse solar energy and the cost/performance capacity of hot water storage; they do not permit cost-effective seasonal storage. Thus a high percentage of solar energy collected during the summer and, to a lesser degree, during the transitional months is lost (see Table 1). This is limiting the heating-oil substitution performance of such systems in Central Europe. The graph also implies that cost/performance trade-offs are necessary for each application and location to optimize a system. For an average system, at a cost of \$350/m^2, the corresponding annual substitution, or savings, of heating oil is about 45 liters; in August 1979, this was about \$12/m^2/yr, without con-

TABLE 5 Price ranges of quality solar energy hardware in the FRG (1978 US$).

Hardware (not installed)	Components' price range ($)	Average price ($)
Single-glazed collectors without selective absorber surface	120–240/m^2	144/m^2
Double-glazed collectors with selective absorber surface	134–288/m^2	168/m^2
Hot water storage tanks		
3–6 m^3	720–1,440/m^3	960/m^3
7–30 m^3	384–624/m^3	480/m^3
Control units	336–960/unit	576/unit

sideration of maintenance costs. The amortization time would obviously be extensive even if the life of a well-constructed system could exceed 30 years. However, large-scale mass production of the systems should reduce the cost to about \$180/m^2 and the increase of heating-oil prices will eventually facilitate a more favorable cost effectiveness. The cost of long-term financing is not included in these estimates. More important, however, is that the decision process must be based on a life-cycle cost, yielding the benefits of fuel savings, rather than on an acquisition cost.

The conceptual evolution of a single-family solar house is shown in Figure 3, integrating the energy-saving features, identified in Table 4, with a large-scale energy management potential, illustrated in Figure 1. Optimum insulation is taken as a prerequisite, as is floor or wall heating that can function with working-fluid temperatures below 30 °C. Heat recovery from waste water and exhaust air, and heat-pump integration with the solar system, are viewed as the optimum long-term alternative.

The application of passive solar systems is in an early developmental stage, but their performance in prototype houses is indicative of their long-term potential.

MODERATE-TEMPERATURE SOLAR OPTIONS

The production of process heat for industry and agriculture is in the early developmental phase. Nearly 25 percent of primary energy for industry is used for process heat below 300 °C, indicating a potential utilization of solar energy for either preheating, to save fuel, or for direct conversion to process heat. The process-heat demand has two major categories:

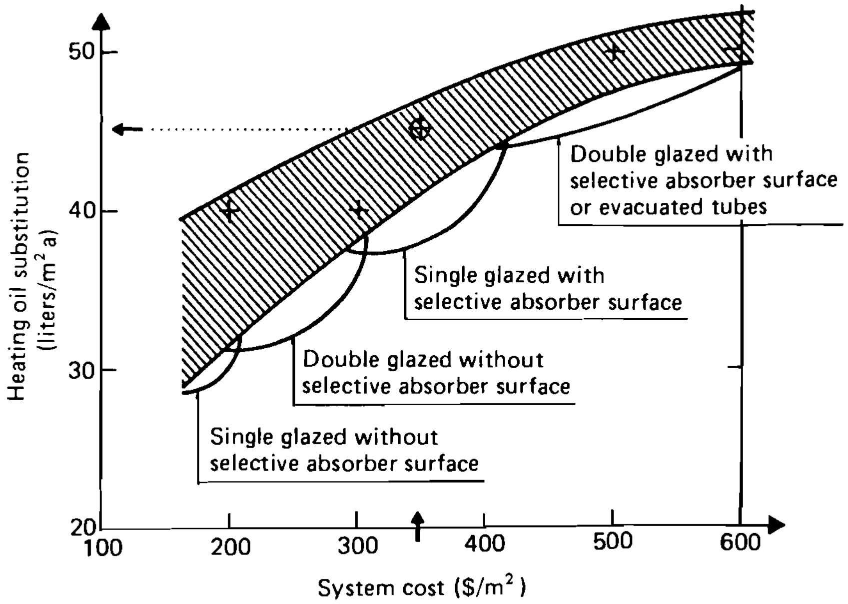

FIGURE 2 Heating-oil substitution potential of various collectors with the referenced solar space and water heating system.

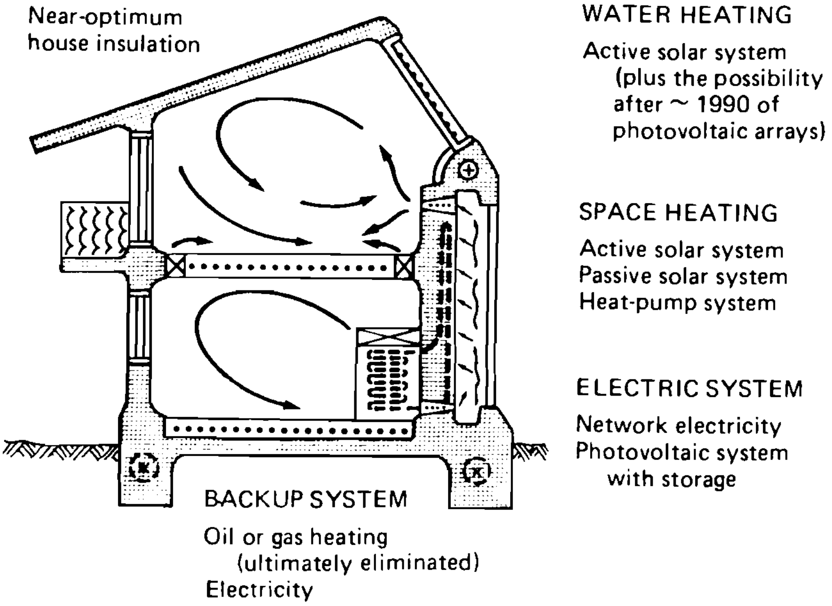

FIGURE 3 Evolution of solar house options.

1. *Hot water for*:
   Chemical industry
   Textile industry
   Cleaning and washing facilities, and many others
2. *Hot air for*:
   Drying (agricultural products, lumber, food, etc.)
   Dehydrating
   Industrial processing, and many others

The direct use of collected solar energy, without storage, may prove attractive enough, in some applications, for integration in the next generation of industrial equipment. The cost would be near the collector cost shown in Table 5.

Moderate-temperature solar options can provide air conditioning, small-scale electric power generation, and other related functions. The rationale offered for the low-temperature options is applicable here. Mass-production of collectors and storage systems, approaching the methods of the automotive industry, will ultimately open new opportunities for the use of moderate-temperature solar options.

HIGH-TEMPERATURE SOLAR OPTIONS

The interest in *high-temperature* solar technology in Central Europe is motivated by export possibilities. A range of medium- to high-temperature concepts, from a high-performance flat plate collector system to heliostat fields and a central tower receiver, were evaluated for generating electricity and manufacturing synthetic fuels in arid areas (insolation about 2,300 kWh(t)/m^2/yr and 2,500 hours of usable sunshine per year). The principal criteria for the most promising STEC concept (heliostats and a tower) are shown in Table 3. Estimates indicate that the electric power generating cost for commercial versions of 100-MW(e) daytime power generating plants may be about US\$0.12 to 0.16/kWh(e), with operating and maintenance costs accounting for nearly 10 percent, because of the large mirror surfaces and the numerous tracking subsystems.

Paraboloidal dish systems may prove suitable for hydrogen production via a thermochemical cycle, which could attain an overall systems efficiency of ~25 percent, *if current projections are realizable*. The capital cost for a commercial version of this concept is estimated at \$1,400/kW for hydrogen gas production, or about \$1,750/kW for the production of liquefied hydrogen (LH$_2$), storage not included.

Two-dimensional troughs could prove useful in areas with favorable insolation, to deliver higher-grade process heat, electricity, air conditioning, or even hydrogen. With a capital cost estimate at $2,000/kW (rated, without energy storage), the cost of electricity would probably be $0.16/kWh(e), including operation and maintenance costs.

Conceptual and prototype efforts are sponsored in the USA, aiming at 100 MW(e) STEC (heliostats and a tower) with 420 MWh(e) storage capacity. The prototype's direct cost ranges from $13,000 to $15,000/kW(e) for current (1978–1979) constructions.

Baseload configurations of such plants would require large-scale energy storage, either of a pumped hydro category for about $320/kW (rated), or thermal storage for about $430/kW (rated).

Most of the information on STEC concepts is still too speculative for the long-term projection of their large-scale use. Furthermore, it ought to be realized that the indirect cost must be added to the direct cost, which may increase the capital requirements for STEC systems by 70 percent or more, depending upon the remoteness of the site, the access to it, and the overall logistics. In the case of conventional electric power plants, the indirect cost has been up to 50 percent of the direct cost – a trend that is increasing with demands for better environmental protection.

PHOTOVOLTAIC OPTIONS

The versatility and the promise of development trends of photovoltaic systems indicate that if the cost-reduction objectives are met, photovoltaic arrays may become competitive with solar-thermal systems before 1995.

The long-term objective of the US Department of Energy calls for the reduction of the direct cost to $500/kW(e) peak for photovoltaic arrays. This could yield systems cost in high insolation regions ranging from $1,600/kW(e) peak for residential sizes (~10 kW), to $1,800/kW(e) peak for small-size electric power generators (~500 kW), and perhaps as low as $1,500/kW(e) peak for large, central stations (~100 MW). The added indirect cost depends upon the location, access, preparation, and logistics. In the case of residential buildings, it could be absorbed in the building costs. But even $2,000/kW(e) would become reasonably competitive, if the relatively high system efficiencies are obtained. For example, the combination of gallium arsenide (GaAs) and silicon (Si) or cadium sulfide (Cds) cells to capture a broader range of radiation spectrum, and the use of concentrators, may produce system efficiencies of nearly 30 percent.

Because the photovoltaic systems utilize both direct and diffuse solar radiation, and because they do not have to attain thermal equilibrium for effective operation, their application in Central Europe would be very useful.

The multitude of photovoltaic arrays in research and development phase include:

Fixed flat plate arrays
Periodically adjustable arrays
Concentrating arrays (with or without cooling)
Hybrid arrays (with two or more cell materials)

All of these can be used for the production of electricity and hydrogen, and it is the latter which would enhance the feasibility of load leveling and baseload configurations. It will be about 5 to 8 years before the research and development and prototype system phase is completed and the choices among these options are clarified. The desired systems cost reductions may require an additional 20 years of commercial operation when the 85 percent learning curve is assumed. The time it takes will depend upon a rapid increase of market potential for such systems.

INSTITUTIONAL ISSUES

There are numerous legal, administrative, and tax issues that are interfering with the implementation of solar options in Central Europe. These include constraining building codes, tax regulations, absence of quality assurances and the availability of guarantees, and financing problems, all of which vary according to the country and region. National and regional governments must correct such a situation and develop incentives for effective and timely applications of solar options.

EXPORT POTENTIAL

Table 3 shows the representative performance estimates of solar systems in regions with favorable insolation. In large-scale diffusion considerations, the indirect cost associated with the on-site installation of solar technology must be identified with each given region and added to the direct system cost projections, and evaluated in terms of a corresponding life-cycle cost, showing the benefits of eliminating the need for fuel logistics. However, large-scale exports of solar hardware that is capital- and materials-intensive, and thus energy-intensive, should be channeled into the compensation trade (i.e., trading hardware for commodities) mode of operation.

The cost for meeting a basic energy demand that would provide a composite of energy requirements *per capita* in developing countries, where improvement over the bare subsistence level is needed, is optimistically estimated at $1,500/kW (later this century), with an energy content of about 12 MWh(t)/kW. This composite includes irrigation, water purification, crop drying, initial electrification, and other necessary functions. The risk of exporting hardware with such large capital and energy content would be significantly reduced by the development of an effective compensation trade.

CONCLUSIONS AND RECOMMENDATIONS

When macroeconomics is considered, solar energy conversion technology cannot make a significant contribution to either near-term or mid-term energy supplies; its key potential is in the long-term perspective, characterized by fully integrated solar options and their contribution to environmental progress.

Large-scale implementation of renewable energy systems, e.g., solar energy conversion systems, may require 50 to 80 years for effective large-scale diffusion, depending upon the trends in petroleum pricing, the evolution of other alternate-energy systems and overall energy management. Continuing research and development is expected to produce new techniques for the conversion, transportation, and storage of energy, while increasing and improving the recycling of materials will reduce energy investment in the next generations of both industrial and private equipment. It is too early to formulate a realistic future contribution of solar options for the energy mix of Central Europe. Once current research and development reach a tangible maturity, a more specific technological assessment of solar options will have to be undertaken. Until then care must be exercised to prevent premature commitments in speculative areas. The time for solar options will undoubtedly arrive – the difficulty is to recognize the concept that has the best long-term potential.

In the more immediate future, however, the following measures ought to be given priority:

1. Reduction of solar hardware cost by adapting to mass production processing, together with the standardization of the external dimensions of collectors, and other major components, to facilitate interchangeability and replacements by fitting spares.
2. Formulation and implementation of quality control regulations and facilities to assure the integrity of solar hardware, reduce its maintenance requirements and extend its operational life well beyond the amortization period.
3. Development of efficient and cost effective thermal energy storage systems to maximize the use of solar energy collected during the favorable sunny periods of the year.

4. Development of passive solar energy building techniques, and near-optimum insulation, to facilitate the application of active solar systems, and the integration of heat-pumps.
5. Formulation and implementation of well-coordinated courses and seminars in technical universities and trade schools, to train architects, engineers, and all future builders in the key aspects of the application of solar technology and in the development of building designs which reflect the need to drastically reduce energy consumption.
6. Structuring of national and regional programs, stipulating that all future public buildings and any others financed by public funds (i.e., schools, hospitals, recreational facilities, airports, administrative buildings, railway stations, etc.), should receive priority consideration for the use of applicable solar options. This will increase the knowledge of the emerging technology and its energy saving potential, while stimulating the development of innovative architecture for low energy consumption buildings.
7. Formulation and implementation of *administrative and economic incentives* for the use of solar options by:
   - Creating *tax incentives* for the installation of retrofit and integrated solar systems in residential and commercial buildings
   - Passing "*solar rights*" laws to prevent the future shadowing of solar collectors, both active and passive
   - *Reassessing constraining regulations* and building codes that are jeopardizing the accelerated use of solar options
   - Creating a *comprehensive insurance program* to protect house owners, and institutions willing to provide financing, against premature failure or damage to solar hardware (perhaps with the manufacturers' participation and national support).

These measures would accelerate the acceptance of solar options and aid the development of a mature market for solar hardware, while gradually motivating a sensible transition to an independence from nonrenewable energy sources. It would be advantageous if such measures could be implemented uniformly throughout Europe, or by subgroupings such as the European Economic Community.

It seems appropriate to conclude this summary on the potential of solar options with a quote from the book *The Bankers* by M. Mayer: "The quality of life becomes a function of the energy resources at the disposal of the individual and the capital investment that multiplies his benefits from his efforts. . . ."

THE AUTHOR

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