SYSTEM STUDY ON THE POSSIBILITIES OF INTENSIFIED USE OF SOLAR ENERGY IN THE FEDERAL REPUBLIC OF GERMANY (ET 5006A)

Final Report
Prepared for the Ministry of Research and Technology, F.R.G.

C.R. Bell, F. Jäger, W. Korzen

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System Study on the Possibilities of Intensified Use of Solar Energy in the Federal Republic of Germany

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BMFT Project No. ET 5006A

Final Report

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The Federal Ministry of Research and Technology

of the

Federal Republic of Germany, Bonn

Prepared by

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FOREWORD

Evaluation of the possibilities for intensified use of a technology still in the research and development stage is a difficult and potentially non-rewarding task. An unexpected breakthrough in any critical aspect of such a technology might significantly alter the present findings.

Such an evaluation of solar energy conversion utilization for the Federal Republic of Germany is subject to even more complexities, because of the unpredictable variables in collection, conversion, storage and distribution. All of these are sensitive to climatic, as well as to design variations, the cumulative effects of which can cause different performance behaviour even in locations of relatively close proximity, rendering a solar option reasonably successful in one place and economically marginal in the other.

Dealing with such complexities required a genuine team effort capable of synthesis of priority issues. In this spirit, the study was performed by the IIASA Solar Group -- C. R. Bell, F. Jäger and W. Korzen -- under the leadership of Professor W. Häfele, with significant contribution from H.G. Wagner and R. Turowski from KFA - Jülich*, G. Schäfer and R. Bierhals from ISI - Karlsruhe**, N. Weyss and numerous members of IIASA staff, who assisted in creative inquiries and constructive criticism. Stimulating assistance was also rendered by the participants of the IIASA Workshop on Solar Options for the Federal Republic of Germany in May 1977. Expression of gratitude is hereby noted to all.

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SUMMARY AND RECOMMENDATIONS

The critical areas of solar technology are still in the developmental process, the outcome of which is at present uncertain, because of the large number of variables affecting the technical, as well as the economic, aspects of solar options. Nevertheless, it is now essential to attempt identification of the appropriate timing for the economically and institutionally justifiable integration intensity of solar options as a significant part of the future energy mix, to minimize the impact of anticipated scarcity of petroleum products, and to contribute to an orderly long-term transition from the non-renewable energy sources to the renewable ones.

It is recognized that a premature large-scale implementation of the capital and materials intensive solar energy conversion systems would not be in the best interest of the consumers, nor of the national economy. However, a late market penetration of solar options could aggravate the emergence of a fuel shortage. The timing for an accelerated implementation of solar options must therefore be considered very carefully. The success of an intensified use of solar systems depends on further progress in the applicable research and development, and on the attainability of an economically competitive status with other future energy supply alternatives. The synthesis for the subject study was constrained not only by the developmental status of solar technology, but by the unpredictable evolution of petroleum prices as well.

Analysis of meteorological data for the FRG shows that an average value of solar insolation is near 1000 $kWh(t)/m^2 \cdot year$* and that average sunshine hours are about 1650/year. These values vary by year and location, and are only a broad indicator of the applicability of solar energy as a resource. The useful insolation for the purposes of energy conversion systems

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*direct and diffuse radiation on horizontal surface.

must be adjusted to local weather patterns, shadowing effects (causing the loss of early and late sunshine exposure) consideration of the less effective diffuse component of solar radiation, positioning of collectors, as well as pollution, wind and humidity effects. In specific assessments, for example, a stipulation of 20^{o} minimum elevation of the sun for decreasing shadowing effects and a time allowance for attainment of systems' thermal equilibrium, may decrease the actual useful sunshine to about 1100 hours/year (or less) in southern parts of the FRG (near 46^{o}N latitude). In the northern parts (near 56^{o}N latitude) the useful sunshine is less than 900 hours/year, unless availability of suitable areas and favorable site-topography enhance the collectors' exposure to direct solar radiation. Regretfully, information on actually useful direct insolation for most locations is generally not available from meteorological stations; however, the correlations of annual sunshine hours with derived measurements of direct solar radiation indicate that a significant number of the measured sunshine hours are at times when the elevation of the sun over the horizon is not sufficient to provide adequate energy. A composite map of FRG insolation zones was constructed to provide an overview of the available solar insolation measurements. Basic criteria for the evaluation of solar energy as a potential resource were identified.

A realistic evaluation and synthesis of the technological and economic trends were conducted to provide the necessary foundation for assessing the possibilities of intensified use of solar energy in the FRG. The potentially useful solar options for mid-term and long-term* considerations in the FRG are identified by four solar energy conversion concepts:

(1) <u>Low temperature solar-thermal systems</u> ($T<100^{o}C$) for water and space heating.

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*In this report short-term = 1978-1983, mid-term = 1983-1995, and long-term = beyond 1995.

(2) Moderate temperature solar-thermal systems ($100^oC<T<300^oC$) for production of industrial or agricultural process heat; or for absorption type of air conditioning.

(3) High temperature solar-thermal systems ($T>400^oC$) for production of steam, electricity (STEC*), and possibly synthetic fuels.

(4) Photovoltaic array systems for direct production of electricity, hydrogen and/or for other energy storage media.

Low temperature solar-thermal systems are the closest to large-scale commercialization. Numerous versions of them are already on the market, although neither standardization, nor quality control assurance exists as yet on a regional or national level. Critical areas of development are the absorber surfaces of the flat-plate collectors to maximize the use of diffuse as well as direct radiation, and the effectiveness of economically acceptable hot water storage tanks to increase useful applications of the collected energy. The solar heating systems offered on the 1976-1977 market averaged in installed system cost nearly DM 900/m^2 for space and water heating, designed for an operating life in excess of 15 years, and with typical overall system efficiencies from 0.25 to 0.40. Retrofit installations were given most attention, although the integrated versions for the "low energy houses" of the future will offer near optimum performance and economic viability. Because of the economy-limited storage capacity for hot water, the actual heating oil substitution potential for typical solar space and water heating systems approaches 40 to 60% of total demand, replacing annually about 35 to 50 liters of oil per m^2 of collector area in the climatic conditions of FRG. The water heating versions yield higher substitution values (~ 125 liters/m^2)** because of the unfavorable heating oil efficiencies of conventional systems in summer months. Their contribution to the reduction of heating

*STEC - Solar-Thermal-Electric Conversion
**Composite of substitutions for present water heating methods in residential buildings.

oil requirements, however, is only about 15% of residential heating oil consumption.

In absence of life-expectancy and maintenance data on such systems, the economic payback evaluations are primarily reflecting the anticipated cost increases of heating oil. Generally, the solar-water heating versions can attain economic payback at current (1977) heating oil prices in less than 15 years, while the solar space and water heating versions may require over 25 years--all subject to design and location. The gradual increases of annual savings (as fuel cost goes up) may eventually yield more encouraging payback times, particularly if the cost of solar hardware should decrease in the future. Systems cost reduction facilitated by mass production of the solar-specific hardware should enhance the long-term viability of solar space and water heating, providing it is supported by improvements of house insulation, and ultimately by integration of passive solar heating features into the designs of residential and other buildings.

Currently, specific cases of solar water heating in favorable locations are already proving economically encouraging. Such results are especially attainable for commercial installations in favorable locations, where the time of energy supply (sunshine) and demand (heating) coincides, decreasing hot water storage requirements, and where the maintenance cost is not excessive.

Analysis of overall system aspects for the low temperature solar options shows that residential space and water heating in 1974 used up nearly 30% of primary energy (of which nearly 65% is oil and gas). This is equivalent to about 102 million tce/year*, or 500 million barrels of heating oil/year, meaning nearly 8 barrels of heating oil equivalent/capita per year. Due to the high cost of large hot water storage tanks, the current economically supportable limits of heating oil replacement by solar

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*1 million tons coal equivalent = 8.14 TWh(t)
$\doteq 8.1395(10^{12})$ Wh = $4.78(10^{6})$ bbl.

energy in a single family house are about 40 to 60% or nearly 1540 liters of heating oil per year*. Using the current state of the art as first approximation, this would equate to 35 m^2 of solar collectors/family house, or DM 25 000 per house**, for a theoretical upper limit for solar space and water heating retrofits in FRG. Review of the potentially suitable residential houses in the FRG yields an upper limit estimate of 3.2 million of one- and two-family houses that could be equipped with solar space and water heating systems by the year 2010. The equivalent prime energy savings in the year 2000 would be about 4 million tce, or less than 1 percent of total primary energy demand, depending on whether more retrofit installation, or integration into new houses is performed. Three categories of houses were identified in the systems analysis for this task:

- The first category of potential suitable houses covers structures built prior to 1977, where the retrofitting of solar systems would have to be customized, causing expensive installations with marginal cost effectiveness at best.

- The second category are houses built after 1977, offering significant improvements, due to the (1977) mandated house insulation and more appropriate orientation of the buildings, but still featuring conventional architecture.

- The third category are future houses offering new optimum use of solar energy by integration of energy systems in buildings designed for low energy consumption, made possible by effective insulation, orientation for maximum exploitation of passive solar system for space heating, as well as active solar system and heat-pump for water and space heating. Supplemental and emergency back-up would be provided by electric power. If well designed

*2.11 tce/a for a typical reference system (Table 7.1).
**due to cost reduction projections attainable by mass production.

and built, conventional oil or gas heating would no longer be required in suitably located buildings. The collectors will be part of the roof, thus functioning as energy collectors, roof, and part of the building insulation. This, together with elimination of conventional heating as a back-up, would provide the basis for competitive developments. A number of other applicable concepts was evaluated, but their potential for significant savings of primary energy was not identifiable because it would have to include small commercial consumers as potential users of solar heating systems. The complex variety of such installation possibilities precluded their inclusion in the analysis.

The key issue is, of course, identification of the appropriate timing for initiating large-scale use of the solar options when they become economically viable--this with consideration of other available energy alternatives. Development of a "time window" for the deployment of solar heating systems showed that if the market penetration program started before 1985 Federal subsidies would be necessary; conversely, potential scarcity of fossil fuels for heating could be aggravated, if the program started after the year 2015. The most favorable time for intensified marketing of solar systems for space and water heating would probably be in the 1987-2010 period, at which time fully developed and economically attractive hardware should be available. Residential heating oil demand in the FRG could be further reduced by full-scale support of the integrated low energy demand buildings with electrical back-up, but without conventional heating systems.

The necessary motivation for market penetration of the solar heating systems could be fostered by the following measures:

1. Cost reduction of solar hardware and installations, promoted by standardization and mass production of principal components (external dimensions, standardized for the sake of exchangeability) and attainment of long-lasting reliability.

2. Development of cost-effective high density thermal energy storage for long, maintenance-free operating life.

3. Development of effective passive solar system architecture, compatible with the active solar system's integration, as well as with installation of heat-pumps.

4. Formulation and implementation of legislative and institutional incentives to support intensified use of solar options, including favorable building codes; voiding taxation for residential solar systems; establishing "sun-laws"; streamlining financing; and supporting an adequate insurance program.

The critical aspects for removing constraints to large-scale application of solar options were fully delineated in a parallel study, ET 5008A, "REDUCTION OF ECONOMIC AND SOCIAL CONSTRAINTS TO INTRODUCTION OF SOLAR ENERGY", by the Institut für Systemtechnik und Innovationsforschung (ISI) in Karlsruhe. "A Development of Optimization Aids for Solar Technology" was also conducted by this institute for the Commission of the European Communities. One of the conclusions of that analysis is that a generalized optimization of solar systems is not possible at present, because of the developmental status of solar technology, with excessive number of designs and wide variation in pricing approaches.

Energy payback estimates developed in cooperation with KFE-STE* indicate that a well built (roof integrated) solar space and water heating system of contemporary design has an energy in-investment of about 800 to 1200 kWh(t)/m^2 (system). This will decrease as more recycling of materials is implemented. Indeed, up to 70% saving of energy investment will be attainable by recycling the materials needed for solar systems. This shows that the energy investment for solar space and water heating systems

*Kernforschungsanlage Jülich, Programmgruppe Systemforschung und Technologische Entwicklung: "Energy-contents Analysis of Solar Energy Facilities, Heat-pump and of Improved Insulation of Single Family Houses" by H.J. Wagner and R. Turowski, Nov. 1977.

will not cause a constraint for effective integration of solar heating systems, particularly if the stipulated recycling measures are implemented. A comparison of energy payback estimates for solar heating and related systems provides the following relationships (prior to materials recycling):

- Energy payback time for retrofit solar heating system ~ 1.6 to 3.3 years.
- Energy payback for heat-pump ~ 0.5 to 1.2 years.
- Energy payback for house insulation ~ 0.2 year.

The energy investment payback is, in all these cases, favorable because the payback time is a relatively small fraction of the life-time of these systems. It is also clear that even an intensified use of solar energy options would not cause materials diversion beyond the capacity of the FRG industry.

The rate of solar systems commercialization will be affected by numerous decision-making criteria, ranging from economic and performance considerations to insurance availability and desire for innovative heating concepts. The uncertainties about future shortages of conventional fuels also provide motivation for the acquisition of a solar heating system as a method of securing a heating resource. If rapid increases of conventional fuel prices should occur in the near-term or mid-term future, then the retrofit solar heating systems as well as house insulation will rapidly gain market acceptance without much assistance. If, however, the prices of conventional fuels merely follow inflation trends, perhaps with some minor increase of the real price, then the time for development of integrated, low energy demand houses will be available, and the Federal as well as the regional governments will have to create a market through public ventures* to aid the survival of the industry specializing in manufacturing and installation of solar systems.

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*e.g. integration of solar systems in Federal and public buildings.

The application of solar energy for aiding district heating was also examined to evaluate scale effects for low temperature solar systems, as well as potential fuel savings. It is readily obvious that the large-scale fuel requirements of such systems could not be economically matched by solar energy conversion methods. The heat density level at which conventional district heating is economically feasible cannot be supplied by solar systems because of area limitations for collectors and cost. However, small groups of houses (about 30 to 50) in favorable locations may benefit by a "community" heating system with centralized hot water storage, and either centralized or decentralized collection system, when the appropriate technology for energy storage is developed. The economics of scale and standardized installation techniques should provide increasing cost effectiveness of such projects. Relatively large hot water storage can be built for less than the small storage units for individual houses.

Moderate temperature solar-thermal systems for most applications would use concentrating collectors to reach the temperatures needed for process heat, small scale generation of electricity, or for absorption type of air conditioning. The system efficiencies of such devices are generally under 10%, if a two-dimensional, parabolic trough is used for collecting and concentrating the direct solar radiation; or under 4%, if flat-plate collectors are used. The collector areas needed for even moderate requirements are rather large. For example, replacement of a 37 kW diesel-electric generating set (~ DM 420/kW(e)≈$200/kW(e)), by a solar system, based on concentrating collectors, would require about 560 to 1120 m^2 of collector area (depending upon the site selected). At present, the price of such system would be between DM 6700 and 12600/kW (~ $3200-6000/kW(e)). A variety of similar devices are at an early developmental stage, which is not adequate for derivation of macroeconomic projections. Demand for such equipment is in developing countries and other, generally remote, areas where the cost of conventional energy transportation is excessive.

Industrial process heat must be generally available on demand, which for solar systems means availability of an effective and economic heat storage--a technology that is still in the research stage. The timing of process heat in agriculture is usually less critical, which makes solar heating more applicable, if enough area is available for the collectors, and if the insolation levels are adequate. The use of capital intensive systems should be rejected if a well planned and implemented energy conservation program can provide competitive results for the life-cycle of a given system.

High temperature STEC systems* can use only concentrated direct solar radiation at times when the sun's elevation over the horizon is high enough to minimize excessive shadowing (i.e. 20^{o} over the horizon subject to the topography of the site). This places limitations on their use in the FRG, because in most locations the number of useful sunshine hours/year is not adequate to yield an acceptable cost of electricity. Nevertheless, with regard to the export potential of such systems in the future, a prototype installation in conjunction with an existing conventional powerplant (possibly with a capacity before 50 MW) may prove desirable, if a suitable site is located. For example, such a facility may have heliostats (mirrors) located on top of existing structures (buildings) and a receiver (boiler) attached to a smokestack would produce steam during sunshine hours for the turbine of the powerplant. This will reduce the consumption of the fossil fuels, offering at least a partial payback for such a development; but more importantly, it would provide a development tool for such critical subsystems as the receiver, the heliostats and the aiming controls that assure proper distribution of the concentrated solar energy on the receiver surfaces. The commercial viability of STEC is not only a function of capital investment (current estimates for arid desert sites are DM ~ 2500 to 4500/kW(e) or ~ \$1100 to 2100/kW(e), with limited internal energy storage), but also of attainable system efficiencies (~ 17% to 22%), of operating hours at rated capacity, and of operating and

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*Solar-Thermal-Electric Conversion Systems; in this case heliostats and receiver-tower concepts.

maintenance cost. The latter is significant because of the relatively large site for STEC. Comparative assessments of STEC concepts for Alpine regions and for regions with high insolation values were made to show the potential of such solar options in desert areas. Future innovations may, of course, broaden the potential of STEC for electric power and for generation of hydrogen or synthetic fuels, which would overcome the energy storage problems.

Photovoltaic array systems in current developments contain various forms of silicon, cadmium sulfide and gallium arsenide cells, with (system) conversion efficiencies of ~ 10%, ~ 6%, and ~ 12% respectively, at different stages of usefulness. Evaluation of mass production and encapsulation processes is in progress, which may produce suitable panels (arrays) for collection of direct and diffuse solar radiation at a cost that may become competitive with solar-thermal systems before 1990. The relatively efficient conversion of both diffuse and direct solar radiation make this option attractive for the FRG, where nearly half of the solar radiation in a year is diffuse. It is conceivable that future research may be able to combine photovoltaic arrays with highly efficient electrolyzers, producing hydrogen for energy storage and load leveling functions, thus opening a new era of energy generation and storage.

In the USA, the goal is to reduce the cost of photovoltaic arrays to less than $1000/kW(e) (peak) by 1985, which could place photovoltaic systems on the same price level as solar-thermal systems even earlier. The ease of their integration in a wide variety of sizes and functions, and the absence of moving parts, would broaden the usefulness of such systems for domestic, as well as for export, applications.

Identification of the potentially viable solar options is based on technology assessment, including economic and institutional considerations. The economic considerations revolve around the availability and prices of petroleum estimated through the year 2000 and beyond. Large-scale implementation of renewable energy systems may require 30 to 50 years, or even longer, depending upon the availability of oil, as well as on the future phasing out of other conventional energy resources. The cost-intensive nature of current solar systems stipulates the need for appropriate timing of progressively managed market penetration. For photovoltaic systems, the primary prerequisites will be major cost reduction affected by mass production of cells and the manufacturing of efficient arrays for long operating life.

If the secondary and tertiary extraction of petroleum and further exploitation of coal and gas are technologically and economically successful, the retrofit solar systems may not become competitive on a macroeconomic scale for a long time, allowing the integrated energy system's development with electric heating back-up that could replace conventional heating system in favorable locations. This would mean decreased emphasis on retrofit installations, which are often economically marginal, and increased emphasis on integrated design of "low energy houses".

An assessment of developing technologies for solar-electric, and/or solar-thermal production of hydrogen and synthetic fuels, revealed that it is too early for the identification of solar systems that would be attractive enough to penetrate the energy market in a conceivable future. The combination of photovoltaic systems with hydrogen production may offer an attractive alternative in the long term.

The analysis of FRG energy supply criteria and scenarios for market introduction of solar heating systems did not provide a basis for a meaningful assessment of other solar options. Innovations in any of the technologies, particularly in energy storage methods, would provide new possibilities.

Evaluation of the institutional aspects identified numerous legal, administrative, and tax issues interfering with implementation of solar options in the FRG. These include constraining building codes, unfavorable legal procedures, and tax regulations penalizing the acquisition of solar energy systems. This part of the study was closely coordinated with the Institut für Systemtechnik und Innovationsforschung (ISI), where a broader assessment of these issues was made.

The potential of solar options in developing countries opens new opportunities for export-oriented industries. Local energy resources of many such countries are either limited, or the necessary funds for their large-scale development are not available. Since the application of solar options is feasible in modular form, their acquisition by developing countries is ideally suited to compensation business--that is, trading of raw materials for technology and hardware. Solar options application on a large scale means substantial diversion of capital, materials, and skilled manpower, and therefore it is not particularly suitable for massive aid programs in the present state of global development. The drain on industrialized countries would most probably be prohibitive. The composite of energy requirements per capita in countries where improvement over bare subsistence level is needed to enter new thresholds of agricultural and industrial potential (and where productivity must increase to cope with population increases) indicates that 1 kW/capita* in the form of irrigation, water purification, crop drying, and electricity for various tasks, would provide the desired impetus. Even an optimistic estimate of the cost for such a venture is about DM 3150/kW (~ $1500/kW) for the composite energy needed. The risk for the FRG exporting under the prevailing conditions would be substantially reduced if a compensation trade in the field of solar options is developed. Some of the criteria were examined in this study.

It is recommended that a broadened implementation program for solar options in the FRG be formulated and aided by a gradual

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*composite of the identified energy functions distributed on a per capita basis.

implementation of the identified measures. The needed motivation for large-scale acceptance of solar options for the mid-term and long-term replacement of fossil fuels for heating should be developed in parallel with the identified measures, and in harmony with the overall formulation of a future energy mix. Because of the uncertainties of market penetration timing and the high cost of solar energy conversion hardware, the Federal government should create a market for solar options large enough to support continuity of the growing solar industry, in case the increases of oil prices are so gradual that amortization of the solar systems is not attractive enough to stimulate a viable market. The Federal and regional governments ought to evaluate every building to be constructed with public funds in the future (such as administrative, schools, hospitals, military facilities, and any other public buildings) in terms of its suitability for the application of one or several of the described solar options, and fund the application of solar systems wherever useful.

Most importantly, however, well structured and coordinated curricula and/or seminars on technology of solar options should be taught at all technical universities and appropriate trade schools, to train future architects, engineers, and other professionals in all the pertinent disciplines and optimization methodologies necessary for the intensified use of solar options.

All the measures outlined, together with periodic updating in standardization and optimization, would broaden experience with solar systems, and ultimately accelerate their use in the FRG.

1. INTRODUCTION: OBJECTIVES AND METHODOLOGY

The objectives of the study are to determine what actions must be taken, and at what points in time, in order to speed up the introduction of the various possible methods of exploiting solar energy in the FRG, so that they contribute significantly to the future energy mix; and to identify and analyze all those factors that could affect the deployment of the solar energy options. The substitution potential of solar energy for fossil fuels was adopted as a measure for the contribution of solar energy systems to the future energy mix for meeting energy demands of the FRG, either by direct application of solar energy, or in combination with other systems and/or measures.

The popularity of solar energy conversion concepts in recent years has caused an excessive buildup of data of varied quality and at various stages of research and development. This made necessary the organization of a data validation effort, which was initiated by a workshop (May 1977) and continued through making inquiries in research and development establishments, and in industry; it is a continuing effort in view of the fact that solar technology is still in a developmental stage.

Because of the limitations caused by fluctuating solar energy intensity in the climatic conditions of the FRG, and the large area requirements for the collection and conversion of solar energy, the most promising concepts for solar energy conversion selected for this study were:

- low temperature systems for water and space heating.
- moderate temperature systems for supply of process heat for agriculture and for industry.
- high temperature systems for generation of electricity and application to thermochemical processes.
- photovoltaic systems as a potential long-term option for generation of electricity and power for electrolysis.

All these concepts are potentially suitable for the development of small systems, such as for residential units, as well as large systems, such as for communities, and/or industrial or agricultural complexes, if and when they become competitive with other options.

A large-scale application of new technologies tends to evolve successfully if the innovations bring about distinct improvements in functional and/or economic aspects. In such cases, the obvious incentives provide the motivation for rapid acceptance of the new technology. However, in cases where the benefits are not always tangible in the short term (i.e. reversal of pollution trends), yet may become decisive in the long term, some effective measures have to be developed to secure support for competent (and competitive) developments, without causing any economic, industrial, social, or institutional perturbations.

A technology that is still in the developmental stage, attempting to compete with other technologies, must be evaluated in terms of its relative potential for timely implementation. In the case of solar options, such an evaluation must be complementary to the emerging new energy policies, and in harmony with the existing energy supply systems and those that will gradually replace them in the future.

Enterprising industries entered the solar energy conversion business on the assumption that continuing increases in oil price will drive energy cost rather rapidly to a level where the solar options will prove competitive. Such trends have not been confirmed by recent developments. While the era of inexpensive energy ended, the anticipated increases now reflect more the inflationary trends, without large increases in real prices. This means that it may be a long time before the oil prices reach a level where the solar options will compete on the basis of their economic performance.

There seems to be general agreement that solar options in the future will give a tangible part of energy supply in many countries; the questions are how much, how soon? The transition from nonrenewable energy sources to renewable ones might prove to be very gradual in the industrialized countries, because of the vast inertia of existing energy enterprises and all the associated industries and institutions. Yet, the gradual introduction of the alternative energy systems ought to be guided by a sense of urgency and a desire for a greater share of energy self-reliance. It should not only be viewed in the framework of a new business, but as a national priority. Solar options are among the alternative energy systems that have to be called upon to secure a gradual transition to a new energy supply system of the State, and for that part of the energy supply sector, where they will in the long-term be most effective.

Recognizing the complexities of the study, the Solar Energy group of the International Institute for Applied Systems Analysis (IIASA) in Laxenburg (Austria), established a working relationship with the Institut für Systemtechnik und Innovationsforschung (ISI) in Karlsruhe (FRG), and with the Programmgruppe Systemforschung und Technologische Entwicklung der Kernforschungsanlage (KFA-STE) in Jülich (FRG), to strengthen the analytical scope with a realistic assessment of institutional aspects for the FRG, and with reference systems representing major elements of the FRG energy demands. The preparatory phase for the study started at IIASA in 1975 with the acquisition of information needed for technology assessment of solar options in general, and their usefulness for FRG in particular.

In order to organize the scope of the study into manageable tasks reflecting the developmental and the applied interrelationships of solar technology, and facilitate delineation of the progress in each of the tasks, the subdivision into nine (9) distinct, mutually interrelated tasks was made (Table 1.1). Each member of the IIASA Solar Energy group was assigned tasks in the area of his expertise, and directed to establish appropriate contacts for specific data acquisition and validation.

Table 1.1 illustrates the fundamental interrelationships of the tasks during the 1976/77 time period:

Table 1.1. Organization and interrelationships of the study on solar options for the FRG.

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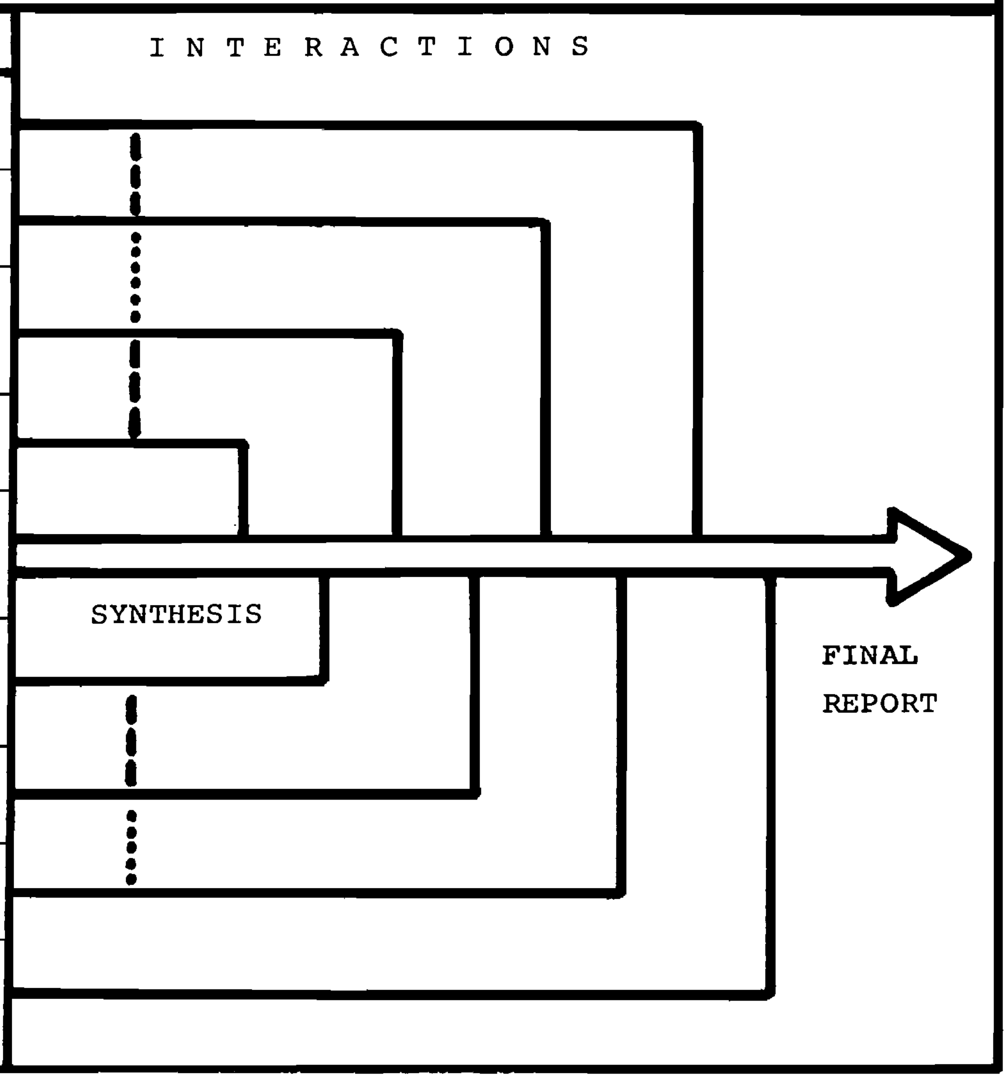
System Study Tasks:

Chapter	(Assignments)	% effort
2.	TECHNOLOGY ASSESSMENT (C.R.Bell, W.Korzen)	15
3.	SOLAR DISTRICT HEATING (W.Korzen)	4
4.	SOLAR/ELECTRIC CONCEPTS (C.R.Bell, N.Weyss)	6
5.	HYDROGEN PRODUCTION (C.R.Bell)	6
6.	SYSTEMS ASPECTS (C.R.Bell with KFA-STE)	30
7.	SCENARIOS FOR MARKET-PENETRATION (F.Jäger)	15
8.	PROJECTIONS FOR F.R.G. (F.Jäger)	15
9.	INSTITUTIONAL ASPECTS (F.Jäger with I.S.I.)	6
10.	TRADE WITH DEVELOPING COUNTRIES (C.R.Bell)	3



- Technology Assessment (T.A.) of the principal solar options is viewed as the foundation of the study effort, because it provides the current state of the art of the various alternatives and their potential large-scale viability.
- Solar District Heating was treated as a separate T.A. issue, because its limited potential depends upon future developments in energy storage technology.
- Solar/Electric Concepts are of prime importance for the FRG as a new possible category of export items (to regions with favorable solar insolation) subject to future developments of these concepts, parallel with suitable energy storage systems.
- Hydrogen Production potential (with solar options) depends on the success of electrolyzer and/or thermochemical systems developments, together with compatible hydrogen storage or recombination processes; primarily for export to regions with favorable solar insolation.
- System Aspects were structured to provide composite syntheses of all the findings of the study, with emphasis on highlights and recommendations for appropriate actions.
- Scenarios for Market Penetration were formulated to identify the limits of possible use of the best applicable solar options and associated criteria in the FRG.
- Projections for the FRG are used to exemplify the energy mix in which the applicable solar options could evolve among the alternate energy sources.
- Institutional Aspects in the FRG have been evaluated to identify contemporary constraints in their application, and the remedies that would render assistance toward an intensified use of the applicable solar options.
- Trade with Developing Countries was included as a task of the study effort merely to provide an overview of the criteria for export of solar hardware and/or technology.

The interrelationships of these tasks and the priorities for enhancing an intensified use of solar options will be governed by the degree of success in research and development of solar energy conversion systems and compatible energy storage systems.

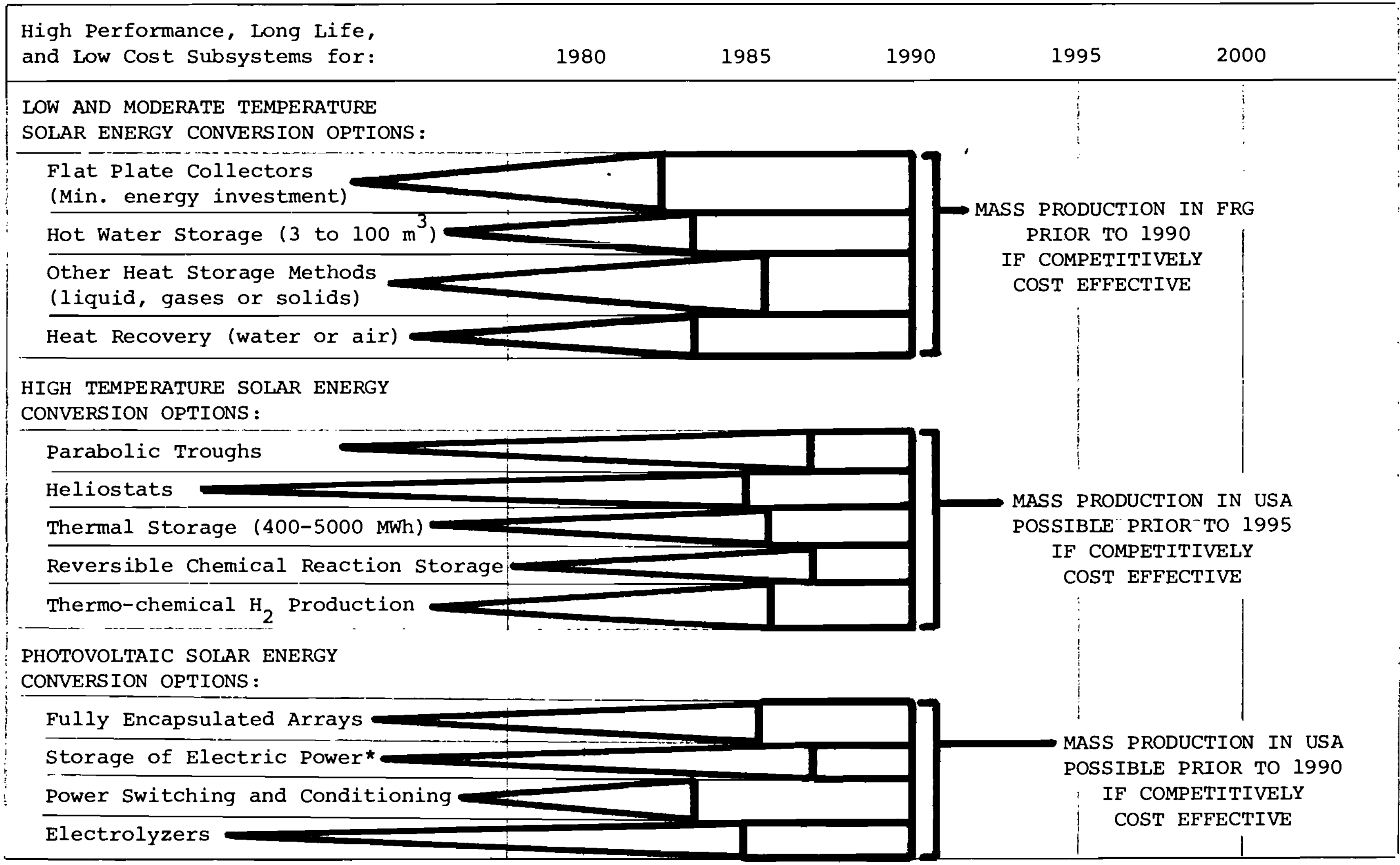
The subject of intensified use of solar options in the FRG is of broad interest to decision makers, as well as to the energy planners. The aspects of technological feasibility have been well covered in contemporary literature. Rather than repeating the contents from the large volume of generally available information, the final report was condensed to provide an overview of the technology assessment highlights, and concentrate on the issues that could indeed enhance the possibilities of an intensified use of solar energy. These issues are common to the application of new technologies:

- Identification of technical and economic risks, and measures to cope with them.
- Identification of the long-term competitive status in relation to alternative technologies and/or other alternatives to perform equivalent function(s).
- Identification of capital, materials, and manpower diversions (from other products and/or activities), required to attain the desired rate of new technology integration.
- Amendment of legal and regulatory measures constraining the rate of new technology implementation.
- Amendment of tax laws that make the implementation of the new technology unattractive.

In the case of solar technology, there are fundamental uncertainties in all these areas, characterized by the energy collection dimensions that make the contemporary methods of solar energy conversion capital, materials and, to a degree, even labor intensive.

It must be emphasized, nevertheless, that a substantial part of solar technology still needs at least several years to reach the industrial level of maturity. The justifiably anticipated improvements and their effect on commercial viability is, however, still a speculative issue. Table 1.2 offers a

Table 1.2. Possible development schedule of technologies for large-scale deployment of solar options.



*hydro, gas, chemical, mechanical, etc.

composite of possible development schedules* of the technologies which are expected to contribute to a large-scale deployment of solar options provided, of course, that the progress is not only in terms of performance improvements, but in terms of economic competitiveness as well. Evaluation of environmental benefits attainable by large-scale use of solar options is beyond the scope of this study, but their value must be among the long-term economic considerations.

The study effort was formulated with the guidance of Dr. Helmut Klein from the Federal Ministry for Research and Technology (BMFT in Bonn, FRG) and Dipl.Ing. Franz J. Friedrich from the Nuclear Research Facility (KFA in Jülich, FRG). The developmental status of solar options generated an excessive volume of information from the 1975/1977 time period, a substantial part of which was collected for analysis during the performance of the study.** Maintaining the objectives of the study in view, this report offers the key results of the synthesis, without reiterating the often reported technological details. Wherever necessary, references are made to pertinent sources of data, but no attempt was made to compile all the information in areas subject to change by future research and development. It is, therefore, envisioned that this report will contribute in establishing a foundation for periodic technology assessment of solar options, timed by the degree of national and international efforts invested in making them a useful part of the future energy supply spectrum.

Principal sources of current information, based on the IIASA data collection and access to international technical information, are identified in the list of references.

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*based on composite of FRG and USA sources.

**Note that:

- economic estimates were normalized to 1977 DM = $0.48 (or $1 = DM 2.1), without inflation rates beyond 1977.
- preferred measures of work and power are kWh and kW (and their multiples) to enhance clarity for the general reader.
- short term = 1978-1983; mid-term = 1983-1995; long-term = beyond 1995.

2. TECHNOLOGY ASSESSMENT

2.1 Introduction and Summary

Possibilities of intensified use of solar energy are closely related to the performance, reliability, and cost of the solar energy conversion and energy storage systems. Technology assessment (T.A.) thus provided an insight into the state of the art of the hardware for use of solar options, their 1976/1977 price structure, as well as an overview of their economic, institutional, environmental, and social impact.

Because of the limitation of solar energy as a resource due to the climatic conditions in the FRG, the more promising solar options are in the low temperature solar-thermal category (mid- and long-term), and in the photovoltaic category (long-term). Designs of quality hardware for these categories are capital, materials and (skilled) manpower intensive, because collection and/or concentration of solar energy requires large collector areas.

Synthesis of the solar options assessment confirmed that the currently supportable option for the FRG is residential (and small to medium commercial) water heating, followed by space and water heating systems, as soon as their prices decrease, and the prices of heating oil increase to a level making solar space and water heating competitive. The conflicting situation is such that the decrease of solar hardware prices requires attainment of mass production levels that do not appear realizable in the short-term energy market development--and the oil prices may not be increasing fast enough to stimulate the market for solar hardware until the late mid-term time period.

Solar options for industrial process heat may become economically interesting when the applicable storage systems become adequate and cost effective at the same time. The few prototype systems cannot yield enough price structure information and diversity of application potential to make a reference case for a macroeconomic model. For agricultural process heat, where the "on demand" availability of required temperatures is less critical, the use of solar options may evolve faster, but here again the large collector areas (and their cost) are the main constraining factors.

The low-to-moderate temperature solar-thermal concepts for electric power production are of interest as possible mid-term and long-term export items, particularly for regions where fuel supply logistics for conventional energy systems is expensive. The large collector area requirements are particularly visible in application of these concepts. For example, taking a typical contemporary design of a 37 kW(e) solar power plant (without energy storage) in a near peak solar insolation environment of 0.8 kW(t)/m^2, the collectors' area would cover nearly 465 m^2. This system delivers the rated power only during the time when direct sunshine delivers 0.8 kW(t)/m^2, which amounts to less than 1000 hours/year in the FRG, and perhaps nearly 3000 hours/year in favorable insolation regions (i.e. arid desert). For comparison, it ought to be remembered that 37 kW is equivalent to 50 H.P., the power of an automobile engine as that, for example, of an Opel Kadett 1,2; here, of course, the power is "on demand", and not only during sunshine. If the 37 kW(e) solar power plant is dimensioned for power delivery "on demand", the area of the collectors will be much larger, depending upon the number of hours of useful, direct solar insolation in the given region. The current cost of such facility would exceed DM 300 000 (= $143 000); but substantial reduction can be anticipated, if such units were mass produced. Nevertheless, it is unlikely that the specific cost of such systems will be under $2000/kW(e) before the year 2000 for the favorable insolation regions, which compares to about DM 284/kW(e), or $135/kW(e)* for the automotive-derived version. Yet, there are regions where such concepts would be relatively competitive because of remoteness from conventional energy supplies.

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*disregarding fuel supply.

The high temperature solar options are subject to numerous developments and prototype evaluations. It remains to be seen whether or not their performance, reliability and cost can be brought to such a level that they would offer economically attractive energy alternatives before the year 2000. This presumes that the development of compatible sizes of energy storage would be available and cost effective in the mid-term developmental time phase. Detailed synthesis of these options is non-productive (beyond appropriate sections in Chapters 2 to 5), because the outcome of future developments cannot be evaluated accurately enough to determine their potential contribution to future energy alternatives.

The large-scale usefulness of photovoltaic systems depends upon the solution of mass production problems for photovoltaic arrays with acceptable system efficiencies. Their contemporary versions are priced in the vicinity of DM 31 500/kW(e) peak ($15 000/kW(e) peak) for relatively simple systems with efficiencies not exceeding 10%. The desired goal is to bring the price down to DM 2100/kW(e) peak ($1000/kW(e) peak) before the year 1990. Should this goal prove achievable, the photovoltaic systems will become competitive with the solar-thermal systems in about 15 years, or perhaps even sooner. Such a possibility tremendously complicates the delineation of objective recommendations in this study, because of the many technical advantages of the photovoltaic systems over the solar-thermal versions. The long-term potential of photovoltaic systems in terms of relative application simplicity, reliability, and long operating life, might make it a major contender for the solar energy market.

Summarizing the technology assessment (for the stated objectives of this study), it is obvious that the overall technological aspects, as well as the environmental, institutional, and social, are of secondary importance for enhancing the use of solar energy in the FRG. The primary importance rests in the cost reduction of durable solar hardware, and the identification of the appropriate time-scale for its cost-effective integration in the future energy supply mix of the FRG.

2.2 Solar Energy as a Resource

The evaluation of the possibilities of intensified use of solar energy depends on the availability of usable insolation data for the regions under consideration. Analysis of available meteorological data [2.1,2.2] showed that such data cannot be used for accurate assessment of the actually usable solar energy for a given location, because they include early and late hours and energy readings when the low insolation intensity and long shadows make solar energy conversion ineffective.

Average data on solar insolation vary by year and location, and are only an indicator of the solar energy conversion potential for a given location. The measurements are taken on a horizontal surface and include direct solar radiation (about 400 to 980 W_t/m^2 depending upon time of the day and visibility) and diffuse solar radiation (up to 200 W_t/m^2 for dark clouds, and about 200 to 400 W_t/m^2 for light clouds). The daily distribution of insolation values is theoretically comparable to normal distribution (or "bell curve"), with the peak values reached at noontime. The actual distribution of the direct and diffuse insolation values cannot be derived from the meteorological data, with a few exceptions--stations taking hourly readings.

An empirical computer program was attempted at IIASA, using data from the FRG weather stations that provide more accurate readings. The objective was to extrapolate data from the few sources to the entire FRG. It turned out, however, that the results of the lengthy process were within the annual variations, and therefore offered no improvement. Making an extrapolation of the data over the published map of ESSO A.G. [2.3] a map of solar insolation zones was made to show the typical variations of solar energy in the FRG (Figure 2.1). The average value of solar insolation on horizontal surface for northern parts of the FRG (near 56^oN latitude) is from 930 to 1000 $kWh(t)/m^2 \cdot a$, with 1600 to 1800 sunshine hours per year; in the southern parts (near 46^oN latitude) the values are from 1060 to 1240 $kWh(t)/m^2 \cdot a$

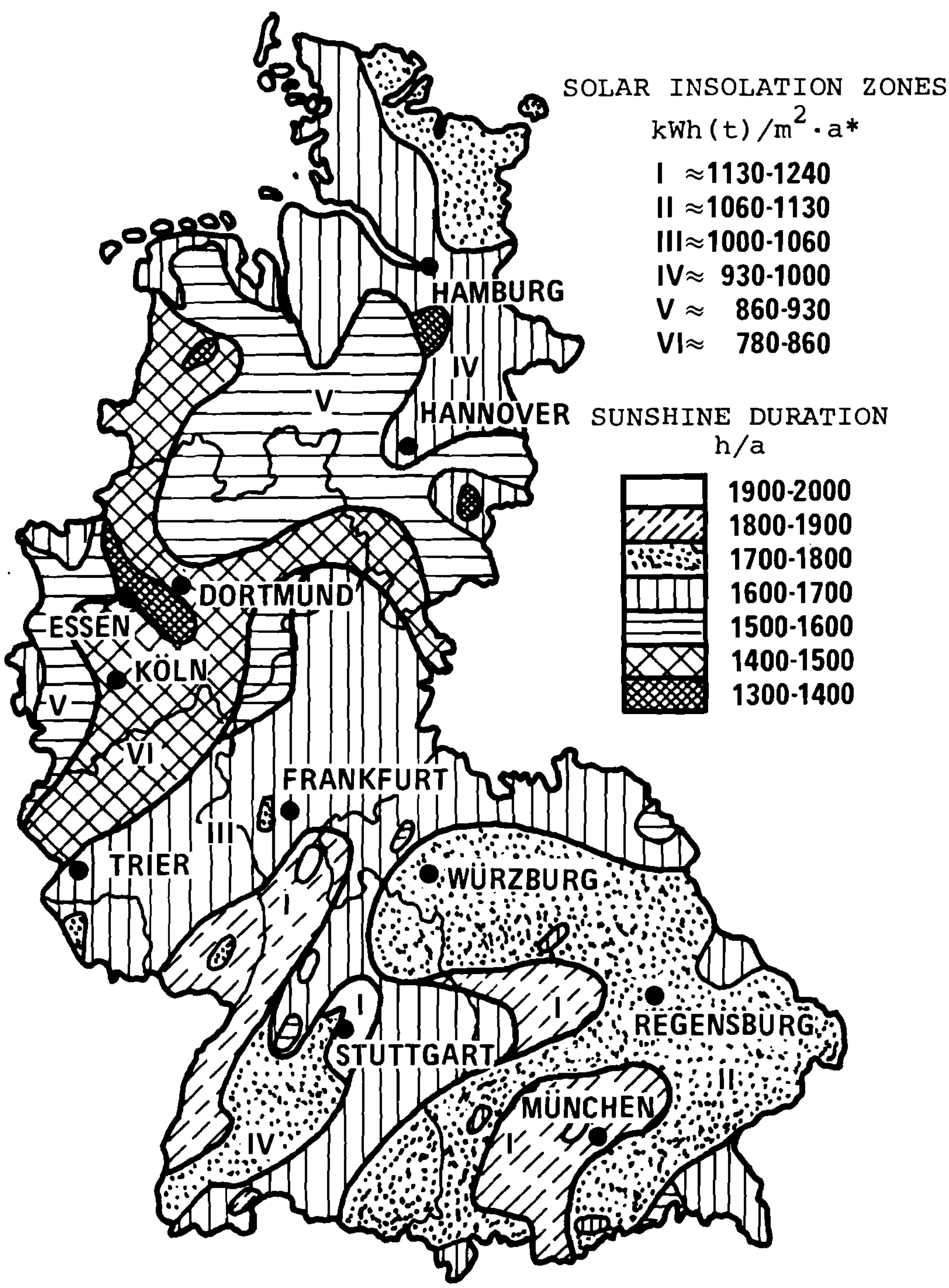

Figure 2.1: Solar insolation in the FRG.**

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*on horizontal surface (meteorological data), annual averages.
**derived from FRG Weather Service data and ESSO A.G. map.

with a similar number of sunshine hours. The FRG average is about 1000 kWh(t)/m^2·a and 1650 hours of sunshine per year. Over 50% of the solar insolation is diffuse and cannot be concentrated for attaining higher collector temperatures. This prevails particularly from November to January, during which time the insolation may be as low as an aggregate 100 kWh(t)/m^2 for the three months. The daily values range from less than 1 kWh(t)/m^2·d in winter to over 5 kWh(t)/m^2·d in summer; all measurements being made on horizontal surface.

The median performance of direct insolation is about 0.48 kW/m^2·a (yielding the median absorber performance of flat-plate collector of 0.30 kW/m^2·a).

The solar energy inputs are improved by proper orientation of the collectors, ranging from about 15% energy input increase for south orientation, and tilt set at latitude angle (from horizontal), to nearly 50% energy input increase with two-axes tracking. All this is, of course, subject to air quality, large industrial heat-releases, air pollution, increases of carbon dioxide (CO_2) in the air, and similar problems [2.4,2.5]. The zone VI shown on Figure 2.1 illustrates such effects. Evaluation and simulation programs dealing with air quality [2.6,2.7] indicate that significant loss of solar energy intensity is indeed developing in the areas of poor air quality.

Availability of solar energy as a resource is therefore closely related to climatic conditions, geographic location, and air quality. Positive effects are obtained by optimized positioning of collectors, higher elevation of the selected site for solar energy conversion, and by utilization of topographic features.

2.3 Solar Heating and Cooling Technologies

The evaluation of low temperature solar options was performed, using the international resources of IIASA in all the principal areas that could be of use for identifying improvements leading to intensified use of solar energy for heating and cooling. Contacts were established with the Arbeitsgemeinschaft Solarenergie (ASE) in Essen, FRG (now the Bundesverband Solarenergie--BSE), the German Association for Solar Energy (Deutsche Gesellschaft für Sonnenenergie--DGS), and their equivalents in Austria, Switzerland, the UK, and the USA [2.8 to 2.23] and their publications were analyzed. The results of sponsored research in the FRG, and of emerging industrial activities were considered in collaborative efforts to search for potential breakthroughs, the consequences of which could be incorporated in the study [2.24 to 2.34]. It was established that for a reference space and water heating system (see Table 7.1 and Appendix) for a single family house with hot water storage capacity limited by economic considerations, about 40% to 60% of the heating oil used can be substituted for with the use of a retrofit solar heating system, if the house is adequately insulated. The range of system efficiencies was affected by location (generally increasing toward south), as well as by quality of the collectors and the associated systems, as can be seen in Table 2.1, which essentially represents the current state of the art.

Table 2.1. Average efficiencies of solar heating systems.

Systems: / Collector Types:	Single Glazed Without Select.Absorber Surface	Single Glazed With Select.Absorber Surface	Double Glazed With Select.Absorber Surface
Water heating (~100%) and space heating (~50%)	~0.18-0.20	~0.20-0.30	~0.35-0.40
Water heating only (~100%)	~0.20-0.25	~0.30-0.35	~0.45-0.50

An analysis of the market prices for major quality components of the solar heating systems was made and correlated with

ISI [2.35]. This revealed the following range of (1977) prices (Table 2.2) for components in systems with flat-plate collectors. Because the subject study is concerned with the mid-term to long-term potential of solar heating systems, the price estimates were normalized to retrofit units for single family house as follows:

- Solar water heating DM 5000 to 8000/system (= $2380 to 3810).
- Solar space and water heating DM 15 000 to 25 000/system (= $7143 to 11905).

Table 2.2. Average prices of major components of solar heating systems in the FRG.

Components: (not installed)	Average Price		Price Range	
	in DM	in $	in DM	in $
Single glazed collectors without selective absorber surface; per m^2	~300	~144	~250-500	~120-240
Double glazed collectors with selective absorber surface; per m^2	~350	~168	~280-600	~134-288
Warm water storage				
$3m^3$ to $6m^3$; per m^3	~2000	~960	~1500-3000	~720-1440
$7m^3$ to $30m^3$; per m^3	~1000	~480	~800-1300	~384-624
Control units; per unit	~1200	~576	~700-2000	~336-960

The lower limits of the price range would be applicable when the installation rate reaches 300 000 systems per year [Chapter 7 and Table 7.1].

Solar space cooling is still at an early developmental stage using either absorption cooling or the Rankine cycle heat engine, both of which are still in the early developmental stage, and the available information is not adequate for macroeconomic projections.

2.4 Industrial and Agricultural Process Heat

The production of process heat up to 100°C would require similar collectors as the residential heating systems, but the storage capacity would have to be large enough to satisfy commercial requirements. The market potential for such systems may be significant, if future developments of the storage concepts provide cost-effective solutions [2.36]. Using process heat for drying, the dehydration of agricultural products, processing of wooden products, and various chemical and industrial products, may prove feasible where the cost of solar systems will prove acceptable; or where the environmental benefits are desired. The price range of solar components, as shown in Table 2.2, would be the prime, constraining factor.

Moderate temperature solar-thermal systems will require, in most cases, concentrating collectors to satisfy the 100 to 300°C temperature range [2.37-2.38]. Because of the limitation of direct sunshine hours per year in the FRG, such systems will probably be limited to special applications, and may gain more significance for export.

Moderate temperature solar-thermal systems are also in the research and development stage for generation of electricity (i.e. in the 10 kW(e) to 100 kW(e) range), cooling of agricultural products and pumping of water for irrigation purposes. The requirement for direct solar radiation for these devices makes them decisively more effective in regions having favorable insolation, but even there the collector areas needed for practical sizes of such systems present area and economic constraints. For example, a 37 kW(e) solar-thermal plant, without energy storage, using parabolic trough type collectors in a solar insolation environment of 0.80 kW(t)/m^2 (midday hours) would need nearly 465 m^2 of the collectors trailing the sun along a north-south axis. If flat-plate, fixed collectors were used, more than twice the collector area would be needed, because the system efficiency would drop to about two percent. The 465 m^2

collector system would function only about 1000 hours per year in the FRG (because of the limited availability of useful sunshine), but up to 3000 hours per year in regions with favorable insolation (i.e. 2300 kWh(t)/$m^2 \cdot a$). The current cost of such a device would exceed DM 300 000, or DM 8108/kW(e) ($143 000, or $3865/kW(e)). If such a system would be equipped with energy storage to a baseline configuration, the collectors' area would exceed 1200 m^2, depending upon the functional requirements. Curiously enough, a 50 H.P. automotive engine such as in an Opel-Kadett 1,2 has an equivalent performance for DM 284/kW (≈ $135/kW), using gasoline.

There are a number of prototype systems under development in various industrial countries, but considerable performance improvements and cost reductions will have to be made before they can be considered for large-scale market penetration.

2.5 Solar-Thermal-Electric Systems

High temperature solar-thermal-electric conversion (STEC) systems are at an early prototype stage [2.39-2.43]. In addition, numerous configurations are evaluated as hybrid versions combined with hydroelectric plant, as well as with a variety of fossil fueled plants. The inherent energy storage capacity of hydroelectric plants is favored for large-scale STEC. Earlier studies at IIASA indicated the feasibility of STEC in connection with hydroelectric plants, which would eliminate the difficulties of large-scale energy storage. The pending developments of critical subsystems for STEC such as the heliostat (mirror) and the receiver assemblies are among the items that may affect the performance and cost effectiveness of STEC. Table 2.3 shows contemporary estimates for mass-produced 100 MW(e) STEC powerplants from four sources. Although all the concepts were aimed at the same specifications in regions with high insolation*, the heliostat areas range from 8.65 to 10.10 m^2/kW(e), and the cost

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*2300 kWh(t)/$m^2 \cdot a$ and over 2500 hrs sunshine.

Table 2.3. 100 MW_e solar-thermal-electric-conversion (STEC) cost estimates.

For Operation in Favorable Insolation Regions*
(all with 420 MWh storage)

Concept** of:	McDonnell	Martin	Honeywell	JPL
Land area, km^2	3.1	6.2	3.6	3.4
Heliostats area, km^2	0.90	0.86	0.94	1.0
Heliostats, m^2/kW(e)	9.00	8.65	9.42	10.10
• Cost estimates, $/kW(e)				
Heliostats	626	812	623	1000
Tower	76	193	↑	↑
			100	246
Receiver	57	195	↓	↓
Turbogenerator	61	89	137	↑
Cooling (water)	49	65	64	267
Controls	26	↑	↑	
		123	326	
Electric Plant	23	↓	↓	↓
Storage & Plant Miscel.	205	326	445	543
• Estimated total*** $/kW(e)	1123	1803	1695	2056
or DM/kW(e)	2358	3786	3559	4318

* ~2300 kWh(t)/m^2·a and at least 2500 hours of useable sunshine (such as in parts of desert locations in Southwest US or in the Sahara).

** Developed from data presented at ERDA by Mitre Corp. in 1976 and correlated with other sources.

*** Cost of land, site preparation, and construction-related expenses (such as building of access roads and accommodation of labor) are not included, because they vary greatly as a function of site selection. The estimates pertain to the mass production phase of solar hardware, and are not applicable to prototypes.

$1.00 = DM 2.10

estimates for storage varied from DM 230 to 960/kW(e) (~ $110 to 458/kW(e)), or DM 55 to 230/kW(e) (~ $26 to 109/kW(e)). There are other examples of STEC concepts, but they too indicate merely various design concepts, with limited emphasis on capital expenditure and even less on operating cost, which is, after all, the determining factor in any large-scale potential for STEC.

Interim assessments of materials demand and overall energy investment varied greatly from concept to concept in the range from 7 to 22 MWh(t)/kW(e). The related energy pay-back time range is too broad for making economic assessments.

The remaining key issue is energy storage, the study of which also revealed substantial discrepancies [2.44]. Table 2.4 illustrates a contemporary spectrum of energy storage technologies compiled at the Mitre Corporation [2.45]. The most often quoted estimate for large-scale thermal storage (such as in STEC) is ~ DM 63/kWh (~ $30/kWh). The confidence level for all these estimates can only be brought to a workable status when sufficient experimental and operational data become available.

The high temperature solar-thermal systems may become a nucleus of electric power generation in the arid desert areas of developing countries, where the earlier concept of the Aerospace Corporation [2.46] could be applied. With insolation values over 2300 $kWh(t)/m^2 \cdot a$ and a sunshine duration of nearly 3000 hours per year, a STEC facility may become economically feasible in long-term applications.

2.6 Photovoltaic Systems

The potential versatility of photovoltaic systems and the chance that some of them may become competitive with solar-thermal systems before the year 1990, places them on the priority list in many industrialized countries. Their development was described in the references quoted in section 2.3 of this report, because they are emerging as a long-term potential for generation

Table 2.4. Assessment of energy storage concepts.

Concepts:	Pumped Hydro Storage	Batteries (Pb-acid)	Thermal Storage	Compressed Air	Liquid Hydrogen
Minimum economic size for utilities application, MWh	10 000	10	600	100	10
Turnaround efficiency, percent	75	75	80+	50	55
Expected operating life, years	50	15	20	20	30
Dispersed storage capability	No	Yes	Yes	No	Yes
Estimated capital cost, $/kW (rated)	300	200	400	260	350
Estimated year of availability	Now	Now	1982	1982	1985

of electricity and for production hydrogen from water as an energy storage concept. Various forms of silicon (Si), cadmium sulfide (CdS), gallium arsenide (GaAs), and other materials are under development to produce sealed arrays with system efficiencies of ~ 10%, ~ 6%, and ~ 12% respectively. The goals that are particularly strongly pursued in the USA [2.47] include development of mass production processes for completely encapsulated arrays, which could be marketed for DM 2100/kW(e) peak ($1000/kW(e) peak), or less, as early as in 1985. In the FRG, the AEG research with polycrystalline silicon and the work at the Institut für Physikalische Elektronik, University of Stuttgart, where a pilot line for Cu_2S-CdS solar cells is under continuing development, are important examples of ongoing activities in this field. Nevertheless, it will be a few years before the attainability of the performance and cost effectiveness goals will be verified.

2.7 Conclusions

The synthesis of technology assessment for the possibilities of intensified use of solar energy in the FRG revealed that most of the solar energy conversion hardware is capital and materials intensive. This is constraining delineation of the quantitative aspects of the subject study. It can be reasoned, however, that solar technology is still at a relatively early stage of development, and the existing systems are either experimental prototypes, or products of small scale manufacturing programs, which is reflected in the relatively high prices of quality systems.

In the subsequent, function-oriented evaluation of the solar options, the attainable lower limit of retail prices for solar system's hardware will be assessed by using the mass-production methods of automotive industries. The hardware complexity in automotive design exceeds that of low temperature solar hardware, but is generally relatable to the overall complexity of solar technology. A composite of 12 least expensive automobiles yields a retail price average of DM 12/kg (or $5.76/kg) of their empty weight [Chapter 6]. Interestingly enough, the prices of their engines average about DM 307/kW (or $147/kW).

A completely installed (retrofit) solar space and water heating reference system for a single family house averages about 1000 kg of materials, the estimated retail price of which should be near DM 12 000 (or $5760), if large-scale production, comparable to automotive industry, can be established. The current retail price of such system is about DM 31 500 (or ~ $15 120), and the mid-term price about DM 25 000 (or $12 000). It is apparent that there is room for improvement, once mass production is a going activity.

Retrofit installations are more or less custom-built effort, which is inherently more expensive. Integrated "low energy demand" houses will offer a better package deal, both in capital and energy investment.

Outside the area of solar space and water heating, the desirable price reductions will be substantially slower because of the smaller number of required systems and installations that may not be readily adaptable to standardization.

Functional projections of the potential of solar options, relatable to other mid-term and long-term energy supply options, are beyond technology assessment of the state of the art. Systems considerations are included in Chapters 3 to 6 and 10.

3. SOLAR DISTRICT HEATING

3.1 Introduction and Summary

The advantages of district heating are in the attainment of higher combustion efficiencies and reduced pollution, due to the better operating features of large heat-generating plants, as compared to individual household heating systems. Furthermore, the heat-generating plants can use less expensive, heavy oils and other fuel combinations that are not suitable for use in household heating systems. The combination powerplants that deliver heat as well as electric power are a major part of district heating networks.

Nearly 7% of space heating in the FRG is supplied by district heating. Studies indicate that up to 30% of space heating could be delivered by district heating in 1990, if the planned goals are met. The district heating distribution network is capital intensive, and the heat losses are often substantial. The reduced demand for heating in summer months, when only water heating and industrial process heat comprise the demand, causes inefficiencies of operation that postulates some sort of "load leveling", such as could be available by seasonal heat storage.

The question raised in this context is aimed at the possibilities of using solar energy for a part of the district heating, and thereby further contributing to the reduction of dependence on imported fuels.

Theoretically, large fields of solar energy collectors, connected to large hot water storage systems and with the district heat network, could supply at least a part of the heating required during summer months, and during the transitional months (spring and autumn). However, such facilities would be ineffective during the winter months. It would also have reduced usefulness in times of diffuse insolation (over 50% in the FRG), thus requiring a complex interface with conventional heating plants.

The cost of collectors, large-scale hot water storage, and the expenses associated with the acquisition of suitable land, bring about a high capital investment, which causes a heat-generating and distribution cost at least ten times higher than the current cost in conventional heat-generating plants. It is therefore unlikely that solar district heating becomes a viable alternative, until the cost of solar hardware is substantially lower, and that of fuels much higher.

In favorable locations, small groups of residential buildings may benefit from a well designed "community solar heating system", with centralized hot water storage, supplied by either a centralized, or decentralized (roof installed) collector system. Such concepts are subject to selected climatic and topographic conditions, and therefore difficult to integrate into the scheme of macroeconomic considerations. These would be, of course, relatively small systems, not fully relatable to conventional district heating.

3.2 Technical Characteristics

The conventional district heating characteristics are distinctly different from individual household heating systems, which must be taken into consideration when evaluating the adaptability of solar energy for district heating.

District heating plants operate with efficiencies from about 50% to 80%, depending upon size, type, and operating conditions. Their utilization factor is between 45% and 70% [3.1-3.4]. Efficiencies of residential heating systems average about 65%, but their utilization factor is very low because in the summer months most of the heat demand is only for water. About 68% of the heat for district heating networks comes from combination power plants, delivering heat as well as electricity. About 65% of the heat is distributed by hot water networks.

Solar heating systems cannot provide an "on demand" service, unless an appropriate storage of heat is provided. The consumer, whether living in an apartment house or a single family house, is primarily concerned with convenient availability of heat at a competitive price. District heating in the FRG has been a convenient method of space heating, but not necessarily competitive in annual cost, as can be seen in the estimates in Table 3.1. The comparison of heating cost for various dwellings, based on the life-cycle of the heating systems, shows that wherever the existing district heating is accessible, it is indeed competitive with other alternatives; it is, however, close enough to oil heating, so that the added cost of solar system to district heating network would cause drastic increase of heating cost. The combined efficiencies of solar energy collection, conversion, storage and distribution are too low to offer an economically attractive option.

A reference version of retrofit solar heating system with oil heating back-up was added for comparison. Although an (optimistic) anticipated price reduction of solar (due to mass-production and standardization) to DM $428/m^2$ of system ($\sim\$204/m^2$) was used in these sample cases*, the heating cost with such retrofit systems may only become competitive when the oil prices increase at least by a factor of two. Nevertheless it ought to be remembered that the amortization of such solar systems depends mainly on their performance during the transitional months (in autumn and in springtime). This is because nearly 75% of annual global insolation ($\sim$750 kWh(t)/$m^2\cdot$a, measured on horizontal surface) is obtained during the summer half of the year (April to September), and only about a half of it ($\sim$370 kWh(t)/$m^2\cdot$a) is from direct sunshine. Assuming that about 2.8 kWh(t)** per user per day is required for water heating (including storage and distribution losses), nearly 4 m^2 of collector area and 0.1 m^3 hot water storage increment would be needed per user, if only water

*reflecting the low estimate in Table 7.1.
**useful energy or ~5.2 kWh(t) primary energy, if oil heating used.

Table 3.1. Comparison of heating cost in various dwellings. (average, typical dwellings in F.R.G.)

Type of Dwelling / Estimated Averages	Apartment ~8kW(t)			Terraced Family House** ~12.5kW(t)				Separate Standing Family House ~18kW(t)			
Type of heating*	Oil	El.	D.H.	Oil	Oil +S.	El.	D.H.	Oil	Oil +S.	El.	D.H.
Heated area, m^2	80	80	80	100	100	100	100	120	120	120	120
Spec. heat demand ~$kWh(t)/m^2 \cdot a$	170	170	170	210	210	210	210	250	250	250	250
Cost of heating system											
~DM	5000	6000	3500	8000	23000	9000	5500	12000	31300	13500	8000
~$	2380	2857	1667	3810	10950	4286	2620	5714	14900	6428	3810
Annual cost of heating											
~DM/a***	1350	1560	1180	2130	3600	2370	1840	3210	5050	3570	2770
~$/a***	643	743	562	1015	1710	1128	876	1528	2400	1700	1320
Tot. annual heating, spec. cost											
~DM/m^2	16.8	19.4	14.7	21.3	36.0	23.7	18.4	26.8	42.0	29.8	23.1
~$\$/m^2$	8.0	9.2	7.0	10.1	17.0	11.3	8.8	12.8	20.0	14.2	11.0

*El. = electric heating; D.H. = district heating; Oil+S. = Solar heating with oil back-up; all 1700 hours/a and 20a life cycle with 10% interest.

**Terraced house means a family house with walls to houses on both sides.

***Includes fuel cost, amortization payments and maintenance estimates. In case of solar heating, 50% of fuel substitution assumed and future retrofit system cost of DM $428/m^2$.

heating in the time period from April to September is desired. This alone adds up to an investment of DM 1500/user (~$714), to be amortized in 20 years*, or DM 0.47/kWh(t) production cost (~$0.22/kWh(t)). The current production cost of low temperature heat in large plants varies from DM 0.009 to 0.016/kWh(t), or $0.0043 to $0.0076/kWh(t)--the low cost is attainable in large, conventional back-pressure plants [3.1], or some large nuclear power plants, and the higher cost from boiler plants using heavy oil. Heat distribution cost is not included, but can be estimated from the preceding quotations of average prices to the consumer (ref. Table 3.1). Current estimates indicate that if solar systems were integrated with conventional functions of a district heating network, the heat-generating and distribution cost would be at least 10 times higher than the current cost for district heat production. All of this shows that solar district heating could not compete even with plants using heavy oil.

The apparent advantage of "nuclear heating reactor concepts" [3.2] may lead to development of new systems for district heating, as another competitive alternative for replacing fossil fuels.

3.3 District Heating Potential

District heating and distribution facilities are constructed in locations where the anticipated heating demand should be realized, the planned cost effectiveness is not attainable [3.4]. Nevertheless, studies about the future potential of district heating in the FRG have shown that up to 30% of space heating, or about four times the present (1977) level, could be supplied by district heating facilities.

Synthesis of current solar energy conversion systems of a commensurate size showed that such options are excessively capital intensive, and therefore do not offer a competitive alternative in the climatic conditions of the FRG. Whether or not the

*total annual charges 15%, including interest, operations and maintenance cost.

future cost reductions of solar collectors and storage systems, and/or major improvements in their technology can change the situation is uncertain.

3.4 District Heating Facilities and Potential Solar System Applications

There are about 112 public district heating enterprises that collectively supply nearly 80% of the district heating in the FRG, using ~104 heating power plants (electricity + heat), ~363 heat-supply plants, and ~527 heating networks, with the combined delivery capacity of ~38.3 TWh(t), which is nearly 7% of all space and water heating. The remaining 20% of the district heating are mostly private companies that provide heat for housing projects. It is possibly this smaller sector of district heating where some use of solar alternatives could be realized in the future--if the increasing cost of fossil fuels, together with the anticipated decreases of solar hardware prices create the market for it.

In regions with favorable insolation and topographic features that would enhance construction of small housing groups with maximum solar exposure (minimum of shading effects), a "community solar heating system" with centralized hot water storage might prove attractive. A centralized bank of collectors, or roofs with integrated collectors on well insulated single or two-family houses, built for use of passive solar energy conversion as well, may offer optimum energy savings, once the technology for such integrated buildings is well developed. These would be relatively small groups of houses, and the "community solar heating" would not be comparable to regular district heating systems. It is too early for the introduction of such concepts into the macroeconomic evaluation of energy trends.

4. SOLAR-ELECTRIC CONCEPTS

4.1 Introduction and Summary

The contemporary status highlights of solar-electric concepts are summarized in sections 2.5 and 2.6. The issue requiring clarification for the purposes of this study is the evaluation of the future potential of electricity generated by the use of solar energy. Extensive study of existing concepts revealed a varied spectrum of developments, including prototype testing activities with promising performance, but without adequate information on long-term economics and competitive status of such concepts that would facilitate their large-scale use in the FRG, or as a potential export product.

Table 4.1 summarizes a comparison of the large STEC concepts, which shows that even their long-term projections, assuming mass production of solar specific hardware, will approach competitive status only after substantial increases in conventional electricity generation cost, and possibly after more innovative designs become available. The comparison shows that heliostats with a central receiver are leading contenders for the large-scale generation of electricity, but could be challenged by the anticipated progress of photovoltaic array developments. The data obtained on paraboloidal dishes appear to be too optimistic and require further monitoring. The two-dimensional trough and the flat-plate collector versions are obviously without merit for large-scale facilities, but are included to illustrate the relative criteria of STEC concepts.

The uncertainties of fossil fuel price structure development in the future make meaningful study of the possibilities of intensified use of these options too speculative, However, because of these uncertainties, the development efforts must continue to provide alternative solutions to the energy supply dilemma when needed. In such a perspective, even the Alpine regions were considered as possible sites for STEC facilities [Chapter 6]. Beyond

Table 4.1. Comparison of 100 MW(e) "daytime only"* mass produced solar energy conversion system estimates (in high insolation areas)**

Collector Concepts / Parameter Estimates		Flat Plate	Two Dimensional Trough	Paraboloidal Dish	Heliostats & Central Receiver	Photovoltaic Arrays***
Approximate site (km^2)		7.5	2.1	2.0	2.1	4.5
Sun tracking		None	1-axis	2-axes	2-axes	None
Water requirements		Yes	Yes	Yes	Yes	None
Collector ($/kW(e))		2340	1030	700	950	1200
Receiver ($/kW(e))		-	310	40	165	-
Energy transport ($/kW(e))		200	290	170	200	90
Power conversion ($/kW(e))		420	200	180	275	110
Other (incl. land) ($/kW(e))		120	110	110	130	120
Capital investment ($\$/I_t kW(e)$)		3080	1940	1200	1720	1520
Plant load factor (%) f_p		0.20	0.25	0.28	0.27	0.30
Overall efficiency (%)		0.03	0.15	0.20	0.18	0.10
Availability (year)		1980	1980	1985	1990	1990
Electric power generating cost	~$/kWh(e)	0.23	0.12	0.06	0.09	0.07
	~DM/kWh(e)	0.48	0.24	0.13	0.20	0.16

*without energy storage, based on JPL estimates [4.1 to 4.3].
**~2300 $kWh(t)/m^2 \cdot a$ and 2500 hrs. of usable sunshine or more.
***anticipated values, based on the assumption that the mass production objectives will be met.

that, the large-scale utilization of STEC is subject to future trends in regional and global energy policies.

4.2 Solar-Thermal-Electric Systems Potential

Technology assessment of the solar-thermal-electric conversion (STEC) systems illustrated their dependence on usable, direct solar radiation, which is significantly lower than indicated by the contemporary meteorological information, because of the shadowing effects during early morning and late afternoon hours. The average usable hours of sunshine in the FRG are about 1000/year, which limits the use of STEC for centralized power generation. In the selected arid desert areas, the usable sunshine exceeds 2500 hours per year, which could make STEC concepts useful in long-term considerations.

The industrial estimates of STEC cost in the USA [section 2.5, Table 2.3] ranged from $1123 to 2056/kW(e), or ~DM 2500 to 4500/kW(e), for mass produced systems without energy storage, for selected desert sites in the Southwest USA. With a plant load factor of 0.27, and a 25 year plant life estimate, and ten percent interest rates, such STEC plants would have electric power generating costs of $0.062 to 0.113/kWh(e), or DM 0.13 to 0.24/kWh(e) for daytime operation only. Extension of such plants to dimensions providing base-load supply of power, that is, with a load factor of the order of 0.7, would require an increase of solar energy collection area by a factor of three or more, depending upon the distribution of solar energy input values, and upon the efficiency of the substantial energy storage needed for the base-load configuration. Current USA estimates for thermal storage [4.1] are near $30/kWh(e). This indicates that STEC plants will be at least initially more attractive in hybrid configurations, which means in combination with conventional powerplants. They can substitute for conventional fuels during daytime operations. Because the energy storage technology is also in developmental stage, the long-term potential of STEC plants is not quantifiable as yet.

It is essential to distinguish between conventional power plants, delivering power on demand, and the "daytime" STEC concepts, capable of delivering power for about a third of the time on a daily basis. Furthermore, it is not only the large area needed for collection of solar energy, but also the operation and maintenance cost, that may be more than ten times as high as with most conventional power plants [4.2], or about $0.02/kWh(e) ≈ DM 0.04/kWh(e). All this does not necessarily mean that STEC plants will not have a useful function in the long-term energy mix; it merely shows that more research and development is needed to come up with competitive concepts.

An assessment of various STEC concepts was made [4.1 to 4.3] to determine which has a potential for mid-term application. Table 4.1 provides an overview of the comparison, which shows, as would be expected, the effects of required collector areas, and plant load factors that may be expected. The 100 MW(e) rating was used, because it is about the maximum practical size for STEC in the regions of favorable insolation. Smaller plants may not reach these overall efficiencies, yet may be attractive for electrification projects in developing countries, where the absence of electricity networks makes generation of electricity more expensive.

Because a prototype STEC plant can earn sizeable revenues when properly sized for given function, a construction of such a plant in the FRG as an instrument for developing exportable technology ought to be considered. For example, if a suitably located conventional powerplant with capacity of less than 50 MW(e) can be modified to use solar energy during usable sunshine hours for generating steam, the installation could be used either for preheat function, or even for full scale operation under some conditions, thus reducing the fuel consumption of the plant. This would produce a pay-back for the experimental installation. There is no reason why, in case of favorable location and existing structures, the heliostats cannot be located on such structures and the receiver attached to the smokestack (structurally reinforced for the purpose). Only a sizeable prototype can assist in effective development of receivers, because smaller versions do not simulate the energy impingement patterns on the receiver, nor can they produce the effects of random concentration of energy on relatively small areas, as can happen within reasonable tolerances of heliostat control. In effect, the controls and all the other STEC subsystems could be subject to practical development of such a prototype.

The broad spectrum of parametric studies and concepts evaluated for this study [4.4 to 4.6] manifested the accelerated research and development activities, but also demonstrated the level of uncertainties in critical aspects of STEC development. On the positive side, there is no evidence that the materials requirements or the operational integration of STEC would be prohibitive. An evaluation of load curves in terms of electricity supply economics [4.7] did not reveal unsurmountable problems either. It remains to be the issue of research and development success in the next several years, that will determine the potential of competitive utilization of STEC plants.

4.3 Solar-Photovoltaic Systems Potential

In spite of the uncertainties of meeting the mid-term objectives in cost reduction of photovoltaic systems, the mere possibility of their gaining competitive position in relation to solar-thermal systems necessitates consideration of their role in a future energy supply mix.

The assessment of the current status of photovoltaic research and development [section 2.6] revealed a variety of promising activities with silicon (Si), cadmium sulfide (CdS) and gallium arsenide (GaAs) cells with calculated system efficiencies of ~10%, ~6% and ~12% respectively*, when using a variety of innovative developments. Conservatively, even somewhat lower performance levels

*subject to operating temperatures.

would be acceptable, if the cost reduction objectives are met before 1985. A number of schemes to reduce the expensive cell areas are in the development stage, ranging from concentrating lenses or mirrors to tracking systems and means of heat dissipation--the latter being necessary in concentrating systems, because the increasing array temperatures decrease their performance [4.9 to 4.12]. Predictions of long-term system efficiencies up to 21% [4.12] are documented. Parallel developments of DC/AC converters are facilitating the application aspects of photovoltaic systems.

The photovoltaic option shown in Table 4.1 is representative of the planned mid-term potential of photovoltaic central stations. The uncertainties of the parametric data are essentially economic, rather than technical. The electric power storage technology has about the same level of uncertainty as the photovoltaic technology. Reasonable estimates of advanced lithium batteries, for example, are in the range of $30-40/kWh(e), which could be reduced by up to 50%, if large-scale production would materialize. This does, of course, indicate that systems requiring substantial storage capacity will be much less competitive than those where energy supply meets demand.

4.4 Conclusions

The intensive emphasis on the development of low cost photovoltaic cells with acceptable performance tends to overshadow the fact that development of low cost encapsulation process is of equal importance. The research leading to polycrystalline and even amorphous cells yields superior adaptability for mass production processes, which enhances attainment of the competitive status of photovoltaic systems.

In the FRG, the promising activities are at AEG with polycrystalline silicon and at the University of Stuttgart (Institut für Physikalische Elektronik), where a pilot line for the production of Cu_2S-CdS is under continuing development. How soon these efforts will reach the maturity needed for large-scale implementation is, as yet, uncertain. It should be stated, however, that should this indeed be the case prior to 1990, a wide spectrum of new products will emerge on the market with the net effect of a tangible decrease in conventional energy demand. The applied system aspects of photovoltaic technology are contained in Chapter 6.

If the anticipated cost reduction of the photovoltaic arrays is realized, then their competitive position with the STEC concepts would increase significantly not only for production of electric power, but for production of hydrogen as well. Comparison of the estimates on Tables 4.1 and 6.1 shows a potentially competitive levels of capital investment for both of these options; likewise, in the case of performance and energy pay-back time. In addition, the operations & maintenance cost was estimated to be over DM 0.025 per kWh(e), or $ 0.012/kWh(e), but only about a half of that for large photovoltaic arrays. If the future experiences with prototype facilities will support such estimates, the photovoltaic option may emerge as a winning concept, because the stationary arrays are decisively easier to maintain than the complex heliostats.

Because the operation of photovoltaic arrays is not limited to direct solar radiation, their use in FRG would be assured.

5. HYDROGEN PRODUCTION

5.1 Introduction and Summary

The use of solar energy for hydrogen production is closely related to the development success of STEC plant and/or of photovoltaic systems [sections 2.5,2.6,4.2,4.3]. Both of these solar options are in the development stage and the uncertainties are such that an accurate assessment of their economic potential is not yet feasible.

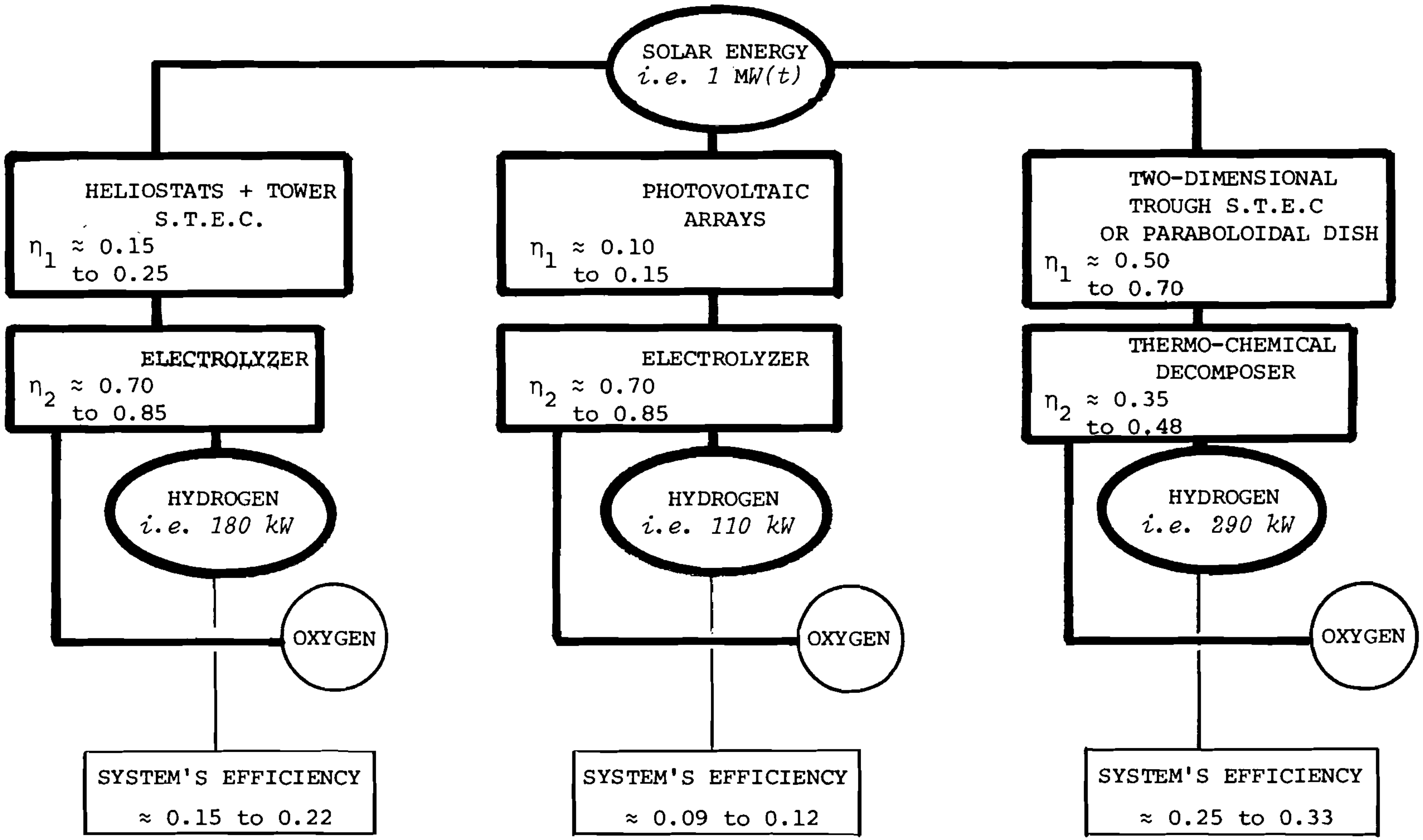
Table 5.1 illustrates three promising paths for production of hydrogen. The "STEC path" and the "photovoltaic path" depend upon successful development of more efficient electrolysis, while the "concentrating collectors path" depends upon successful development of thermochemical process, which appears to be the most advantageous at this time.

5.2 Solar-Thermal-Electric Hydrogen Potential and Related Issues

The environmental and social cost issues that favor solar energy conversion options also favor the utilization of hydrogen as an energy carrier (lower heating value ~33 kWh/kg*), as well as an energy storage medium. A considerable number of electrolytic processes with system efficiencies from 60% to 90% were evaluated, and hydrogen applications reviewed [5.1 to 5.8]. The long-term potential insolation may have a system efficiency of 22% with a capital investment near DM 4800/kW ($2300/kW) equivalent. Conservative estimates show a system efficiency of 15%. There are still many uncertainties in these estimates to be used for the identification of macroeconomic potential.

*lower heating value represents here the usually quoted minimum for a given fuel.

Table 5.1. Three major paths for hydrogen production with solar energy.



5.3 Solar-Thermal-Hydrogen Potential and Related Issues

The thermochemical (closed cycle) decomposition of water appears to be the most favorable method of hydrogen production with potential system efficiencies from 25% to 33%. Three solar-thermal configurations have been evaluated for this task:

- Parabolic trough with concentration ratios up to 40, and attainable temperature up to 400°C.
- Paraboloidal dish with concentration ratios up to 10 000, and attainable temperature up to 3000°C.
- Heliostats with receiver tower, having concentration ratios up to 2000, and attainable temperature near 800°C.

The paraboidal dish and the heliostats with receiver tower appear to be particularly suitable for hydrogen production at relatively lower cost than the STEC-plant. Again, the data are not yet entirely conclusive for macroeconomic evaluation.

5.4 Solar-Photovoltaic Hydrogen Potential and Related Issues

The long-term potential of large photovoltaic systems for hydrogen production may be realized at system efficiencies from 9% to 12% depending upon the success of electrolyzer and photovoltaic array development. The cost estimates of the various subsystems are too broad to derive accurate projections. The most attractive advantage of this option is the flexibility of scale ranging from small devices to central power stations. If the cost reduction objectives for photovoltaic arrays are met, their competitive potential with solar-thermal systems could be realized.

5.5 Conclusions

Hydrogen production with solar energy is subject to numerous research and development efforts, some of which may offer long-term alternatives in the formulation of nonpolluting energy systems. The thermochemical alternative appears most promising both technologically, as well as economically, but it is too early to formulate final conclusions.

6. SYSTEM ASPECTS

6.1 Introduction and Summary

The organization of the system study on solar energy utilization in the FRG [Table 1.1] was planned to provide a synthesis for the identified solar options and an assessment of their capacity for fossil fuel replacement in the future spectrum of energy supply. The assessment of the solar options in Chapters 2 to 5 indicates that the current development status of solar technology yields a broad difference between the upper and the lower performance and economic estimates for the evaluated options. The resulting level of uncertainty precludes an integrated approach, which would tend to magnify the biases of the estimates and possibly lead to erroneous conclusions. The obvious implication is that it is unlikely that solar options can substitute for more than few percent of primary energy demand of the FRG by the year 2000, even when the recommended measures for an intensified use of solar options are implemented.

The low temperature solar options presently have an identifiable potential to displace a certain amount of fossil fuels. This can be accomplished by providing energy for residential and some commercial water heating and gradually space heating for houses with adequate insulation suitably oriented for solar exposure and in regions with sufficient insulation values. The relatively high cost of retrofit installations stipulates that more emphasis ought to be directed to integrated "low energy demand houses", where the solar systems fulfill a multitude of functions; i.e. the solar collectors are also part of the roof and the insulation. The next generation of buildings can be designed to use passive, as well as active solar systems, together with heat pumps and heat recovery equipment and, of course, with nearly optimum house insulation. Ultimately, the conventional heating system can be replaced by electric back-up that would be more cost effective.

An estimate of principal characteristics of the major solar options in Table 6.1 reflects the current state of the art of solar technology, but uses projected production cost estimates for all but low temperature options, rather than prototype cost. The uncertainties in the future development of solar hardware are reflected in the broad range of system cost estimates, variations of energy investment and range of estimated performance [general references]. This is particularly obvious in the high temperature and photovoltaic options, where the selection of materials does not yet show concern with energy investment issues. The use of aluminum, for example, with energy investment of ~ 100 kWh(t)/kg in areas where steel could be used, requiring only ~ 8 to 14 kWh(t)/kg (depending upon quality, source, etc.), is responsible for some of the variations. The widest range of energy investment is for the variety of STEC concepts, due to design features and allowances for site adaptation. The relative ease of STEC construction in desert areas with ready access and favorable soil mechanism, as compared with alpine site, where more intensive site preparation and construction of access roads would be required, is among the issues affecting the broad variations. Altogether, it is obvious from the tabulated estimates that a careful life-cycle assessment will have to be made for each application of solar options before their relative viability can be judged. The state of the art of the high temperature and photovoltaic options is not sufficiently advanced to evaluate accelerated market penetration strategies or to draw macroeconomic conclusions.

6.2 Hot Water Preparation Systems and Potential of Their Large-Scale Application

Water heating in the FRG represents only about 6% of the final energy consumption or less than 2% of the primary energy consumption. Solar technology, here, can already be economically attractive, because it can be dimensioned to provide water heating on an annual basis, thus permitting shut-off of conventional water heating systems in summer months, at which time their efficiency is very low (i.e. 20%).

Table 6.1. Estimates of principal characteristics of major solar options.

Parameters	In 1000 kWh(t)/m^2·a Region Global Insolation			In 2300 kWh(t)/m^2·a Region Global Insolation		
	Low Temp. Retro-fits	High Temp. Daylight STEC	Photo-voltaic Daylight Arrays	Low Temp. Retro-fits	High Temp. Daylight STEC	Photo-voltaic Daylight Arrays
Collector Area, ~m^2/kW	6	21	16	3	8	13
Use	Space and water heating	Electricity and/or synthetic fuels (no storage)		Space and water heating	Electricity and/or synthetic fuels (no storage)	
System Cost ~DM/kW	3020 to 6050	9480 to 11900	3860 to 6050	1510 to 3020	3610 to 4530	3150 to 4910
~$/kW	1440 to 2880	4515 to 5670	1840 to 2880	720 to 1440	1720 to 2160	1500 to 2340
Energy Investment ~MWh(t)/kW	5.0 to 7.2	18.4 to 57.8	12.3 to 18.5	2.5 to 3.6	7.0 to 22.0	10.0 to 15.0
Availability (year)	1979	1990	1990	1979	1990	1990
Attainable Primary Ene. Replacement ~tce/kW·a	o.22 to o.37	o.20 to o.30	o.15 to o.21	0.40 to 0.55	0.32 to 0.56	0.30 to 0.37
Energy Payback Time (years)	1.6 to 4.0	7.3 to 36.0	7.2 to 15.4	0.6 to 0.8	1.5 to 8.0	3.3 to 6.2

Notes: System cost estimates in 1977 DM or $ for fully developed systems, in series mass-production and year of availability.

Low temperature systems for space and water heating are dimensioned as reference systems (Table 7.1).

High temperature systems reflect wide range of concepts and uncertainties in materials selection. Recycled materials would reduce the energy investment drastically. Transportation and financing cost not included.

Photovoltaic systems are subject to feasibility of cell and encapsulation mass production, yielding array cost below $1000/kW(e) (peak).

Thermal storage cost is estimated at about $30/kWh, which would substantially increase the cost for baseload configurations.

There is a need for consumer protection laws and regulations based on supervised quality standards to secure long-term reliability of the heating systems.

6.3 Space and Water Heating Systems and Potential of Their Large-Scale Application

The potential impact of solar space and water heating in terms of heating oil savings was evaluated by the use of existing technology and by organizing a solar options workshop in May 1977. Thirty experts from the FRG and Austria, together with observers from other countries, cooperated on a critical evaluation of solar heating with the aid of a "Delphi inquiry", designed to identify the critical system aspects of solar options. The conclusions of the workshop participants were as follows:

(1) Several reference systems should be established to deal with the delineation of the solar heating potential in the FRG. This suggestion was implemented through the cooperation with KFA-STE (Appendix).

(2) The industry marketing solar heating systems tends to be optimistic. Performance estimates based on industry information were re-evaluated and lowered nearly 15% in terms of heating oil substitution values.

(3) A delineation of potential cost reductions of retrofit solar space and water heating systems, dimensioned for a 50% substitution of heating oil, was made by evaluating subsystem cost as a percentage of the system's cost (Table 6.2). The inquiry showed that about 50% of the system's cost is for solar specific hardware, the cost reduction of which is attainable by standardization and mass production. The retrofit design fees would also tend to decrease in the future; but the standard plumbing, pumps and structural members, as well as the transportation, assembly and installation cost would tend to increase with inflation. Thus, it will require a major effort to bring about the desired reduction of prices.

Table 6.2. Solar space and water heating subsystems cost as percentage of the system's cost*.
(retrofit installations for existing buildings)

Subsystems:		Percent of System's Cost: Range of Estimates:	Average:	Median:
(1) Solar Specific Hardware:		~40 to 60%	~48%	~50%
Collectors	~22%			
Hot water storage	~15%			
System Controls	~5%			
(2) Standard Hardware:		~12 to 30%	~21%	~25%
Pipes, plumbing and pumps	~14%			
Structures	~12%			
(3) Transportation, Assembly and Installation		~10 to 30%	~16%	~17%
(4) Retrofit Design Fees		~2 to 12%	~8%	~8%

*dimensioned to provide 50% substitution of heating oil in a single family house.

(4) In evaluating alternate means for energy savings in single and two-family houses, the following sequence of priorities was established:

(a) house insulation improvements,
(b) reduction of hot water storage cost,
(c) reduction of collectors' cost.

(5) Other solar options will not have a significant effect on energy savings before the year 2000 (such was the concensus of the majority of workshop participants).

The standards should also provide for uniform external dimensions of solar collectors to insure availability of spares. A government-sponsored insurance should be considered to protect the consumer against premature failure of solar hardware. A solar system should at least outlast its amortization time.

Subsequent assessments confirmed this composite evaluation rather closely. The projected reference system was subjected to solar heating sizing from zero to 100 percent of heating oil substitution by solar energy. Figure 6.1 shows typical characteristics of such a parametric assessment in terms of collector area and hot water storage volume. Considering the roof area limitation of a single-family house, and the economically acceptable size of the hot water storage system [Table 2.2 and Figure 6.1], the 50% substitution by solar appears near optimal, when the corresponding cost of solar heating also is subjected to such sizing, as illustrated in Figure 6.2. This is relatable to the solar-specific investment [Table 7.1] and the gain of useful energy only by the solar system. Continuing the modelling effort of the projected reference system, the contemporary selection of flat-plate collectors is evaluated in terms of their heating oil substitution potential. Figure 6.3 illustrates the effects of collector type on the cost of solar systems and their heating oil substitution capacity. This provides the system aspects visibility of trade-offs between collector design, the system's performance and the system cost. Table 3.1 illustrates the comparison of heating cost as envisioned with a mass produced solar system. It is evident that increased sophistication of collector design does not necessarily enhance the system's performance commensurate with the cost.

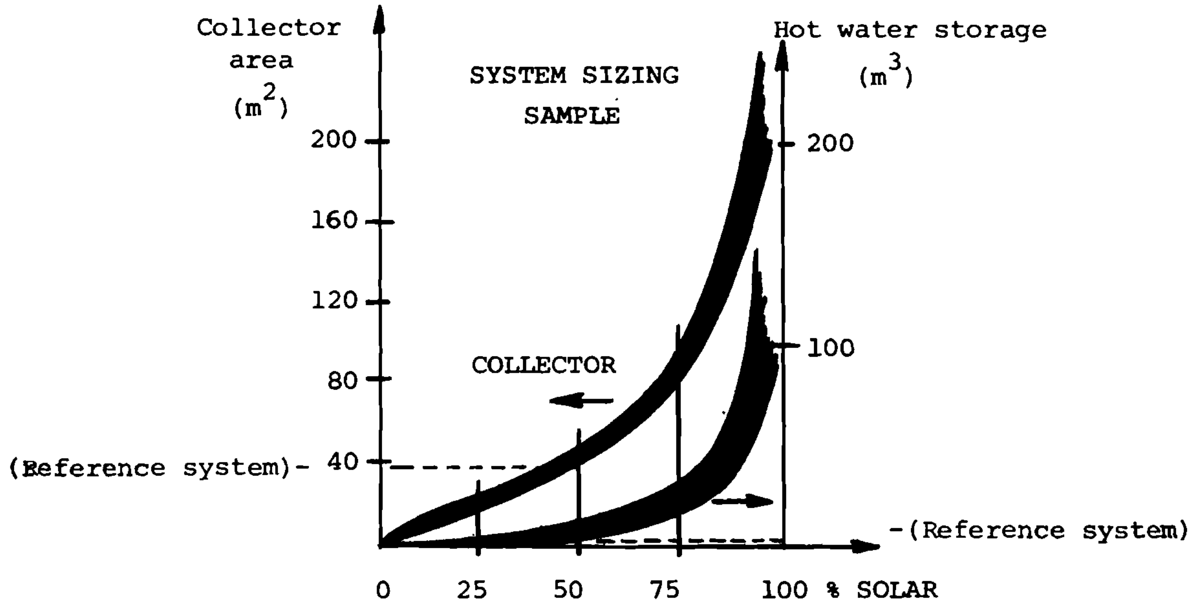


Figure 6.1: Collector area and hot water storage volume as a function of heating oil displacement by solar space & water heating.

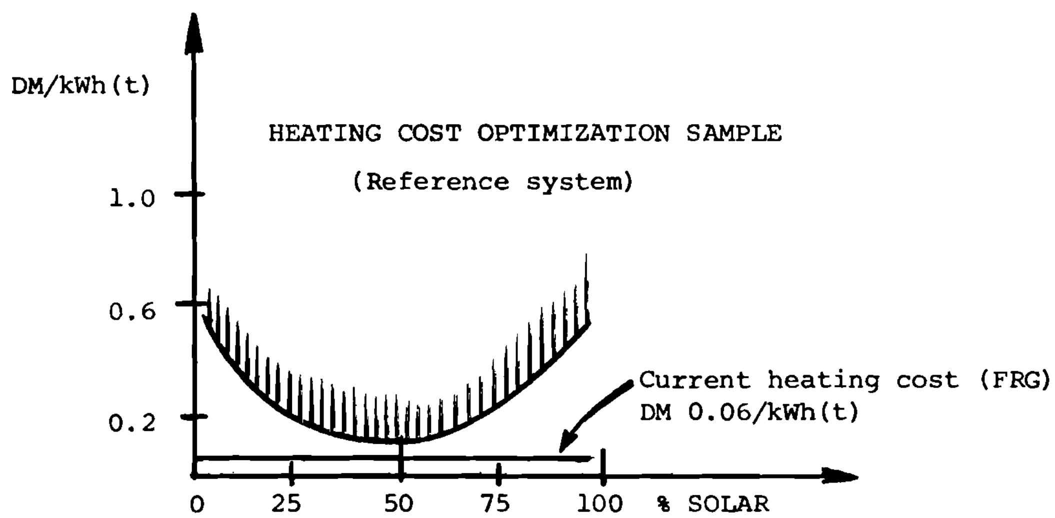


Figure 6.2: Cost of solar heating as a function of heating oil displacement by solar space & water heating.

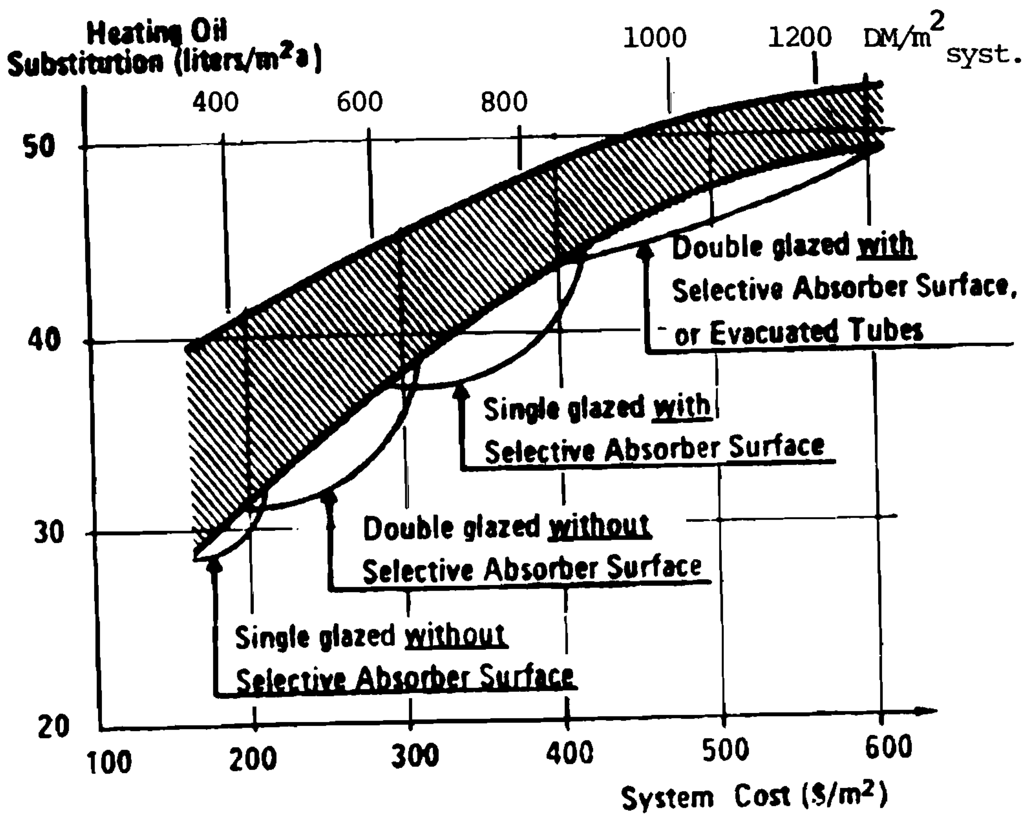


Figure 6.3 Heating Oil Substitution Capacity of Space & Water Heating System with Various Collector Types Dimensioned to the Reference Single Family House

Since the application of learning curves to new technology is not quite dependable, a correlation analysis was made to pursue further the cost distribution issues implied in Table 6.1.

The 1967-77 average solar systems for space and water heating, sized to the reference house, were selling for DM 900/m^2 (~ \$428/m^2) installed. With the average price of heating oil at DM 0.35/liter, the amortization time for such an energy system does not inspire intensified market penetration of solar heating systems. The subsystems cost distribution on Table 6.1 would theoretically permit 25% cost reduction, bringing the contemporary price of the system from DM 31 500 (~ \$15 120) to about DM 23 450 (~ \$11 256). The hardware weight of such system is about 1000 kg, which means an overall average of DM 23.45/kg (~ \$11.26). The next step is to evaluate the lowest reasonable price for large-scale mass production of such hardware. The obvious example can be seen in the automotive industry which is quite effective in mass production methods. A typical compact automobile is a composite of mechanical, structural and sheet-metal hardware, somewhat similar (but certainly not less complex) to a solar system. Table 6.3 is a compilation of weight and power characteristics of 12 automobiles, averaging DM 12/kg (~ \$5.76/kg) retail cost. Using this as a guideline, a solar heating systems cost in the range of DM 12 000 (~ \$5760) appears attainable for retrofit installations of standardized type in the quoted reference house.

To visualize the transition from retrofit installations to "integrated, low energy demand houses", three categories of single and two-family houses were formulated:

I. Houses built prior to 1977, requiring customized, and therefore relatively expensive retrofit installation of solar systems. The appearance of retrofit installations is reviewed in some regions as a constraint.

II. Houses built after the 1977 mandated house insulation laws were enacted, but still not designed for fully integrated solar options. These provide significant improvement of fuel saving performance and reduction of installation cost. While the appearance issue can be minimized, it may still be a constraining factor in some regions.

III. "Low energy demand" solar houses, optimized for integration of passive, as well as active solar systems, heat pump application and heat recovery systems. The integrated systems should not pose aesthetic problems.

It is obviously the third category that provides the best performance and economy. Figure 6.4 shows schematics of a possible evolution of such house. Its cost effectiveness is enhanced by integration of heating systems using passive as well as active

Table 6.3

Automotive Mass-Production Samplings

For Composite Materials-Hardware Cost Estimates for "STECs"

(Data Cut-off, Nov. 1977, Vienna)

Product*	Empty Weight, kg	Engine Rating, kW	DM/kW	DM/kg
Citroen 2CV4	560	17,6	384,-	12,-
Datsun 100 A/2	720	33,0	285,-	13,-
Eliette (USSR)	760	30,0	193,-	8,-
Fiat-Steyer 126PA	600	17,6	399,-	12,-
Ford Fiesta	790	29,0	339,-	12,-
Mercedes 200	1340	69,0	340,-	17,-
Opel Kadett 1,2	785	37,0	284,-	13,-
Peugeot 104 GL5	775	33,0	313,-	13,-
Renault 4L	695	25,0	321,-	11,-
Skoda S105S	855	34,4	210,-	8,-
Toyota 1000	740	33,0	287,-	13,-
VW 1200	760	25,0	333,-	11,-
● Est. Retail Cost Averages			DM 307,-/kW	DM12,-/kg
● Est. Product Cost Averages			DM 192,-/kW	DM7,5/kg
		or	$86/kW	$3.37/kg

Notes:

*The most inexpensive production models were used for the sampling.

The production cost is at factory (incl. profit margins).

Various origins were used to include free vs. controlled economy bias consideration.

Automotive industry's capability to optimize production cost is considered guideline for evaluating the bottom boundaries of "learning curves" for solar systems on open market.

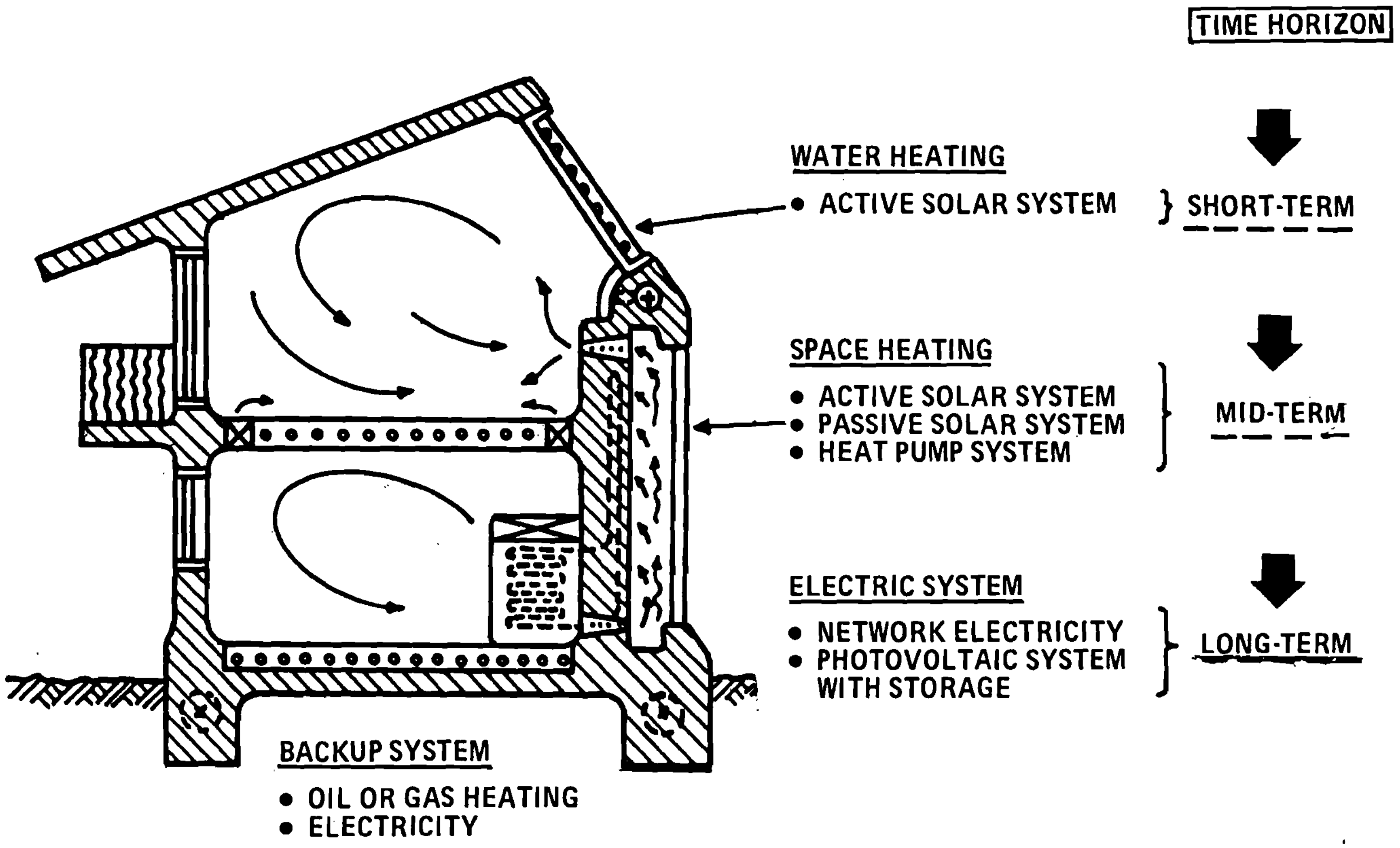


Figure 6.4 Evolution of Solar House and Options.

solar energy conversion, heat recovery from waste water and air together with heat-pump in a configuration that should lead to ultimate elimination of conventional heating back-up. The back-up function would be provided by electric power.

6.4 Space and Water Heating and Space Cooling Systems and Their Potential Large-Scale Application

The state of development for combined heating and cooling is not yet sufficient to derive specific strategies for systems aspects and their intensified use.

In solar heating systems using heat-pump, the cooling function is feasible by appropriate design of heat-pumps that can meet both the heating as well as the cooling requirements. Solar cooling (without heat-pump) requires working fluid temperatures higher than generally attained by flat-plate collectors. This means that either high efficiency (cost intensive) flat-plate collectors, or concentrating collectors would be needed in connection with absorption cooling, possibly using lithium bromide/water cycle that operates already with working fluid inlet temperature of ~85°C. The other alternative would be an ammonium/water cycle that needs a working fluid temperature of 135°C. Such systems will not be marketable until their reliability is established.

6.5 Solar Systems for Process Heat Supply in Industry and/or Agriculture

Prototype installations for various types of process heat show promise, but the variety of requirements for process applications is such that generalizations for the use of solar energy would not yield useful projections. In the industries where the process heat is required "on demand", the heat storage requirements are the economically constraining factor. In agriculture, the process heat appears to be less critical in terms of availability time, and may therefore find faster utilization.

The process heat systems can be subdivided into two categories: (1) hot water systems and (2) hot air systems. The hot water systems are used in such areas as

- chemical industry,
- textile industry,
- cleaning and washing,
- curing and processing, etc.

and the hot water systems find application in

- drying (lumber, food, agricultural products, etc.),
- dehydrating,
- industrial processing, etc.

The heat storage technology that is needed to provide a leveling between availability and application of solar heat is in the development stage.

6.6 High Temperature Solar-Thermal Systems Potential

The STEC technology may become a desirable export item, and the synthesis in Chapter 4 and sections 2.5 and 5.3 shows that the capital and materials intensive characteristics of STEC plants may delay their long-term considerations until more experience is gained with the prototypes currently under construction and in the planning stage (Tables 2.3, 2.4, 4.1 and 6.1).

A study of STEC application in Alpine regions was made to determine their potential in connection with hydroelectric power plant facilities, that could resolve the energy storage and load leveling problems. Although such a concept appeared initially promising, the limited amount of useful sunshine and the uncertainties of the economic estimates stipulated the need for deferment of such an assessment. When the information about the prototype STEC plants, currently under construction in the USA and elsewhere, becomes available, the evaluation of these options should be reopened.

The STEC options for desert regions have significantly more potential in the long term, but here too the prototype experiences will have to be gathered first.

6.7 Photovoltaic Systems Potential

The uncertainties of the attainability of the cost reduction of photovoltaic systems make a quantitative assessment of their large-scale potential speculative. But, because they may become competitive with solar-thermal systems, their progress must be monitored to minimize commitments for supporting solar options that may loose their competitive status. While it may be difficult today to imagine a solar house with a roof consisting of photovoltaic arrays in the late mid-term period, there is indeed such a possibility. The progress of photovoltaic technology in the USA has actually been faster than originally anticipated, which is another indicator of the evolving potential of photovoltaic systems.

The combination of photovoltaic systems with electrolysis of water to produce hydrogen is among the long-term possibilities. The high efficiencies of future electrolyzers could lead to effective storage of energy and load leveling that would become a nucleus for innovative concepts based entirely on renewable energy.

6.8 Conclusions

The contradictions in the large volume of data acquired for the evaluation of system aspects of solar options indicate that it is too early in the development stage of solar technology to draw up suitable strategies for the intensified use of solar energy in the FRG. The recognized exceptions are the low temperature solar systems for water and, to a lesser degree, for space heating.

There are, of course, numerous other considerations in the decision-making processes for application of solar options. Random inquiries with businessmen involved with marketing of solar systems resulted in tabulating the issues (Table 6.4) mentioned as being influential in considering acquisition of solar heating. Economy and performance (items 1 to 8) are only a part of the concern, combined with the desirable guarantees of operating life-time (items 9 to 11), and long-term availability of spares (items 12 to 13). The strong interest in standards (items 17 to 20) is at least partially a result of the concern about availability of spare parts. Inasmuch as manufacturers of small size solar hardware may not be able to develop mass production methods, their competitive position may be lost, and some of them (who do not have other supporting businesses) may discontinue their work. In the absence of proper standards, it will then be difficult and costly to procure fitting of spare parts. A government-sponsored insurance program (items 21 to 23) would enhance financing (items 13 to 16) and increase consumer confidence that is needed for intensified marketing.

Well structured and coordinated curricula and seminars on solar options should be offered at all technical universities and trade schools to familiarize future architects, engineers and builders with solar technology and provide continuity for its development.

Related recommendations for enhancing the long-term viability of solar options are summarized in the synthesis of Chapter 11.

Table 6.4

PRINCIPAL CRITERIA CONSIDERATIONS IN DECISION-MAKING FOR APPLICATION OF SOLAR OPTIONS

	ECONOMY & PERFORMANCE								OPER. LIFE GUAR.			LONG TERM SPRS*		FINANCING			STANDARDS				INSURANCE		
INVESTMENT TERM :	OVERALL ECONOMIC COMPETITIVENESS	MID-TERM FUEL COST SAVINGS	LONG-TERM FUEL COST SAVINGS	POLLUTIONS REDUCTION	INNOVATION ATTRACTION	INSURANCE AGAINST FUEL SHORTAGES	MANUFACTURER'S RATING	EST. RELIABILITY (LOW MAINTENANCE)	< 5 YEARS	> 5 YEARS	EXCEED AMORTIZ.TIME	UNCERTAIN	GUARANTEED	C A S H	UP TO 10 YEARS 10% DOWN	UP TO 20 YEARS 50% DOWN	MIN.PERFORMANCE	SIZE (EXTERN.DIMS)	INLET/OUTLET LOCATIONS	WORKING FLUIDS	NONE	PARTIAL	FULL
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
LONG-TERM (20 - 25 years)	A	B	A	B	B	A	A	A			A		A	B	A	A	B	A	A	B			A
MID-TERM (10 - 20 years)	A	A		B	B	B	A				A		A		A	B	B	A	A	B			A
SHORT-TERM (5 - 10 years)	B	A	B	B		B	B			A	B	B		A	B		A	B	B	B		A	

*SPARES

NOTES: A = first priority considered; B = second priority considered.

9 - 11 = operating life-time guarantee offered by manufacturer.

12 - 13 = long-term availability of spares.

7. SCENARIOS FOR THE MARKET INTRODUCTION OF SOLAR SYSTEMS

7.1 Introduction and Summary

A comparison of the various technological possibilities of solar energy utilization in the FRG has shown that the most practical application for such systems is for water and space heating. If a significant substitution level of fossil fuels is to be reached, millions of solar energy conversion systems will have to be marketed and used. The purpose for such a massive expansion of the solar market evolves from the need for broader use of renewable energy resources. An increased use of solar heating systems may also become necessary to cope with an earlier shortage of imported energy carriers than originally envisaged.

The low density of solar insolation requires large collector areas, and therefore, high material and capital investments. A large-scale production program for solar systems will therefore create a much heavier burden on industrial production capacities and the capital market than conventional heating systems. For this reason, alternative scenarios for the market introduction of solar systems in the BRD will be discussed in this section of the study. These scenarios illustrate capital and material expenditures in view of the attainable substitution of fossil fuels and with regard to the preservation and creation of employment. The scenarios refer to the application of solar systems for hot water preparation and space heating in the household sector. In this field, there is an abundance of theoretical and some practical experience available at the present time, which serves as a basis for projections. However, our present state of knowledge does not allow an assessment of the consequences of solar systems applications in similar detail for other consumer sectors (crafts and service industries, cellulose and paper industries, industries of food and luxury goods, textile industries, agriculture). Such assessments will remain difficult for some time, because there are only few operational projects for the implementation of solar technologies in these fields, and in addition, the requirements of each industrial sector are too specific to render generally applicable estimates.

With the market introduction of a new technology, such as solar energy utilization, the share of the market of the conventional technology is taken over by the new one. The process of substitution over time of one technology for another can be clearly described by the logistic model function. According to this theory, the increase of the market share "f" of a new technology over time can be illustrated by an S-shaped curve (Fig. 7.1).

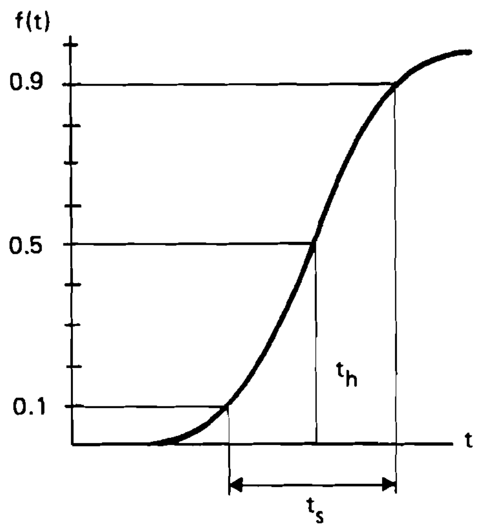


Figure 7.1: Time dependence of the market share "f" of a technology entering the market (according to the logistic function.

The course of the curve as shown in Figure 7.1 can be described by the following equation (7.1):

$$f(t) = \frac{1}{1+e^{-c(t-t_h)}} \tag{7.1}$$

where t_h is the point of time at which half of the market has been taken over by the new technology. The time period t_s during which the market share increases from 10% to 90% gives the take-over rate of the market, expressed by c in equation (7.1).

This logistic model function helps to describe the individual phases of the market introduction of a new technology. The introductory phase is characterized by low growth due to the hesitant acceptance of the new technology. The high growth rate of the break-through phase is then followed by a saturation phase of the market potential. The applicability of such models to energy substitution processes has been confirmed by several studies [7.2,7.3]. It will thus be assumed that the above given function may also be used to describe the market introduction of solar heating systems. Within the context of the present study the replacement of competing energy systems on the heating market is only of minor concern; the main objective is to investigate the number of solar systems that can be installed, and the conditions, the time period, and the consequences of the solar market penetration with reference to the market introduction curve of Figure 7.1. For this purpose it will be necessary to study in detail the point of market entry of a larger number of solar systems, the available market potential and the possible annual deployment rates of solar systems.

It is generally assumed that the economic competitiveness of solar systems with other available heating systems is a decisive factor for determining the point of their <u>market entry</u>. Apart from purely economic considerations, the consumer is also influenced in his choice of a suitable heating system by the aspects of clean and simple operation. The economic criteria may, however, be generally expected to dominate over the demand for convenient energy supply. A series of estimates on the economic viability of solar space heating systems has shown that present prices of such systems are still too high to be economically attractive. Although the situation is better for solar water heating systems, such options are competitive only in some cases (i.e. with electric heating systems). Even if mass production should cause a considerable price decrease, solar space heating systems may only become economically competitive with a doubling of today's (1977) heating oil price in real terms. In the absence of governmental subsidies the market entry of solar systems will thus depend on the time such a doubling occurs. It is, however, very difficult to predict the future development of heating oil prices. For this reason, two parameters have been introduced in the economic estimates (real doubling within 10 and 20 years).

An assessment of the market potential of solar systems for space heating and hot water preparation must be based on an investigation of the present and future housing situation with regard to the feasibility of solar installations. It is assumed that in the long term (after the year 2000) about 3.2 million one- or two-family houses, situated outside areas supplied by gas or district heat, could be equipped with solar systems for space heating (compare with Chapter 7.3).

The rate of development of this potential will depend on the respective growth rates. If the market introduction of solar systems follows the pattern of the S-shaped curve of Figure 7.1, and a maximum growth rate of 300 000 installed systems per year is assumed, about 3 million systems could be brought on the market within 20 years. With regard to the present annual construction rate of one- or two-family houses (190 000 per year [7.4]) it is clear that the above figures will only be reached by a combination of solar installations in new buildings and retrofitting of older ones.

Model calculations give a primary energy demand of 590 million tce* in 2000 for low economic growth (compare Chapter 8).

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*tce = tons (metric) coal equivalent
1 tce = 8139 kWh(t)

With regard to this value, a primary energy substitution by 2.6 million solar space heating or hot water preparation systems in the year 2000 would amount to 0.95% (for solar space and water heating) and 0.6% (for water heating) of the overall energy supply. It is to be noted that these figures do not apply to the total potential of low temperature systems in the FRG, as they do not include the small consumer and industrial sectors.

In a more detailed analysis of the benefits of developing an alternative energy supply system for the national economy, the energy production of the respective system must be compared to the energy expenditure for the construction and operation of such a system. For this purpose a comparative energy analysis of solar heating systems, heat pumps and of improved heat insulation in single family houses was made in this study.

The analyses have shown that the energy payback time is

- nearly 2 months for improved house insulation,
- 5 to 14 months for installed heat pump system, and
- 16 to 23 months for solar systems.

Since the useful life of such systems ought to exceed 20 years, the energy payback itself does not impose any restrictions on the introduction of these energy saving technologies.

Although the material requirements for a development program as described above are high, they are not likely to present a problem for the market introduction of these systems. It would, however, still be desirable to work on the development of less materials intensive collector types, in particular, as 12% of the present annual aluminum production and about 13% of the glass production of the FRG would be required just for manufacturing collectors in case of a maximum development rate of 300 000 solar systems for space heating.

7.2 Alternative Scenarios for the Market Introduction

In the following, two alternative scenarios are examined for the large-scale market introduction of solar systems, their effect on the economy and on the energy supply of the FRG. The quantitative estimates only refer to the application of solar systems in the field of space and water heating in households. Since research and development activities have concentrated on this field in the past few years, there is a number of theoretical and experimental investigations available to serve as reference systems.

Two scenarios for market introduction

- scenario 1: solar water heating systems and
- scenario 2: solar space and water heating systems

were based on the types of systems used in one- or two- family houses.

Compared to conventional heating systems, the solar system's efficiency depends to a much higher degree on the constructural aspects of the building and the lifestyle of its occupants. The installation costs of a solar system will, for example, be much lower in a new building, where such a system has been planned ahead of time, than retrofit installations in old houses. In many cases the improvement of house insulation will be currently less expensive than the installation of a solar system for fuel saving, and the lower investment will obviously be preferred. The extent to which an improvement of house insulation is economically justified before it would be worthwhile to consider installation of a solar system, will again depend on the structural conditions of the respective building. These considerations will differ, in cases of old buildings as compared to new ones. There are frequently problems with the installation of retrofit systems in old houses, which are particularly due to the rating of existing radiators for higher operating temperatures. It is furthermore important to note that the solar contribution to the energy supply of a household is also influenced by the daily energy demand profile, i.e. by the lifestyle of the occupants of a building. In order to assess these effects, extensive simulation programs are being run in which the systems behavior is simulated on an hourly basis over one year of operation [7.5].

The reference heating systems defined by Table 7.1 are "active" solar systems [Section 6], the components of which are clearly separable from those of the (conventional) back-up heating systems, and therefore it is feasible to estimate their performance and their (solar specific) capital demand. Such estimates are more complicated for "passive" solar systems [Section 6]. In the case of passive solar systems the respective buildings have to be designed to low energy consumption specifications and maximum utilization of solar irradiation for heating purposes. Intensified utilization of solar energy for space heating in these houses may be achieved by an appropriate arrangement of windows, or thermal storage walls, or by making use of the natural reradiation, conduction, and convection of heat. Generally a 15% to 30% increase of house construction cost for integrated passive systems was quoted in various US studies. The information is too limited to permit a formulation of appropriate scenarios for macro-economic projections.

Against the background of the outlined limitations, the scenarios encompassing active systems offer merely a cursory projection of the possible market penetration trends. In view of the developmental status of solar technology such simplifications are, however, necessary to provide at least some fundamental quantitative estimates.

Table 7.1. Reference systems for large-scale market introduction.

Type of System	System Price DM	Gain of Useful Energy kWh/a	Heating Oil Savings Liter/a	Primary Energy Equivalent tce/a
Solar water heating (8 m^2 collectors)	5000-8000 ($2380-3810)	2000[1)]	1000[2)]	1.37[3)]
Solar space & water heating (35 m^2 collectors)	15000-25000 ($7143-11905)	10000[4)]	1538[5)]	2.11

1) 50% from 4000 kWh (4-person household, 70 liter/person day)

2) 20% efficiency of oil-heating in summer

3) 1 liter heating oil = 1.23 kg SKE
1 liter heating oil = 1.37 kg SKE (primary energy equivalent including 10% refining losses)

4) 50% of 20000 kWh

5) 65% annual efficiency of oil heating
1 liter heating oil = 10 kWh

7.3 Economic Competitiveness and Market Entry

The evaluation of the economic competitiveness of solar heating systems in private buildings applies mainly to average single family houses. Such houses can be equipped merely with a solar water heating system, or with combined space and water heating systems with roof-mounted collectors facing south. It is assumed that such buildings have a central (oil) heating, compatible with the water temperatures from the solar heating system.

In view of the FRG climatic conditions, an economically competitive solar heating system will cover only a part of the water and space heating demand. Thus, the temperature of the water heated by means of solar energy will have to be raised in winter months to the required level by a conventional heating system. The conventional central heating becomes a heating back-up system when the house owner decides to invest in solar heating retrofit. The solar specific investment includes all the expenses arising from the acquisition and installation of a solar heating system, as shown in Table 7.1. There, the higher values are generally comparable to mid-term prices, and the lower ones correspond to the long-term prices that are expected to be attained by future mass production methods. Estimates of economic competitiveness of the solar specific investment are related to attainable heating-fuel savings. The energy prices for oil heating systems and gas heating systems are at present approximately on the same level (oil: DM 0.042/kWh, gas: DM 0.043/kWh). The lowest rate of the energy price for an electric heating system is on the average higher (DM 0.065/kWh) [7.6]. With the method used for the economic evaluation in this study for this type of economic estimate, the results of a coupled solar and gas heating system would thus be similar to that coupling solar and oil heating. Consequently, coupled solar and electric heating systems would yield more favorable economic results.

The amortization of the solar specific investments in terms of fuel savings depends mainly on the mode of financing on the part of the house owner, and on the future price development of the replaced fuel. As the extent of actual fuel cost savings will increase throughout the operating life of a solar heating system, a reliable estimate of the economic payback of the solar investment can only be given at the end of its useful life. For an assessment of this situation the present value method was applied. Although this method is widely used for industrial and economic investment planning, it is rather uncommon in the field of private investment decisions. The application of the present value method for amortization evaluation of the solar heating system was made, primarily using the retail value of attainable heating oil savings.

In reality, there are various possibilities for the house-owner to finance a solar heating system. This can be best described by interest rates:

0% corresponds to the investment of the owner's capital resources (i.e. savings),
4% corresponds to a building loan, and
7% corresponds to a mortgage on favorable terms.

As the projections for the future development of the heating oil prices are highly uncertain, several alternatives were investigated. On the basis of current heating oil price of 0.30 DM/ liter the following alternatives of linear price increases are assumed in the present value calculations (in 1977 DM):

- oil price constant
- price doubling within 20 years
- price doubling within 10 years.

Figure 7.2 illustrates the results of the economic analysis of solar heating systems for combined space and water heating. The costs and performance estimates are given in Table 7.1.

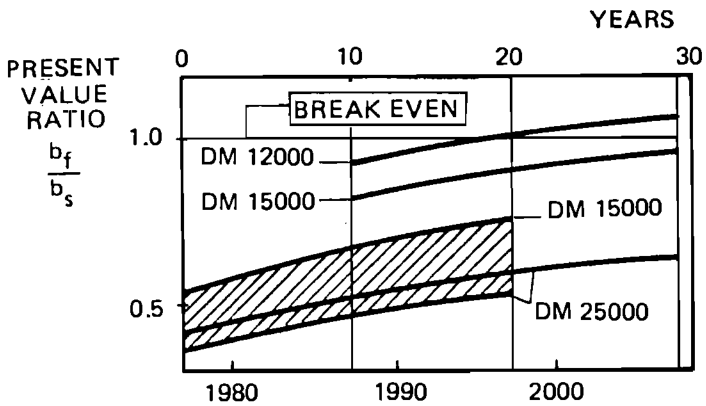


Figure 7.2: The effect of different prices of solar space and water heating systems on their amortization (amortization for "b_f/b_s" = 1.0; oil price doubling in 10 a; interest rate on capital loan: 7%).

The main issue for investigation in the respective series of calculations was the effect of a reduction of the original investment for solar specific parts on the amortization of costs. The ratio of the present value b_f of fossil fuel savings to the present value b_s of interest payments and the redemption of the solar-specific investment is plotted on the ordinate. At the time when this ratio reaches the value of 1.0, the investment costs will be paid off and the heating system will start operating on a profitable basis.

Figure 7.2 shows that the economic payback of currently installed solar heating systems, at a price of DM 25 000, yielding about 10 000 kWh annual energy savings [Table 7.1], will not be reached within 20 years of operation. Such assumed measures as a drastic reduction of the initial investment costs to DM 15 000, an extension of the useful life of the systems from 20 to 30 years, or an improvement of the systems efficiency by 20% are within the range of the shaded area of the graph and do not really change the situation. Although a reduction of the initial investment to DM 15 000 has proved to be the most effective of these measures, economic payback is still not reached after 20 years of operation of the solar system. An amortization of the invested capital costs appears to be only feasible if the solar system starts operating 10 years later (or after a doubling of the oil price) or if the costs of the solar system could be further decreased to DM 12 000.*

The situation is more favorable for water heating systems than for space heating systems, because of a better time-correlation between available solar energy and hot water demand. Figure 7.3 gives a comparison for solar water heating systems and solar space heating systems. The solar water heating systems that are available on the market today at a price of DM 8 000 and yield annual energy savings of about 2 000 kWh (Table 7.1), will become economically competitive when the system's cost can be reduced to DM 5 000. The amortization time for such systems will be 12 years.

*correlate with mass-production samplings in Table 6.3.

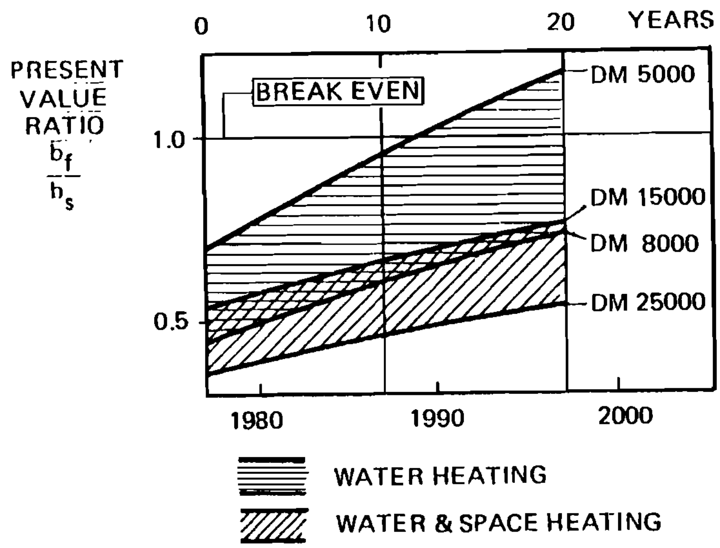
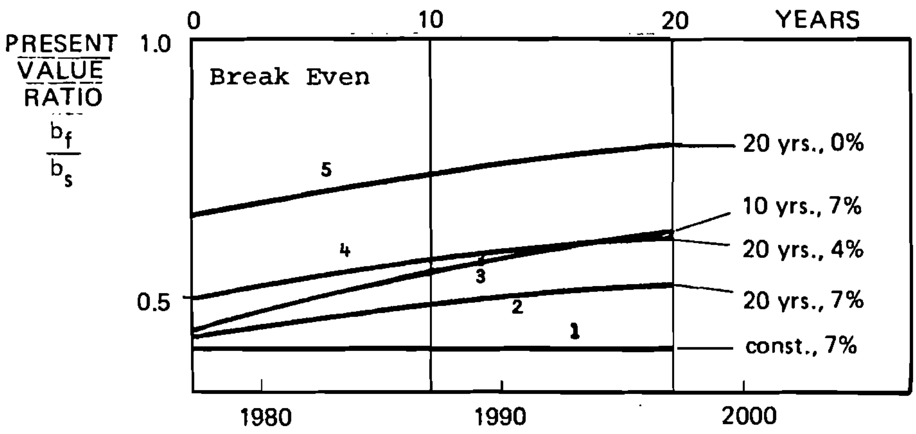


Figure 7.3: Comparison of the economic competitiveness of solar water heating systems and combined space and water heating systems.

Figure 7.4 summarizes the results of a series of sensitivity investigations, which were made to assess the effect of various oil price increases and financing conditions on a DM 20 000 solar space heating system. A solar system of this price category might be a system which is brought on the market today for a price of DM 25 000, and which is subsidized with DM 5 000 by the government for the promotion of energy saving investments.

Figure 7.4 illustrates that the capital interest rates are even more decisive for the economic viability of a retrofit solar system than the increases of the heating oil prices. Comparing a doubling of the oil price within 20 years and an interest rate of 7% (curve 2), to a doubling of the oil price within half that time (curve 3) results in a small improvement of the economic situation. An additional reduction of the interest rate to 0% (curve 5, investment of the owner's capital resources) would substantially improve the economic compatibility of solar heating systems. Here it shows again that a reduction of the required capital investment and/or capital cost for solar systems will improve the overall economic viability (compare with Figure 7.2). It is thus concluded that, from a purely economic point of view, the development of low-cost solar collectors is to be preferred over the development of highly efficient collectors, if their prices are relatively high, while their performance improvement is not commensurate.



Curve 1: constant heating oil price and interest rate 7%.
Curve 2: doubling of oil price in 20 years and interest rate 7%.
Curve 3: doubling of oil price in 10 years and interest rate 7%.
Curve 4: doubling of oil price in 20 years and interest rate 4%.
Curve 5: doubling of oil price in 20 years and interest rate 0% (cash investment).

Figure 7.4: Sensitivity analyses of different oil price increases and financing conditions for a solar space heating system.

A recapitulation of the results of the economic assessment made in this section shows that

- under the present conditions, economic competitiveness has not yet been established for the reference systems considered (Table 7.1).

- even in view of a big heating oil price increase (a real price doubling within 10 years), amortization of solar space heating systems and solar water heating systems will not be reached for 20 and 10 years respectively.

- for an improvement of economic competitiveness of solar plants, first preference should be given to measures aiming at a reduction of capital investments for acquisition of solar heating systems and/or reduction of capital cost by favorable interest rates.

If the introduction of solar heating systems were left to the market alone, there would be most probably only a very slowly growing amount of installed solar systems in the next two decades.

The measures taken by the FRG for promotion of solar energy systems [1977/78] may lead to a temporarily accelerated sale of heating systems. Although governmental subsidies are granted in the decisive areas of capital cost (by tax reliefs, investment grants, or low interest loans), they are generally not sufficient to make the retrofit solar heating systems economically competitive. The promotional measures of the Federal and the Provincial governments may, however, assist in creating a certain initial market for solar heating systems which might motivate the manufacturers to develop mass production of solar hardware. Such combination of governmental assistance and decreasing costs through mass production could gradually make solar heating systems attractive to house owners. It was therefore assumed in the formulation of the subsequent scenarios that an increasing number of solar heating systems will be installed as retrofits, as well as integrated systems in new houses, in the following years.

7.4 Market Potential and Deployment Rates

In addition to the time of market entry, the introduction of solar energy conversion systems into the market is determined by the market potential and the possible installation rates. The characteristics which describe a large-scale market penetration are presented in Figure 7.5. It is assumed that the time of market entry of a particular type of solar system essentially depends on the system costs, performance of the system, the expected increase of conventional fuel costs and the available possibilities for financing. The market potential is understood as the upper limit of the number of buildings suited for a solar system installation. In order to make a reasonable estimate of the attainable market penetration rates for solar systems, some of the relevant turnover rates in the building and heating sectors of the FRG have been investigated. These are, for example, the past substitution rates for heating systems, or the rates of new construction of buildings. With this information, a market penetration curve for solar systems has been constructed and this is the basis for the assessment of the consequences of the large-scale introduction of solar systems.

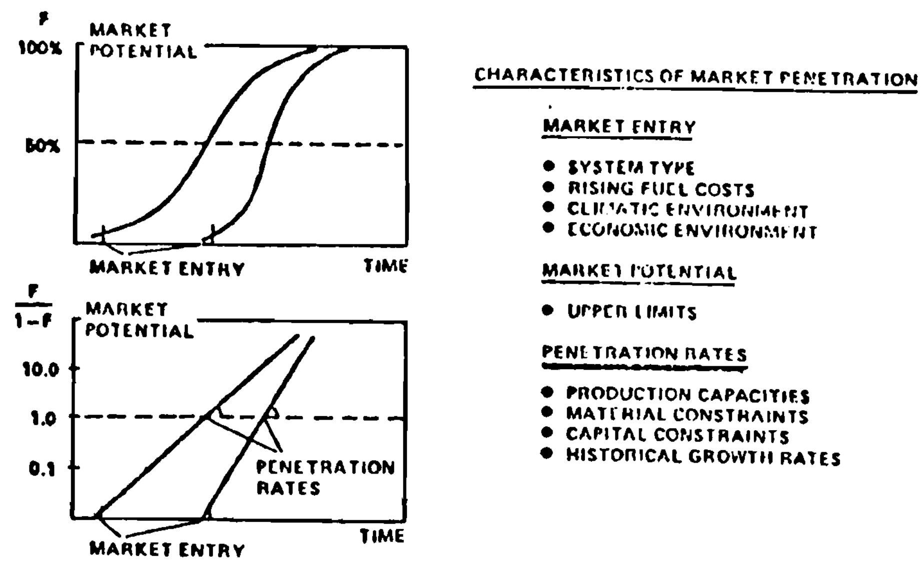


Figure 7.5: Determinants of market penetration of solar systems.

In a reasonable analysis of the market potential for solar systems, the present and future building inventory should be examined with regard to the possible installation of such systems. The most important criteria for the installation of solar systems in residential buildings are:

- appropriate orientation of the buildings (sun exposure),
- availability of a central heating and/or hot water supply systems, and
- adequate thermal insulation of the buildings.

Correlation of heating demand with the potentially useful roof slope and areas of the different building types [7.12] determined that, with present technology, one- and two-family houses will be the major market for solar space heating systems. These houses should have a central heating and hot water supply system to facilitate easy integration of the solar space and water heating systems.

About 50% of all buildings in the FRG were built before 1949 and 22% even before 1900. The deterioration of many of these buildings is such that the investment for modernization is no longer attractive [7.9]. About 70% of all residential buildings are one- and two-family houses (6.1 million buildings in 1974). No quantitative information is available on the age, structure, and condition (i.e. how many buildings can be modernized) of this building category. However, the majority of these buildings were constructed at a time when energy conservation was considered only as incidental. Therefore, such measures as improvement of roof insulation, basement and exterior wall insulation, reduction of ventilation losses or installation of double-glazed windows have economic priority [7.10]. The extent to which these possibilities should be used, before installing roof collector systems or heat pumps, has not yet been satisfactorily assessed.

Solar heating systems are especially appropriate in combination with low temperature (about 35°C) systems such as floor heating. It has been shown, however, that conventional radiator systems could also be used [7.11]. This permits the installation of solar systems in existing buildings (retrofiting). The capacity of most of the central heating systems in the FRG is such that when the outside temperature is $0^{o}C$ then the radiator inlet temperature of $60^{o}C$ is sufficient to cover the heating requirement of the house. This temperature level is within the range of those achievable in some locations by efficient flat-plate collectors, even with reduced solar radiation input.

Since sufficiently detailed quantitative information for a precise evaluation of the building potential for solar installations was not available, an estimate was made. Assuming that starting with the present inventory of residential houses (total number of buildings in 1976: 10.4 million [7.4]), and that the number of buildings will stabilize at 13 million in 2000-2010, then approximately 3.2 million one- and two-family houses will be suitable for installation of solar space and water heating systems. This is illustrated in Table 7.2.

Table 7.2. Estimate of the number of one- and two-family houses suitable for installation of solar space heating systems.

Total number of residential buildings after 2000:	13 million
~50% of which are expected to be one- and two-family houses outside of areas with gas and district heating distribution grids:	6.5 million
~50% of which are expected to show suitable orientation and inclination of roofs:	3.2 million

The time period in which this market potential can be achieved depends upon assumption of possible annual installation rates for solar systems. The annual construction rates for one- and two-family houses were on the average between 150,000 and 200,000 units in recent years. Assuming that this trend continues and that all newly built units will have solar heating systems installed, the market potential of 3.2 million systems could be reached in 15 to 20 years. However, the market penetration is described more realistically by the logistic growth curve as illustrated in Figure 7.1. This curve shows the individual phases of market penetration, the initially slow acceptance of the new technology by the market, the phase of acceptance, and the saturation better than a simple linear growth model. Although several models exist for the description of the dynamic substitution process [7.3], no attempt has been made to apply them in this study. Instead, a scenario technique, which assumes a hypothetical development and assesses the consequences, has been used.

Assuming a maximum growth rate of 0.3 million solar systems per year and applying Equation (7.1), a time series describing the number of installed systems are obtained (Table 7.3).

Table 7.3. Logistic time series for the deployment of solar systems (upper limit of market potential: 3.2 million systems, maximum annual growth rate: 0.3 million systems, growth constant in Equation (7.1): c = 0.375).

Year	Number of Systems (in millions)
1985	0.054
1990	0.321
1995	1.347
2000	2.643
2005	3.100
2010	3.180

The extrapolation of the logistic time series gives a value of about 4000 installed solar systems for the year 1978. The market penetration curve is illustrated in Figure 7.6, in which the total number of installed systems, the corresponding annual growth rates and relatable historical growth rates are also presented.

The comparison of the assumed annual growth rate of 0.3 million systems per year with the present construction rate of one- and two-family houses shows that in this scenario the retrofitting by solar systems into existing buildings must be taken into consideration. Moreover, the diagram shows that in the past the FRG oil-fired central heating market attained even higher growth rates. Between the years 1965 and 1973 the average growth rate of dwellings having oil fired central heating systems installed was about 0.67 million per year [8.9].

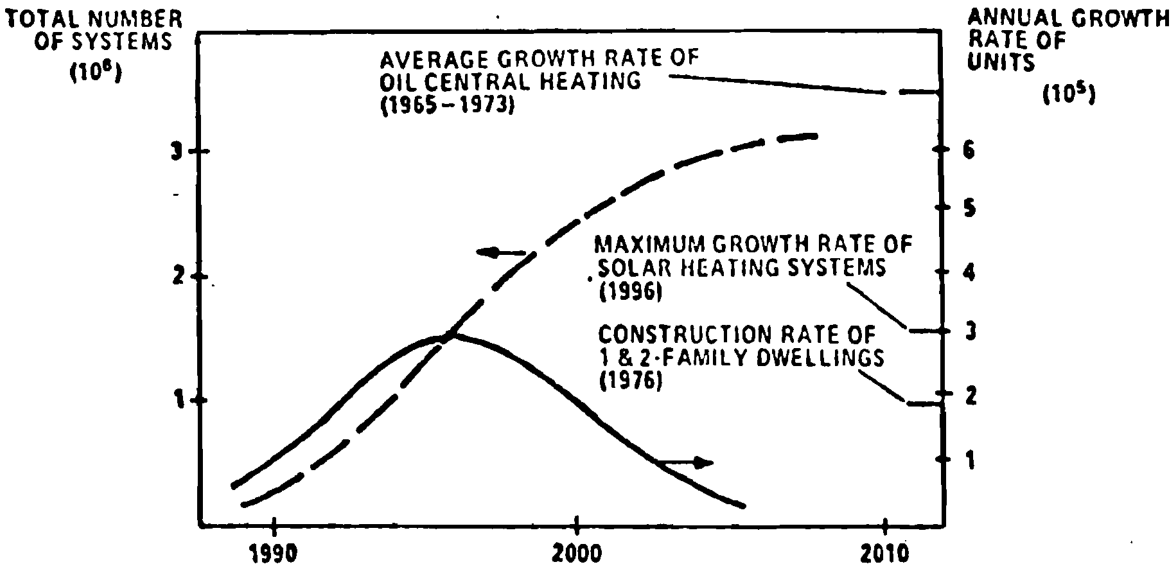


Figure 7.6: Market penetration curve for solar systems and relatable historical growth rates.

7.5 Contribution of Solar Energy to the Total Energy Supply

The reference system for solar water heating defined in Table 7.1 is able to substitute in one year of operation for approximately 1.37 tce, and the one for solar space and water heating for 2.11 tce of heating oil. It has been assumed that the required collector area would be 8 m^2 and 35 m^2, respectively. These values together with the time phases for the deployment of solar systems given in Table 7.3 yield the primary energy savings given in Table 7.4. Although the market penetration curve shown in Figure 7.6 was derived for the introduction of solar space and water heating systems, it has also been used for comparative purposes for the water heating systems.

Table 7.4. Primary energy savings attainable by large-scale application of solar water and space heating systems.

Year	Number of Systems (in millions)	Primary Energy Savings (million tce)	
		Space Heating	Hot Water
1985	0.054	0.11	0.07
1990	1.321	0.68	0.44
1995	1.347	2.84	1.85
2000	2.643	5.57	3.62
2005	3.100	6.54	4.25
2010	3.180	6.71	4.36

Model calculations for the FRG indicate that with settling economic growth a primary energy demand of 590 million tce can be expected in the year 2000 [8.2]. With reference to this value and the assumptions made with regard to market penetration, it is estimated that the contribution to the primary energy supply in the year 2000 will be 0.94% for solar space heating and 0.6% for solar hot water supply.

7.6 Assessment of the Consequences of an Introduction of Solar Systems on the Market

In order to evaluate the potential macro-economic impact of the deployment of an alternative energy supply technology, and the possible relief of the primary energy supply situation, an energy analysis was carried out as a subtask of this study. In this analysis the energy production of several million solar space heating systems is correlated with the energy expenditure for these systems. From a macroeconomic point of view, the implementation of an energy supply technology becomes less attractive when the energy content in the system's hardware is too high. The methodology of the process chain analysis and the systematics of input-output tables permit the evaluation of the net energy production. In the case of the reference solar space and water heating system, the energy payback time is 16-23 months, which is relatively small when compared to the lifetime of such systems. Although there is no adequate experience with long-term durability of solar systems, continuing improvements should lead to system-lifetime exceeding 20 years.

Determination of the favorable macro-economic impact can include theoretical stipulation for using the energy gain by the systems already operating for building the next generation systems. A critical growth rate exists which gives a zero net energy generation during the solar system deployment. Since solar systems are comparatively material intensive, it was felt that a low critical growth rate could represent a constraint for the system deployment. With solar space heating systems this critical deployment rate lies between 54% and 77% per year and is considerably higher than the maximum growth rate assumed in the market penetration scenario. Basically, this means that in spite of the material-intensive nature of the solar systems, an accelerated system deployment is not constrained in terms of net energy generation.

Table 7.5 gives values for the material requirements of 35 m^2 of selected roof collectors for a solar space and water heating system.

Table 7.5. Material requirements for 35 m^2 of roof collectors for a solar space and water heating system.

	Aluminum	Copper	Steel	Glass
1 system (kg)	280	105	175	350
3 x 10^5 systems (10^3t)	84	31.5	52.5	105
% of 1974 FRG production	12.3	7.5	0.1	12.6

Table 7.5 also relates the material requirements associated with the maximum growth rate assumed in Figure 7.6 (0.3 million

systems per year) to the annual production of these materials in the FRG. It is concluded that the amount of materials consumed for a typical contemporary system is considerable, and that the development of less material intensive collector types should be intensified. Significant savings are obtainable by an increased utilization of recycled materials.

In addition to the substitution for heating oil (or other comparable resource) by an intensified use of solar heating systems, it is useful to investigate how much added employment can be created by a national program for solar heating deployment. Assuming that in the industry branches dealing with solar technology an annual business volume of DM 100 000 is equivalent to one man-year employment, annual installation of 0.3 million solar heating systems priced between DM 15 000 and 25 000 each (see Table 7.1), is equivalent business volume of DM $6(10^9)$/a, or $2.86 billions/year, meaning about 60 000 new opportunities of employment during the peak years of such a program.

7.7 Conclusions

Various scenarios for the market penetration of solar systems in the FRG have been investigated. Sensitivity analysis of the economic competitiveness of the solar systems showed that with the present level of oil prices, and with the prevailing climatic conditions in the FRG the solar heating systems are not yet economically attractive. Assuming that much lower prices of solar hardware are realized through mass production, and an at least doubling of real heating oil prices in 10 years may occur, the solar space heating systems will still have an amortization period exceeding 20 years, unless a technological breakthrough brings about more favorable conditions. For solar hot water systems the amortization time is generally less than 15 years under these conditions. Although capital investment for solar space heating is a factor of three higher than for water heating systems, the heating oil substitution capacity of the space heating systems is only about 50% higher on an annual basis. This may raise the question of whether or not governmental support should increase support of solar water heating over solar space heating systems.

The time estimate for the market penetration of more than 3 million solar heating systems shows that this is possible within 20 years, probably without exceeding industrial capacity in the FRG. On this basis, several timing alternatives for setting up a national solar program are conceivable. The alternatives are illustrated in Figure 7.7.

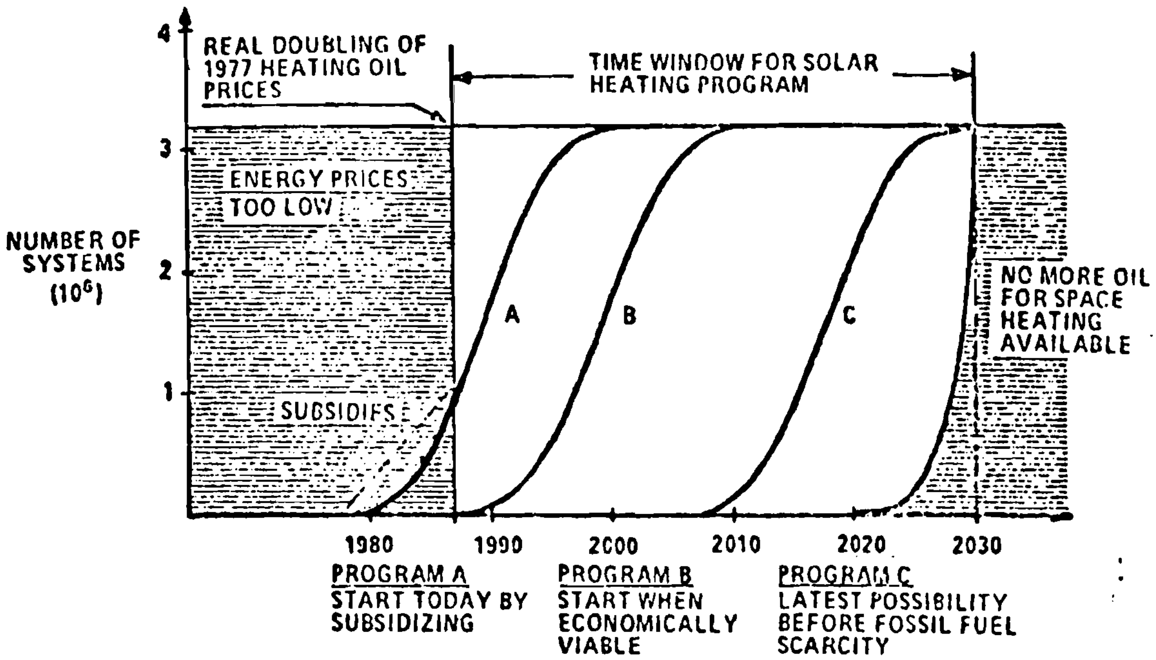


Figure 7.7: Programs for marketing intensification of a large number of solar heating systems in the FRG.

The market penetration curves correspond to the logistic curve shown in Figure 7.6 with a maximum growth rate of 0.3 million systems per year. Program "A" illustrates a case in which, in spite of economic constraints, a large number of solar systems would be introduced into the market. The economic analysis indicated the need for a price reduction of DM 10 000 per system, in order to bring the solar heating systems to the threshold of economic viability. In this case, a governmental subsidy for a million solar heating systems would require

DM 10 billion (or $4.76 billion). Such expenditures do not appear to be justifiable in view of the limited primary energy substitution of about one percent for 3.2 million of systems installed by the year 2010. It is therefore recommended that under present conditions alternative possibilities for energy conservation should also be carefully investigated; for example, house insulation improvements frequently shows a more attractive cost-benefit ratio. Program "B" presents the most plausible market penetration program for solar systems, in which market entry occurs after economic viability is achieved. Finally, Program "C" shows the time at which a program must begin if it is a governmental objective to have all solar systems installed before a severe scarcity of oil is felt.

8. ENERGY SUPPLY SITUATION IN THE F.R.G. AND FUTURE DEVELOPMENT POSSIBILITIES

8.1 Introduction and Summary

The assessment of the effects of solar energy utilization on the future energy supply system of the FRG is one of the objectives of the solar case study. A delineation of the structure of the national energy market, and its projected developments, will serve as a basis for such an investigation. For this purpose the energy program of the Federal Government [8.1] and a recently completed study and simulation of the energy economy of the FRG [8.2] will be taken into consideration. The study focuses on low temperature solar systems for space and water heating for private households and small commercial consumers. To estimate the future impact of this solar option, current projections for the development of the heating demand in this sector are described.

If solar heating systems prove to be economically viable, their integration phase into residential housing may carry over well into the next century, as was shown in the basic scenario for market penetration of solar heating systems [Chapter 7]. In the same time period a major reorientation in the energy supply structure is to be expected on a global scale as well as within the FRG, as this period will coincide with the transition from the gradually depleting energy carriers, such as petroleum and natural gas, to alternative energy supply. According to the energy demand projections for the FRG, a further increase of petroleum consumption up to the year 2000 is anticipated. Some recent estimates of crude oil availability have, however, shown that there could already be an oil shortage in the next decade on the world market [8.3,8.4]. Decreased availability as well as increasing demand will both contribute to an increase in oil prices. The development of price increases over time will not only be subject to the price policy of the oil exporting countries, but also affected by the increasing capital intensive methods of extraction. It is very difficult to develop quantitative estimates on future oil prices, so that only speculations can be made as to the appropriate timing for major energy saving investments.

8.2 Present Structure of Energy Supply and Demand

The primary energy consumption and the end energy consumption in 1975 is shown in Table 8.1.

Table 8.1. Structure of the final energy consumption in the FRG.

	Million tce*	%
Primary Energy Consumption	347.7	100
Crude Oil	181.0	52.1
Coal	66.5	19.5
Lignite	34.4	9.9
Natural gas	48.7	14.0
Nuclear energy	7.1	2.0
Other	10.0	2.9
End Energy Consumption	234.0	100
Industry	84.0	35.9
Transportation	46.2	19.7
Households and small commercial consumers (incl. governmental)	103.8	44.4

*1 million tons coal equivalent = 8.14 TWh(t)

During the past three decades this structure evolved in three separate phases. In the first decade of the 1950's, the major part of the energy demand was covered by the national coal resources. In the following decade the solid energy carriers were largely replaced by liquid fuels; and in the early 1970's an increasing use of natural gas and of nuclear energy took place. Figure 8.1 gives the distribution of energy consumption within the individual sectors.

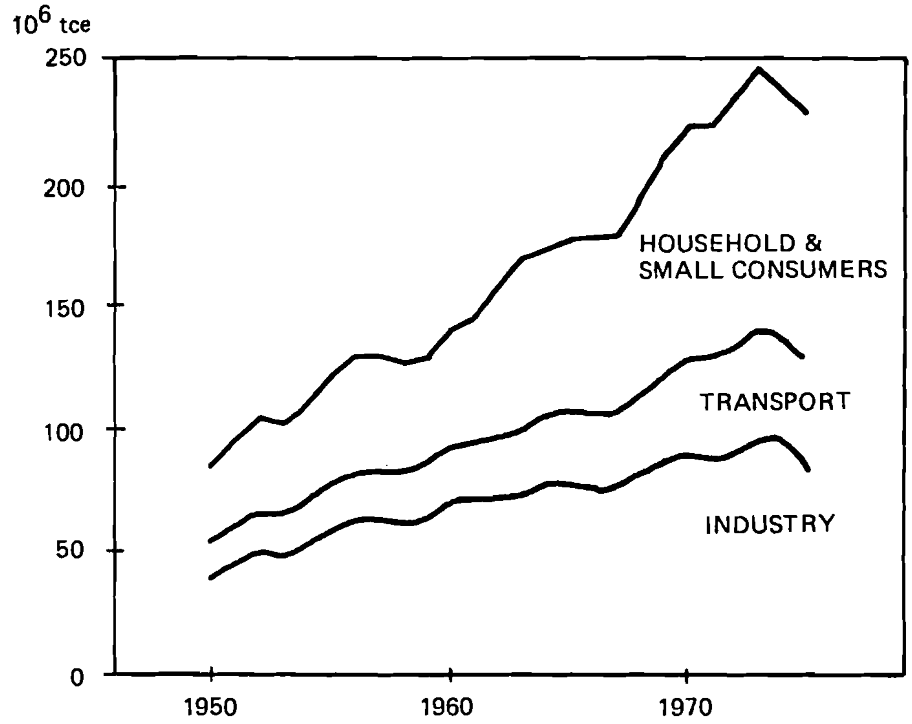


Figure 8.1: Final energy demand of the FRG by consumer sectors [8.2].

There was a marked increase of energy consumption in the household and small consumer sector. This significant increase can mainly be attributed to the growing space heating requirements, relatable to the more than a 100% growth in housing between 1950 and 1970, and to the improvements of the living standards. Figure 8.2 identifies the energy sources that backed the final energy demand for households and small consumers during the same time period.

In 1974 the share of the total final energy demand of this sector was 42.6%. Almost 60% of the demand was covered by oil [8.2]. With an oil consumption of 61 million tce, this sector is thus the largest oil consumer of the FRG. The other oil consumers in 1974 were industry with 33 million tce, and transportation with 42 million tce. If we consider the individual sectors

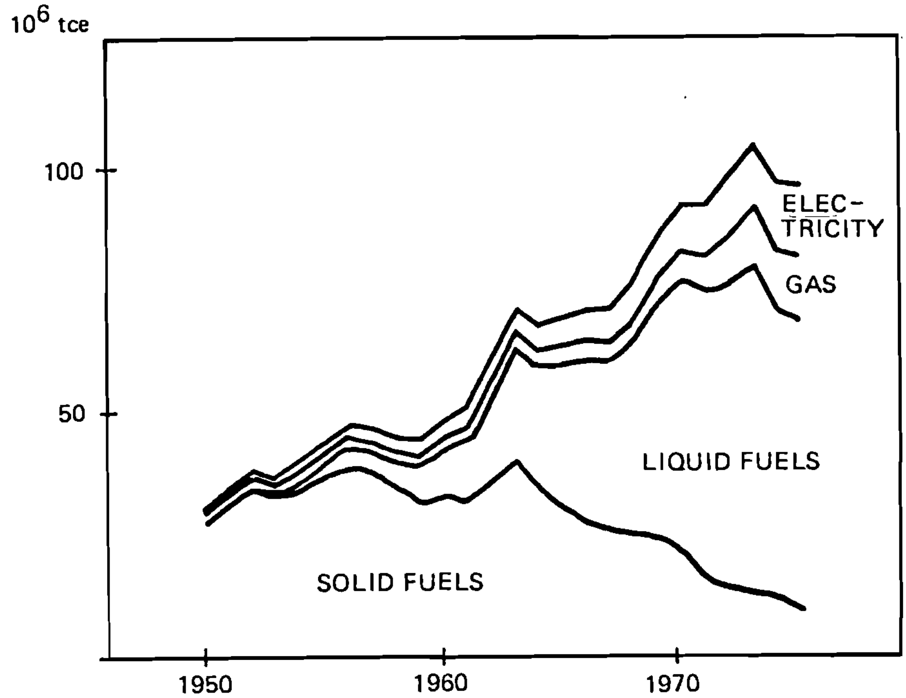


Figure 8.2: Evolution of final energy demand for households and small consumers [8.2].

of the potential market for solar space heating and hot water preparation, the main emphasis is therefore on the households and small consumers sector. About 40% of the total 1971 final energy consumption in the FRG (Table 8.2) was used for space heating. Considering just the sector of private households in Figure 8.3 and relating it to the total final energy consumption for 1974 the space and water heating in the private household sector amounted to 23% of the total final energy consumption.

Table 8.2. Final energy consumption for low temperature and process heat in percent of the total 1971 energy consumption of 226.4 x 10^6 tce [8.5].

	Total	Households	Small Consumers	Industry	Transportation
Space Heating	40%	19.8%	14.3%	5.3%	0.6%
Process Heat & Water Heating	36%	2.8%	3.6%	29.6%	-

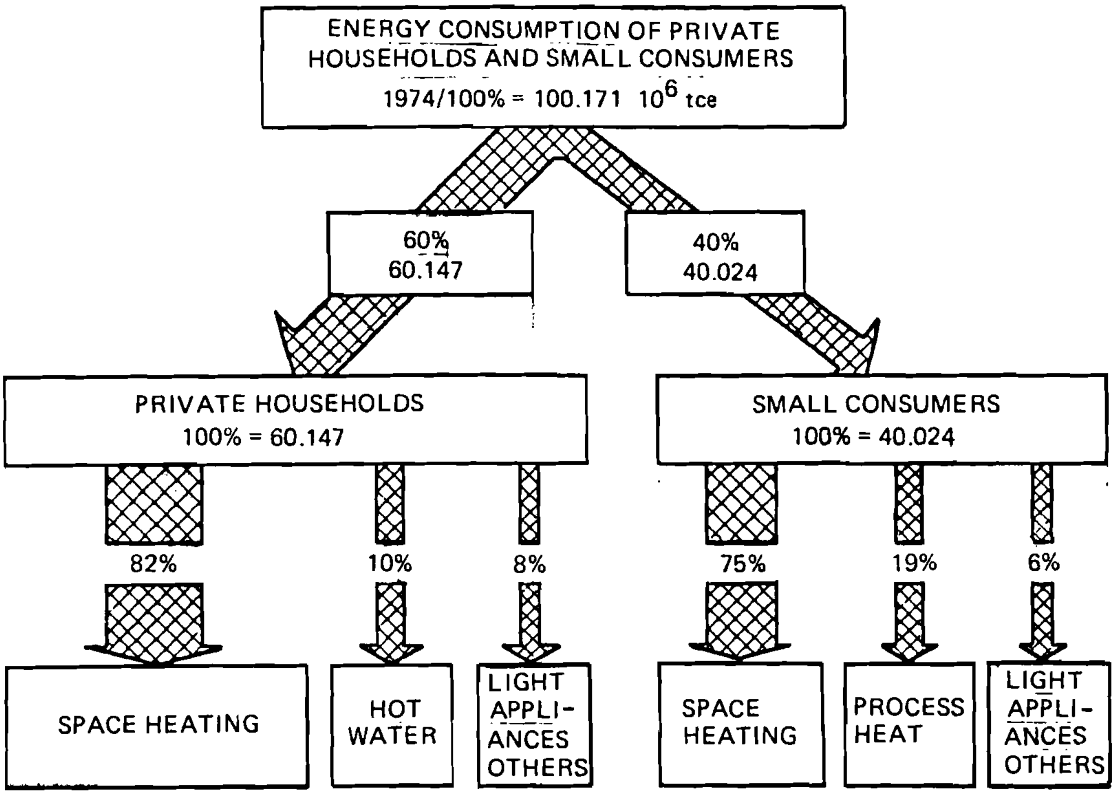


Figure 8.3: Distribution of the 1974 final energy consumption for households and small consumers sector by end use [8.2].

8.3 Scenarios for the Future Development of Energy Demand

For the impact assessment of an intensified use of solar energy in the FRG, it is not enough to know the amount of energy that can be substituted by solar systems, it is also essential to estimate the relative market share of solar energy to be obtained in view of growing energy demand. For this purpose two reference scenarios of the future energy demand for different economic growth rates are given.

Although it can be observed that economic growth and primary energy consumption are starting to develop more independently from each other [8.7,8.8], the future economic growth is still the most important factor for determining a country's energy demand. This situation will only change slowly, since a decreasing elasticity of the energy consumption with respect to the gross national product requires structural changes in the individual sectors of energy consumption. If energy is used more effectively, future growth in energy consumption will increasingly lag behind the economic growth. The envisioned trends toward intensive energy conservation and the use of renewable energy could contribute to decoupling of energy demand from economic growth by reducing the demand for primary energy and stimulation of economy at the same time.

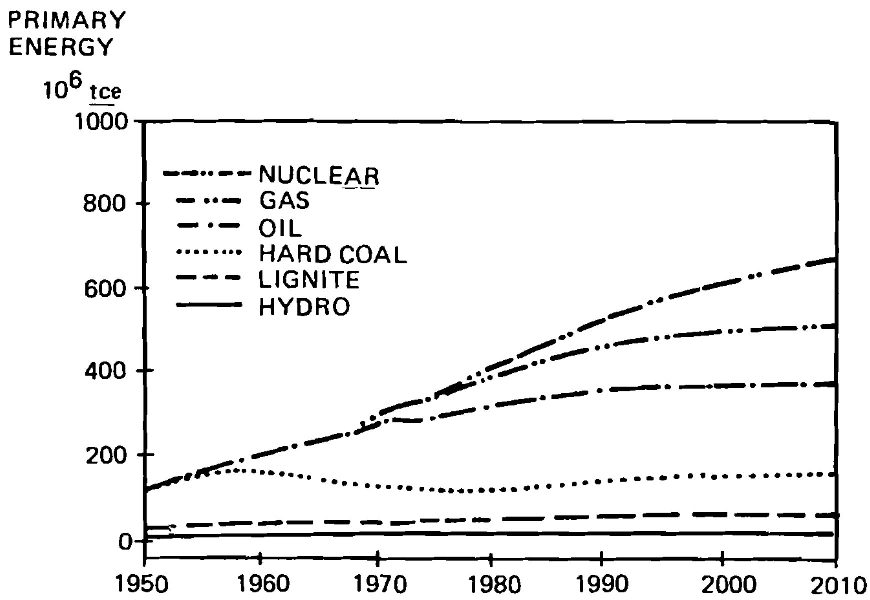
A moderate economic growth is considered to be necessary "to solve employment problems, to guarantee the financial support of social security systems and the consolidation of public funds, and to materialize a series of other important social and economic goals" [8.1].

The average growth rates of the GNP for the two reference scenarios for a lower and a higher growth are shown in Table 8.3.

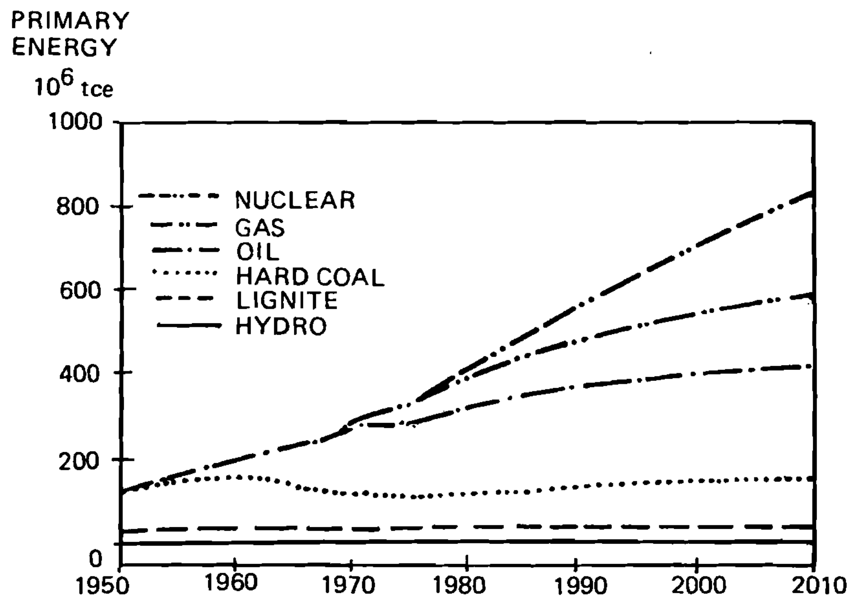
Table 8.3. Average annual growth of the GNP (%) in the two reference scenarios.

Time Phase	Lower Growth Scenario (% GNP)	Higher Growth Scenario (% GNP)
1975 - 1985	3	4
1985 - 2000	2	3
2000 - 2010	1	2

The expected evolution of primary energy demand during the time phases of both scenarios is obtained by an assessment of the categories of final energy consumption, the non-energy consumption and the final energy demand in the conversion sector of the energy economy, as shown in Figure 8.4. The appropriate numerical values are in Table 8.4.



Low Economic Growth



High Economic Growth

Figure 8.4: Evolution of the primary energy consumption for low and high economic growth [8.2].

Table 8.4. Evolution of primary energy sources for different economic growth rates [8.2].

Scenario for Low Economic Growth (in millions tce):					
	1975	1985	1990	2000	2010
Hydropower, other	10.0	10.0	11.2	13.6	15.1
Lignite	34.4	36.0	37.2	38.9	40.0
Coal	66.5	77.0	87.7	91.5	97.7
Crude oil	181.0	208.8	215.2	214.2	216.5
Gas	48.7	82.4	98.9	123.3	133.8
Nuclear energy	7.1	36.0	59.7	108.6	152.8
Total (ca.)	348	450	510	590	656
Scenario for High Economic Growth (in millions tce):					
	1975	1985	1990	2000	2010
Hydropower, other	10.0	10.1	11.8	14.9	17.5
Lignite	34.4	36.1	37.6	39.1	40.0
Coal	66.5	81.5	92.6	100.8	112.5
Crude oil	181.0	224.0	232.8	249.9	260.7
Gas	48.7	87.4	107.2	144.1	163.3
Nuclear energy	7.1	48.8	79.1	161.7	239.1
Total (ca.)	348	488	561	710	833

For comparison, an assessment is reviewed that was carried out upon request of the Federal Government jointly by three German economic institutions, and gives a primary energy demand of 485 millions tce (1985), 530 millions tce (1990) and 600 millions tce (2000) [8.1]. The results presented in this assessment were taken as a basis for the energy program of the Federal Government; they lie between the two projections of Figure 8.4.

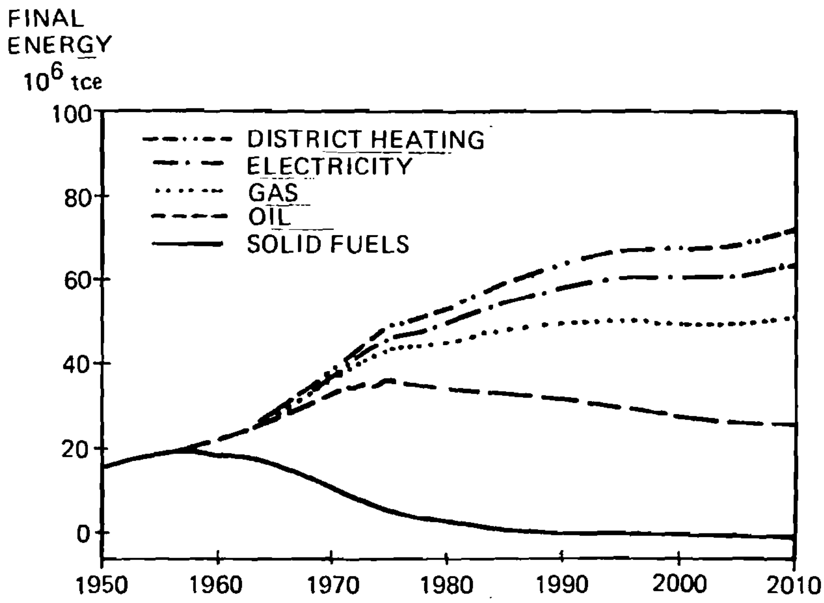
The shares of the various primary energy sources identified in the model projections [8.2] reflect their corresponding availability: the increase of primary energy consumption expected according to Table 8.4 would be primarily covered by nuclear energy. The growth of coal, gas, and crude oil use is relatively slower. The total consumption of crude oil will, however, still continue to rise in both scenarios throughout this century. This evolution is not supported by the oil consumption estimates for space heating in the sector of private households. On the contrary, it is assumed that the number of oil heating systems and, correspondingly, the oil consumption in this sector will begin to decrease in the next decade [8.9].

According to other projections, the overall energy consumption for space heating in the private household sector is expected to increase, as shown in Figure 8.5.

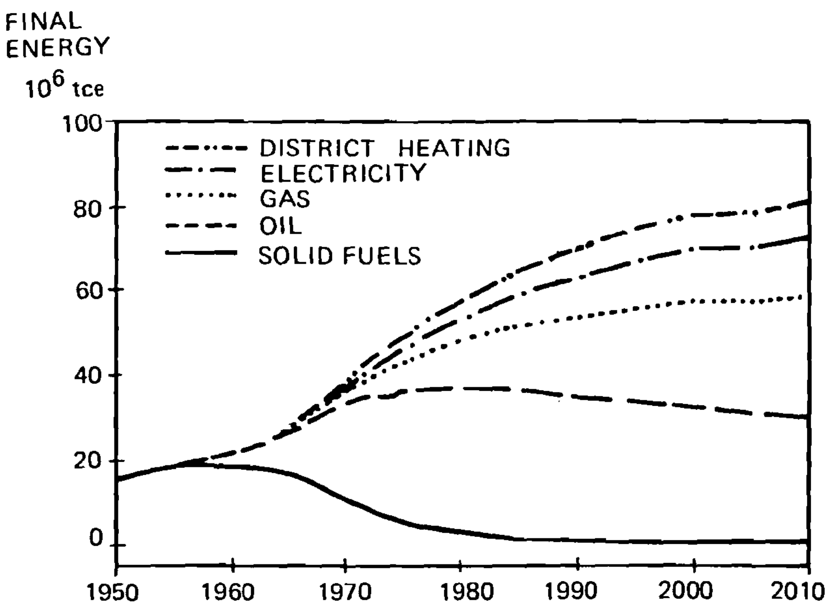
It should be noted that the model calculations for Figure 8.4 also include the effects of house insulation regulations as of November 1977. A 40% reduction of the heating demand was assumed for all private houses that were built after this date, as compared to earlier house designs. Current developments of new fuel saving concepts, such as solar heating systems or heat pumps are not included in these calculations.

The major reason for the growth of heating energy consumption is seen in the trend towards larger living area requirements per capita, and in the steadily increasing living standards. Since 1950 the per capita living area has about doubled. However, the high growth rates of the past may not continue in the future, because the population, as well as the number of households, may decrease slightly in the coming decades. The approximate number of dwellings of 23.6 millions (state of 1975) to that of private households of 23.7 millions, illustrates that a saturation will be reached on the housing sector.

It is assumed in the various studies about the future structure of the FRG heating market that the growing demand for heating energy and the former market shares of oil heating systems will be covered by gas, electricity, and to a lesser degree by district heat [8.10,8.11].



Low Economic Growth



High Economic Growth

Figure 8.5: Energy consumption for space heating on the private household sector by energy sources.

In the past, the substitution for one of these energy sources and supply systems by another followed a certain pattern, as shown in Figure 8.6. Solid energy carriers were increasingly substituted by liquid ones, with a simultaneous increase in the market shares of energy transported by transmission grids.

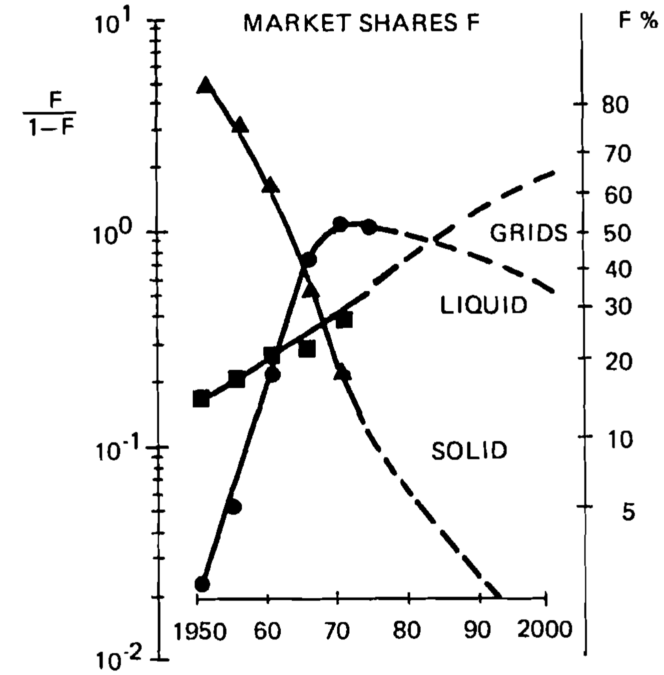


Figure 8.6: Development of market shares of solid and liquid energy carriers and grids for covering the energy demand of the FRG [8.12].

The driving force of this development seems to be the demand trend of the consumer for a convenient and clean energy supply. Apart from purely economic aspects, this demand of the consumer will partly determine the market shares of future energy supply technologies.

8.4 Internal and External Resources to Cover Future Energy Demand

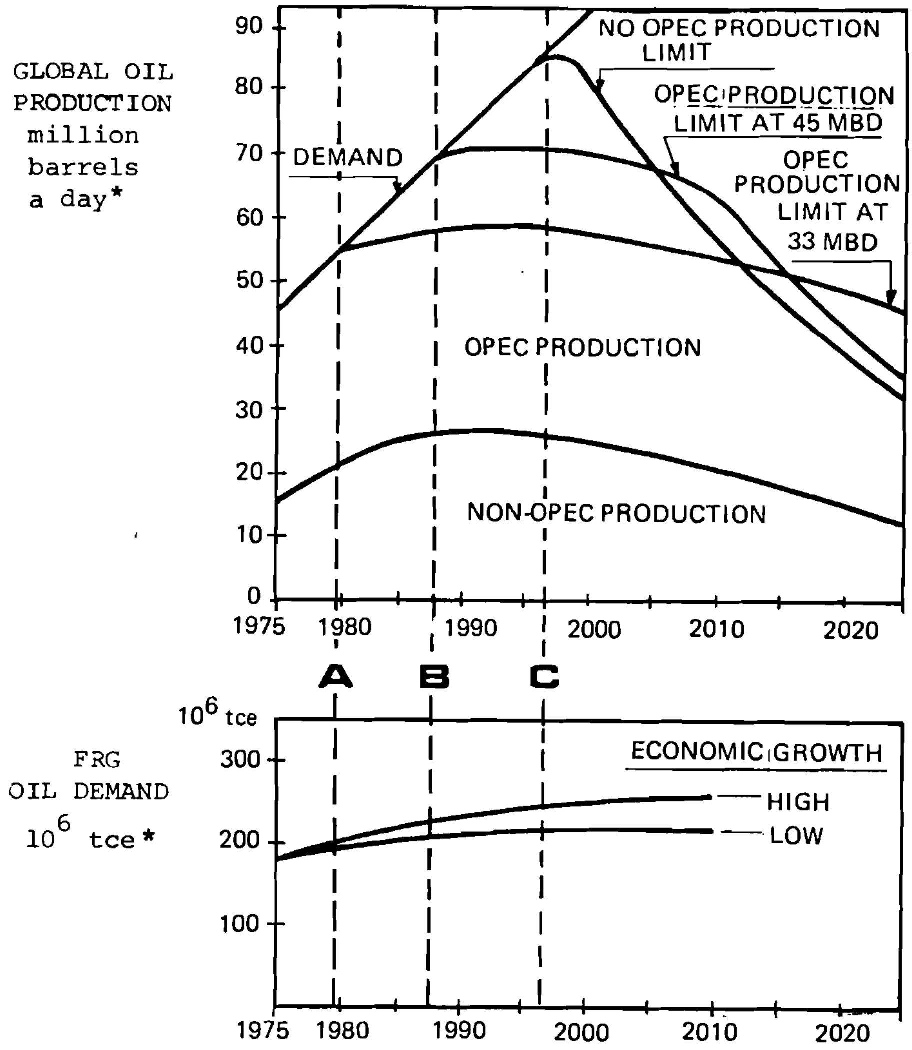
The market penetration of solar heating systems is likely to be a process extending over several decades. The successful integration of such systems not only depends on their reduced cost, but also on the growth of conventional fuel prices. Such growth will, of course, also benefit the development and the market introduction of other alternative energy sources, such as provided by gasification and/or liquefaction of coal. In order to make a realistic assessment of the long-term potential of solar heating systems, it is essential to have an idea of the presumable energy supply structure in which the solar systems may be integrated, and to investigate more closely those energy sources which may be developed in the long-term to cover future heating demands.

The world resources of natural gas are considered abundant and a reduced supply does not seem likely within the next 25 years [8.3]. The future contribution of natural gas for the mid-term supply of energy is not so much constrained by resource availability, as by the growing expenses for transportation and distribution. The presently known resources in FRG will be exhausted within about 15 years [8.13]. It is therefore expected that natural gas from Norway and the Netherlands will continue to provide the major part of the gas supply. It is the objective of the Federal government to secure future supplies of natural gas by long-term contracts.

Synthetic gas is a fuel that meets consumer requirements and can be used for the production of low temperature heat without major equipment changes. There are concepts for large-scale production of synthetic gas from lignite or from coal by means of fossil process heat. Owing to the high coal prices in the FRG, however, less expensive nuclear process heat may have to be used. Assessments of the production costs of synthetic gas from coal resulted in DM 0.032/kWh(t) (8.8 DM/GJ) and from lignite in DM 0.019/kWh(t) (5.2 DM/GJ) [8.14,8.20]. In a conventional production process of synthetic gas from coal with today's technology and without nuclear process heat the costs would be considerably higher, i.e. DM 0.058/kWh(t) (16 DM/GJ). As the expenses for distribution systems are not included in these cost estimates, heating oil, with an average consumer price of DM 0.035/kWh(t), is still more attractive today. This may, however, change with a doubling of oil prices.

As far as coal and lignite are concerned, there are large reserves available in the FRG itself. Owing to the impact of lignite on the environment and the high extraction costs of coal, the extraction rates of these fuels cannot be infinitely increased; and it is quite impossible to achieve an extraction rate which would make coal the leading energy carrier of the FRG. Since 1960 the share of coal in primary energy supply has steadily decreased, in percent as well as in absolute figures. Although an increase of this share is at this time technologically feasible, it would not be suitable to meet the demand of the consumer for a convenient energy supply. In order to promote the use of available coal, medium- to long-term development of liquefaction and gasification processes will be necessary to produce energy carriers that meet consumer requirements and are compatible with the long-term trends of the energy market [Figure 8.6]. Since the energy carriers produced by the new coal conversion technologies can be integrated into the existing organizational infrastructure and distribution systems of the conventional liquid and gaseous fuels, their marketing would probably be a fairly rapid process. On this basis the share of coal in the overall energy supply mix for the FRG could again be increased after 1990 [8.12].

Estimates of the world oil resource and of the economic aspects of their extraction vary widely. In the OECD study "World Energy Outlook" [8.3] it is assumed that a detectable oil shortage might possibly occur before 1995 and exert increasing pressure on world oil market prices. In the study of the "Workshop on Alternative Energy Strategies (WAES)" [8.4] a discrepancy between oil demand and oil supply is anticipated to occur even before 1990, depending on the restrictive production policies of the OPEC countries (compare Figure 8.7).



*1(10^6)bbl/day ≈ 1.7 TWh(t)/day ≈ 210000 tce/day ≈ 159(10^6)bbl/day
1(10^6) tce ≈ 8.13 TWh(t) ≈ 4.78(10^6)bbl ≈ 760(10^6)bbl

Figure 8.7: Global oil production and starting points of supply shortage A,B,C in relation to the future oil demand in the FRG according to [8.2,8.4].

Figure 8.7 shows the effects of various restrictions of the OPEC countries on their oil production, as assessed by the "Workshop on Alternative Energy Strategies". Depending on their extent, such restrictions will delay the depletion of reserves, but they will also determine the starting points of diverging demand and supply patterns on the world market (points A,B,C). A comparison with the time-phased development estimates of the oil consumption in the FRG shows that the consumption will continue to increase in spite of a possible world-wide oil shortage.

It is difficult to estimate how far the oil consumer will be affected by oil price increases, and only a few projections have been published on this subject [8.15]. With respect to the wide range of costs of oil extraction under the various geological conditions, it is nearly impossible to give an average development tendency for the world market price of oil. Account must furthermore be taken of the fact that the prices of the OPEC oil trust are heavily influenced by macroeconomic and political factors. Generally, a prediction of oil shortage means the shortage of oil at a certain price. An increase of the oil prices enhances exploitation of resources that may not have been economically competitive, thus further expanding the energy supplies.

In a joint conference of UNITAR* and IIASA in 1977 the most recent estimate of worldwide oil and gas resources were adjusted [8.16]. One of the conclusions was that additional oil and gas reserves will--at higher costs--most probably be available throughout the next three decades. It is doubtful whether the world market oil prices will increase from the current $12.70/bbl for crude oil, when the extraction cost, that ranges from $0.5/bbl in some Middle East locations to $2.50/bbl elsewhere, become a multiple of this cost. As the various more expensive methods of secondary extraction are used on a large scale, a revision of the assessment will have to be anticipated.

The various possibilities of future crude oil price increases indicated in the WAES study [8.4] do not exceed $20/bbl (1977 $) by the year 2000. Accordingly, the possibilities of a real price decrease, of a long-term constant price and of a price increase of 50% by 1985 or 2000 were assumed. These growth rates are to be regarded as low projections, when compared to the intentions stated by some OPEC countries, but they seem to be confirmed, at least for the time being, by the present "freezing" of the crude oil price.

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*United Nations Institute for Training and Research.

One of the alternatives of an energy policy aiming at greater independence from oil imports is the large-scale expansion of the electricity supply system. After the oil crisis, the European Community gave priority to an independent energy supply structure, and electricity was planned to be the leading energy carrier in Europe. In this planning it was assumed that up to 1990 about half of the generated electricity would be consumed in the household sector mainly for low temperature heat supply [8.18]. A combination of an intensified expansion of power plants with distribution networks for district heat would furthermore relieve the demand for crude oil.

The electricity supply companies are willing to provide the largest possible share of the total energy supply by expanding the capacity of the power stations and the distribution networks accordingly [8.19]. This policy is due to the fact that these companies are obliged to supply the consumer with convenient, reliable energy for a reasonable price. The electricity generating companies actually have the technological potential to supply electricity for all the consumer sectors on a long-term basis. Such a supply system is, for example, projected for the household sector. Although an implementation of these plans would result in a significant reduction of the dependence on energy imports, the public is engaged in questioning the merits of such plans.

8.5 Conclusions

The utilization of solar energy for generation of low temperature heat is now considered to be a potential contribution to the future energy supply mix in the FRG. The growing interest in the use of solar energy for water and space heating is evident from the analysis of the energy consumption share for heating; at present a major part of that share is provided by imported and depleting primary energy sources.

The present structure of the energy market in the FRG is characterized by a primary energy supply which depends more than 50% on crude oil, and the rest is mainly produced from coal and natural gas. In 1976, 95% of the crude oil supply was imported. The household and small consumer sector accounts for the largest share (44%) of the total final energy consumption. Since 60% of the imported crude oil was used to meet this demand, this sector is the main oil consumer of the FRG. The major part of the oil is used for space and water heating. These trends underline the importance of policy measures aiming at a reduction of oil consumption.

Model calculations concerning evolution of energy consumption in the FRG have shown that a continued increase in crude oil consumption is to be expected through the year 2000. This trend will probably be affected by a decreasing supply of crude oil on the world market. Thus, the need for substituting for crude oil by the use of renewable energy sources will become increasingly urgent. The state of oil shortage is viewed in connection with the evolution of oil prices. Yet, an increase of oil prices makes exploitation of the oil resources that were formerly not economically competitive increasingly attractive; thus, energy reserves tend to increase with growing oil prices. The extent of exploitable oil resources enhanced by price increases is not yet known, but one conclusion--that also applies to natural gas in this formulation--may certainly be drawn: According to our present state of knowledge there will probably not be a sudden energy crisis in the foreseeable future for lack of available reserves. Instead, there will be a gradually rising oil price (when we disregard the possibility of unexpected perturbations), reflecting the increases of extraction and exploration costs and by the up-dated estimates of available oil reserves. It is, however, doubtful whether this evolution will cause a rapid, large increase of oil price (i.e. real price doubling within 10 years) that would significantly enhance the economic pay-back of solar space and water heating systems.

The reserves of natural gas available to the FRG are generally assumed to exceed those of oil. With the current, gradual transition to natural gas deposits, requiring more expensive extraction techniques, and/or having lower yield, the overall price evolution will be comparable to that of crude oil.

From a technological point, electricity could in the future contribute a much higher share for low temperature heat supply than is the case at present. Desiring the best possible utilization of the generated energy, an increasing use of heat pumps would also be required. At present, however, the large-scale expansion of the electricity supply system is opposed in public discussions on the basis of environmental and safety issues.

The gasification and liquefaction of coal is also gaining importance for the future energy supply mix, as the price of conventional energy carriers is increasing. Although there are uncertainties as to the economic viability of these concepts, they could become attractive at a time when the level of oil prices is high enough to justify the use of solar heating systems.

9. CONSTRAINTS TO AN INCREASED USE OF SOLAR ENERGY IN THE FRG

9.1 Introduction and Summary

The preceding chapters have shown that even with the moderate insolation values in the FRG, some contribution to the water and space heating energy demands can be made. The baseline scenario in Chapter 7 indicates that in the year 2000 solar heating systems may contribute up to 7% of the space heating demand of the household sector and nearly 1.4% to the final energy requirements. The attainment of these values will depend heavily on the rate of heating cost increases for conventional heating systems. Should these increases be too low, the missing economic competitiveness of solar systems will be a significant barrier to the acceptance of solar heating.

In addition to the unpredictable influences on the market, there are a number of other resisting factors which indicate that neither the population, nor the institutions are oriented towards accelerated use of solar energy. These complex issues were analyzed in cooperation with the "Institut für Systemtechnik und Innovationsforschung (ISI)" of the Fraunhofer-Gesellschaft in Karlsruhe, FRG [9.1]. This brought up the following problem areas:

- Technical problems caused by insufficient experience of the installers, as well as absence of manufacturing and performance standards.
- Retrofit installation problems due to marginal applicability of houses for the solar systems.
- Building code and regulation problems based on legal and administrative issues of the building permit issuing agencies.
- Property and tax liability issues resulting from installation of solar systems.
- Uncertain attitude of plumbing tradesmen toward solar retrofits, and limited availability of experienced manpower.

While some of these problem areas would be resolved in due time, it is essential that an active resolution of such contraints is undertaken in order to reduce the risks associated with an acquisition of the solar option:

(1) Standardization of collector sizes to make collectors from various manufacturers exchangeable. This would make the buyer more confident and independent.

(2) Legal constraints associated with acquisition of building permits for installation of collectors, due to various structural, safety and aesthetic regulations of regional authorities.

(3) The need for "sun rights", assuring that no shadow producing structures will be erected in the near proximity, after a solar system was installed.

(4) Formulation of incentives for house owners who rent out dwellings that could be equipped with solar heating.

The inquiries conducted by "ISI" provided generally positive reactions from experts and tradesmen who would be concerned with installations of solar heating [9.1].

9.2 Constraints in Building-Codes and Administration

In the field of building rights and construction planning, the structural considerations and the design configurations govern the issues. Some of these are inadvertently constraining the installation of solar collectors. There are essentially three categories of constraining regulations that ought to be reassessed by local government to facilitate growth of solar system installations:

(1) the building aspects not covered by the regional building planning regulations, but left to the discretion of the community.

(2) local regulations dictating orientation of buildings, inclination of roofs and other design features that may not be

compatible with optimum installation of collectors.

(3) future building plans that do not as yet recognize the orientation requirements that would benefit the installation of solar systems.

Because each regional administration may have different regulations affecting the installation of solar collectors and/or large hot water storage vessels, the initiative for implementing appropriate amendments ought to be managed by the Federal government.

9.3 Altered Structure of Heating Cost as a Constraint

The characteristic of a solar system's use rests in the fact that reduction of the operating cost of heating is preceded by the requirement for high initial investment. In the cases where a house, or an apartment is rented out by the owner, he has to make the investment and recover it by charging higher rent. In such a case, it is essential that the owner offers proof to the tenant that he is benefiting from the installation, and that in fact the tenant is compensated through the savings of heating expenditures. This has certain tax consequences that could be resolved by tax incentives and write-offs for the tenant.

9.4 Taxation Consequences of Solar Installations

The real estate property tax in the FRG is paid at the time of improvement acquisition at the rate of 7%. This means if a solar system for DM 10 000 is installed, a tax of DM 700 must be paid. There are several other tax liabilities that are fully described in the reference [9.1]. Emphasis ought to be placed on the fact that fuel saving equipment should not be subjected to taxation, if an intensified use of solar energy is desired.

9.5 Conclusions

Analysis of existing laws and regulations shows that considerable barriers still exist that tend to constrain acquisition of solar systems. Review of regional formalitites that govern building trade should be inspired by the Federal government to enact amendments that would enhance the issuance of permits for solar systems installation.

Serious constraints in the environmental, and social sectors were not identified. The issues of capital, materials and (skilled) manpower diversion, that would take place if a large scale implementation of solar options would materialize, are well within managable range of FRG capacities. However, in the case of developing countries, each region would have to be evaluated individually before any major transfer of hardware, or personnel, is contemplated.

10. TRADE WITH DEVELOPING COUNTRIES

10.1 Introduction and Summary

It has been demonstrated that solar energy conversion systems are capital and material intensive. The rapidly growing demand for energy in developing countries is aggravated by the migration of population from rural into urban areas, where the dependence on centralized energy systems is higher. Solar energy conversion options are particularly attractive for some remote rural regions, because of the expensive logistics for conventional energy systems and availability of large areas for the collectors. Most developing countries have substantially higher values of solar insolation, which enhances the cost effectiveness of solar options.

Because of the uncertainties of development progress of solar technology, and the fact that the economic and lifetime aspects of solar options are yet to be determined, the strategy for specifically deploying solar options must be deferred. However, certain possible guidelines for trading with solar hardware deserve immediate consideration.

(1) Because solar energy systems are capital and energy intensive the best form of applicable trade is compensation trading, which minimizes excessive export of energy intensive hardware by trading for energy containing commodities.

(2) Because each country, indeed often each region in a given country, has unique energy-related resources and energy demand patterns, an on-site evaluation of these patterns should precede formulation of compensation arrangements.

In order to assess the possible spectrum of solar energy services, a composite package of solar options was constructed. Table 10.1 identifies the items of the package tailored for the broad application of solar options.

Table 10.1. Possible solar energy services for rural regions in developing countries.

"Soft/Hard" Technology Mix		Minimum Effective Energy Avg. Family* Year
		kWh(t)/a ≈ tce
o Space heating and/or crop drying		~ 3250 ≈ 0.40
o Water heating and/or distillation		~ 1630 ≈ 0.20
o Cooking		~ 810 ≈ 0.10
o Lighting, pumping, cooling and/or refrigeration		~ 2440 ≈ 0.30
	Tot.	8130 ≈ 1 tce

*average rural family of 4.

These estimates were calculated as additive to current energy supply to foster agricultural or light industrial production developments. The "and/or" options were tailored to match a variety of climatic conditions and related requirements. Because the economic spread of current "soft technology" ranges from ~ $100 to $1200/kWh(t) (DM 210 to 2500); and that for "hard technology" from ~ $2000 to $17 000/kW(e) (DM 4200 to 35 700), a flexible energy supply mix had to be developed from a variety of industrial and institutional proposals that yielded a target value of ~ $1500 (DM 3150) minimum energy unit. Part of the price range is due to the varied quality of the proposed hardware, but the target for minimum effective energy unit is only achievable by a well coordinated mass production of the solar systems.

10.2 Regional Supply and Demand Variations

Evaluation of the regional supply and demand variations can be arbitrarily based on the study of "Oxford Economic Atlas"

[10.1] and data from United Nations, as well as contemporary studies on reshaping the international order [10.2]. Recognizing that hydropower potential is available in many countries, the review of all regional resources must attempt identification of the most suitable form of energy--not just the solar options. The designs of solar systems for regions where their use would be competitive to other alternatives should take into consideration local resources and customs.

10.3 "Soft vs. Hard" Technology Aspects

Regional capabilities assessment will identify the suitable options after the current uncertainties of solar technology developments are resolved. "Soft" as well as "hard" technology is of interest, depending upon the local resources and the level of skill of maintenance personnel. The modular capabilities of solar systems permit a combination of hardware and technology transfer that enhances familiarization with the new technology on an economically and logistically favorable scale.

10.4 Technology and/or Hardware Transfer Issues

In regions where training of reliable manpower is feasible, the technology transfer version is rewarding, particularly when combined with a form of compensation trading. In such case the hardware design should be compatible with local resources and the scale of the hardware transfer should be moderated by the energy contents of the hardware, for which an equivalent energy compensation should be sought whenever the scale is substantial.

10.5 Trading Scenario Considerations

The energy intensive characteristics of solar hardware make a consideration of compensation trading a realistic element of sound energy policies. The wealth of untapped resources in many developing countries [10.1 to 10.3] is to be viewed as a trading subject for energy intensive hardware. Table 10.2 illustrates

Table 10.2
Marketable Resources in Some Developing Countries
(Selection of Examples for Compensation Trading)

Resource	Bolivia	Brazil	Chile	Dominican Republic	Gabon	Honduras	India	Jamaica	Malagasy	Malaysia	Mexico	Nigeria	Peru	Surinam	Thailand	Venezuela	Zaire
Aluminum*				●				●						●			
Antimony	●										●						
Barium											●		●				
Bismuth											●		●				
Cadmium											●						
Cobalt																	●
Columbium		●										●			●		
Copper*			●										●				●
Fluorine*											●						
Gas (Natural)											●					●	
Iron*		●					●									●	
Lead											●		●				
Manganese*		●			●		●										
Mica		●					●		●								
Petroleum											●	●				●	
Selenium											●						
Silver											●		●				
Tantalum		●													●		
Tellurium													●				
Tin	●									●		●			●		
Titanium							●			●							
Tungsten*	●												●		●		
Vanadium						●											
Zinc			●								●		●				

*Energy industry demand as 5% of all industry or more.

the variety of currently tradeable commodities for solar hardware. Because most solar systems can be transfered and operated on a modular basis, they can rapidly assist in earning revenues for the recipient country--a type of "solar breeder" can be formed in the regions with favorable insolation values.

10.6 Conclusions

In spite of the uncertainties of the economic and technical potential of solar technology for trade with developing countries, which made a delineation of a practical strategy impractical, leading qualitative observations were provided for the key aspects of trading. Most important in the trading consideration with solar hardware is its relatively high energy contents. It is therefore suggested that development of compensation trade is considered to minimize the export of energy contained in a large volume of solar energy conversion hardware.

A trading potential evaluation and a suitable strategy for each region of developing countries will have to be made to provide effective guidelines for the exporting industries and institutions in the FRG. Such guidelines must contain technical and societal considerations, resources assessment and the envisioned scenarios for increased energy supply requirements in the given region. It should be emphasized to the developing countries that the unfavorable aspects of energy production (such as pollution) in the industrialized countries can be minimized, or altogether avoided by proper implementation of solar options.

11. SYNTHESIS

11.1 Introduction and Summary

The system study on the possibilities of an intensified use of solar energy in the FRG was performed during a time period when accelerated funding of solar research and development caused a rapid rate of change of experimental developments, most of which were aimed at the improvement of solar energy conversion efficiencies. The uncertainties of the ultimate outcome of these developments, and the many discrepancies in economic estimates of the various solar options limited to some extent the synthesis to qualitative observations, which nevertheless provide the milestones for future inquiries in this field.

The current uncertainties of oil price evolution are among the constraining factors to the intensified use of solar options. The life-cycle evaluations of energy systems show, however, that it is merely a question of time when non-renewable energy resources become costly in meeting the most common categories of energy demand.

Solar water and space heating is one of the options that is adequately advanced in the developmental status and allowed quantification of its potential. But even that is subject to many uncertainties, because the current evolution of oil prices is not providing the anticipated impetus for the marketing of solar heating systems.

Adaptation of laws and regulations to facilitate application of solar systems and creation of taxation incentives are needed. Likewise resolution of the consumer protection issues, such as enforcement of quality standards and suitable insurance are among the measures requiring the involvement of the Federal government.

11.2 Technical and Economic Conclusions and Recommendations

It was observed that a major part of solar technology research and development in the USA is concentrating on conceptual studies of centralized solar-thermal and photovoltaic plants, while in Europe the emphasis appears to be on applied research of energy conversion processes and improvement of their overall efficiencies. Development of energy storage systems is, however, of equal importance, but substantially less information was available in that area. Several attempts at a systematic correlation of the current (and referenced) information were made, but the discrepancies among the performance and cost assessment data were too broad to obtain an accurate delineation of the potential of selected solar options. The acquired solar heating technology data also lacked consistency, but being closer to serious commercialization they offered more tangible information for a quantitative assessment of their potential in the FRG.

Three typical examples are used here to manifest the rate of change that created the atmosphere of uncertainties in which the study was made:

(1) Estimates of primary energy demand for the FRG for the year 2000 were reduced from about 928 (10^6) tce in December 1975 [11.1] to 600 (10^6) tce in December 1977 [11.2]. This is a reduction of 35% in two years which affects all the elements within these assessments.

(2) Because the complete production chain of large-scale solar systems is energy intensive, the total calculated risk per unit energy output may turn out to be higher than that associated with nuclear plants [11.3]. Specifically, the hereby quoted evaluations from the Atomic Energy Control Board in Canada show 10 total man-days lost per 1 MWa nuclear powerplant, and nearly <u>700</u> total man-days lost per 1 MWa solar-thermal plant.

(3) The thermal performance of the "Zero Energy House" in Denmark [11.4] was so low during the winter of 1976/77 that about "57 percent of the required heat had to be supplied from outside sources...". If thousands of such houses were suddenly to depend on utilities, the network could easily be overloaded (long-term scenario).

The implication of these examples is that a great deal more confidence must be established before realistic projections on the viability of solar options can be made; which means an extensive validation effort of the already acquired and future information.

11.3 Societal and Institutional Conclusions and Recommendations

Intensified use of the solar options in the FRG requires elimination of institutional and taxation penalties, adaptation of building codes, and development of quality, as well as performance standards, to enhance the marketing of such systems.

To strengthen the solar hardware market, the Federal government and the regional administrations should consider the integration of solar options in each new building that is adaptable for such systems. This should exemplify designs of low energy demand houses, utilizing integrated passive and active solar systems and possibly heat-pumps. For the mid-term considerations, the use of fossil fuels for heating swimming pools should be prohibited, which will foster the use and familiarization of solar systems. Certified component and system testing should become mandatory for all solar hardware to provide needed quality assurance.

Most importantly, well coordinated curricula should be formulated in all engineering and architecture faculties in the FRG to inspire students to innovative building designs. Technology assessment and trade-off among house insulation, active solar systems, passive solar systems, and heat-pump utilization should be stressed in lecture presentations, together with all other energy conservation methods, emphasizing the benefits of integrated systems. Design and development contests would provide further awareness and motivation. The value of environmental benefits should also be emphasized. An information, validation, and clearing house could be formed at one of the faculties to foster availability of objective data. Seminars should be organized for trade schools in the building branches, to familiarize builders with solar options and optimization methods for their use.

Last, but not least, a government sponsored and/or supervised insurance program should be established to provide assurance and confidence for the potential and existing owners of solar systems.

> "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 Bankers", M. Mayer, p. 565).

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ENERGETISCHE ANALYSE VON SONNENENERGIEANLAGEN, WÄRMEPUMPE UND VERBESSERTER WÄRMEDÄMMUNG IN EINFAMILIENHÄUSERN

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1. Zusammenfassung

Neben den bisher zur Bewertung von Energieversorgungstechnologien herangezogenen Kriterien wie z.B. Wirtschaftlichkeit, Umweltfreundlichkeit, Bedienungskomfort, etc. tritt als weitere Größe die Energieökonomie. Dieses Kriterium stellt den Energielieferungen eines Systems die Energieaufwendungen gegenüber, die für Bau und Betrieb der Anlage bereitzustellen sind. Bewertungsmaßstab ist dabei die energetische Amortisationszeit. Das ist die Zeit, in der durch die Technologie gerade soviel Energie geliefert oder eingespart wird, wie sie zuvor an Energieaufwendungen erforderte.

Im Fall der hier untersuchten Technologien,

- der Sonnenenergienutzung (3 Anlagenvarianten),
- der Wärmedämmung und
- der Wärmepumpe (2 Anlagenvarianten)

bedeutet das, daß die Primärenergieeinsparungen durch den Einsatz dieser Technologien der Primärenergie gegenübergestellt werden, die für die Produktion der zusätzlich benötigten Anlageteile benötigt wird. Zum Vergleich wird eine konventionelle Ölheizungsanlage herangezogen. Die Untersuchungen zeigen, daß

- bei der Wärmedämmung mit knapp 2 Monaten,
- bei der Wärmepumpe mit 5 bis 14 Monaten und
- bei der Sonnenenergie mit 16 bis 23 Monaten,

die energetische Amortisationszeit weit kürzer ist als die Lebensdauer der Anlagen. Von Seiten der Energieökonomie ergeben sich daher keine Restriktionen für die Einführung dieser Technologien. Selbst ein forcierter Ausbau - im Beispiel Sonnenenergienutzung wurde ein Zubau von 3,2 Mio Anlagen bis zum Jahr 2010 angenommen - ändert nichts an diesem Ergebnis. Die maximal mögliche exponentielle Zubaurate liegt im Falle der Sonnenenergie sogar zwischen 54 %/a und 77 %/a.

Die Primärenergieeinsparung, die durch die Einführung der betrachteten Technologien gegenüber der Vergleichsanlage erreicht werden kann, beträgt

- bei den Sonnenenergieanlagen 13 % bis 59 %,
- bei der Wärmedämmung 47 % und
- bei den Wärmepumpenanlagen 27 %.

Da die einzelnen Technologien jedoch zum einen unterschiedliche Investitionen erfordern, zum anderen unterschiedliche Einsatzpotentiale aufweisen, können diese Zahlen nur unter Vorbehalt zum Vergleich herangezogen werden.

2. Energieanalysen

2.1 Zielsetzung

Neue Technologien, dienen sie zur Herstellung neuer Produkte oder auch zur Substitution bereits bestehender Systeme, werden in der Regel nur dann eingeführt, wenn sich damit eine positive wirtschaftliche Erwartung verknüpft. War es bisher hauptsächlich die Anforderung des Marktes, die zu stetiger Evolution zwang, so müssen heute eine Reihe anderer Sachzwänge in die Überlegungen einbezogen werden. Beispielhaft seien Umweltschutz und Sicherheitsauflagen genannt. Ein weiterer Gesichtspunkt ergibt sich aus der heutigen energiewirtschaftlichen Situation, die dazu zwingt, eine neue Technologie auch unter energetischen Aspekten zu bewerten. Eine solche Energieanalyse hat insbesondere die Frage zu beantworten, ob der Verbrauch von Energieträgern beim Bau und beim Betrieb neuer Anlagen gegenüber bereits bestehenden Anlagen reduziert werden kann. Dabei ist zu beachten, daß nicht nur die direkt - in Form von Energieträgern - in die Anlage geflossenen Energieaufwendungen berücksichtigt werden, auch die beim Bau benötigten Investitionsgüter und Materialien benötigen Energie zu ihrer Herstellung und sind daher mit einzurechnenden Energieaufwendungen belastet.

Von besonderer Bedeutung sind Energieanalysen für Energieversorgungs- und -einspartechnologien. Sie eröffnen die Möglichkeit, Aussagen über die Energieökonomie von Anlagen oder Technologien zu machen. Da Energielieferungen einer Anlage den Energieaufwendungen für Bau und Betrieb der Anlage gegenübergestellt werden, läßt sich so der Nettobeitrag der Anlage zur Energieversorgung einer Volkswirtschaft ermitteln. Aus diesem Grund spricht man bei Energieanalysen angewandt auf Energietechnologien von Nettoenergierechnungen.

2.2 Methodik

Für das Erstellen von Energieanalysen existieren zwei unterschiedliche Vorgehensweisen. Zuerst sei die Methode der Prozeßkettenanalyse genannt, deren Vorgehensweise bereits durch den Namen charakterisiert wird. Ein komplexer Vorgang wird in eine Vielzahl kleiner, überschaubarer Einzelprozesse aufgegliedert, für die dann alle relevanten In- und Outputs erfaßt und energetisch bewertet werden können. Am Ende einer solchen Kette entsteht dann das Endprodukt, in dem alle vorausgegangenen energetischen Aufwendungen kumuliert sind.

Die zweite Möglichkeit bedient sich der Systematik der Input-Output-Tabelle, die die wertmäßige Verflechtung der Sektoren der Volkswirtschaft angibt. Werden diesen Wertströmen Energieströme zugeordnet, die sich aus der Energiebilanz entnehmen lassen, so kann eine Energiematrix entwickelt werden, die aufzeigt, wieviel Energie unter Einschluß aller vorgelagerten Produktionsschritte aufzuwenden ist, um eine Werteinheit des betrachteten Sektors zu erzeugen.

Die Erstellung einer Anlage benötigt Investitionsleistungen aus unterschiedlichen Wirtschaftssektoren. Sind die Beiträge der einzelnen Sektoren bekannt, so läßt sich mit Hilfe der Energiematrix der Energieaufwand für die Erstellung einer Anlage ermitteln.

In jedes Produkt gehen Endenergieträger unterschiedlichster Art und Qualität ein, deren Palette von den festen Brennstoffen Kohle oder Koks über die flüssigen und gasförmigen Brennstoffe bis hin zum elektrischen Strom reicht. Um hier eine Rechenbasis zu schaffen, die die Energieträger miteinander vergleichbar macht, wird der Verbrauch an Endenergieträgern mit den charakteristischen Wirkungsgraden zu deren Bereitstellung auf Primärenergieeinheiten zurückgeführt. Wird ebenso der Energieoutput einer Anlage auf Primärenergieeinheiten umgerechnet, dann läßt sich durch Vergleich von energetischem Aufwand und Nutzen eine energetische Amortisationszeit definieren. Darunter ist die Zeit zu verstehen, die die Anlage in Betrieb sein muß, um genau soviel Energie geliefert zu haben, wie für Erstellung und Betrieb der Anlage aufgewandt werden mußte (Bild 1). Bei der Bewertung von Anlagen, die regenerative Energiequellen nutzen, wird davon ausgegangen, daß bei Fortfall dieser Nutzung die benötigte Energie über fossile Energieträger bereitgestellt werden müßte.

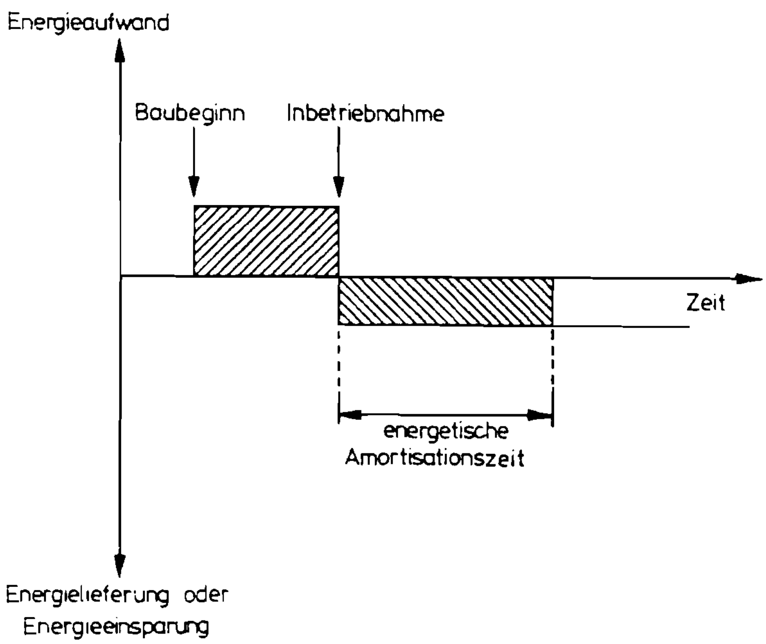


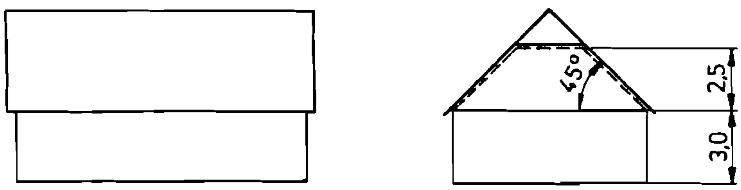
Bild 1: Definition der energetischen Amortisationszeit

3. Sonnenenergienutzung zur Raumheizung und Warmwasserbereitung

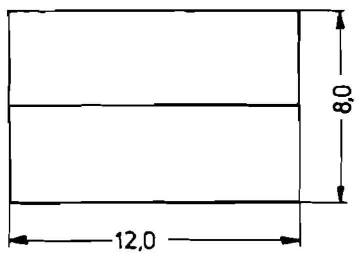
3.1 Konzeption eines Vergleichshauses

Die Energieanalyse ist eine Methode, die zur Bewertung realer Anlagen angewandt wird. Zur Ermittlung der Energieeinsparung durch Sonnenenergienutzung im Vergleich zu einer konventionellen Heizungsanlage ist es deshalb erforderlich, die betrachteten Anlagen in ein Wirkungsfeld einzupassen, d.h. ein Gebäude zu konzipieren, in dem die Anlagen die Wärmeversorgung übernehmen. Obwohl Sonnenenergieanlagen im Haushaltsbereich ausschließlich die Versorgung von Ein- und Zweifamilienhäusern übernehmen können, läßt sich bei der Vielfalt baulicher Ausführungsmöglichkeiten kein allgemein gültiger Fall konstruieren. Es soll daher auf ein Beispiel aus der DIN 4108 zurückgegriffen werden, das in leicht veränderter Form als Referenz für viele in der Praxis auftretende Fälle dienen kann.

Abmessungen



Maße in m



Grundfläche:	96 m^2
Fensterfläche:	37 m^2
Wandfläche:	111 m^2
Dachfläche:	121 m^2
Umfassungsfläche:	365 m^2

Umfassungsfläche zu Volumen 0,8/m

Wohnfläche

- Erdgeschoß 96 m^2
- Dachgeschoß 20 - 40 m^2, je nach Ausbauart

Maximaler mittlerer Wärmedurchgangskoeffizient: 0,84 W/m^2 K

Lebensdauer: 30 a

Als zum Vergleich heranzuziehende "konventionelle" Heizungsanlage bietet sich die ölgefeuerte Zentralheizung an, denn rd. 60 % des Endenergiebedarfs der Haushalte wird über leichtes Heizöl gedeckt /1/ und mehr als 90 % aller in den letzten Jahren gebauten Ein- und Zweifamilienhäuser wurden mit einer Zentralheizung ausgerüstet /1/.

Der jährliche Energiebedarf des Hauses, der durch das Heizungssystem gedeckt werden muß, entsteht durch

- Raumheizung und
- Warmwasserbereitung.

Der Raumwärmebedarf ergibt sich als Produkt des mittleren Wärmedurchgangskoeffizienten mit der Gradtagzahl. Als Mittelwert für die Bundesrepublik Deutschland kann eine Gradtagzahl von 3500 d ^{o}C angesetzt werden.
Der Warmwasserbedarf hängt von der Anzahl der Bewohner und deren Lebensstandard ab. Der in Tabelle 1 angegebene Wert gilt unter Annahme

- eines mittleren Verbrauchs von 70 l pro Person und Tag,
- eines 4-Personen-Haushaltes,
- einer Austrittstemperatur des Warmwassers an der Zapfstelle von 45 ^{o}C und einer Kaltwassertemperatur von 10 ^{o}C

Aus dem Nutzenergiebedarf für Raumheizung und Warmwasser läßt sich mit Hilfe eines über das Jahr gemittelten Wirkungsgrades der Ölheizung der Heizölbedarf errechnen (Tabelle 1). Werden zusätzlich die Energieaufwendungen für die Destillation von Heizöl aus Rohöl, die Rohölförderung und den Transport von Rohöl und Heizöl berücksichtigt, dann ergibt sich der zur Deckung des Wärmebedarfs erforderliche Primärenergieeinsatz.

Bedarf	kWh/a
Raumwärme	25000
Warmwasser	4000
Nutzenergie	29000
Endenergie bei mittlerem Wirkungsgrad der Ölheizung $\eta_H = 0,60$	48300
Primärenergie Wirkungsgrad der Prozeßkette Rohöl $\rightarrow$ Heizöl $\eta_V = 0,90$	53700

Tab. 1: Energiebedarf des Vergleichshauses

Die wesentlichsten Merkmale der Ölzentralheizungsanlage gehen aus Bild 2 hervor.

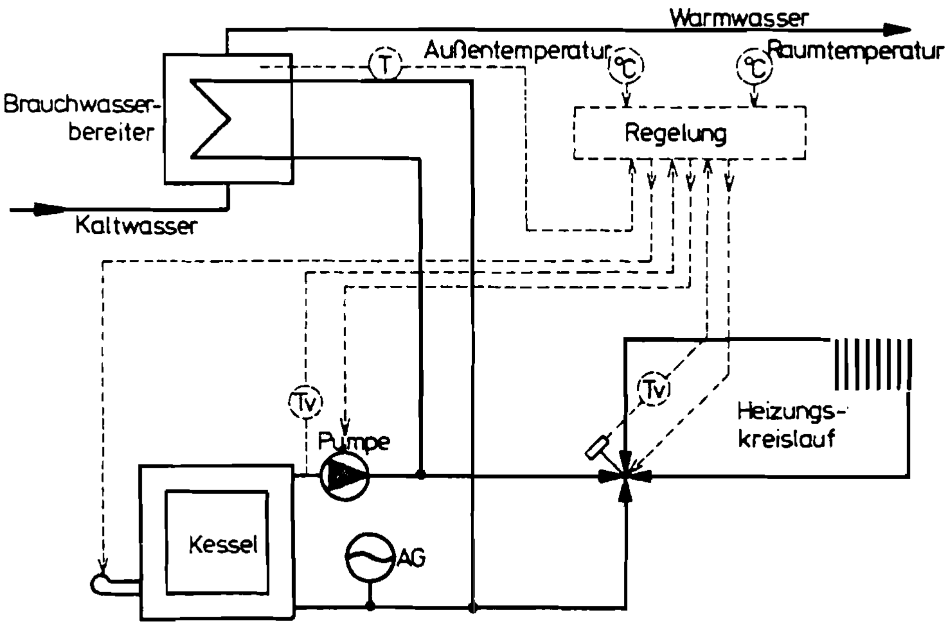


Bild 2: Prinzipschaltbild der Ölzentralheizungsanlage

Die Brauchwasserbereitung geschieht ganzjährig über einen Heißwasserboiler mit ca. 200 l Inhalt. Über das Heizungssystem im Haus werden keine Annahmen getroffen. Es können eine Fußbodenheizung oder Radiatoren oder Konvektoren installiert sein. Die Anlage wird von einer außentemperaturabhängigen Regelung so geregelt, daß die gewünschte Raumtemperatur eingehalten wird. Weitere wichtige technische Merkmale enthält Tabelle 2.

Installierte Kesselleistung	kW	15
Niedrigste zugrundegelegte Auslegungstemperatur	C	- 15
Benutzungsdauer	h/a	1700
Mittlerer Wirkungsgrad	%	60
Mittlere Lebensdauer	a	20
Öltank Volumen (Würfelförmiger Stahlblechtank)	l	4700

Tab. 2: Technische Merkmale der Ölzentralheizungsanlage

3.2 Betrachtete Sonnenenergieanlagen

Um die Vielfalt der möglichen Anlagentypen zu erfassen, werden bei der energetischen Analyse 3 Typen betrachtet, deren Unterscheidungsmerkmale in Tabelle 3 zusammengestellt sind. Bei allen Anlagenvarianten deckt die Sonnenenergie nur einen Anteil des Jahreswärmebedarfs. Den Rest übernimmt die Ölzentralheizungsanlage bzw. bei der Brauchwasserbereitung im Sommer ein elektrischer Durchlauferhitzer.

Unterscheidungsmerkmale	Typ I	Typ II	Typ III
Warmwasserbereitung mit Sonnenenergie	ja	ja	ja
Raumheizung mit Sonnenenergie	nein	ja	ja
Speicher (Volumen)	nein	ja (6m^3)	ja (15m^3)
Kollektorfläche	8 m^2	35 m^2	65 m^2

Tab. 3: Unterscheidungsmerkmale der betrachteten 3 Sonnenenergieanlagen

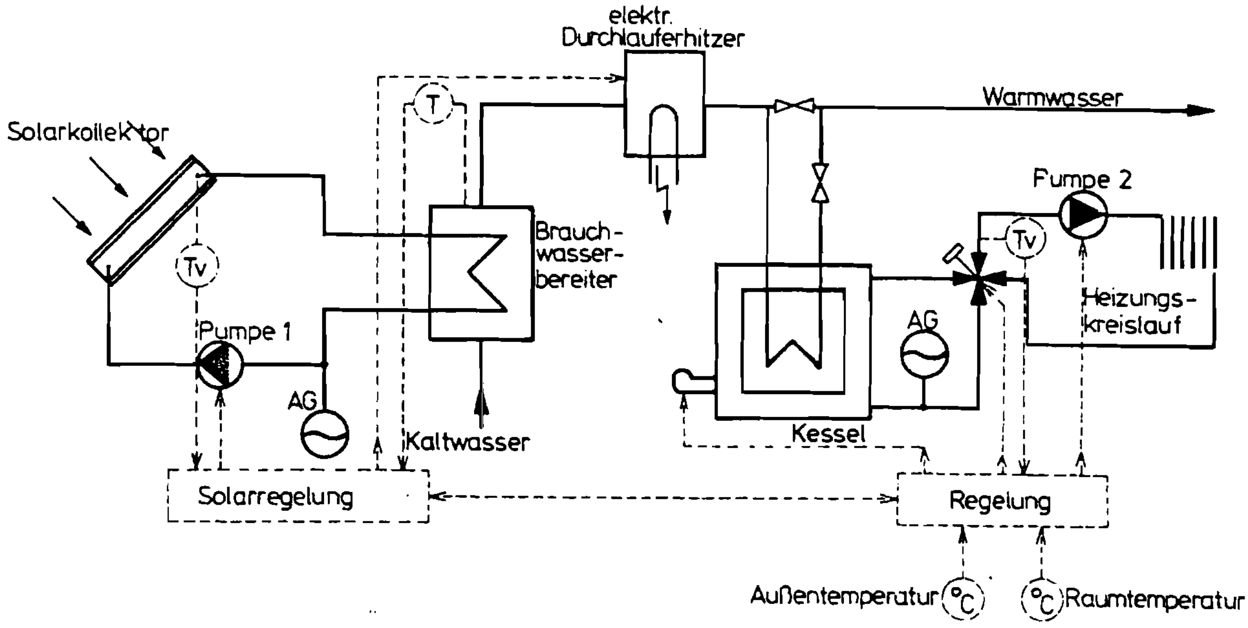
Das Verhältnis Kollektorfläche zu Speichervolumen bei den Typen II und III ergibt sich aus der wirtschaftlichen Optimierung in /2/. Während bei Haustyp II das Kostenminimum, bezogen auf die nutzbare Sonnenenergie erreicht ist, entspricht der Typ III derjenigen Kombination, bei der Kostengleichheit gegenüber einer 100 % - Versorgung mit einer Ölzentralheizungsanlage erreicht ist. Die Optimierungsrechnungen in /2/ wurden bereits Ende 1975 abgeschlossen. Die Preise der einzelnen Anlagenkomponenten haben sich seither verändert und für die Bestimmung der Kollektorparameter sind Meßprogramme angelaufen. Es kann deshalb nicht ausgeschlossen werden, daß sich die Ergebnisse bei einer Aktualisierung der Optimierungsrechnung verschieben würden. Da aber noch keine neue Rechnung vorliegt, muß auf die Werte in /2/ zurückgegriffen werden.

3.3 Prinzipschaltbilder der Sonnenenergieanlagen

Um den Energieeinsatz zur Produktion der zusätzlich benötigten Bauteile gegenüber einer Ölzentralheizung zu erfassen, ist es erforderlich die Prinzipschaltbilder der 3 Sonnenenergieanlagen anzugeben.

Typ 1 (Bild 3)

Die Sonnenenergie wird in den Brauchwasserbereiter eingespeist. Ein dem Brauchwasserbereiter nachgeschalteter elektrischer Durchlauferhitzer ermöglicht eine Nachheizung, wenn das Sonnenenergieangebot nicht ausreicht und die Heizungsanlage abgeschaltet ist. Bei eingeschalteter Heizungsanlage erfolgt die Nachheizung nicht mehr elektrisch, sondern über einen Durchlauferhitzer im Heizungskessel. Die Pumpe 1 und der elektrische Durchlauferhitzer werden in Abhängigkeit von der Vorlauftemperatur des Solarkollektors und der



<u>Bild 3:</u> Prinzipschaltbild einer solaren Brauchwasserbereitungsanlage und einer Ölzentralheizungsanlage

Temperatur im Brauchwasserbereiter automatisch gesteuert.
Gegenüber der Vergleichsanlage werden im wesentlichen folgende zusätzliche Anlagenkomponenten benötigt:

- Kollektor
- 1 Umwälzpumpe, Absperrarmaturen, Füll-, Entleerungs-, Entlüftungshähne, Ausgleichsgefäß, Durchlauferhitzer im Ölkessel, elektr. Durchlauferhitzer
- Regeleinheit.

<u>Typ II und Typ III (Bild 4)</u>

Die Sonnenenergie wird in den Brauchwasserbereiter und in den Warmwasserspeicher eingespeist. Falls es erforderlich ist wird das Brauchwasser wie bei Typ I in einem elektrischen Durchlauferhitzer bzw. in einem Durchlauferhitzer im Heizungskessel nacherhitzt. Falls das Energieangebot des Kollektors nicht ausreicht, wird der Fehlbetrag aus dem Warmwasserspeicher entnommen, solange dessen Vorlauftemperatur ausreichend hoch ist. Die Pumpen und Ventile werden von der Solarregelung entsprechend den gemessenen Temperaturen im Kollektor, Brauchwasserbereiter und Warmwasserspeicher gesteuert.

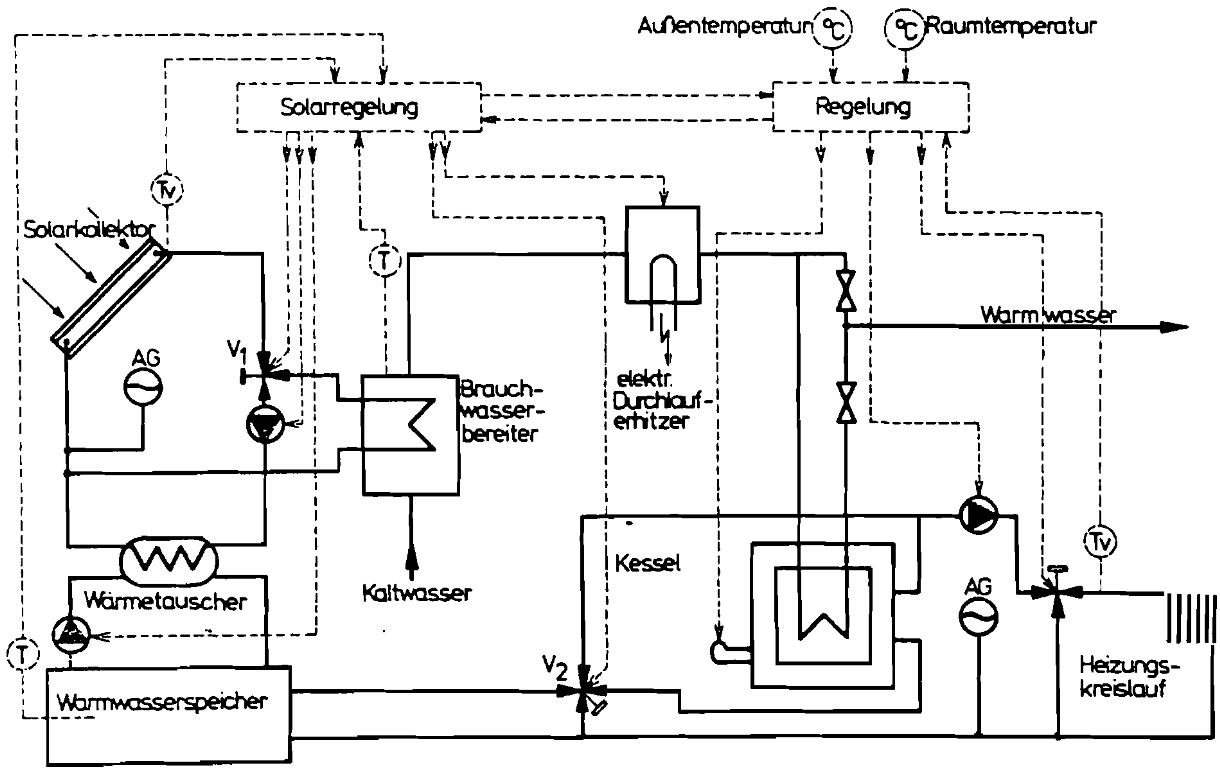


Bild 4: Prinzipschaltbild der Heizungsanlage zur Raumheizung und Brauchwasserbereitung unter Einsatz von Sonnenenergie

Gegenüber der Vergleichsanlage werden im wesentlichen folgende zusätzlichen Anlagenkomponenten benötigt:

- Kollektor
- Warmwasserspeicher
- Wärmetauscher, 2 Umwälzpumpen, 2 motorgetriebene Mischventile, Absperrarmaturen, Füll-, Entleerungs-, Entlüftungshähne, Ausgleichsgefäß, Durchlauferhitzer im Ölkessel, elektr. Durchlauferhitzer
- Regeleinheit.

3.4 Der Energieaufwand für die zusätzlich benötigten Bauteile

Dem Energieaufwand für die zusätzlich benötigten Bauteile müssen Gutschriften für

- den kleineren Öltank und
- die Dachziegel, die durch den Kollektor ersetzt werden,

gegenübergestellt werden.

Bei der Rechnung werden die in Tabelle 4 zusammengestellten spezifischen Primärenergieaufwendungen verwendet, die in /3/ berechnet worden sind.

	kWh/t	kWh/m^3	kWh/100 DM
Materialien (aus Prozeßkettenanalyse):			
Aluminiumbleche, -profile	72500	195750	
Stahlblech	7780	61462	
Flachglas	6000	15000	
Kalksandstein	518	357	
Gasbeton	324	405	
Beton	244	440	
Dachziegel	534	908	
ND-Polyäthylen	13700	12600	
PVC	9500	12825	
Polystyrolschaum	19000	475	
Glaswolle	5000	150	
LKW-Transport 850 Wh/t km			
Wirtschaftssektoren (über Input-Output-Methode):			
Baugewerbe			187
NE-Metall Industrie			340
Maschinenbau			171
Elektrotechnik			171
Holzverarbeitende Industrie			170

Tab. 4: Spezifische Primärenergieaufwendungen verschiedener Werkstoffe und Wirtschaftssektoren /3,9,10,11/

Im folgenden werden die Energieaufwendungen der einzelnen Bauteile detailliert berechnet.

Kollektor

Verwendet wird ein Flachkollektor, dessen Aufbau Bild 5 zeigt.

	kWh/m^2 Kollektor
Absorber (2 mm Dicke)	392
Glasscheiben (4 mm Dicke)	121
Dämmaterial (Polystyrol, 40 mm Dicke)	20
Rahmen (ca. 5 kg Al-Profile)	363
	896 kWh/m^2

bei Haustyp I (8 m^2 Kollektorfläche)	7168
bei Haustyp II (35 m^2 Kollektorfläche)	31360
bei Haustyp III (65 m^2 Kollektorfläche)	58240

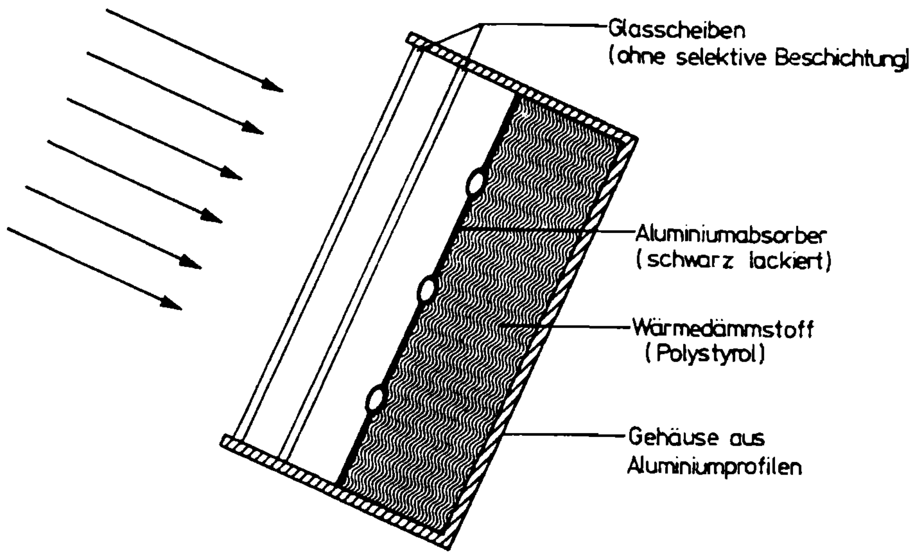


Bild 5: Schematischer Aufbau des Sonnenenergiekollektors

Speichertank aus Beton

Der Warmwasserspeicher wird als zylinderförmiger, isolierter Betonspeicher ausgeführt, der im Erdboden versenkt ist.
Zylinder, Durchmesser = Höhe, 10 cm Glaswolle-Isolierung, Wanddicke d/m/,
d/m/ = 0,07 + 0,05 log /m^3/ /2/

Typ (Speichervolumen V)	II (6 m^3)	III (15 m^3)
	kWh	
Beton (2,3 m^3 bzw. 4,8 m^3)	1010	2110
Isoliermaterial (2,5 bzw. 4,4 m^3)	375	660
Aushub des Erdreiches (11 m^3 bzw. 25 m^3, 15 DM/m^3, /4/, Baugewerbe)	310	700
Transport des Baumaterials (50 km, Leichtbeton 0.8 t/m^3, Glaswolle 0,03 t/m^3)	80	170
Energieverbrauch auf der Baustelle	30	30
Summe:	1805	3670

Zusatzinstallationen

Die Preise beruhen teilweise auf Angaben verschiedener Firmen /5,6/. Sie stellen Mittelwerte dar, die im Einzelfall nach oben oder unten differieren können. Sie wurden, soweit erforderlich mit dem Inflationsindex für Investitionsgüter auf das Jahr 1974 umgerechnet.

Typ	I		II		III	
	DM	kWh	DM	kWh	DM	kWh
Wärmetauscher[1] (NE-Industrie)	-	-	700	2380	1000	3400
Umwälzpumpen, Ausdehnungsgefäß (Maschinenbau)	150	257	250	428	250	428
Rohrleitungen (Cu, Ø 22 mm, 3 DM/m x 50 m, NE-Industrie)	150	510	150	510	150	510
2 Mischventile mit Stellmotor (Maschinenbau u. Elektrotechnik)	-	-	500	855	500	855
Durchlauferhitzer im Ölkessel (Cu-Ni, NE-Industrie)	600	2040	600	2040	600	2040
Absperrhähne, Entlüftungsarmaturen (Maschinenbau)[1]	100	171	150	257	200	342
Elektr. Durchlauferhitzer (Elektrotechnik[1])	100	171	100	171	100	171
Regelung[1] (Elektrotechnik)	200	342	400	684	400	684
Montage (10 h bzw. 20 h á 30 DM, Maschinenbau)[1]	300	513	600	1026	600	1026
Summe	1600	4004	3450	8351	3800	9456

[1] Preise bzw. Stundenzahl geschätzt

Gutschrift für Dachziegel

Typ (Kollektorfläche)	I (8 m^2)	II (35 m^2)	III (65 m^2)
Dachziegel (2 cm Dicke, 1,7 t/m^3)	145 kWh	636 kWh	1180 kWh

Gutschrift für kleineren Heizöltank

Würfelförmiger Tank aus Stahlblech (Blechstärke 5 mm, 7,9 t/m^3)

Inhalt deckt den Heizölbedarf eines Jahres

Typ (Tankvolumen)	I (3,9 m^3)	II (2,5 m^3) kWh	III (1,6 m^3)
Tank	4550	3318	2654
Tank im Vergleichshaus (4,7 m^3)	5166	5166	5166
Gutschrift = Differenz	616	1848	2512

Zusammenfassung (Tab. 5)

Typ	I	II kWh	III
Kollektor	7168	31360	58240
Speichertank	./.	1800	3660
Zusatzinstallationen, Regelung	4004	8351	9456
abzüglich Gutschrift für Dachziegel	- 145	- 636	- 1180
für Öltank	- 616	- 1848	- 2512
Mehraufwand	10411	39027	67664

Tab. 5: Primärenergieaufwand für die zusätzlich benötigten Bauteile der Sonnenenergieanlage

3.5 Energetische Analyse einzelner Anlagen

Die energetische Analyse der 3 Haustypen hat das Ziel, die Einsparung an Heizöl und Primärenergie anzugeben, sowie unter Berücksichtigung der Energieaufwendungen für die zusätzlichen Bauteile die Energieökonomie der Anlagen zu überprüfen. Dazu muß zunächst der Nutzenergiebedarf auf die drei zur Verfügung stehenden Energieträger Sonne, Heizöl und Strom aufgeschlüsselt werden. Schlüsselgröße dazu ist der Anteil der Solarenergie an der Wärmebedarfsdeckung des Hauses.

Die Auswertung der Rechnungen in /7,8/ ergibt bei der Brauchwasserbereitung und damit für den Haustyp I einen Jahresanteil von 58 % und einen Anteil von 85 % während der Sommermonate Mai-August. Die Anteile der Solarenergie am gesamten Jahreswärmeverbrauch (Raumwärme und Brauchwasser) ergeben sich aus der Optimierungsrechnung in /2/ für Haustyp II zu 42 % und für Haustyp III zu 63 %. Mit diesen Werten ergibt sich die Aufschlüsselung in Tabelle 6.

	Typ I kWh/a	Typ II kWh/a	Typ III kWh/a	Vergleichs-anlage kWh/a
Sonne	2320	12 180	18 270	-
Heizöl	26480	16 620	10 530	29 000
Elektrizität	200	200	200	-
Nutzenergiebedarf	29000	29 000	29 000	29 000
Endenergiebedarf				
Heizöl (mittlerer Wirkungsgrad der Ölheizung η =0,65)	40739	25 569	16 200	48 330
Elektrizität (mittlerer Wirkungsgrad des Durchlauferhitzers η = 0,95)	210	210	210	-

Tab. 6: Aufschlüsselung des Nutz- und Endenergiebedarfs auf die eingesetzten Energieträger

Der Jahreswirkungsgrad der Ölheizung steigt bei Haustyp I, II, III gegenüber dem Vergleichshaus (60 %), an, weil der Sommerbetrieb mit geringem Wirkungsgrad entfällt.
Wird die Endenergie auf ihr Primärenergieäquivalent umgerechnet ergibt sich die folgende Primärenergiebilanz (Tabelle 7).

Primärenergie-äquivalent	Typ I kWh/a	Typ II kWh/a	Typ III kWh/a	Vergleichs-anlage kWh/a
Heizöl (Rohöl → Heizöl η_W = 0,9)	45266	28410	18000	53700
Elektrizität (Primärenergie → Strom η =0,3)	700	700	700	-
zusätzliche Anlagenteile (umgelegt auf 20 a Lebensdauer)	521	1951	3383	-
Summe	46487	31061	22083	53700

Tab. 7: Primärenergiebedarf für Bau und Betrieb der betrachteten Heizungsanlagen mit Sonnenenergiekollektor

Die Nutzung der Sonnenenergie führt zu den in Tabelle 8 zusammengestellten Energieeinsparungen.

Einsparung		Typ I	Typ II	Typ III
Heizöl	l/a	730	2180	3077
Primärenergie	kWh/a	7213	22639	31617
Primärenergie	%	13	42	59

Tab. 8: Energieeinsparung durch den Einsatz der Sonnenenergieanlagen

Die Energieökonomie der Sonnenenergieanlagen wird durch die energetische Amortisationszeit charakterisiert.
Es ergeben sich folgende Zeiten (gerundet)

Typ I : 1,3 a
Typ II : 1,6 a
Typ III : 1,9 a

Gemessen an der zugrunde gelegten Lebensdauer von 20 a sind diese Zeiten gering. Das bedeutet, daß die Energieökonomie der Anlagen gewährleistet ist.

3.6 Maximal mögliche Zubaurate bei der Einführung der Sonnenenergieanlagen

Die maximale Zubaurate beim Ausbau der Sonnenenergieanlagen ist dann erreicht, wenn für die Erstellung der Anlagen genauso viel Primärenergie aufgewendet werden muß, wie die in Betrieb befindlichen Anlagen einsparen können. Ein Ausbau mit noch höherer Zuwachsrate würde dazu führen, daß durch die Einführung der Sonnenenergie eine zusätzliche Belastung der Primärenergiebilanz eintritt.
Für ein exponentielles Zubauprogramm dessen erste Anlagen im Zeitpunkt m = 1 in Betrieb gehen, ist der kumulierte Energieaufwand zum Bau der Anlagen I_m im Jahr m gegeben durch

$$I_m = \frac{I_o}{j} \cdot \frac{1}{q} \; (1 + q)^m \left[(1 + q)^j - 1\right]$$

und die kumulierte Energieeinsparung E_m im Jahr m errechnet sich aus

$$E_m = E_o \cdot \frac{1}{q} \left[(1 + q)^m - 1\right]$$

In diesen Formeln bedeuten

I_o = Primärenergieaufwand zum Bau einer Sonnenenergieanlage
E_o = jährliche Primärenergieeinsparung einer Anlage
q = Wachstumsrate
j = Bauzeit der Anlage

Hieraus ergeben sich die maximal möglichen Wachstumsraten q_{max} bei einer Bauzeit $j \leq 1a$.

	Typ I	Typ II	Typ III
q_{max}	75 %	64 %	54 %

3.7 Analyse eines Zubauprogramms

Die maximal möglichen Zubauraten werden bei der praktischen Einführung der Sonnenenergieanlagen außer in den ersten Jahren nicht erreicht. Interessant ist deshalb die Beantwortung der Frage, nach welcher Zeit eine Entlastung der Primärenergiebilanz eintritt und wieviel Primärenergie bei einem vorgegebenen Ausbau der Sonnenenergieanlagen eingespart werden kann.

Der Ausbau der Sonnenenergieanlagen soll nach einer logistischen Funktion erfolgen, die im Jahre 1978 startet und im Jahre 2010 ihre Sättigung erreicht. Obwohl in der Praxis Anlagen aller 3 betrachteten Typen gleichzeitig zugebaut werden, wird hier nur der Zubau mit jeweils einem Anlagentyp analysiert. Die Ergebnisse für den Typ I liefern den minimalen und die Ergebnisse für den Typ III die maximalen Werte für die Energieeinsparung und die Amortisationszeit. Die wichtigsten Werte für das vorgegebene Zubauprogramm enthält Tabelle 9. Die Lebensdauer der Anlagen beträgt 20 a.

Zeit	1978	1982	1990	2000	2010
Anzahl /10^6/	0,003 (Typ I) 0,0003 (Typ II,III)	0,017	0,32	2,64	3,2

Tab. 9: Vorgegebenes Zubauprogramm für die Sonnenenergieanlagen

Die energetische Analyse (Bild 6) zeigt, daß frühestens nach 2,5 a (Typ I) spätestens aber nach 6,5 a (Typ III) eine Entlastung der Primärenergiebilanz eintritt. Die Primärenergieeinsparung bis zum Jahr 2010 beträgt zwischen 550 TWh und 1407 TWh. Die entsprechenden Werte für Typ II, die in Bild 6 nicht eingetragen sind, lauten 5,5a und 1017 TWh.

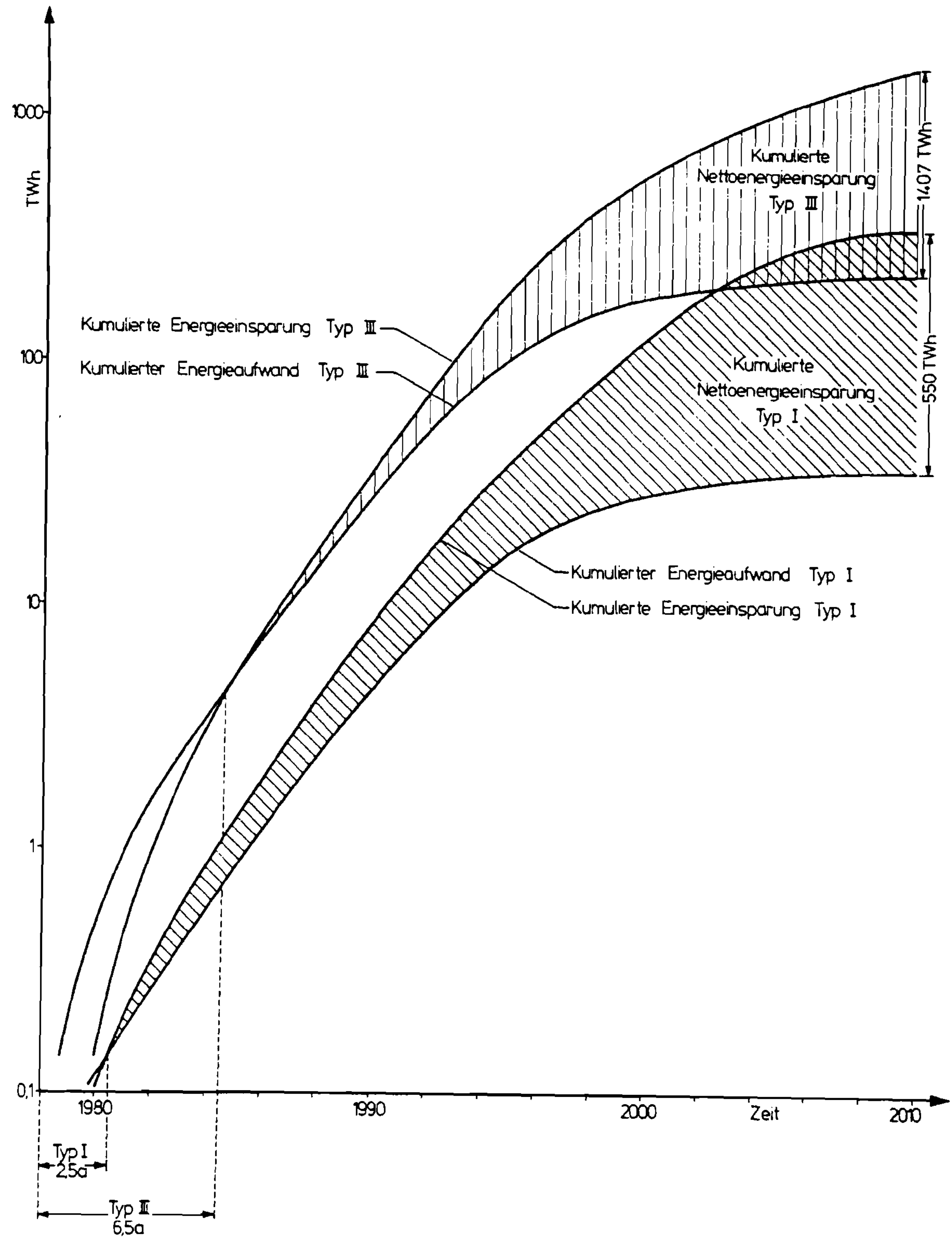


Bild 6: Kumulierter Primärenergieaufwand und kumulierte Primärenergieeinsparung bei Ausbau von Sonnenenergieanlagen entsprechend Typ I und Typ III
(Typ I: Nur solare Brauchwasserbereitung - Typ III: Solare Raumheizung und Brauchwasserbereitung)

4. Ausgewählte sonstige energiesparende Technologien

4.1 Verbesserte Wärmedämmung

Die Installation von Heizungsanlagen, die regenerative Energiequellen nutzen, ist ein Weg, der zu einer Einsparung von zu importierender Primärenergie führt. Maßnahmen dieser Art bleiben aber unbefriedigend, wenn sie nicht mit zusätzlichen Maßnahmen verbunden werden, die die Wärmeabflüsse durch die Gebäudehüllfläche reduzieren. Damit ist die verbesserte Wärmedämmung von Gebäuden angesprochen. Wärmedämmaßnahmen und Modifikation der Heizungsanlage sind daher zwei parallel zu beschreitende Wege.

Am 1.11.1977 trat die Rechtsverordnung zum Gesetz zur Einsparung von Energie in Gebäuden (EnEG) betreffend verbesserte Wärmedämmung in Kraft. Anhand der darin vorgeschriebenen Verbesserungen soll dargestellt werden, wie wirksam Wärmedämmaßnahmen sind.
Für das konzipierte Vergleichshaus ist nach DIN 4108 - Beiblatt ein maximaler, mittlerer Wärmedurchgangskoeffizient $k_{m,max} = 0{,}84\ W/m^2\ K$ vorgeschrieben. Dieser Wert läßt sich z.B. durch folgende bauliche Ausführung, die hier zugrunde gelegt werden soll, erreichen /9/:

- Wände -	30 cm starkes Gasbetonmauerwerk	$k_W = 1{,}0\ W/m^2 \cdot K$
- Fenster -	Isolierverglasung mit 12 mm Luftzwischenraum	$k_F = 3{,}0\ W/m^2 \cdot K$
- Dach -	Holzbalkenkonstruktion mit Wärmedämmschicht	$k_D = 0{,}46\ W/m^2 \cdot K$
- Fußboden -	Kiesbeton, Holzparkett auf schwimmenden Estrich und Wärmedämmschicht	$k_G = 0{,}7\ W/m^2 \cdot K$

Der jährliche Raumwärmebedarf beträgt dann 25000 kWh/a.
Die durchschnittliche bauliche Ausführung des Hauses vor Inkrafttreten der Rechtsverordnung zum EnEG kann wie folgt angenommen werden:

- Wände -	30 cm starkes Kalksandsteinmauerwerk	$k_W = 1{,}54\ W/m^2 \cdot K$
- Fenster -	einfach verglaste Holzfenster	$k_F = 5{,}2\ W/m^2 \cdot K$
- Dach -	Holzbalkenkonstruktion mit Verkleidung	$k_D = 1{,}17\ W/m^2 \cdot K$
- Fußboden -	Kiesbeton, Holzparkett auf schwimmenden Estrich	$k_G = 1{,}32\ W/m^2 \cdot K$

Für dieses Gebäude errechnet sich ein $k_m = 1{,}52\ W/m^2 \cdot K$ und damit ein jährlicher Wärmebedarf von ca. 47000 kWh/a. Durch die verbesserte Wärmedämmung läßt sich also ein Rückgang des Raumwärmebedarfs um ca. 46 % errechnen. Diesen

Einsparungen steht ein zusätzlicher Energiebedarf für die Produktion der besser wärmedämmenden Baustoffe bzw. des Isolationsmaterials gegenüber. In Tabelle 4 sind die spezifischen Primärenergiebedarfswerte für die benötigten Baustoffe aufgeführt.

Mit den Werten dieser Tabelle läßt sich für das zugrunde gelegte Standardhaus ein zusätzlicher Primärenergiebedarf für die Wärmedämmaßnahmen von 6129 kWh errechnen. Dabei wurde davon ausgegangen, daß die isolierverglasten Fenster in Holzrahmen montiert sind. Bei Verwendung moderner Kunststoff- bzw. Aluminiumrahmen erhöht sich der Energiebedarf entsprechend. Die mögliche Primärenergieersparnis durch verbesserte Wärmedämmung stellt sich wie folgt dar:

Reduktion des Raumwärmebedarfs 22000 kWh/a

- mit $\eta_{Heizung} = 0{,}60$ und
  $\eta_{Raffinerie} = 0{,}9$ ergibt sich daraus ein

Primärenergieäquivalent	40741 kWh/a
abzüglich Mehrbedarf für die Baustoffe (auf 30 a Lebensdauer umgelegt) 6129 kWh/30a	204 kWh/a
Primärenergieersparnis	40537 kWh/a

Die Reduktion des Primärenergiebedarfs für die Bereitstellung der Heizwärme beträgt demnach rd. 47 %. Als energetische Amortisationszeit lassen sich 55 Tage errechnen.

4.2 Einsatz der Wärmepumpe

Um auch Altbauten mit bereits installierten Heizungssystemen für den Wärmepumpenmarkt zu erschließen, wird vielfach ein bivalentes Heizungssystem, be-

Bauart: Elektrisch angetriebene Kompressionswärmepumpe	
Typ (Wärmequelle):	1. Luft/Wasser
	2. Erdreich/Wasser
Betriebsart:	Alternativbetrieb
Umschalttemperatur:	3 C
Leistungszahl (Jahresmittelwert[1])	3
Leistung (thermisch)	8 kW
Leistung (elektrisch, einschließlich Hilfsantriebe)	2,7 kW
Mittlere Lebensdauer	20 a

[1] Unter Berücksichtigung der Pumpen für den Erdreichkollektor bzw. der Lüfterantriebe

Tab. 10: Charakteristische Daten der Wärmepumpe stehend aus einer Wärmepumpe und einem konventionellen Heizungskessel, die alternativ betrieben werden, vorgeschlagen. Ein solches System wird im folgenden betrachtet. Die charakteristischen Daten der Wärmepumpe sind in Tabelle 10 zusammengestellt.

Gegenüber der Ölzentralheizungsanlage müssen neben der Wärmepumpe selbst noch eine Reihe weiterer Bauteile installiert werden. Die dazu erforderlichen Primärenergieaufwendungen sind in Tabelle 11 zusammengefaßt.

	Erdreich/Wasser kWh	Luft/Wasser
Wärmepumpe	4100	6600
Zusatzinstallationen (Regelung, Rohrleitungen, Pumpen, Armaturen)	1163	1163
Erschließen der Wärmequelle	15210	667
abzüglich Gutschrift für Heizöltank	- 2512	- 2512
Mehraufwand	17961	5918

Tab. 11: Primärenergieaufwendungen für die Wärmepumpenanlage /11/

Es zeigt sich, daß die Verlegung des Wärmesammlers im Erdreich wegen der großen Erdbewegungen nicht nur kosten - sondern auch energieintensiv ist.

Die Wärmepumpe übernimmt an Tagen, deren Außentemperatur über 3 C beträgt, die Brauchwasserbereitung. Das sind ca. 73 % aller Tage. Ihr Beitrag an der Deckung des Raumwärmebedarfs beträgt ca. 62 % /12/. Aus diesen Angaben ergibt sich nun die Aufteilung des Nutzenergiebedarfs und daraus läßt sich wiederum der Endenergieverbrauch des Hauses mit Wärmepumpenanlage bestimmen. Die Ergebnisse enthält Tabelle 12.

	kWh/a
Wärmepumpe	18420
Ölheizung	10580
Nutzenergiebedarf	29000
Endenergiebedarf	
Heizöl (mittlerer Wirkungsgrad der Ölheizung η_H = 0,65)	16277
Elektrizität	6140

Tab. 12: Nutz- und Endenergiebedarf bei Einsatz der Wärmepumpe

Wird der Endenergiebedarf auf sein Primärenergieäquivalent umgerechnet, ergibt sich die Primärenergiebilanz in Tabelle 13.

Primärenergieäquivalent	Wärmequelle:Erdreich kWh/a	Wärmequelle: Luft kWh/a
Heizöl (Rohöl→Heizöl η_V=0,9)	18086	18086
Elektrizität (Primärenergie→Strom η=0,3)	20467	20467
zusätzliche Anlagenteile (umgelegt auf 20 a Lebensdauer)	898	296
	39451	38849

Tab. 13: Primärenergiebedarf für Bau und Betrieb der Heizungsanlage mit Wärmepumpe

Gegenüber dem Vergleichshaus lassen sich folgende Primärenergieeinsparungen erreichen:

- Wärmequelle Erdreich 14249 kWh/a, das sind 26,5 %
- Wärmequelle Luft 14851 kWh/a, das sind 27,7 % .

Die Heizölersparnis beträgt 3070 l und die energetischen Amortisationszeiten ergeben sich zu

- Wärmequelle Erdreich: 14 Monate
- Wärmequelle Luft: 5 Monate

Gemessen an der zugrunde gelegten Lebensdauer von 20 a sind diese Zeiten gering. Das bedeutet, die Energieökonomie der Wärmepumpe ist gewährleistet.

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