**A Technology
Assessment of
Solar Energy Systems**

**Land Use and Environmental Impacts
of Decentralized Solar Energy Use**

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A Technology Assessment of Solar Energy Systems

Land Use and Environmental Impacts of Decentralized Solar Energy Use

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FOREWORD

This study is part of the "Technology Assessment of Solar Energy Systems (TASE)" project supported by the U.S. Department of Energy, Technology Assessments Division/Office of Technology Impacts, Assistant Secretary for Environment. The objective of the TASE project is to provide policymakers an analysis of the potential health, environmental, and social/economic consequences of large-scale (national in scope) commercialization of solar technologies. This study is one of three concentrating on the potential community-level impacts of such commercialization. The results of these studies provide enrichment of the national-level TASE project by identifying for policymakers specific community-level issues that may arise as a result of federal policy. The three studies are:

1. Community-Level Environmental Impacts of Decentralized Solar Technologies
2. Community Impediments to Implementation of Solar Energy
3. Three Solar Urban Futures: Characterization of a Future Community under Three Energy Supply Scenarios.

Throughout the document scenarios and views of social/economic and institutional futures are presented. These should be viewed as illustrations for exploring impacts of policy implementation strategies, not as projections of a likely future.

Robert Blaunstein, Chief
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EXECUTIVE SUMMARY

The objective of this study is to examine the physical, spatial and land-use impacts of decentralized solar technologies applied at the community level by the year 2000. The results of the study are intended to provide a basis for evaluating the way in which a shift toward reliance on decentralized energy technologies may eventually alter community form. This project has been conducted in parallel with two related efforts: a study of end-state community design and an analysis of institutional impediments to widespread solar technology implementation. These community level studies will supply inputs into the Technology Assessment of Solar Energy (TASE) Program which is being conducted cooperatively by six of the Department of Energy national laboratories.

The project assumes that, in many physical respects, communities in the year 2000 will resemble parts of cities as they exist today and that the level and types of solar technologies identified by the "maximum solar" scenario of the Policy and Review Committee (DPR) will be used. For the purposes of this study, a land-use impact is related to competition for space and, more specifically, to insufficient collector area on-site to achieve a particular level of solar penetration.

Six land-use types representative of those found in most U.S. cities are analyzed according to solar penetration levels identified in the DPR "maximum solar" scenario for the year 2000. The scenario is translated into shares of end use demand in the residential, commercial and industrial sectors. These proportions become the scenario goals to be met by the use of decentralized solar energy systems. The percentage of total energy demand is assumed to be 36.5 percent, 18.8 percent and 22.6 percent in the residential, commercial and industrial sectors respectively (Table 1). The community level scenario stipulated that a certain percentage of the total demand be met by on-site solar collection, i.e. photovoltaic and thermal collectors, and by passive design. This on-site solar goal is 31.9 percent (residential), 16.8 percent (commercial) and 13.1 percent (industrial).

Table 1

COMMUNITY LEVEL SCENARIO GOALS:

Percent of End-Use Demand Met by Solar Technologies

Sector	All Solar Technologies	On-Site Solar Technologies
Residential	36.5%	31.9%
Commercial	18.8%	16.8%
Industrial	22.6%	13.1%

For this evaluation of land use and environmental impacts, the scenario has established proportional goals of five different on-site solar technologies in each of three sectors of the economy. These various contributions to the total on-site supply are listed in Table 2.

The land-use types evaluated in this study may be thought of as "energy sensitive land-use patterns". Patterns studied are:

Residential Sector

- single family detached dwellings
- multiple family dwellings
 - town houses
 - row houses
 - low rise apartments
 - high rise apartments

Commercial Sector

- strip commercial development
- warehousing
- central business district

Industrial Sector

- central city facilities

These land-use types vary with respect to end use demand and physical characteristics which influence on-site solar supply. Table 3 identifies the energy demand and density for the land-use types considered in the study.

Six different solar energy supply systems are examined, ranging from thermal collectors with current output and short-term storage (i.e. two to three days), to cogenerating photovoltaic arrays with long-term storage (i.e. between seasons). Each of these technologies has a theoretical potential to meet any given mix of end use demands based on its output of thermal and electrical energy. Characteristics of the technology that determine its potential are the storage capacity, quality of energy produced and system efficiency. These factors define the proportion of demand for each land-use type that can be met if the required amount of collector area is available. Table 4 lists the theoretical potential of the selected technology systems.

TABLE 2

SOLAR PENETRATION GOALS BY SOLAR ENERGY SOURCE
 (DPR Maximum Solar" Scenario for 2000)

	Percent of Sector End Use		
	<u>Residential</u>	<u>Commercial</u>	<u>Industrial</u>
Passive Design	6.15	2.15	0
Active thermal collectors	23.05	10.74	12.42
Photovoltaics/thermal electric	2.65	3.87	0.65
Biomass (wood or MSW)	3.52	0.45	9.23
Wind	1.15	1.61	0.26
<hr/>			
TOTAL SCENARIO GOAL	36.52	18.82	22.56
<hr/>			

Table 3

Land-Use and Energy-Use Characteristics of Study Areas

LAND USE TYPE	LAND USE DENSITY	ANNUAL END USE ENERGY DEMAND (BTU/FT ²)	ANNUAL END USE ENERGY DEMAND ³ PER GROSS ACRE
Residential: SFD Single Family Detached	8 units/ net acre	62,000	0.3×10^9 BTU
Residential: MFD Row House and High Rise Apartments	31 units/ net acre	62,000	7.9×10^9 BTU
Commercial: STRIP Strip Commercial Development	F.A.R. ² .23	110,000	1.3×10^9 BTU
Commercial: WH Warehousing	F.A.R. .46	53,300	1.1×10^9 BTU
Commercial: CBD Central Business District	F.A.R. 6.7	102,100 ³	10.0×10^9 BTU
Industrial:	In the industrial sector, central city facilities identified as adaptable to solar energy use by Battelle (1977) and ITC (1977) were selected for case study.		

Notes:

1. These land-use types occur in all large metropolitan areas and comprise most of the residential and commercial land area. The case study examples were drawn from three cities in the United States: Denver, Baltimore, and Minneapolis.
2. F.A.R.: floor area ration, the ratio of a building's floor area to the parcel area.
3. Assumes the same electrical energy demand as in a low rise commercial structure, thereby excluding energy use for elevators and other equipment specific to high rise structures.
4. Energy demand in this table is normalized to Baltimore to facilitate comparison among land-use types.

TABLE 4

POTENTIAL OF SIX TECHNOLOGY SYSTEMS
TO MEET ENERGY END USE DEMANDS

Technology	Short-term storage	Long-term storage
Thermal collectors with performance comparable to currently available	1. 70% heat 80% hot water 70% cooling ¹	4. 100% heat 100% hot water 100% cooling ¹
Thermal collectors with a 33 percent increase in efficiency and using planar reflectors to increase output 50 percent (50 percent reduction in collector area)	2. 70% heat 80% hot water 70% cooling ¹	5. 100% heat 100% hot water 100% cooling ¹
Cogenerating photovoltaics with 80 percent the output of current photovoltaics and 80 percent the output of current thermal collectors	3. 70% heat 80% hot water 100% cooling 100% power	6. 100% heat 100% hot water 100% cooling 100% power

NOTES:

1. Use of solar thermal air conditioning is assumed only for the commercial sector.

The method for analysis of land-use and environmental impacts begins with a determination of the maximum on-site collector area for each land-use type in the residential, commercial and industrial sectors. This determination includes an evaluation of passive (south wall) design potential and measurements of the available unshaded collector area from aerial photographs. The evaluation of solar potential of each individual parcel is augmented with an estimation of several alternative schemes for sharing collector area among parcels in the block, neighborhood, or district. The study area as a whole is analyzed to determine the physical impacts likely to occur when achieving the scenario goal and to identify community characteristics of the natural and built environment which affect the ability of the study area to rely on decentralized solar technologies. The study concludes with a comparison among land use types of the percentage of total on-site energy demand that can be provided by each on-site technology using the available collector area. Table 5 illustrates the on-site solar energy supply for each land use examined.

Technology 1 represents thermal collectors currently in use. The subsequent technologies (2 through 6) represent existing technologies which have not achieved widespread use at the present time, but which are likely to be economically feasible in the next 25 years. The performance of each technology is evaluated for the five non-industrial land use patterns and is presented vertically in the table. For each technology in each study area, on-site solar supply is compared with the total scenario goal and with the potential of the technology to meet that study area's total energy demand. Performance is recorded as a percentage of total energy demand.

The supply of solar energy from a particular technology that can be used on-site is limited by quality and availability of the energy produced and by the demand for that particular quality of energy within each land use sector. The proportion of various end use demands which can be provided by each technology is listed for each technology. Column B translates these end use energy supply potentials into a single percentage of the total energy demand for each land use.

Table 5

ON-SITE SOLAR ENERGY SUPPLY AS A PERCENTAGE OF TOTAL ENERGY DEMAND BY LAND USE TYPE AND TECHNOLOGY

Percentage of Total Energy Demand

				Collector Location				
				C.	D.	E.	F.	
				Roofs	On-Site Open Space	Total On-Site	Surplus or Deficit Relative to Scenario	
<u>Direct Solar Technology and its end use energy supply potential</u>								
1. Thermal Collectors w/existing output and short term storage (80% DHW; 70% space heat 70% cooling ³)	SFD	37	40	40 ¹	NN ²	40 ⁴	+ 3	
	MFD	37	44	26	7	33	- 4	
	Strip	18	43	32	11	43	+25	
	CBD	18	39	3.6	0.1	3.7	-15	
	WH	18	56	56	NN	56	+38	
2. Thermal Collectors w/improved output & short term storage (80% DHW; 70% space heat 70% cooling ³)	SFD	37	40	20 ⁵	20 ⁵	40 ⁵	+ 3	
	MFD	37	44	38	6	44	+ 7	
	Strip	18	43	43	NN	43	+25	
	CBD	18	39	7.2	0.2	7.4	-11	
	WH	18	56	56	NN	56	+38	
3. Cogenerating photovoltaics w/short term storage (80% DHW; 70% space heat; 100% lights & power 100% cooling ³)	SFD	37	85	40 ⁵	20	60 ⁵	+23	
	MFD	37	86	44	18	62	+25	
	Strip	18	86	35	51	86	+68	
	CBD	18	86	6.2	0.4	6.6	-11	
	WH	18	87	78	.9	87	+69	
4. Thermal Collectors w/existing output and long-term storage (100% DHW; 100% space heat)	SFD	37	55	55 ⁵	NN	55 ⁵	+18	
	MFD	37	66	31	15	46	+ 9	
	Strip	18	61	27	34	61	+43	
	CBD	18	56	3.3	0.3	3.6	-14	
	WH	18	79	65	14	79	+61	
5. Thermal Collectors w/improved output and long-term storage (100% DHW; 100% space heat 100% cooling ³)	SFD	37	55	55 ⁵	NN	55 ⁵	+18	
	MFD	37	66	61	5	66	+29	
	Strip	18	61	48	13	61	+43	
	CBD	18	56	6.7	0.4	7.1	-11	
	WH	18	79	79	NN	79	+61	
6. Cogenerating photovoltaics w/long-term storage (95-100% of total demand)	SFD	37	100	54 ⁵	26 ⁵	80 ⁵	+43	
	MFD	37	100	66	26	92	+55	
	Strip	18	100	57	43	100	+82	
	CBD	18	100	9.7	0.4	10.1	- 7.9	
	WH	18	100	93	7	100	+82	

1. Assumes removal of up to 35% of the tree canopy.
2. Not needed as collector area to meet technology's potential in the study area.
3. Active solar cooling is assumed to be feasible for commercial uses only.
4. Assumes removal of 15-20% of the tree canopy.
5. Assumes no removal of tree canopy.
6. 20% national goal includes provision of the following portion of land use sectors' total demand by decentralized solar technologies, i.e. direct solar, wind and biomass: residential 37%, commercial 18%, and industrial 23%.

Table 5 (continued)

	HEAT LOAD (Btu/ft ² / degree day) ⁴	Total end use energy demand in a 5200 heating degree day climate with 78° wet bulb and 94° dry bulb summer design conditions (°F) (Btu/ft ² /year) ⁴
Single Family Development (SFD) 8 Units/Net Acre	6.0	97,100
Multiple Family Development (MFD) 30 Units/Net Acre	5.5	65,400
Strip Commercial Development (Strip) ² Floor Area Ratio ¹ of 2.3	10.5	110,000
Central Business District (CBD) ³ Floor Area Ratio ¹ of 6.7	10.5	102,100
Warehousing District (WH) Floor Area Ratio ¹ of 4.6	5.0	53,300

1. Floor Area Ratio is the ratio of floor area to parcel area
2. Consists of 75% offices, 15% hotels, 10% retail stores
3. This value reflects a low estimate because it excludes elevators and assumes the same demand as in low-rise structures
4. Analysis assumes that retrofit conservation measures have reduced demand to the following levels

The major conclusions of the study are arranged in three sections to parallel the topical headings of the main body of the report. These sections are first, solar energy supply, second, environmental characteristics that limit solar supply, and third, the land use and environmental impacts that can be expected if on-site solar technologies are installed to achieve the DPR scenario goals. The conclusions are:

Supply Conclusions

1. Assuming a typical land-use mix of the land-use types studied, a community can achieve the DPR "maximum solar" goals for the year 2000 using on-site technologies with current performance.
2. In the commercial sector, only the central business district cannot achieve the scenario goal on-site. The deficit in the central business district, however, can be more than offset by the ability of other land-use types to achieve a greater level of solar development.
3. In the residential sector, low density detached single-family development (i.e. urban sprawl) is not required in order to meet the solar scenario since even moderately high density low rise development has sufficient available collector area on-site.
4. Detached single-family development can achieve greater independence from conventional energy sources than denser residential patterns only by using cogenerating photovoltaic systems with long-term storage. With all other technologies examined, a higher percentage of total end use demand can be met in denser patterns.
5. Central-city industrial locations would require use of other renewable sources (e.g. cogeneration, wood or municipal residues) in addition to direct solar technologies to meet the solar scenario.
6. Decentralized solar technologies can produce substantially greater amounts of on-site energy supply than the DPR scenario projects. The increased levels are limited by the quality and availability of energy supply by a given technology and by the

demand for that particular quality of energy within each land-use sector.

7. Communities will be required to take one or more of the following actions in order to produce levels of on-site solar energy beyond the DPR scenario goals:
 - select technologies which maximize output of both thermal and electrical energy including use of long-term storage and generating systems;
 - implement shared energy systems in which a number of individual energy collectors are combined with a single storage facility;
 - transfer surplus thermal and electrical energy to land-use types deficient in on-site solar potential; and
 - control land development patterns through land-use regulations to eliminate environmental characteristics that constrain on-site collection.

Limiting Characteristics

8. Environmental characteristics of a community which reduce the opportunities for on-site solar energy use include:
 - vegetation shading of potential collector locations;
 - street orientation or lot configurations that limit southern exposure and therefore reduce the opportunities for passive design;
 - density of development which limits the availability of on-site collector area;
 - roof configurations that limit the installation of south-facing collectors; and
 - variation in the heights of buildings within an area sufficient to shadow adjacent rooftops at critical solar collection periods.
9. The use of either shared energy supply systems or long-term storage can alleviate the limitations imposed by environmental characteristics within a community.

10. Environmental characteristics of the community limit on-site collectors primarily in the higher density land-use types (i.e. multiple family residential and central business district).

Impact Conclusions

11. Demand for water to meet thermal storage requirements although an impact with each technology is insignificant relative to total water consumption within the community.
12. Potentially significant secondary impacts may occur from the disposal of hazardous wastes associated with the working fluids.
13. Visual intrusion of solar collectors will be more significant in the central business district, central-city industrial locations, and high density residential areas than in low density commercial or residential types.
14. Meeting the scenario goal in the single-family dwelling case, using on-site thermal collectors, will require either the removal of 15-35 percent of the tree canopy or the implementation of long term storage or shared systems.

In summary, the implementation of decentralized solar technology systems to meet the DPR "maximum solar" goals for the year 2000 will not produce significant physical impacts using even direct thermal technologies with current performance. All but the most dense development, i.e. central business district, high rise apartment and high density row houses, can achieve the solar scenario goal without a transfer of surplus energy from other land-use types. In addition, substantially greater amounts of on-site energy demand can be provided when communities implement certain land-use controls.

The results of this analysis illustrate that there are identifiable environmental characteristics that individually or collectively limit the community's ability to meet end use demand. In cases where these characteristics limit on-site collection, their influence decreases when a large number of individual installations are combined into a district system. Implementation of district systems, however, will introduce a new set of considerations involving the integration of future energy planning goals into the broader social and institutional setting.

1. INTRODUCTION

The purpose of this study is to examine the physical impacts of decentralized solar technologies applied within communities. Only those impacts which occur within the community itself are considered. These potential impacts are evaluated for the level of "solar penetration" identified by the Domestic Policy and Review (DPR) "technical limit" scenario for the year 2000. This project has been conducted in parallel with two related efforts: a study of end-state community design and an analysis of institutional impediments to widespread solar technology implementation. These community level studies will supply inputs into the Technology Assessment of Solar Energy (TASE) Program which is being conducted cooperatively by six of the Department of Energy national laboratories.

Analytic Approach

Impacts were assessed by, first, quantifying the extent to which environmental characteristics of existing land use patterns and building forms limit solar energy use in order to, second, evaluate the way in which those environmental characteristics will be impacted by its use. This approach, which is applied in a series of case studies, provides a basis for evaluating the way in which a shift toward reliance on decentralized energy technologies will impact the physical form of communities and how that form may be manipulated to avoid impacts. Are some land use patterns better suited to on-site energy production than others? Will some land-use patterns have to be altered to accommodate on-site solar energy production?

The most significant physical impacts which occur within communities from the use of decentralized solar technologies are land-use impacts, i.e. they derive from the spatial requirements of the technologies. All solar technologies have such spatial or land-use requirements: to convert solar energy directly into thermal or electrical energy, structures or other land area must be fitted with collectors; to produce electricity from wind, land must be used as a buffer against wind flow disruption and accidents;

to convert biomass into a usable energy source, land area is needed for the conversion facility and in some cases for biomass production.

Because decentralized solar energy use requires land area in close proximity to the site of energy end use, the potential for solar energy use within a community is influenced by that community's land-use patterns. These patterns are defined by building form, uses, and density.

The ability of a land use pattern to meet a particular solar penetration goal may be limited by: 1.) characteristics of energy supply provided by the solar technology, relative to the characteristics of the end use demands, and/or 2.) the availability of collector area. The proportion of the total energy demand that can be provided by a particular solar technology depends on the quality and availability of the energy produced and the quality and pattern of the energy demand over time. For example, thermal collectors with short-term storage can provide 56 percent of a warehouse's on-site energy demand and only 39 percent of a high rise commercial structure's demand since a larger portion of the warehouse's total energy demand is thermal.

A shortage of collector area may be the result of insufficient surface area. Or, there may be sufficient area but it may be shaded by vegetation or structures or it may be oriented away from south. These constraints on on-site solar supply are the result of specific characteristics of the natural and built environments: vegetation patterns, density of the development, spacing and heights of structures, street patterns, and/or architectural style and form of structures.

If there is not enough collector area on-site to meet a solar penetration goal, land-use and/or energy use patterns would have to be altered in order to meet that goal. Either the physical constraints on collector area would have to be eliminated or energy demand would have to be reduced or redistributed over time to produce a pattern of energy use that could be provided by the available on-site collector area. The first, and in some cases, the second action will require changes in the form of physical development.

On-site solar energy production is only one of many ways to reduce the consumption of non-renewable resources. Conservation measures and increased land-use densities may save as much or more on-site and transportation energy than solar collection. For the purpose of comparing energy use among various land patterns, then, it is not the level of solar energy penetration

but the remaining consumption of nonrenewable fuels that must be considered.

However, this project is limited by the scenario-defined technology mix and by its specific purpose. Variables, alternatives and influences that are equally important to land-use related energy planning in a community have been ignored. Three primary considerations that have not been incorporated into the study are the potential for passive design and cogeneration to reduce community energy demands and the role of transportation-related energy consumption. Points at which cogeneration and passive design could be used are identified in the case studies. The study as a whole attempts to provide a basis for evaluating the relationship between on-site energy savings and transportation energy savings by linking the analysis of potential impacts to the density of land use patterns.

Land Use Patterns Evaluated

Because the physical impacts of on-site solar energy production vary among land use patterns, this impact analysis is conducted for six land use patterns representative of most land use in U.S. cities and suburbs. The land use types evaluated in this study may be thought of as "energy sensitive land-use patterns". Patterns studied are single family detached dwellings and multiple-family townhouses, row houses and low rise and high rise apartments in the residential sector; strip commercial development, warehousing and central business district in the commercial sector; and central-city facilities in the industrial sector.

Land uses were categorized according to those variables expected to influence the on-site solar energy supply and the energy demand. Solar supply is determined primarily by the availability of collector area, and, therefore, can be correlated with the intensity, i.e. on-site density, of land use. Demand is determined by the quantity and quality of energy requirements. These vary among land use sectors and are influenced by land use density.

Most urban and suburban development in the U.S. is composed of land use patterns similar to these six land use types. Industrial land use is not as well represented in this study as the other two sectors because industrial sites are most variable both in land use and energy use patterns and because no suburban sites were analyzed. However, some conclusions can be drawn on the basis of studies which have compared land area available on suburban industrial sites to that available on central city sites (Boykin, 1973).

Physical characteristics of these land use types remain much the same regardless of geographic location. Consequently, although energy demand and solar energy supply vary in absolute value geographically as climate and latitude change, the relative differences in that demand and supply among land use patterns will remain more consistent. Similarly, although the mix is expected to change in the next 25 years, i.e. an increase in density and multiple family residential units, the characteristics of the patterns themselves are less likely to change significantly.

Obviously land use patterns could change if there were a compelling reason, e.g. economic or regulatory. For example, new development between 1980 and 2000 could be modified to minimize impacts of solar energy use, especially of passive design (see Living Systems, 1976 and 1979; McClenon, 1977; Harwood, 1977). One of the purposes of the project is to identify which characteristics of physical development need to be manipulated in various land use patterns during the next 20 years to increase on-site solar reliance. Consequently, this analysis will identify more impacts than are likely to occur if environmental constraints on solar energy use are taken into consideration in land use planning and design in the next 20 years.

Case Study Examples Selected

The specific case studies used are intended to represent densities and building forms most typical of each land use pattern. The land and energy-use characteristics of the six case study areas are summarized in Table 1.

To be most informative, an analysis of this type should evaluate a series of morphologically different cities within a range of climatic conditions. Evaluation was limited to those cities with available land use and energy use data and with climates representative of average U.S. conditions. The residential and commercial case studies were selected from Baltimore and Denver. Baltimore is considered to be representative of the national average, weighted by population (Hittman, 1974), with peak energy demands in the summer. Denver is an example of the growing sunbelt cities which are assumed to be best suited for solar energy use; it has a relatively high heating demand and winter peak demand. Baltimore is an older metropolitan region with a high density core surrounded by low-density suburbs. Denver is a newer, more uniformly medium-to-low density metropolitan area. Both are mid latitude cities (40° North latitude).

Table 1 Land-Use and Energy-Use Characteristics of Study Areas

LAND USE TYPE	LAND USE DENSITY	ANNUAL END USE ENERGY DEMAND (BTU/FT ²)	ANNUAL END USE ENERGY DEMAND ³ PER GROSS ACRE
Residential: SFD Single Family Detached	8 units/ net acre	62,000	0.3×10^9 BTU
Residential: MFD Row House and High Rise Apartments	31 units/ net acre	62,000	7.9×10^9 BTU
Commercial: STRIP Strip Commercial Development	F.A.R. ² .23	110,000	1.3×10^9 BTU
Commercial: WH Warehousing	F.A.R. .46	53,300	1.1×10^9 BTU
Commercial: CBD Central Business District	F.A.R. 6.7	102,100 ³	10.0×10^9 BTU

Industrial: In the industrial sector, central city facilities identified as adaptable to solar energy use by Battelle (1977) and ITC (1977) were selected for case study.

Notes:

1. These land-use types occur in all large metropolitan areas and comprise most of the residential and commercial land area. The case study examples were drawn from three cities in the United States: Denver, Baltimore, and Minneapolis.
2. F.A.R.: floor area ration, the ratio of a building's floor area to the parcel area.
3. Assumes the same electrical energy demand as in a low rise commercial structure, thereby excluding energy use for elevators and other equipment specific to high rise structures.
4. Energy demand in this table is normalized to Baltimore to facilitate comparison among land-use types.

The industrial case studies are located in Minneapolis at 45° North latitude. Although Minneapolis experiences more extreme climatic conditions than the national average, insolation rates are comparable to those in Baltimore (ITC, 1977). Therefore, the potential for solar energy use in industrial applications remains comparable.

Energy Supply and Demand Characteristics

The level of solar penetration established by the Domestic Policy Review 95 - quad technical limit scenario for the year 2000 was used to evaluate impacts. This energy supply scenario identifies a national solar penetration goal for each primary energy use sector, i.e., transportation, industrial, and a combined residential/commercial sector.

The national goal, expressed in equivalent units of fossil fuel, was converted into end use energy consumption values assuming a primary-to-end use energy conversion efficiency of 31 percent for electricity, 70 percent for gas as a direct fuel and 60 percent for oil as a direct fuel. It was assumed that the residential sector uses 60% and the commercial 40% of the two sector total. These values represent the solar share of end use energy consumption to be met in each community in all land-use types within each energy-use sector. Table 2 expresses solar supply goals of the DPR scenario as percentages of end use energy.

In some land uses, meeting the DPR scenario goal produced no land use impacts, even with currently available technologies. In order to evaluate the relationship between decentralized energy use and impacts more thoroughly, constraints and impacts were also evaluated for an additional, higher solar supply goal: the maximum proportion of each study area's energy demand that could be provided by each direct solar technology assuming that collector area is not limited. This is referred to as the technology's potential. Comparison of the solar supply achievable in each study area with the technology's potential makes it possible to identify all situations in which environmental characteristics limit on-site solar supply.

Technologies Evaluated

The technology mix identified in the DPR scenario emphasizes direct on-site solar technologies. Direct solar technologies are expected to provide 75 percent of the total penetration, with biomass providing 18 percent,

Table 2

SOLAR PENETRATION GOALS BY SOLAR ENERGY SOURCE
(DPR Maximum Solar" Scenario for 2000)

	Percent of Sector End Use		
	<u>Residential</u>	<u>Commercial</u>	<u>Industrial</u>
Passive Design	6.15	2.15	Ø
Active thermal collectors	23.05	10.74	12.42
Photovoltaics/thermal electric	2.65	3.87	0.65
Biomass (wood or MSW)	3.52	0.45	9.23
Wind	1.15	1.61	0.26
<hr/>			
TOTAL SCENARIO GOAL	36.52	18.82	22.56
<hr/>			

largely in the industrial sector, and wind providing 7 percent. Because of this proportional mix, this study will focus on the impacts of direct active solar technologies.

Direct Solar Technologies for Residential and Commercial Applications

In this study the physical requirements and especially the land-area requirements of the decentralized technologies are of primary importance. It is necessary to calculate the collector area available on each site to determine whether the scenario goal can be achieved. It is equally important to identify the technologies' performance. However, solar technologies, especially direct solar technologies, are changing rapidly. Performance of thermal collectors and supply systems is expected to improve substantially in the next 20 years. In addition, photovoltaics are expected to become economically feasible, making it possible to produce electrical as well as thermal energy on-site. On-site solar energy supply could be further increased by the use of long-term storage of thermal energy collected during the non-heating season. Since shadows are considerably less severe in the fall than in the winter banks of collectors could be placed closer together and surface areas shaded by vegetation or structures during the winter could be used as collector area, thereby increasing the amount of available collector area on a site.

In order to evaluate the influence of these technological advances on solar potential and community impacts, six direct solar technologies are evaluated. These six represent a likely sequence of implementation during the next 20 to 50 years. Initially, thermal collectors with a short term thermal storage tank might be installed on individual sites, e.g., on roof tops, and over parking lots to provide heat and hot water. As the cost of direct solar conversion technologies drops relative to the cost of alternative fuels, solar systems located within a geographic area, e.g., a block, neighborhood, or commercial center, may be integrated with a single storage facility to increase the area's solar reliance. Increased reliance could occur as a result of the increased feasibility of long-term storage due to reduced heat losses from the single large storage volume and from the ability of individual sites to share energy, i.e., a collector deficit on one site could be supplemented with a surplus from another site within the same system.

Eventually, if photovoltaics become economically viable and the first-generation thermal collectors "wear out", photovoltaics with the ability to collect their own waste heat, i.e., to cogenerate, may be installed. If this occurs prior to the installation of shared storage, they may simply provide energy for a single site using short-term heat storage. If photovoltaics are installed after shared thermal storage has been implemented, the photovoltaic array could replace the thermal collectors and utilize the same heat storage and distribution system.

The potential of six direct solar energy supply systems is evaluated in each residential and commercial case study. The systems vary with respect to collector characteristics, storage capacity, the number of structures served by the system, and maximum reliance possible.

System 1 consists of thermal collectors with efficiencies comparable to those currently in use which utilize short-term storage. In order to determine solar energy production using short-term storage it is then assumed that in any month the storage capacity is sufficient to allow for use of all heat collected during that month (ITC, 1976). This is assumed to approximate the performance of typical short-term systems with 1.5 to 2 gallons of water storage per square foot of collector area.

System 2 consists of thermal collectors with improved efficiency and short-term storage. This assumes that system efficiencies could be increased by one-third with improvement of all system components and that, together with the use of planar reflectors, could double collector output.

System 3 consists of cogenerating photovoltaics which produce electricity at 80 percent the efficiency of current photovoltaics and heat at 80 percent of the output of current thermal collectors with short-term heat storage.

System 4 consists of thermal collectors with current efficiencies and long-term storage in a shared system. Long-term storage capacity will vary with the needs of each situation. A 20 percent heat loss from the storage system is assumed. Long-term storage is assumed to be possible when a number of structures share the same large storage volume. An additional 20 percent heat loss is assumed to occur during distribution.

System 5 consists of thermal collectors with improved efficiency and shared long-term storage.

System 6 consists of cogenerating photovoltaics with shared long-term heat storage.

Table 3 lists the percentage of various end use energy demands that can be provided by each system assuming unlimited collector area. When these percentages of end-use demand are applied to a particular land use

TABLE 3

POTENTIAL OF SIX TECHNOLOGY SYSTEMS
TO MEET ENERGY END USE DEMANDS

Technology	Short-term storage	Long-term storage
Thermal collectors with performance comparable to currently available	1. 70% heat 80% hot water 70% cooling ¹	4. 100% heat 100% hot water 100% cooling ¹
Thermal Collectors with a 33 percent increase in efficiency and using planar reflectors to increase output 50 percent (50 percent reduction in collector area)	2. 70% heat 80% hot water 70% cooling ¹	5. 100% heat 100% hot water 100% cooling ¹
Cogenerating photovoltaics with 80 percent the output of current photovoltaics and 80 percent the output of current thermal collectors	3. 70% heat 80% hot water 100% cooling 100% power	6. 100% heat 100% hot water 100% cooling 100% power

NOTES:

1. Use of solar thermal air conditioning is assumed only for the commercial sector.

2. METHODOLOGY

The methodology used in this study is summarized in a flow chart in Figure 1 and outlined below.

General Data Collection

The first set of activities undertaken is described as general data collection. This included placing the DPR scenario into a community-level context, characterizing the technologies to be evaluated, and categorizing land uses into representative patterns. These activities have been described in Chapter 1. Two other major steps were: 1) a literature review and identification of generic impacts expected to occur as a result of the use of decentralized solar technologies, and 2) the identification of environmental characteristics expected to influence and be impacted by solar energy use. Chapter 4 contains a matrix of generic impacts in which those that appeared in the case study analyses are identified; Appendix C contains a detailed discussion of the generic impacts. Appendix B provides a discussion of characteristics in the natural, built and social environments which may potentially constrain solar energy use.

Study Area Data Collection

Analysis of solar energy reliance constraints and impacts in each study area required the compilation of three types of data: land use, energy use and technology output.

Land use data was obtained from aerial photographs and the land use files of planning departments in the case study cities. The case study areas within each city were selected, with the assistance of planning personnel, as examples of typical land use densities and building forms within each land use pattern. Then, total surface area available on each site in the study area was measured. Next, the extent to which environmental constraints limited the usefulness of that area for solar collectors was evaluated; the collector area potential of each site was recorded. (See Appendix A for assumptions regarding the spatial requirements of solar collectors).

Simultaneously with collector area evaluation, the land use data was used to determine the quality and quantity of energy demand at each site.

Figure 1

pattern, the proportion of the total energy demand that can be provided is the technology's potential.

Appendix A describes the components, physical requirements and performance of direct solar technologies.

Direct Solar Technologies for Industrial Applications

Three solar thermal technologies are used for industrial applications: shallow ponds for low temperature applications (100°F and 125°F); flat plate collectors for 150°F ; and polar mounted tracking cylinder collectors for temperatures above 150°F but less than 550°F .

Appendix A characterizes the physical appearance and performance of these technologies.

Wind Energy Conversion

It is assumed, for the sake of this analysis, that some Wind Energy Conversion Systems (WECSs) will be located within the community. In the high rise commercial and high density residential sectors, turbines could be placed within new structures. In the other land use sectors, and as an alternative in the above sectors, vertical or horizontal blade machines might be located on towers fixed to the ground. The systems evaluated are described in Appendix A.

Biomass Conversion

To evaluate the use of biomass, selected technologies are first matched to end uses. The use of wood burning stoves is assumed for residential applications at an efficiency of 60 percent (Sullivan, 1978). Municipal solid waste (MSW) is assumed to be the source of biomass for commercial applications. Because the pyrolysis process converts waste to low BTU gas which is storable and transportable and produces fewer residuals than other MSW conversion processes (LBL, 1978), it is assumed to be the process used in the case study applications. System inputs and outputs are listed in Appendix A. Net energy production is 0.31 BTU/pound of MSW assuming a primary fuel to electricity conversion efficiency of 31 percent (LBL, 1978.)

To estimate energy requirements of building types, a review of recent studies on energy demand of building types was conducted, focusing on those that relied on heating and cooling loads calculations or energy consumption records of representative building forms. (A.D. Little, 1977; ITC, 1976; Hittman Associates, 1972, 1974; Westinghouse, 1974; and General Electric, 1974).

These studies report a wide range of findings about heating and cooling loads of building types. This variation reflects differences in analytic methods and assumptions as well as actual differences among individual buildings of the same form. Construction specifications, quality of construction, energy use practices, building uses, microclimatic variations and other variables specific to a particular building influence its heating and cooling load. Furthermore, classification of building types into a manageable number of categories requires combining buildings with quite different energy use patterns.

Two primary sources were used to compute on-site energy demand. A study for the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) provided the most complete data for the purposes of this analysis (A.D. Little, 1976). It provided values for total energy consumption rather than for just heating and cooling demands and identified energy savings that would result from modest conservation measures. These values were used in the commercial sector. A series of studies on space heating and cooling energy demand and conservation potential in the residential sectors of Denver and Baltimore (Hittman, 1972, 1974), provided a useful description of the residential sector.

In the third segment of the study area analysis, the energy supply per square foot of collector area was calculated for each technology in each study area's climate. ITC (1976) provided a convenient method for determining solar reliance for space heating, domestic hot water and cooling using short-term storage. Solar supply with long term storage was calculated using ASHRAE monthly clear day insolation data and an established methodology for estimating monthly collectable energy (Anderson, 1976). Assumptions about collector efficiencies, system losses, and performance of wind and biomass technologies used to calculate solar supply are listed in Appendix A. Appendix D contains collector performance values for each study area.

In evaluating the proportion of total energy demand that can be met by solar technologies in the residential and commercial sectors, it is assumed that the conservation measures are initiated before solar energy technologies are installed. Conservation in the form of insulation, weatherizing and double glazing in existing structures, would occur as a more economical first step in reducing centralized energy consumption (Rosenfield, 1977).

Matching On-Site Technologies to End-Use Energy Requirements

The next step was to identify which technologies could be used in each land use to meet the scenario goal for each solar energy source. The six direct solar technology systems were applicable to and were therefore evaluated in every commercial and residential case. Direct solar technologies were matched according to the quality of process heat demands in the industrial cases. Biomass and wind energy conversion technologies were also applied selectively.

Analysis of On-Site Solar Potential, Constraints and Impacts

Next, the portion of a site's total energy demand which could be provided by each on-site technology was determined. This solar supply was then compared with the DPR scenario goal. Solar supply achieved in each study area compared to the total scenario goal is listed in Chapter 3. The application of the above procedure to the case studies is documented in Appendix D.

If any site was unable to meet the scenario goal, the responsible environmental constraints were identified; these are discussed in Chapter 4. When this analysis had been carried out for every site in the study area, the impacts resulting from achieving the scenario goal were evaluated. Chapter 5 contains an assessment of impacts in each study area.

Analysis of Shared Solar Potential, Constraints and Impacts

The next step involved determining the extent to which solar reliance could be increased within the study area by using shared direct solar systems with long-term thermal storage. Again, constraints and impacts were identified.

Analysis of Community-Wide Solar Potential, Constraints and Impacts

The final step in the analysis was to evaluate the potential of the community as a whole, composed of a typical mix of the land use patterns studied, to meet the scenario goal. The primary task was to determine whether an energy supply deficit in one study area could be offset by a surplus in other study areas. If this could be accomplished, impacts could be avoided.

3. DECENTRALIZED SOLAR ENERGY SUPPLY

Major Conclusions

1. Assuming a typical mix of the land-use types studied, a community can achieve the DPR "maximum solar" goal for the year 2000 using on-site technologies with current performance. Table 4 contains the percent of total energy demand for each land-use type that can be provided by the direct solar technologies.
2. In the commercial sector, only the central business district cannot achieve the scenario goal on-site. The deficit in the central business district, however, can be more than offset by the ability of other land-use types to produce more solar energy on-site.
3. In the residential sector, low density detached single-family development (i.e. urban sprawl) is not required in order to meet the solar scenario since even moderately high density low rise development has sufficient collector area on-site.
4. Detached single-family development can achieve greater independence from conventional energy sources than denser residential patterns only by using cogenerating photovoltaic systems with long-term storage. With all other technologies examined, a higher percentage of total end use demand can be met in denser patterns.
5. Central-city industrial locations would require use of other renewable sources (e.g. cogeneration, wood or municipal residues) in addition to direct solar technologies to meet the solar scenario.
6. Decentralized solar technologies can produce substantially greater amounts of on-site energy than the DPR scenario projects. The increased levels are limited by the quality and availability of energy supplied by a given technology and by the demand for that particular quality of energy within land-use sectors (see Table 4).
7. Communities will be required to take one or more of the following actions in order to produce levels of on-site solar energy beyond the DPR scenario goals:
 - select technologies which maximize output of both thermal and electrical energy, including use of long-term storage and cogenerating systems;
 - implement shared energy systems in which a number of individual energy collectors are combined with a single storage facility;
 - transfer surplus thermal and electrical energy to land-use types deficient in on-site solar potential; and
 - control land development patterns through land-use regulations to eliminate environmental characteristics that constrain on-site collection.

Table 4 lists the six direct solar technologies which were evaluated. Technology 1 represents thermal collectors currently in use. The subsequent technologies (2 through 6) represent existing technologies which have not achieved widespread use at the present time but which are likely to be economically feasible in the next 25 years. The performance of each technology is evaluated for the five non-industrial land use patterns and is presented vertically in the table. For each technology in each study area, on-site solar supply is compared with the total scenario goal and with the potential of the technology to meet that study area's total energy demand. Performance is recorded as a percentage of total energy demand.

The supply of solar energy from a particular technology that can be used on-site is limited by quality and availability of the energy produced and by the demand for that particular quality of energy within each land use sector. The proportion of various end use demands which can be provided by each technology is listed for each technology. Column B translates these end use energy supply potentials into a single percentage of the total energy demand for each land use. This value is important for two reasons.

First, a comparison of the scenario goal with the technology potential (column A with column B) indicates whether the scenario goal is matched with the maximum potential of the technology or whether a much greater solar supply could be achieved in a particular land use pattern. For currently available thermal collectors (Technology 1), the scenario goal is very close to the technology's potential in the residential sector. This means that solar technologies or passive design which can provide 80 percent of the domestic hot water and 70 percent of the space heat of a residential unit would be required in almost every residence in order to meet the scenario goal. In the commercial sector, on the other hand, the scenario goal calls for less than half the solar supply which is technically feasible using Technology 1 assuming the use of solar air conditioning. If half of the commercial facilities operating in the year 2000 used thermal collectors to provide hot water and 70 percent of the space heating and cooling loads, the scenario could be met.

In no case does the scenario goal exceed the technology's potential. Therefore, if the scenario goal cannot be met by a technology, it is due to the fact that there is insufficient collector area on-site. Column F

Table 4

ON-SITE SOLAR ENERGY SUPPLY AS A PERCENTAGE OF TOTAL ENERGY DEMAND BY LAND USE TYPE AND TECHNOLOGY

Percentage of Total Energy Demand

				Collector Location			F. Surplus or Deficit Relative to Scenario
	A. Solar Scenario Goal	B. Technology Potential		C. Roofs	D. On-Site Open Space	E. Total On-Site	
<u>Direct Solar Technology and its end use energy supply potential</u>							
1. Thermal Collectors w/existing output and short term storage (80% DHW; 70% space heat 70% cooling ³)	SFD MFD Strip CBD WH	37 37 18 18 18	40 44 43 39 56	40 ¹ 26 32 3.6 56	NN ² 7 11 0.1 NN	40 ⁴ 33 43 3.7 56	+ 3 - 4 +25 -15 +38
2. Thermal Collectors w/improved output & short term storage (80% DHW; 70% space heat 70% cooling ³)	SFD MFD Strip CBD WH	37 37 18 18 18	40 44 43 39 56	20 ⁵ 38 43 7.2 56	20 ⁵ 6 NN 0.2 NN	40 ⁵ 44 43 7.4 56	+ 3 + 7 +25 -11 +38
3. Cogenerating photovoltaics w/short term storage (80% DHW; 70% space heat; 100% lights & power 100% cooling ³)	SFD MFD Strip CBD WH	37 37 18 18 18	85 86 86 86 87	40 ⁵ 44 35 6.2 78	20 18 51 0.4 9	60 ⁵ 62 86 6.6 87	+23 +25 +68 -11 +69
4. Thermal Collectors w/existing output and long-term storage (100% DHW; 100% space heat)	SFD MFD Strip CBD WH	37 37 18 18 18	55 66 61 56 79	55 ⁵ 31 27 3.3 65	NN 15 34 0.3 14	55 ⁵ 46 61 3.6 79	+18 + 9 +43 -14 +61
5. Thermal Collectors w/improved output and long-term storage (100% DHW; 100% space heat 100% cooling ³)	SFD MFD Strip CBD WH	37 37 18 18 18	55 66 61 56 79	55 ⁵ 61 48 6.7 79	NN 5 13 0.4 NN	55 ⁵ 66 61 7.1 79	+18 +29 +43 -11 +61
6. Cogenerating photovoltaics w/long-term storage (95-100% of total demand)	SFD MFD Strip CBD WH	37 37 18 18 18	100 100 100 100 100	54 ⁵ 66 57 9.7 93	26 ⁵ 26 43 0.4 7	80 ⁵ 92 100 10.1 100	+43 +55 +82 -7.9 +82

1. Assumes removal of up to 35% of the tree canopy.
2. Not needed as collector area to meet technology's potential in the study area.
3. Active solar cooling is assumed to be feasible for commercial uses only.
4. Assumes removal of 15-20% of the tree canopy.
5. Assumes no removal of tree canopy.
6. 20% national goal includes provision of the following portion of land use sectors' total demand by decentralized solar technologies, i.e. direct solar, wind and biomass: residential 37%, commercial 18%, and industrial 23%.

Table 4 (continued)

	<u>HEAT LOAD</u> (Btu/ft ² / degree day) ⁴	Total end use energy demand in a 5200 heating degree day climate with 78 ^o wet bulb and 94 ^o dry bulb summer design conditions (^o F) <u>(Btu/ft²/year)⁴</u>
Single Family Development (SFD) 8 Units/Net Acre	6.0	97,100
Multiple Family Development (MFD) 30 Units/Net Acre	5.5	65,400
Strip Commercial Development (Strip) ² Floor Area Ratio ¹ of 2.3	10.5	110,000
Central Business District (CBD) ³ Floor Area Ratio ¹ of 6.7	10.5	102,100
Warehousing District (WH) Floor Area Ratio ¹ of 4.6	5.0	53,300

1. Floor Area Ratio is the ratio of floor area to parcel area
2. Consists of 75% offices, 15% hotels, 10% retail stores
3. This value reflects a low estimate because it excludes elevators and assumes the same demand as in low-rise structures
4. Analysis assumes that retrofit conservation measures have reduced demand to the following levels

indicates whether or not the scenario goal can be met and whether it can be exceeded by each technology. If the scenario goal cannot be met, the physical form of the development would have to be altered in order to provide sufficient collector area or the energy demand would have to be reduced. Reducing energy demand may also require a change in the form of land-use patterns. Unless energy demand can be reduced without altering the form of development, land use impacts will be incurred. Using Technology 1, both the multiple family dwelling study area and the central business district study area fail to meet the scenario goal. Consequently, in those study areas, land use impacts will occur unless energy demand is reduced or a more efficient technology is used to increase the solar energy supply without increasing collector area.

Secondly, a comparison of total on-site energy supply (column E) with the technology potential (column B) indicates whether or not land use impacts will be necessitated in order to use a technology to the greatest extent possible. If total on-site energy supply falls short of the technology's potential, collector area is limited by environmental characteristics. In order to use the technology to the greatest extent possible:

- 1) collector area would again have to be increased by altering physical characteristics of the site, or
- 2) energy demand would have to be reduced, or
- 3) a more efficient technology would have to be used.

Figures 2 - 7 graphically express the on-site solar supply achievable in each study area for each direct solar technology compared to both the DPR scenario goal and the technology's potential to meet the study area's energy demand. They also indicate the portion of total collector area available on roof tops and on-site open space which would have to be used to meet the scenario goal and to meet the technology's potential in each study area for each direct solar technology.

Meeting the DPR Scenario Goal

The major findings of this analysis of the use of solar technologies currently in use (Technology 1) to meet the scenario goal are as follows:

- A community as a whole, comprised of a typical mix of land use types (Manvel, 1968), can meet the total scenario goal on site, relying entirely on currently available flat plate or evacuated tube collectors. Within the community, however, the higher density land use patterns cannot meet the scenario goal on site. The multiple family residential case falls short of the scenario

ENERGY PRODUCTION IN STUDY AREA WITHOUT TREE IMPACTS:
SINGLE FAMILY RESIDENTIAL STUDY AREA.

Figure 2

goal by 4 percent of its total demand. The central business district falls short of the scenario goal by 15 percent of its total demand (see Table 4, column F). However, the strip commercial and warehousing study areas can greatly exceed the scenario goal on site. Because they always comprise a much greater proportion of the land area of a community than the central business district, their on-site solar supplies can more than offset the central business district's deficit. Similarly, the multiple family case study's deficit can be offset by the single family case study's surplus.

- Particularly in new developments, passive solar design combined with passive or active domestic hot water heating can save as much energy as currently available thermal collectors (Balcomb, 1976). Therefore, the scenario goal can be met by passive design in new development projects and in some existing buildings. However, significantly more changes in the physical form of development would be required to accommodate widespread use of passive design.
- In the residential sector, a shift in density and building form from predominantly single family detached to low-rise multiple family dwellings would save more on-site energy than the use of currently available thermal collectors (see Appendix D). Furthermore, the multiple family dwelling case study fell just short of meeting the scenario goal. Therefore, in a typical community which consists primarily of low density single family detached development, increased density in the form of low-rise multiple units or attached townhouses, together with the use of solar technologies or passive design, can save substantially more energy than the use of solar energy alone.
- In the industrial sector direct solar technologies can meet the scenario goal in three of the six central city cases examined on the site itself and in all six cases if adjacent undeveloped land is utilized. Suburban industrial sites contain about 2.5 times as much land area as central city sites. Therefore, it appears that the total industrial sector could meet the scenario goal on-site in more than half the cases.
- In central city industrial locations, other renewable energy sources, e.g. cogeneration and agricultural or forestry residues, would be required to meet the scenario goal on-site.
- In the community as a whole, indirect solar technologies, i.e. wind and biomass, can be used selectively to minimize impacts since direct solar technologies alone can provide the total scenario goal. For example, electricity generated by wind machines located near the community may be sent to the central business district, avoiding the need to alter that land use pattern and minimizing potential impacts of wind machines located within the community.

TECHNOLOGY	Thermal Collectors Existing Output	Thermal Collectors Improved Output	Cogenerating Photovoltaics	Thermal Collectors Existing Output	Thermal Collectors Improved Output	Cogenerating Photovoltaics
PERCENT OF TOTAL ENERGY DEMAND THAT CAN BE MET	44%	44%	82%	66%	66%	100%
PERCENT OF END USES THAT CAN BE MET	70% Heat 80% DHW	70% Heat 80% DHW	70% Heat 80% DHW 100% Cooling 100% Elec.	100% Heat 100% DHW	100% Heat 100% DHW	100% of total end use

KEY	
—	Total Usable Energy Produced On Site
- - -	Total Scenario Goal
■	Corresponding land area used as collector sites.

UNSHADED SITE AREA USED TO MEET SCENARIO GOAL:
MULTIPLE FAMILY RESIDENTIAL STUDY AREA.

Figure 3

UNSHADED SITE AREA USED TO MEET SCENARIO GOAL:
STRIP COMMERCIAL STUDY AREA.

Figure 4

TECHNOLOGY	Thermal Collectors	Thermal Collectors	Cogenerating Photovoltaics	Thermal Collectors	Thermal Collectors	Cogenerating Photovoltaics
	Existing Output	Improved Output		Existing Output	Improved Output	
PERCENT OF TOTAL ENERGY DEMAND THAT CAN BE MET	39%	39%	86%	56%	56%	100%
PERCENT OF END USES THAT CAN BE MET	70% Heat 80% DHW 70% Cooling	70% Heat 80% DHW 70% Cooling	70% Heat 80% DHW 100% Cooling 100% Elec.	100% Heat 100% DHW 100% Cooling	100% Heat 100% DHW 100% Cooling	100% of total end use

KEY	
	Total Usable Energy Produced On Site
	Total Scenario Goal
	Corresponding land area used as collector sites.

UNSHADED SITE AREA USED TO MEET SCENARIO GOAL:
CENTRAL BUSINESS DISTRICT STUDY AREA.

Figure 5

KEY

Total Usable Energy Produced On Site

Total Scenario Goal

Corresponding land area used as collector sites.

UNSHADED SITE AREA USED TO MEET SCENARIO GOAL:
WAREHOUSING DISTRICT STUDY AREA.

Figure 6

PERCENT OF ENERGY DEMAND PROVIDED BY DIRECT SOLAR TECHNOLOGIES AT CENTRAL CITY INDUSTRIAL SITES.

Figure 7

XBL 797 - 2154

Increasing Solar Energy Supply through Technology Selection

Land use and environmental impacts can be avoided to a certain extent by using technologies that increase the amount of thermal energy without increasing the collector area requirement, i.e., more efficient collectors and long-term storage. In addition, on-site solar supply can be increased by using technologies which produce electricity as well as heat, i.e. co-generating photovoltaics. A choice of technologies gives the community as a whole more flexibility in meeting the scenario goal and, therefore, will produce fewer impacts. For example, instead of using thermal collectors with short-term storage on all residences, passive design and photovoltaics or cogenerating photovoltaics could be used on all new construction to meet the scenario goal.

Column B in Table 4 indicates how the potential of the technology increases with each of the more sophisticated technologies. Column E indicates that proportion of total demand in each land use that can be provided by each technology. The following conclusions about the ability of various technologies to increase on-site solar energy supply can be made on the basis of the analysis summarized in Table 4.

- The scenario goal can be greatly exceeded in the lower density commercial land uses without using more advanced technologies, assuming that solar air conditioning is used.
- The scenario goal, which was not achieved in the multiple family dwelling study area using Technology 1, can be exceeded if any of the other technologies are used.
- To exceed the scenario goal to a significant degree in the residential sector, it is necessary to use cogenerating photovoltaics (Technology 3 or 6) or thermal collectors which are both more efficient and employ long-term storage (Technology 5).
- Long-term thermal storage enables all study areas except the central business district to provide 100 percent of the domestic hot water demand and 100 percent of the space heating demand. Solar air conditioning or the use of the thermal storage facility for chilled water storage during the summer would reduce the summer cooling demand, especially during peak load periods. Thus, long-term storage can mitigate the adverse impact on the electrical grid that widespread use of thermal collectors with short-term heat storage is expected to cause.
- Because the per-unit energy demand of the multiple family study area is smaller than that of the single family study area, use of all the solar technologies considered enables the multiple

family study area to use less fossil fuel-derived and/or centralized energy than the single family study area. An analysis of six hypothetical residential land use patterns based on the case study analyses indicates that detached single family houses at a density of 8 dwelling units per acre can reduce their remaining energy demand to less than that of high-rise apartments and row-houses at a density of 24 to 30 dwelling units per net acre only with the use of cogenerating photovoltaics and long term-storage or passive design plus photovoltaics. (See Appendix D).

- The central business district fails to meet the total scenario goal on site with all of the technologies evaluated. Thermal and electrical energy could be transported from the warehousing study area which has a substantial surplus of collector area.
- If cogenerating photovoltaics were available, all portions of the city, except high rise commercial and residential areas, i.e., the central business district, could meet more than 90 percent of their total energy demand on-site without altering existing land use patterns, building form or energy demand.

4. ENVIRONMENTAL CHARACTERISTICS AS LIMITS ON SOLAR SUPPLY

Major Conclusions

8. Environmental characteristics of a community which reduce the opportunities for on-site solar energy use include:
 - vegetation shading of potential collector locations;
 - street orientation or lot configurations that limit southern exposure and therefore reduce the opportunities for passive design;
 - density of development which limits the availability of on-site collector area;
 - roof configurations that limit the installation of south facing collectors;
 - variation in heights of buildings within an area sufficient to shadow adjacent roof tops at critical solar collection periods.
9. The use of either shared energy supply systems or long-term storage can alleviate the limitations imposed by environmental characteristics within a community.
10. Environmental characteristics of the community limit on-site collectors primarily in the higher density land-use types (i.e. multiple family residential and central business district).

The potential of direct solar systems to displace a site's energy demand is ultimately limited by the match between the characteristics of the demand and the characteristics of the supply: the quantity and quality of energy provided and the amount of energy that can be stored for use during sunless periods. As the previous discussion has shown, achieving the technologies' potential may be constrained by the area available for collector location. Whether land area is available and whether it is usable as a collector location is influenced by the characteristics of the particular environment in which the technologies are applied. The kinds of environmental characteristics that can reduce solar supply have been categorized into three types: natural, built, and social. In each category the specific characteristics are:

1. Natural

- latitude
- climate
- topography
- obstruction of solar access by vegetation

2. Built

- roof configuration: area and orientation
- obstruction of solar access by buildings: spacing of structures
- obstruction of solar access by buildings: variation in height and spacing
- street pattern: orientation relative to north
- street pattern: parcel configuration
- intensity of development: ratio of energy demand to unit floor area and of floor area to parcel area

3. Social

- community identity
- community interaction
- activity patterns

The potential solar energy supply which can be provided by each of the six technology systems in each of the land use types has been evaluated in the preceding chapters. This chapter looks to the performance of decentralized solar technologies to see which environmental characteristics actually constrained the level of solar supply achievable.

In Table 5 energy systems, defined by storage capacity and whether they are individual or shared systems, are evaluated within a series of broadening collector area domains. The domains range from a passive south wall of an individual structure to energy import zones outside the study area. This classification permits the assessment of the location and significance of limiting environmental characteristics. If an environmental characteristic, e.g. vegetation shading, contributed to a reduction in solar supply from the maximum possible for any one of the technologies in a particular collector area domain, e.g. roof tops, the effect is identified as a "limiting factor".

No attempt was made to rank the limiting factors. In some cases several environmental characteristics contribute to a reduction in supply potential; the relative importance of each one was not determined.

Natural Environmental Characteristics

- Climate and latitude are basic determinants of solar reliance, influencing energy demand, solar energy supply and the severity of shading as a constraint. In the case studies these variables were held relatively constant in order to focus on variations between land uses so their influence does not appear in the analysis.

TABLE 5
ENVIRONMENTAL CHARACTERISTICS AS LIMITING
FACTORS ON SOLAR SUPPLY¹

	Energy Supply System Characteristics*					
	Individual/ Short-Term Storage			Shared/ Long-Term Storage		
	Passive So. Wall	Roof	Roof ² Site	(Parcels) Block	Study Area	Beyond Study Area
Latitude						
Climate						
Topography						
Obstruction of solar access by vegetation	SFD Strip CBD	SFD	SFD			
Roof Configuration: area and orientation		SFD				
Obstruction of solar access by buildings: spacing of structures	SFD		MFD Strip			
Obstruction of solar access by buildings: variation in height and spacing	SFD MFD Strip CBD	MFD CBD	MFD CBD	CBD	CBD	
Street pattern: orientation relative to north	SFD WH CBD	CBD	CBD	CBD	CBD	
Street pattern: parcel configuration	SFD MFD					
Intensity of develop- ment: energy demand/ floor area/parcel area	SFD CBD	MFD CBD	MFD CBD	CBD	CBD	

SFD: Single Family Dwelling (detached)
MFD: Multiple Family Dwelling
Strip: Strip Commercial Development
WH: Warehousing
CBD: Central Business District

1. Environmental characteristic is a limiting factor when it reduces the solar technology below the theoretical potential.
 2. Site: Area on parcel not occupied by structures.
- * Blank space indicates that no land use type is limited.

- The urbanized areas examined in the case studies are relatively flat. Therefore, though topography is potentially important, it is not significant in the cases examined.
- However, obstruction of solar access by vegetation did appear as a significant environmental limit with individual systems using short-term storage. Tree shading reduced the solar potential of the single family dwelling case. The scenario goal could be met with technology 1 - currently available thermal collectors with short-term thermal storage - only if 35 percent of the existing tree canopy were removed. Vegetation shading was not a limiting factor in any land use type where long-term storage was assumed. Vegetation shading would limit the potential of passive design in three land use types: the single family dwellings, the strip commercial, and the central business district.

Built Environmental Characteristics

- Roof configuration was a limiting factor only in the single family dwelling case where collectors are mounted on roofs which slope in several directions. Roof configuration could potentially limit solar supply in other residential and commercial cases where flat roofs do not predominate, but such examples were not included in the case studies.
- The location of the building on the parcel (the setbacks from property limits) and the heights of the building influence the amount of shading potential on site collector locations. On-site open space may be shaded by the building located on that site or the building itself and the on-site open space may be shaded by another building. Shading as a result of height and siting of a single structure on a parcel limited the on-site solar supply only in the single family dwelling and multiple family dwelling cases. Changes in height or location on the parcel could increase the on-site solar supply in these two land use types.

Obstruction of solar access by adjacent buildings is a limiting environmental characteristic primarily in the high density land uses. This interaction among buildings was especially strong in the central business district where it was a limiting factor throughout the study area. In these dense land use patterns, controls on height and building set backs would have to be applied over the entire area in order to increase on-site solar supply substantially.

- The orientation of the street pattern was a limiting factor for every technology system in the central business district. In the CBD case, the street pattern is at 45 degrees from true north and the resulting roofs are less easily fitted with collectors. It reduced the on-site solar energy supply by about twenty percent. In other land use types, where street orientation did not deviate from the cardinal points, north-south street orientation limited the use of south walls from passive design applications. This was

particularly significant in the single family dwelling case study.

- The configuration of the lot, i.e., its dimensions or proportions, was only a limiting factor for passive design implementation in the residential land uses. In the multiple family dwelling case, the narrow lot width limited passive design opportunities significantly.
- The intensity of development results from a combination of energy intensity and net or on-site land use density, i.e., the ratio of energy demand to floor area and the ratio of floor area to parcel area. Intensity of development constitutes the ultimate limit on the on-site energy supply; either the energy demand must be reduced or site area increased to accommodate more collectors.

Social Environmental Characteristics

No specific measures were developed in this investigation to assess the social constraints on the implementation of decentralized solar technologies. Several of the energy supply systems analyzed, however, assume sharing of storage and collectors among users. Shared systems and energy importation from outside a study area both imply some institutional management. Some social interaction is required in these systems.

Shared systems are most likely to be used when long-term storage is employed. Therefore, social constraints are expected to occur with technologies requiring long-term storage. However, for all technologies in multiple family dwellings, social constraints are likely to arise since more than one family shares the same parcel of land and roof area and are likely to share the components of the solar energy systems.

Overcoming Environmental Limits

Environmental characteristics do limit the solar potential of decentralized technologies. The limits do not apply equally to each land use sector nor to each technology. Many of the characteristics identified in the analysis can be manipulated to increase solar supply. Results of such manipulation would be specific to both particular technologies and land use sectors. For example, active solar energy use is limited primarily by tree shading for single family dwellings. Passive design, on the other hand, must effectively deal with vegetation, street pattern (including orientation and lot configuration), development intensity, and height and setback limits.

In general, the effect of any one modification to the environment, natural, built, or social, will increase the solar supply only for specific land use sectors and for particular technologies. No change in environmental characteristics will yield the same result in every land use sector.

Consequently, controlling a specific environmental characteristic, e.g., changing setbacks from property lines, instituting height controls, or establishing the orientation of new streets and the proportions or new parcels, may not increase the potential for on-site solar energy production throughout the community. A community must either rank characteristics according to their significance in various land use patterns in order to control only the most important ones or control all those characteristics that can reduce potential supply in all land uses.

Environmental characteristics will limit the use of passive design techniques more significantly than they will limit the use of active solar technologies. When economics are taken into account, passive design is likely to be the most viable solar technology, particularly in the case of new development. However, passive design was deemphasized in this analysis. A complete assessment of land use impacts would require the application of this analysis of environmental constraints to the use of passive design techniques.

5. LAND USE AND ENVIRONMENTAL IMPACTS OF DECENTRALIZED SOLAR ENERGY USE

Major Conclusions

11. Demand for water to meet thermal storage requirements although an impact with each technology is insignificant relative to total water consumption within the community.
12. Potentially significant secondary impacts may occur from the disposal of hazardous wastes associated with the working fluids.
13. Visual intrusion of solar collectors will be more significant in the central business district, central-city industrial locations, and in high density residential areas than in low density commercial or residential types.
14. Meeting the scenario goal in the single-family dwelling case, using on-site thermal collectors, will require the removal of 15-35 percent of the tree canopy.

Having determined the potential for on-site solar energy production and identified environmental characteristics which limit that supply, it is now possible to identify impacts.

The impact analysis has been summarized in the form of an impact matrix, Figure 8. The matrix identifies those impacts which would result from using currently available solar technologies to meet the DPR scenario goal for each solar energy source, i.e., passive design, direct solar conversion to heat and electricity, and wind and biomass conversion. Direct solar conversion to heat assumes the use of short-term thermal storage and currently available system components, i.e., Technology 1 of the six evaluated. The matrix evaluates impacts (rows) by solar energy source and the number of structures served by the system, i.e. on-site, shared and centralized within the community (columns). Impacts are classified into eight categories based on those identified in an initial literature review and generic analysis of impacts:

1. Land use impacts
2. Water use
3. Ecological impacts, both terrestrial and aquatic
4. Safety
5. Impacts on the community service infrastructure
6. Visual impacts
7. Noise
8. Water and air pollution

This classification provided a framework for assessing impacts in the case study analyses. For a more detailed discussion of impacts, see Appendix C.

COMMUNITY LEVEL
IMPACTS MATRIX p.1

	PASSIVE	THERMAL			PHOTOVOLTAIC			WIND			BIOMASS		
		Onsite	Shared	Central	Onsite	Shared	Central	Onsite	Shared	Central	Onsite	Shared	Central
LAND USE PREEMPTION													
On Developed Site													
Roof Areas		■	■		■			■					
roof top gardens		■	■		■			■					
signs or billboards		■	■		■			■					
rooftop water collector		■	■		■			■					
Side Yards		■	■					■	■				
Back Yards		■	■					■	■				
Entry Yards		■	■					■	■				
Parking Lots		■	■					■	■				
Entire Parcels													
Parks			▲						▲				
vest pocket parks			▲						▲				
community gardens			▲						▲				
community parks			▲						▲			▲	▲
regional parks			▲	▲					▲	▲		▲	▲
state/federal parks			▲	▲					▲	▲		▲	▲
Other Recreation			▲	▲					▲	▲		▲	▲
commercial cam pgrounds			▲	▲					▲	▲		▲	▲
golf course			▲	▲					▲	▲		▲	▲
miniature/pitch-putt			▲	▲					▲	▲		▲	▲
riding areas			▲	▲					▲	▲		▲	▲
hunting areas			▲	▲					▲	▲		▲	▲
birding areas			▲	▲					▲	▲		▲	▲
public shorelines			▲	▲					▲	▲		▲	▲
ecological reserves			▲	▲					▲	▲		▲	▲
marinas			▲	▲					▲	▲		▲	▲
motocross areas			▲	▲					▲	▲		▲	▲
sports areas			▲	▲					▲	▲		▲	▲
race tracks			▲	▲					▲	▲		▲	▲
concert pavillions			▲	▲					▲	▲		▲	▲

KEY

- EVALUATED IN CASE STUDIES AND FOUND TO BE AN IMPACT
- ▲ EVALUATED IN CASE STUDIES AND NO IMPACT FOUND
- NOT EVALUATED IN THE CASE STUDIES BUT DISCUSSED IN THE LITERATURE OR IDENTIFIED AS A POTENTIAL IMPACT IN THIS ANALYSIS
- △ NOT EVALUATED IN THE CASE STUDIES BUT IDENTIFIED AS A POTENTIAL IMPACT ONLY IN SPECIFIC SITUATIONS

A BLANK INDICATES THAT NO IMPACT WAS FOUND IN THE CASE STUDIES OR REVIEW OF THE LITERATURE

Figure 8

IMPACT MATRIX CONT. p.2

	PASSIVE	THERMAL			PHOTOVOLTAIC			WIND			BIOMASS		
		Onsite	Shared	Central	Onsite	Shared	Central	Onsite	Shared	Central	Onsite	Shared	Central
Residential Uses													
single family detached		▲	▲	▲	▲	▲	▲	▲	■	▲			
multiple family		▲	▲	▲	▲	▲	▲	▲	■	▲			
apartment		▲	▲	▲	▲	▲	▲	▲	■	▲			
Commercial/Industry													
fruit drying		▲		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
stock yards		▲		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
storage yards		▲		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
warehouses		▲		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
greenhouses		▲		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
nurseries		▲		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
vacant parcels		■	○	▲	▲	▲	▲	▲	■	■	▲	▲	■
Public Facilities													
airports				▲		▲	▲		▲	▲		▲	▲
shipping ports				▲		▲	▲		▲	▲		▲	▲
cemeteries		■		▲		▲	▲		▲	▲		▲	▲
parking lots		■	■	○	▲		▲	▲		▲		▲	▲
street intersection		■		▲		▲	▲		▲	▲		▲	▲
utility easements		■	■	○	▲		▲	▲		▲		▲	▲
railroad r.o.w.		■	■	○	▲		▲	▲		▲		▲	▲
Resource Production/Extraction													
agriculture			▲	▲		▲	▲		▲	▲		○	○
grains			▲	▲		▲	▲		▲	▲		○	○
orchards			▲	▲		▲	▲		▲	▲		○	○
row crops			▲	▲		▲	▲		▲	▲		○	○
cash crops			▲	▲		▲	▲		▲	▲		○	○
forestry													
monoculture			▲	▲		▲	▲		▲	▲		○	○
other forests			▲	▲		▲	▲		▲	▲		○	○

KEY

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IMPACTS MATRIX CONT. p.3

	PASSIVE	THERMAL			PHOTOVOLTAIC			WIND			BIOMASS		
		Onsite	Shared	Central	Onsite	Shared	Central	Onsite	Shared	Central	Onsite	Shared	Central
mining													
open pit												○	○
deep shaft												○	○
WATER USE													
Storage Medium or in Process		■	■	▲							■	■	■
Pre-emption of Alternate Use		▲	▲	▲							△	△	△
ECOLOGICAL													
Terrestrial Impacts													
Direct Toxic Impacts on Organisms													
heavy metals													
chlorinated hydrocarbons		△	△	▲									
other petroleum products		△	△	▲									
increased soil salinity				▲			▲						△
loss of foliage				▲			▲						△
plant nutrients													
nitrates/nitrites/phosphates													
arsenic compounds					△	△	▲			△		△	△
ground compaction				▲			▲	△	△	△		△	△
Sublethal Toxic Impacts													
stunting of growth		△	△	▲	△	△	▲					△	△
change in reproductive capacity		△	△	▲	△	△	▲					△	△
changes in survival rates		△	△	▲	△	△	▲					△	△
changes in mutation rates		△	△	▲	△	△	▲					△	△
morphological deformity		△	△	▲	△	△	▲					△	△
Interference with Plant/Animal Population													
Interference with migration routes				▲			▲						
birds tangled in overhead wires				▲			▲			△			
birds tangled in blades								○	○	○			
electromagnetic interference with navigation							▲						
glare nuisance	○	○	○	▲	○	○	▲						
vegetation removal	■	■	■	▲	■	■	▲	○	○	○	○	○	○

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IMPACT MATRIX CONT. p.4

	PASSIVE	THERMAL			PHOTOVOLTAIC			WIND			BIOMASS		
		Onsite	Shared	Central	Onsite	Shared	Central	Onsite	Shared	Central	Onsite	Shared	Central
Ecosystem Level Perturbation													
loss of diversity	○	○	○	▲		○	▲	○	○	○	○	○	○
monoculture													
habitat destruction through vegetation removal	○	○	○	▲		○	▲	○	○	○	○	○	○
alteration of succession rates				▲			▲						
change in primary productivity	○	○	○	▲		○	▲	○	○	○	○	○	○
food web magnification													
Aquatic/Marine Impacts													
Direct Toxic Impacts													
heavy metals					△	△	▲						
chlorinated hydrocarbons		△	△	▲									
other petroleum products		△	△	▲									
salinity		△	△	▲	△	△	▲						
pH		△	△	▲	△	△	▲			△			
plant nutrients							▲						
nitrites/nitrites/phosphates					△	△	▲					△	△
temperature													
Sublethal Impacts													
stunting of growth		△	△	▲	△	△	▲					△	△
changes in reproductive capacity		△	△	▲	△	△	▲					△	△
change in survival rates		△	△	▲	△	△	▲					△	△
change in mutation rates		△	△	▲	△	△	▲					△	△
morphological deformities		△	△	▲	△	△	▲					△	△
Ecosystem Level Perturbations													
change in pH of Salinity causing secondary impacts		△	△	▲	△	△	▲						
nutrient enrichment causing eutrophication and fish kills												△	△
low temperature fluid causing secondary impacts													
loss of diversity		△	△	▲	△	△	▲						

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IMPACT MATRIX CONT. p.5

	PASSIVE	THERMAL			PHOTOVOLTAIC			WIND			BIOMASS		
		Onsite	Shared	Central	Onsite	Shared	Central	Onsite	Shared	Central	Onsite	Shared	Central
SAFETY													
Personal Safety													
Installation		△	△	▲	△	△	▲	△	△	△	△	△	△
falls		△	△	▲	△	△	▲	△	△	△			
Operation													
toxic substances													
eutetic salts		△	△	△									
petroleum oils		△	△	△									
working fluid additives		△	△	△									
gallium arsenide					△	△	▲						
toxic gasses					○	○	▲	△	△	△		○	○
disease vectors		△	△	▲								○	○
burns													
heat		△	△	▲	△	△	▲				△	△	△
chemical					△	△	▲	△	△				
flying objects													
blade throw								△	△	△			
cuts		△	△	▲	△	△	▲				△	△	△
glass breakage													
access													
impedance of emergency egress													
falls													
glare		△	△	△	▲	△	△	▲					
Maintenance													
burns		△	△	△	▲								
cuts		△	△	△	▲	△	△	▲	△	△	△		
glass breakage													
falls		△	△	△	▲	△	△	▲	△	△	△	△	△
Building Safety													
installation		○	○	▲	○	○	▲	○	○	○			
excessive weight		○	○	▲	○	○	▲	○	○	○			
operation		○	○	▲									
leaks		○	○	▲									

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IMPACT MATRIX CONT. p.6

IMPACT MATRIX CONT. p.6													
	PASSIVE	THERMAL			PHOTOVOLTAIC			WIND			BIOMASS		
		Onsite	Shared	Central	Onsite	Shared	Central	Onsite	Shared	Central	Onsite	Shared	Central
INFRASTRUCTURE													
Interference with Underground Facilities													
storm drains		△	○	▲	△								
water supply		△	○	▲	△								
sewer systems													
conventional		△	○	▲	△								
septic tank		△	○	▲	△								
other sewage treatment		△	○	▲	△								
gas		△	○	▲	△								
electric		△	○	▲	△								
steam		△	○	▲	△								
telephone		△	○	▲	△								
cable television		△	○	▲	△								
Relationship to Power Grid		△	○	▲	△								
maintaining grid for back-up	○	○	○	▲	○	○	▲	○	○	○	○	○	○
scale problems					△	▲	▲			▲	▲		
Service Capacity													
water supply		■	■	▲	■	■	▲				■	■	■
sewer capacity												▲	▲
transit													
trucking												○	○
rail												○	○
shipping												○	○
traffic congestion												○	○
Accessibility													
preemption of public easements													
restricted access to open space land													

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IMPACT MATRIX CONT. p.7

	PASSIVE	THERMAL			PHOTOVOLTAIC			WIND			BIOMASS		
		Onsite	Shared	Central	Onsite	Shared	Central	Onsite	Shared	Central	Onsite	Shared	Central
VISUAL													
Conflicts with Surrounding Architecture/Environment													
scale	▲	■	■	▲	■	▲	▲	■	▲	▲		▲	▲
bulk	▲	■	■	▲	■	▲	▲	■	▲	▲		▲	▲
color	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲		▲	▲
texture	▲	■	■	▲	■	■	▲	▲	▲	▲		▲	▲
form	▲	▲	■	▲	■	■	▲	■	▲	▲		▲	▲
other imposition on natural features		▲	▲	▲	▲	▲	▲	▲	▲	▲		▲	▲
glare or reflectivity	■	■	■	▲	■	■	▲						
blockage of view	■	■	■	▲	■	■	▲	△	△	△			
NOISE													
Transmission Line Hum				▲			▲	■	■	▲			
Rotor Blade Vibration													
Water Heating Hum													
Traffic Noise												○	○
Mechanical Noise												○	○
POLLUTION													
Water Pollution													
potable water													
chlorinated hydrocarbons		△	△	▲									
other petroleum products		△	△	▲									
synthetic organics		△	△	▲									
other oxygen demanding wastes													
plant nutrients													
nitrates/nitrites												△	△
Phosphates												△	△
other inorganics													
chromates/dichromates													
disease/allergy causing agents		○	○	○									
heat		○	○	○									
radioactive material													

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IMPACT MATRIX CONT. p.8

	PASSIVE	THERMAL			PHOTOVOLTAIC			WIND			BIOMASS		
		Onsite	Shared	Central	Onsite	Shared	Central	Onsite	Shared	Central	Onsite	Shared	Central
sediment													
metallic compounds		○	○	▲									
stream and groundwater													
chlorinated hydrocarbons		△	△	▲									
other petroleum products		△	△	▲									
synthetic organics		△	△	▲									
other oxygen demanding wastes											○	○	
plant nutrients											○	○	
nitrites/nitrates											○	○	
phosphates											○	○	
other inorganics													
chromates/dichromates													
disease/allergy causing agents		○	○	▲							○	○	
heat		○	○	▲									
radioactive material													
sediment				▲			▲	○	○	○			○
metallic compounds											○	○	
Air Pollution													
hydrocarbons											○	○	
oxides (NOx, SOx, COx)											○	○	
ozone											○	○	
water vapor											○	○	
halogens													
hydrofluoric		○	○	▲									
fluoride		○	○	▲									
chloride		○	○	▲									
arsenic					○	○	▲						
particulates		○									○	○	○
odor causing agents		○									○	○	

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The matrix indicates: 1.) whether or not each impact was evaluated specifically in the case study analyses; 2.) if evaluated, whether or not it was found to be an impact; and 3.) if not evaluated, whether it is an impact that is expected to accompany the use of the technology or whether it is improbable. The expected impacts, based on the case study analyses, are discussed briefly in this section.

In the case study analysis of impacts it was assumed that technologies would be located first on individual sites. Then, if the scenario goal could not be met on each site on an individual basis, shared systems would be employed. If the scenario goal still could not be met, large-scale systems centralized within or close to the community would be used. Therefore, if the scenario goal can be met using on-site systems, the matrix will indicate no impact at the shared and centralized levels.

The impacts encountered in the analysis have been divided into two major categories: land use impacts and environmental impacts. Land use impacts were found to be more significant, potentially requiring: 1.) pre-emption of vacant parcels as collector locations; 2.) multiple use of open space, e.g. parking lots, on developed parcels; and 3.) the transfer of energy within the community from one land use to another for existing buildings; and changes in the arrangement, spacing, orientation and form of new buildings.

Environmental impacts will occur when direct solar technologies are used but impacts appear to be insignificant when the impacts which already occur as a result of physical development in urban and suburban environments are taken into account. Removal of vegetation to preserve solar access to on-site collectors is a primary impact in the low density residential land use pattern.

Environmental impacts of wind machines located on-site are more significant, with safety, noise and interference with television reception as the primary concerns. Since electrical energy is easily transported via the existing grid, siting of wind energy conversion machines in areas removed from the energy users, either within or near a community, is a feasible mitigation measure which would eliminate all of these impacts on the community.

The environmental impacts of biomass conversion facilities are more significant than those of any other technology. The irreversible commitment of resources, air and water quality degradation and water consumption are the major impacts.

Land Use Impacts

Table 6 identifies those decentralized solar technologies which would produce land use impacts in six land use types analyzed in the case studies. A distinction is made between land use impacts resulting from producing enough solar energy to meet the scenario goal (DPR goal), and impacts resulting from producing the maximum amount of solar energy that could be used in a particular land use (the technology's potential). Since the DPR goal is lower than the technology potential, particularly in the commercial sector, substantially fewer land use impacts will result from meeting the scenario goal than from using direct solar technologies to the greatest extent possible.

In addition, more efficient direct solar technologies will produce fewer land use impacts than those with current levels of performance. If more efficient technologies (requiring a greater capital outlay) are available, it is usually possible to select one which will minimize land use impacts.

Meeting the scenario goal will produce the most land use impacts in the central business district where a combination of high energy demand and dense development pattern make the implementation of on-site direct solar technologies the most difficult.

Land Use Pre-emption or Multiple Use

The most common kind of land use pre-emption that would result from achieving the scenario goal--one that appears with many direct solar technologies--is the installation of collectors in open areas on the development site. This impact is labelled "multiple-use" and indicates that the existing use need not be displaced, only modified. Examples are the installation of collectors on raised backyard trellises in the residential sector or on raised structures in parking lots in the commercial sector.

TABLE 6

DECENTRALIZED SOLAR TECHNOLOGIES THAT WOULD PRODUCE
 LAND USE IMPACTS IN SIX LAND USE TYPES IN ORDER
 TO ACHIEVE THE MAXIMUM AMOUNT OF TOTAL ENERGY
 DEMAND POSSIBLE OR TO ACHIEVE THE DPR SCENARIO
 GOAL

	LAND USE TYPE											
	SFD		MFD		Strip		CBD		WAREHOUSE		INDUSTRY ^a (% of cases)	
	Tech Goal	DPR Goal	Tech Goal	DPR Goal	Tech Goal	DPR Goal	Tech Goal	DPR Goal	Tech Goal	DPR Goal	Tech Goal	DPR Goal
IMPACTS ON EXISTING DEVELOP.												
Pre-emption WITHIN Study Area												
Multiple Use of Open Areas on Developed Site	1234 56	12 WB	1234 56	12 4 WB	1234 56	W	1234 56	1234 56W	1234 56	W	83%	50%
Use of Vacant Parcels		W		W		W	1234 56	1234 56W	1234 56	W	50%	50%
Change in Existing Land Use											33%	0
Pre-emption OUTSIDE Study Area												
Multiple Use of Open Areas on Developed Site							1234 56	1234 56			0	0
Use of Vacant Parcels								B		B	0	0
Change in Existing Land Use											0	0
IMPACTS ON NEW DEVELOP'T.												
Changes in Form (to meet goals on-site)												
Roof Configuration (area and orientation)	1234 56										0	0
Building Height and Set-backs (variation and spacing)	6		1234 56	12			1234 56	1234 56			0	0
Street Pattern (Orientation and parcel configuration)											0	0
Density (energy demand floor area: parcel area)							1234 56	1234 56			67%	33%

KEY

Technology Type:

1. Direct Solar Thermal Collectors with existing output and short-term storage.
2. Direct Solar Thermal Collectors with improved output and short-term storage.
3. Cogenerating Photovoltaics with short-term storage.
4. Direct Solar Thermal Collectors with existing output and long-term storage.
5. Direct Solar Thermal Collectors with improved output and long-term storage.
6. Cogenerating photovoltaics with long-term storage.
- W. 10 KW wind machines.
- B. Biomass conversion (wood burning in residential sectors, MSW in commercial sectors, and agricultural and forestry residues in industrial sector).

Tech Goal: The maximum amount of the total energy demand that can be supplied by a particular direct solar technology assuming unlimited collector area.

DPR Goal: The scenario goal established by the Policy Planning Review commission.

NOTES

- a. In the industrial sector, the technologies are matched to process heat requirements (see text) and the % of cases indicates the relative amount of cases analyzed where potential impacts were encountered with the single technology applied.
- b. Alteration of existing setback controls could reduce impacts on vegetation loss (see Environmental Impacts).

Though the case studies were designed to distinguish between impacts within the study area and impacts outside the study area, impacts are nearly always confined to neighborhoods of similar land use development within the community. To meet the scenario goal only the central business district's high energy demand would require the collection of energy somewhere else in the community. In no case was it necessary to eliminate an existing land use to permit the collection of on-site solar energy either to meet the scenario goal or even the more ambitious technology potential.

The pre-emption of vacant parcels would be required for the installation of a MSW conversion facility to meet the biomass goal in the commercial sector. But since this is an industrial use, the economic merits of which must include the market price of the site, this land use impact would not necessarily adversely affect the community. The only potential for pre-emption of vacant parcels to meet the scenario goals for the remaining technologies is in the central business district.

In the industrial land use cases, technologies were selected to meet particular process heat requirements. These technologies are not necessarily the same ones used in the other case studies and in addition to flat plate collectors include parabolic trough collectors and solar ponds. The analysis indicates that using these technologies to meet the scenario goal would require multiple use of on-site open space in three of the six central city industrial sites evaluated and the use of vacant parcels in three of six sites, but would not require any change in existing use. Suburban industrial sites, not analyzed in this study, are typically located on parcels 2.5 times larger than the central city sites analyzed (Boykin, 1975). With this amount of usable collector area on the parcel, land use impacts would probably be reduced.

Changes in the Form of Land Use

A second category of land use impacts results from changes in the form of development necessary to accommodate solar technologies on-site. These impacts are expected to occur in new development designed to specifically accommodate on-site energy production.

Technologies that would induce these changes in the various land-use sectors of a community are indicated in the key to Table 6. A distinction is made between impacts that result from meeting the scenario goal and those that result from meeting the technology's potential. Changes in

the physical form of the local community that are expected include:

1. Alterations of the roof configuration of individual buildings to improve solar orientation;
2. Control of building heights and setbacks from property lines to reduce shading of collector area;
3. Orientation of streets and parcel dimensions to increase south-facing surface area of individual structures; and
4. Reduction in land use density and/or in energy demand per unit of floor area to reduce required collector area.

In order to achieve the scenario goal, changes would be expected only in the higher density land use types. In the multiple family dwellings case study, a uniform height for the primarily 3-to-4-story multiple family case would enable this land use type to meet the scenario goal. Since the study area included 3 high rise residential structures which could not meet the scenario goal on-site and which also shaded portions of the lower, row house development, the study area as a whole failed to meet the scenario goal using thermal collectors with short-term storage. In order to meet the scenario goal in the MFD case, either more advanced technologies must be used (photovoltaics or long-term storage) or the community could impose height restrictions to eliminate collector shading.

In the central business district variation in height is much more extreme and precludes using the majority of roof tops and on-site open space. An illustration of the winter shadow pattern is included in Appendix D. Controlling the variation in building height to reduce shading of roof-top collectors would increase the solar supply. However, with height controls alone it is unlikely that the central business district could achieve the scenario goal on-site. It is also likely that changes in the density of the central business district would be necessary to achieve the scenario goal.

To increase the solar supply to the more ambitious technology potential would result in more severe impacts on the height and density of the two higher density land use types but would add few additional impacts in these or other land use types. Minor modifications to the roof configuration of individual single family dwellings could be expected if the higher technology potential is realized.

In the industrial sector (in central city industrial sites) two of the six cases would require additional collector area to meet the scenario goal on-site.

While Table 6 does not include an evaluation of passive design, it is expected to be the most cost-effective solar "technology" in new development. (Balcomb, 1976; Lovins, 1978; State of California, 1978). However, widespread use of passive design techniques would produce more and greater impacts on the form of new development in each land use sectors. Consequently although changes in community form are not necessary in order to meet the scenario goal, they are expected to occur as a response to the implementation of the more economical passive design.

The case study analysis, representative of a national average energy demand, indicates that the scenario goals for passive and active solar supply can be met by currently available flat plate collectors in well-insulated residences at a density of thirty dwelling units per net acre if structure height is controlled to minimize shading of collectors. Use of more efficient direct solar technologies and long-term thermal storage enables residences at that density to meet substantially more than the total DPR scenario goal for ALL solar technologies. Close to 100 percent of the on-site energy demand can be met at a density of sixteen dwelling units per net acre if cogenerating photovoltaics become available.

Therefore, low density suburban development (typically six to eight dwelling units per net acre) is not essential for decentralized solar technologies to contribute a substantial portion of the community's energy demand.

Environmental Impacts

Table 7 is similar to Table 6 but identifies those decentralized solar technologies which produce environmental impacts in six land use types analyzed in the case studies.

Water Consumption

Water consumption for direct solar technologies will vary as a function of storage volume. Short-term storage in the residential sector requires the equivalent of four to five days of water use every four or five years or an average of one day's supply per year. Commercial facilities will

TABLE 7

DECENTRALIZED SOLAR TECHNOLOGIES THAT WOULD PRODUCE ENVIRONMENTAL IMPACTS IN SIX LAND USE TYPES IN ORDER TO ACHIEVE THE MAXIMUM AMOUNT OF TOTAL ENERGY DEMAND OR TO ACHIEVE THE DPR SCENARIO GOAL

	LAND USE TYPE											
	SFD		MFD		Strip		CBD		WAREHOUSE		INDUSTRY ^a (% of cases)	
	Tech Goal	DPR Goal	Tech Goal	DPR Goal	Tech Goal	DPR Goal	Tech Goal	DPR Goal	Tech Goal	DPR Goal	Tech Goal	DPR Goal
Water Consumption	1234 56	1234 56	1234 56	1234 56	1234 56	1234 56 B	1234 56 B	1234 56 B	1234 56 B	1234 56 B	100	100
Vegetation Removal	123	123									0	0
Hazardous Wastes	1234 56	1234 56	1234 56	1234 56	1234 56	1234 56	1234 56	1234 56	1234 56	1234 56	100	100
Visual Intrusion	1234 56WB	1234 56WB	1234 56WB	1234 56WB	1234 56WB	1234 56WB	1234 56WB	1234 56WB	1234 56WB	1234 56WB	100	100
Resource Consumption	B	B	B	B	B	B	B	B	B	B	50	50
Infrastructure Disruption	1234 56	1234 56	1234 56	1234 56	1234 56	1234 56	1234 56	1234 56	1234 56	1234 56	100	100
Water Pollution	1234 56 B	1234 56 B	1234 56 B	1234 56 B	1234 56 B	1234 56 B	1234 56 B	1234 56 B	1234 56 B	1234 56 B	100	100
Air Pollution	B	B	B	B	B	B	B	B	B	B	50	50
Safety	1234 56W	1234 56W	1234 56W	1234 56W	1234 56WB	1234 56WB	1234 56WB	1234 56WB	1234 56WB	1234 56WB	100	100
Noise	W	W	W	W	WB	WB	WB	WB	WB	WB	0	0

KEY

Technology Type:

1. Direct Solar Thermal Collectors with existing output and short-term storage.
2. Direct Solar Thermal Collectors with improved output and short-term storage.
3. Cogenerating Photovoltaics with short-term storage.
4. Direct Solar Thermal Collectors with existing output and long-term storage.
5. Direct Solar Thermal Collectors with improved output and long-term storage.
6. Cogenerating photovoltaics with long-term storage.
- W. 10 KW wind machines.
- B. Biomass conversion (wood burning in residential sectors, MSW in commercial sectors, and agricultural and forestry residences in industrial sector.

Tech Goal: The maximum amount of the total energy demand that can be supplied by a particular direct solar technology assuming unlimited collector area.

DPR Goal: The scenario goal established by the Policy Planning Review commission.

NOTES

- a. In the industrial sector, the technologies are matched to process heat requirements (see text) and the % of cases indicates the relative amount of cases analyzed where potential impacts were encountered with the single technology applied.

consume twice as much water as residential structures.

Use of long-term storage would increase water consumption, particularly if storage is maintained on an individual basis for each household. However, only short-term storage is needed to meet the scenario goal, and, therefore, the impact on a community's water supply would be insignificant compared to total water consumption.

Vegetation Loss

One of the primary impacts of decentralized solar technologies will be the removal of vegetation to preserve an open sky-space for the on-site collector. The case study analysis indicates that the removal of trees (or pruning and shaping to reduce shading of collectors) will be an impact in the single family dwelling land use type. In order to meet the scenario goal in this residential sector, as much as 35 percent of the existing tree canopy would have to be removed to accommodate individual on-site collectors at each residence.

The loss of tree canopy will affect the microclimate of the neighborhood by: 1) eliminating important summer time cooling effects; or 2) eliminating the energy-saving effects of wind breaks. (Reifsnnyder, 1965, in McClenon, 1977). The loss of tree canopy will also result in some reduction in habitat for birds and other animal populations.

All of the potential impacts due to loss of vegetation can be mitigated in a number of ways. The case study analysis indicates that the scenario goals can be achieved without any loss of vegetation if:

1. Collectors are located in front and back yards as well as on roofs--they could be selectively placed to avoid the shading of existing trees but may conflict with local zoning ordinances;
2. Energy sharing is instituted between adjacent neighbors so that collectors can be located in a single roof-top or yard array and the thermal energy is circulated to two residences; or
3. Removed vegetation is replaced with trees in alternate locations or with lower growing species.

An increase in solar reliance beyond the scenario goal can be achieved and vegetation loss can be held to 3 or 4 percent of the tree canopy if energy sharing is instituted in block-wide systems where collectors are located in any appropriate, unshaded area and thermal

energy is circulated to each residence in the city block.

The trade-offs between loss of vegetation and choice of collector location or energy distribution system will be largely a local decision. Because a community's responses to this trade-off cannot be anticipated, vegetation loss cannot be predicted. The long-term effects may be completely eliminated if new trees are planted where the shade will not interfere with collector performance. Depending on species type, mature, urban trees can be re-established in 10 to 40 years. (McClenon, 1977).

In new developments, loss of vegetation may range more widely than the 15 to 35 percent reduction in vegetation found in existing neighborhoods but the adverse impacts can be minimized by design or regulation. Techniques to maximize the use of vegetation to control micro-climates include: clustering construction to permit larger "green-space" planting and planting design that maintains an effective open sky-space for collectors. (Living Systems, 1979).

Hazardous Wastes

Of 34 currently available chemical additives to collector working fluid, nine present no toxicological hazard to humans while 16 have been found to be toxic to varying degrees and 9 others have not been evaluated due to insufficient data (Buchan, Majestic and Bilaw, 1976). Human safety can be ensured if only the non-toxic additives are used.

Impacts on the non-human environment after disposal of working fluids have not been assessed; virtually no data have been compiled on biodegradability or the potential for concentration of these chemicals in food chains. Avoidance of impacts in the use and disposal of working fluids will require the establishment of regulations and their implementation at the community level.

Visual Impacts

In an effort to enhance community identity, increasing numbers of local jurisdictions have adopted regulations controlling the scale, bulk, form, color and texture of new structures. Such regulations demonstrate a concern for maintaining continuity in the visual appearance of the built environment. Thermal collectors and photovoltaic arrays represent a departure from the form and scale of the cornice or roofline and from

the color and texture of roof materials. Passive design techniques which include south facing windows, green houses, skylights and clerestory windows, together with thermal masses, and a variety of supplemental or alternative techniques, allow for a more harmonious integration with existing architectural style than active solar techniques.

Visual intrusion of solar collectors will be more significant in the higher density residential land use patterns where all available collector area must be used to meet the scenario goal. In low density residential patterns a choice of collector locations usually exists; collectors can be located either conspicuously or discretely, depending on the home owner's and community's values. Local community controls, or lack of them, will largely determine the degree of visual intrusion.

Meeting the scenario goal in the high density commercial land uses (the central business district case study) would require significant changes in the physical form of the development to reduce energy demand, e.g. height restrictions, passive heating and cooling, daylighting and natural ventilation, and to control shading by adjacent structures. These changes would significantly alter the visual character of the central business district of large cities. However, to meet the scenario goals for the community as a whole, solar energy does not have to be used in the central business district, so that these visual impacts need not be experienced.

Where communities are attempting to maintain the architectural character of historic districts, implementation of decentralized technologies may be particularly difficult. When historic districts include high-density land use patterns, the visual intrusion of solar collectors may be inconsistent with preservation policies. For example, in a high density neighborhood of Victorian row houses, meeting the 36.5 percent residential sector scenario goal would require that collectors be located on front yard set backs as well as on roofs and back yards, significantly altering the historic character of the neighborhood. In a small town "Main Street" preservation district, on the other hand, the 18 percent commercial sector goal could be met on roof tops, without necessarily altering the facades. As in the case of the central business district, the scenario goal for the community as a whole could be met without the use of solar technologies in high density historic districts.

Wind machines will alter the visual character of the environment more significantly in rural and urban fringe settings than in cities. They will present a greater contrast with the horizontal character and appearances of rural development and the natural landscape than with the verticality and visual complexity of the city.

Resource Consumption

The conversion of biomass into low-BTU gas or steam represents an irreversible allocation of resources that could be used for other purposes. Materials used for fuel include waste wood, agricultural by-products, lumber by-products, municipal solid waste and sewage sludge. Only 14 percent of the nation's forest and agricultural wastes are currently unused (see Table 8).

Of the major fuel sources for biomass conversion, MSW is the most widely available. Of 13 primary constituents of MSW, seven can be recycled or composted to produce fertilizer. Recyclable materials include paper, glass, ferrous metal, aluminum and wood; sewage sludge, food and other household wastes can be composted. These categories comprise about 90 percent of the total MSW. Only plastics, rubber, leather and textiles cannot be recycled.

Construction of MSW conversion facilities would create a disincentive to recycle resources, to produce organic fertilizer as an alternative to petrochemical fertilizers, and to reduce waste generation.

Water Pollution

One of the major unresolved issues is the disposal of collector working fluids. Although many are known to be toxicologically safe for humans, few have been examined for their consequences in the aquatic or marine environment. All of the MSW conversion technologies generate significant waste streams that include heavy metals, particulates and thermal pollution.

Air Pollution

Minor contributions of particulates and simple gases can be expected from heavy reliance on wood burning stoves. Of the municipal solid waste

Table 8

DISPOSAL OF NATIONAL AGRICULTURAL AND FORESTRY WASTES
(10⁶ Dry Tons)

	<u>Crop</u>	<u>Manure</u>	<u>Forestry</u>	<u>Total</u>
Returned to soil	237	25	---	262
Fed without sale	61	---	---	61
Sold	13	.5	38	56
Fuel	9	---	19	38
Wasted	<u>2</u>	<u>6</u>	<u>59</u>	<u>67</u>
Total	322	36	119	474

SOURCE: Alich and Witner, 1977

conversion processes evaluated, more serious pollution impacts (on the order of 10^6 - 10^7 tons annually for a major city) would be generated from direct combustion or refuse-derived-fuel technologies; pyrolysis does not produce air pollution.

Infrastructure Impacts

Siting of energy-generating devices and their accompanying storage systems have the potential to temporarily disrupt all underground utilities (gas, water, supply, sewage, telephone, cable TV) and to prompt localized traffic congestion. Of the direct solar supply systems evaluated, these impacts are limited for the most part to shared systems. Shared systems are not required to meet the scenario goals; consequently no disruption of underground utilities is expected.

Once in operation, wind generators may interfere with television reception, especially reception of the upper UHF frequencies. Proper attention to siting and phasing new construction can reduce or minimize infrastructure impacts.

The impacts to infrastructure will primarily result from the reduced reliance on the electrical utility grid for base load energy which will increase the gap between base load and peak load demand. Since only twelve percent of residential space heat is provided by electricity (U.S. Census, 1977), and even less in the commercial sector, meeting the scenario goal will have a small impact on the electrical utilities relative to its effect on the natural gas and fuel oil provisions.

If the solar supply is increased beyond the scenario goal, the base load for cooling will be reduced. Consequently, supplying a summer peak load could become more costly. This impact may be mitigated by using thermal storage as chilled water storage during summer months.

Use of long-term thermal storage could eliminate the need for electrical back-up heating systems. More stringent conservation measures could produce the same results in areas with mild to moderately cold winter temperatures. Similarly, passive design techniques can entirely eliminate the need for electrical air conditioning in many areas if people are willing to tolerate some discomfort during the most extreme conditions.

Noise

Decentralized applications of wind technologies will produce the most objectionable noise impacts on homes and neighborhoods. This inconvenience can be largely mitigated by siting wind generators away from population centers. However, tradeoffs may be necessary between mitigating noise for human communities and impacting habitat areas in more remote locations.

Safety

Use of direct solar technologies will produce safety hazards typical of those accompanying construction and maintenance of structures. Generally, the solar supply system will be installed by someone with training in the building trades. However, a homeowner is likely to perform routine cleaning and maintenance. Accidents will include falls, minor burns and abrasions.

A secondary risk from direct solar systems is the glare hazard from collector panels or passive windows which would affect automobile drivers, pedestrians, bicyclists and pilots of light aircraft. Design features such as dark, matte paints can reduce the glare hazard from collector frames.

There may be additional community impacts associated with photovoltaic arrays due to the chemical context and electrical conductivity of the cells. The stability of chemical compounds over the life of a photovoltaic system has not been demonstrated conclusively. In addition, storage batteries could pose minor risks for unsupervised children which could be readily mitigated with design features.

Trade-Offs Among Impacts

All land use impacts, whether pre-emption of uses in existing development or changes in form in new development, are characteristically the result of trade-offs made within the community. The available choice in technologies together with the increased solar supply capability of shared systems will permit local communities to select those land use impacts that are least disruptive to community values. In the single family dwelling case study, several different combinations of technology

selection and impacts can result in meeting the scenario goal. One community may wish to permit flexibility in collector location in order to eliminate loss of vegetation. Another may resort to neighborhood shared-energy systems in order to preserve the architectural form of an historic district. Another may choose to limit collectors to roof tops and sacrifice some tree canopy in order to minimize the social costs of organizing shared systems or regulating the visual impact of collectors placed in the yard.

In general these trade-offs permit the greatest flexibility where development patterns are less dense. Still, even in the high density central business district, a community has options in selecting the impacts. One kind of land use impact can, to a large extent, be traded for another. The four basic choices include:

1. Multiple use of open space in developed areas,
2. Pre-emption of an existing use or of vacant land,
3. Change in the form of development, or
4. Externalization of land use impacts by importing energy collected elsewhere in the community.

Each of the four basic choices implies a different kind of community control in order to minimize the adverse effects of potential impacts. To achieve the market penetration mix identified in the scenario, the typical community will rely to a substantial degree on on-site active systems. In this case, the controls can generally be limited to those that minimize visual intrusion, vegetation loss, and the disposal of working fluids.

Many communities, particularly growing ones that are adding substantially to their existing form, will have the opportunity to emphasize energy collection through passive design techniques. In this case, the more expensive active systems are not necessary. A new home could meet the scenario goal of 36.5 percent of its total end use demand with passive design and active solar hot water heating (Balcomb, 1976). It will be necessary, however, to increase the number of controls on new development if passive design is to be applied on a wide scale. The physical limits and consequential impacts of this potential resource have not been fully explored.

Ultimately, the kinds of land use or environmental impacts that

result from achieving the DPR scenario goal for decentralized solar energy will be the result of decisions made by individuals and local governments operating within the context of an existing pattern of development and value system. In this analysis no particular land use impact was found to be necessary in achieving the scenario's goal.

Application of Findings

This report has evaluated the potential community level impacts that would result from wide spread implementation of on-site solar energy technologies. In the evaluation it was first necessary to establish the connection between community land use patterns and energy use.

The findings indicate that most potential impacts to the community will be those affecting land use. Consequently, many of the findings are of direct interest to local land use planners. Whether a community is a growing metropolis with the opportunity to shape its future energy use characteristics or whether a community is an established, built-out area trying to reduce its reliance on centralized energy sources, the findings in the report illustrate how solar technologies are constrained by development patterns. In any locality, it will be important for land use planners to understand the connection between energy use and land use in order to develop community goals and policies to make cities more energy efficient. Using the framework established in this study, a local community could easily assess potential energy savings from a variety of community interventions. The first step would be to categorize its existing development into "energy sensitive land use types."

The significance of this report's findings to state or regional governments is that it has demonstrated that particular regulatory interventions are going to produce varying results in different land use types. The ultimate goal of reducing energy consumption will not be achieved with a single legislative act.

This report has not evaluated the potential contribution that passive design techniques can make to reducing reliance on centralized energy sources. The potential of passive design has been studied in isolation but not systematically applied to the broader development context. While passive design was largely ignored in the scenario, accounting for only about one-sixth of the residential sector and one ninth of the commercial sector supply, the potential economic advantages of passive energy

design over active systems suggests that it should be given significantly more consideration. An increased effort should be made to demonstrate the practical application of passive design techniques and to assess the community consequences of their implementation.

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Appendix A

Characterization of Decentralized Solar
Technologies and Their Spatial Requirements

PASSIVE SOLAR DESIGN

"Passive design consists of architectural features, components, and/or assemblages thereof which make use of the natural transfer of solar-generated thermal energy (i.e. without the use of fans or pumps) for the purpose of water heating, space heating, and/or space cooling." (Anderson and Michal, 1978)

Passive design can provide as large a share of the space heating and hot water demand of an energy-effective structure as currently available active systems using a comparable collector area (Balcomb, 1976). Passive design applications have been limited for the most part to residential structures. However, recent commercial applications indicate that a low-rise commercial structure can provide a significant portion of its heating, cooling, ventilation and lighting demand using passive techniques.

Passive solar design cannot be characterized in the same way that active solar technologies can, i.e. as a single system applicable in all locations with only the amount of collector area and storage volume varying from one location to another. There is a wide variety of approaches available which must be matched to climatic and environmental conditions and to building types. However, the major passive design techniques can be categorized into generic system types based on differences in the collector, thermal storage media and level of control over heat transfer by occupants (Balcomb, 1976). Balcomb's five systems together with a sixth common type are:

1. Direct gain;
2. Attached greenhouses;
3. Thermal storage walls;
4. Convective loops;
5. Roof ponds; and
6. Concentrating clerestory windows.

Figures A-1 and A-2 depict the systems diagrammatically.

The first four systems share the physical requirement of south-facing wall area for which solar access must be maintained during the winter months. Roof ponds and clerestory windows require solar access to the rooftop similar to an active system. For the purposes of this study, which deemphasizes

Figure A-1. Four generic south-wall passive design techniques

Figure A-2

This passive design employs two rooftop techniques: a rooftop pond and rooftop clerestory window solar access. This figure depicts summer time operation.

passive design, passive design potential is assumed to increase as south-facing, unobstructed surface area increases relative to building volume. While this simplified relationship ignores the complexities of passive design, it allows for a qualitative evaluation of south-wall passive design opportunities. South wall passive design is more likely to be used in retrofitting existing structures than rooftop designs. The potential for rooftop designs in new structures is taken into account in the analysis of active thermal collection.

THERMAL COLLECTORS

The primary direct solar technology is the thermal collector which collects heat, transfers it to water or air and pipes it to a storage tank. Flat plate collectors were, until recently, the only thermal collectors available. However, technological changes in the field are occurring rapidly so that new, more efficient high-temperature collectors are now available. Of particular interest is the evacuated tube collector which, according to advocates, can potentially provide "twice the performance at half the cost" of flat plate devices (Metz and Hammond, 1978). Since evacuated tubes represent a technology which is commercially viable at this time, it is reasonable to assume that thermal collectors used in the next fifty years will be at least as efficient as evacuated tubes. They have a consistently high efficiency of 40 to 50 percent, operate with reflectors at temperatures high enough to drive absorption air conditioners, and are not as sensitive to variations in weather and climate as flat plate collectors (Metz and Hammond, 1978). Flat plate collectors have a lower efficiency ranging from 20 to 40 percent. Typical annual average efficiencies for a Baltimore climate are .21 for flat plate collectors and .41 for evacuated tubes (Besant and Winn, 1976).

If reflectors are used with thermal collectors, the average concentrating factor increases to 2:1 (LBL, 1978⁽¹⁾). This would obviously reduce the amount of collector area required to produce a given amount of heat. Planar reflectors will reduce the collector area required with short-term storage 10 to 30 percent (ITC, 1976).

In a study of four types of thermal collectors usable collector output after heat loss during transport and storage (assuming no heat exchangers) for systems with short-term storage (1.5 gallons per ft.² of collector area), and a desired water temperature of 100°F, was as high as 62 percent of

available insolation in mid-latitude regions (e.g. Baltimore and Denver). For a desired water temperature of 150°F the output was 47 to 50 percent of available insolation. Evacuated tube collectors' usable energy output for 150°F water was 57 percent (ITC, 1976).

In order to evaluate the influence of technology improvements on the spatial requirements of thermal collectors a range of system efficiencies is considered. First a performance level available in currently marketed systems, i.e., a collector efficiency of .4, transport and distribution heat losses of 20 percent, and a storage heat loss of 20 percent for long term heat storage, is considered. Then it is assumed that, using the most efficient collectors available with planar reflectors, a very well insulated storage volume, and an efficient distribution system, output per unit of collector area can be doubled (LBL, 1978).⁽¹⁾

Components and Physical Requirements

Figure A-3 depicts the basic components of a thermal collector/space heating system. The collector consists of a plane which must be more or less south-facing, which should be tilted to optimize insolation, and onto which insolation is not obstructed.

Figure A-4 shows the average reduction in insolation onto a vertical surface due to orientation away from true south for latitudes between 30° and 45° north (most of the United States).

Collector tilt is a less important constraint than orientation. A tilt of 15° to 20° from optimum will reduce insolation by only 10 percent. Figure A-5 shows that the tilt for winter collection can range from latitude plus 15° to vertical; for year-round collection, optimum orientation is considered to be latitude plus 0° and for summer collection, latitude minus 15° .

When an active or passive solar system is designed, a certain number of hours per day of insolation is assumed to be available. In order to operate at its design capacity, insolation must not be blocked during that period of the day. For space heating systems, the most critical day is generally assumed to be December 21. Although the heat load is slightly higher the following month, the amount of insolation reaching the earth is least on December 21 and the length of shadows is greatest; therefore, insolation is most likely to be blocked on that day. This is due to the fact that the path of the sun is closer to the horizon on December 21 than on any other day of the year.

Basic components of an indirect solar heating system. There are two primary heat transport loops — from collector to storage and from storage to the rooms.

The percentage of insolation on vertical walls for orientations away from true south.

SOURCE: Anderson, *The Solar Home Book*, 1976.

Figure A-5

Minneapolis, Minnesota

- NOTES: 1. Base tilt angle = 50°.
 2. Operating temperature = 90°F.
 3. Due South orientation.

Small changes in collector size are required when the tilt angle differs from the optimum.

SOURCE: Anderson, *The Solar Home Book*, 1976.

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A reasonable period during which the sun should not be obstructed on that day has been defined for legislative purposes by several sources.¹ The State of California defines the solar access period as 10 am to 2 pm in its Solar Rights Act of 1978. For this analysis solar access from 10 am to 2 pm on December 21 is assessed; during this period 70 percent of the day's total insolation is available. Figure A-6 depicts the concept of solar skyspace.

Just as collectors cannot be shaded by trees, structures and land forms, banks of collectors cannot be shaded by one another during the critical collection period. Figure A-7 shows the spacing required to avoid shading from 10:00am to 2:00 pm on December 21 at various latitudes. The corresponding ratios of collector area to surface area are also given. In the 40° latitude example a collector surface area equivalent to 40 percent of the surface area is available on space frames supporting collectors above the ground or on the ground surface itself. A collector area equivalent to 48 percent of the roof area is available on flat roof tops oriented within 25° of south.

Figure A-8 illustrates the major spatial requirements of collector banks necessary to minimize shading of collectors by one another, possible collector locations, and the resulting proportion of a given area that is available as collector area. In this analysis it is assumed that collector banks are spaced as in Figure A-7. Although this configuration results in shading of collectors for 20 percent of the heating season collection hours, output for a given surface area, e.g., roof, is greater than if collectors were spaced to avoid shading for a greater portion of a winter day.

It is also assumed that collectors would be placed on space frames when site area is being used for some other purpose, e.g., as a parking lot, and on fences or other on-site structures, e.g., carports and parking structures. Figure A-8 depicts some typical collector locations.

¹A report prepared by the American Bar Foundation identifies a period of time in its definition of "solar skyspace" as: "That three-dimensional space extending from a collector to the location of the sun between 9:00 am (8:00 am for cooling) and 3:00 pm (4:00 pm for cooling) solar time; and where a solar energy system is utilized for heating to all locations of the sun between September 22 and March 22; where a solar system is utilized for cooling, to and where a solar energy system is used for heating and cooling or for hot water uses to the location of the sun throughout the year". (Miller, 1977).

Rooftop skyspace at 40° N. latitude

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Figure A-6

Figure A-7

Collector Area as Proportion of Surface Area

	Latitude		
	30°	40°	45°
Ground Plane	.50	.4	.33
Spaceframe; Fence			
Rooftop, due south	.60	.48	.40
Rooftop, $\pm 45^\circ$	.50	.4	.33

Collector Spacing and Location

Latitude-determined spacing to avoid shading 10 a.m.-2 p.m. December 21

Figure A-8

Locations

Ground plane

Space frames over ground frames

Fences

Rooftops

Due South orientation

South $\pm$ 45° orientation

Table A-1 indicates the proportion of end use energy that each system is capable of providing. The proportion of total energy demand these end uses represent varies with the energy use mix specific to each land use type.

Table A-2 summarizes assumptions regarding system efficiencies of direct solar technologies. For collectors located in banks and spaced to provide for insolation from 10 am to 2 pm on December 21, shading of collectors by one another reduces the amount of energy collected during the heating season (October through April) by 20 percent.

Table A-1

Percent of End Use Energy Provided by Direct Solar
Energy Supply Systems

System	Heating	End Use		Power and Lights
		Hot Water	Cooling	
1	70	80	70 ¹	0
2	70	80	70 ¹	0
3	70	80	100	100
4	100	100	100 ¹	0
5	100	100	100 ¹	0
6	100	100	100	100

Note: 1. It is assumed that thermal air conditioning would be used in the commercial sector only.

Table A-2

Conversion Efficiencies of Direct Solar Technology Systems

	Thermal Collectors	Cogenerating Photovoltaics
<u>Average collector efficiency:</u>		
Electrical conversion	N/A	.09 ¹
Heat collection	.4	.32 ²
Efficiency of heat transport and distribution	.8	.8
Efficiency of long term heat storage	.8	.8
Increased output with improved technology and reflectors	2.0	N/A

Notes: 1. 80 percent of non-cogenerating cell's efficiency of .12.
2. 80 percent of a thermal collector efficiency of .4.

A volume of space is required for the location of a storage tank. With short term storage, 1 to 2 gallons per square foot of collector is assumed. For a 550 square foot collector (which at 40 percent collector efficiency and 20 percent heat loss during distribution would provide 75 percent of the heat load of a 1300 square foot single family detached residence) with a heat load of 50,000 Btu per square foot per year this is equivalent to 100 cubic feet or a tank 5 feet in diameter and 5 feet tall. The other system components have no unique spatial requirements. Storage volumes as small as 4 gallons per square foot of collector area can provide 100 percent solar heating for an individual house in the United States (Lovins, 1978).

Thermal Collector System Performance Using Short-Term Heat Storage

To simplify the analysis of solar potential, values for collector area and proportion of heat load provided that were developed in a study of 12 climatic regions (ITC, 1976) are used. These values are based on the assumptions that the collector's effective absorptance-transmittance product at zero incidence is 0.75 and collector efficiency is approximately 0.4. Performance calculations were carried out on a monthly basis. It was assumed that "all the heat collected during any month is either fully utilized or the excess is not carried on to the next month." (For a complete listing of assumptions see ITC, Vol. 3, pp. 41-43 and p. 53). Values were modified to a collector tilt angle of latitude plus 0° for optimum year-round collection. These values are used for both commercial and residential structures since performance is calibrated by heat load per unit floor area. Collector area relative to proportion of heat load values derived from ITC were within 10 percent of the values derived using the method developed by Balcomb at Los Alamos Laboratory which assumes "typical" flat plate collector characteristics and that distribution system heat loss flows into the structure.

In the ITC analysis the proportion of the cooling load that could be met was determined for a collector area that would provide 70 percent of the heating load. In this analysis the potential for solar air conditioning in single family residential units is not considered since the most viable technology, absorption air conditioning, is not likely to be economic at that scale for some time. (The components are not only costly but also consumptive of space.) In commercial structures, particularly existing ones, cooling consumes a significantly larger proportion of the total energy

demand than heating. The use of solar-driven air conditioning is assumed to be likely at this scale and is therefore included in the determination of solar reliance. In cases where a limited amount of collector area is available, solar energy is likely to be used in conjunction with a heat pump in a "total energy system."

In ITC's analysis, the cooling load was assumed to consist of two components: one fixed and one proportional to the number of cooling degree days. The load for buildings requiring "general comfort" control, e.g. offices, is $5100 \text{ Btu/ft}^2/\text{month} \times 17.2 \text{ Btu/ft}^2/\text{cooling degree day} \times \text{cooling degree days}$. The coefficient of performance (C.O.P.) of absorption air conditioners is assumed to be 0.6.

Because less data is available on solar-driven air conditioning than on solar heating, it is difficult to quantify the potential for solar reliance on this technology in the next 50 years. In this analysis it is assumed that the values given in ITC's analysis apply proportionally to case study areas where the solar share of the heat load is less than 70 percent. For example, if the solar share of the cooling load is 50 percent when the solar share of the heating load is 70 percent, the solar share of the cooling load would be 37 percent when the solar share of the heating load is 50 percent.

Thermal Collector System Performance Using Long-Term Heat Storage

It has been estimated that with system efficiencies of 50 percent, sufficient summer surplus could be accumulated to increase the solar share of the domestic hot water (DHW) load and the heat load from 71 percent to 110 percent in Vancouver and from 64 percent to 93 percent in Toronto for a 1500 square foot structure with a heat load of $10 \text{ Btu/ft}^2/\text{degree day}$ and a collector area of 750 ft^2 oriented to maximize midwinter radiation reception (which greatly reduces summer collection) (Hay, 1976). Lovins documents other studies in which long-term or seasonal storage can provide 100 percent solar heating (Lovins, 1978).

Long-term storage, then, has the potential to nearly eliminate the need for back-up fuel. It may not be adopted in the near term in most United States climates due to its high cost compared to the incremental increase in heat load that is achieved. However, the fact that it is technically feasible suggests the opportunity for modifying a system with short-term storage at a later date in order to eliminate the need for a backup

Figure A-9

Neighborhood solar system installed by the San Berna Community Development Corporation.

XBL 798-2553

fuel source. It is important to note that if long-term heat storage becomes seasonal, it may eliminate or reduce the availability of solar heat for air conditioning or the use of the storage volume for chilled water storage.

To obtain a rough estimate of usable heat available with a system having long-term storage, the following method was used: direct and diffuse radiation was calculated hourly using ASHRAE clear day insolation and average hours of sunshine data. The useful energy collected for each hour was calculated and summed over all hours of the month and for all months of the year. It was assumed that energy surplus in excess of short-term requirements could be stored and made available with a 20 percent heat storage loss. (Hay, 1976).

Shared Energy Supply Systems

Shared solar systems combine the individual contributions of roof and/or ground mounted collectors, utilize common storage facilities and distribute heat via conventional district heating systems. The scale of such systems can range from a single block to an entire community. At the block scale, roof and ground area on residential parcels and/or undeveloped lots and public land could be used for collector location. The storage system might be located in the basement of a community facility, e.g., library, school or recreation center; on public land or a vacant lot, a park or a street intersection.

Shared systems have several potential advantages over individual systems. According to Lovins (1978) costs appear to be generally twice as low in neighborhood-scale systems (10^1 - 10^3 dwelling units) because the large shared storage tank has a very low marginal cost per unit of volume and very low heat losses, typically of the order of 5 percent per year. Lovins concludes that the system can therefore be operated on a true seasonal cycle using several cubic feet of storage per square foot of collectors. Because collectors can function at full capacity all year around, collectors can be sited with fewer restrictions on orientation and solar access. Structures with insufficient collector area for maximum individual solar heating can rely on collector area in other locations. In summary, shared systems can eliminate the need for a back-up heating source, reduce collector area and storage volume requirements, reduce impacts from placing collectors where physical constraints are present, and, at the same time, reduce costs.

An example of a small scale shared system is depicted in Figure A-9. This shared system was constructed during the renovation of ten small single family houses by the San Bernardino Community Development Corporation. At a slightly larger scale, a development was planned in Brookline, Vermont, designed by People/Space Company and engineered by Dubin-Mindell-Bloome Associates. Although the 20-unit development was never built, the solar system was designed to consist of 4500 square feet of collector area facing south at a tilt of 57° and using 15,000 gallons of storage in the form of water-glycol solution. A heat pump and an oil-fired boiler provide back-up system heat; wood burning stoves were to provide individual back-up heat.

Community-scale hot water/space heating systems are used in several northern European countries. The source of heat is generally fossil fuels or waste from industrial or electrical generator processes (Larsson, 1976).

In this analysis, Technologies 4, 5 and 6 characterize systems with long term heat storage. In low-density areas where each individual structure can provide 70 percent of its space heating demand on its own site, Technologies 4, 5 and 6 represent either on-site or shared systems. In high-density areas where some sites cannot provide 70 percent of their space heating demand on site, Technologies 4, 5 and 6 necessarily assume some use of shared systems. However, collector spacing and siting still assumes that only areas unshaded from 10 am to 2 pm on December 21 are used as collector locations.

Direct Solar Technologies for Industrial Applications

Three different solar thermal technologies have been selected for industrial applications based on two studies of industrial applications of solar energy (ITC, 1977; Battelle, 1977). These are: shallow ponds for low temperature applications (100°F and 125°F); flat plate collectors for 150°F ; and polar mounted tracking cylinder collectors for temperatures above 150°F but less than 550°F .

Table A-3 depicts the proportion of a given field area that can be utilized for solar energy collection if collectors are spaced to avoid shading of one another on December 21 from 10 am to 2 pm. Table A-4 expresses energy output per unit of surface area rather than collector area. This takes into account the spacing requirements in Table A-3 and shading of banks by one another (i.e., output is reduced 10 percent due to winter shading for all bank configurations and an additional 10 percent due to

summer shading for polar mounted collectors).

Table A-3

Direct Solar Energy System				
LATITUDE	POND	FLAT PLATES EVACUATED TUBES	POLAR MOUNTED PARABOLIC TROUGHS	EAST-WEST MOUNTED PARABOLIC TROUGHS
30°N	1	.5	.25	.5
40°N	1	.4	.20	.4
45°N	1	.33	.17	.33

COGENERATING PHOTOVOLTAICS

Cogenerating photovoltaic arrays can produce both electricity and heat (LBL, 1978)⁽¹⁾. The modules consist of single-crystal silicon cells on an aluminum structure. The array described is cooled by air flow. It is assumed a liquid cooling medium would be used to permit long-term heat storage. The heat and electricity obtained from the hybrid consists approximately of both 80 percent of the output of an ordinary thermal collector together with 80 percent of the electrical output of a heating non-cogenerating photovoltaic. The output for a given surface area could be maximized by placing the collector at a tilt of 4° from horizontal.

BIOMASS CONVERSION

15

To evaluate the use of biomass selected technologies are first matched to end uses. Wood burning stoves are assumed for residential applications at an efficiency of 60 percent (Sullivan, 1978). Municipal solid waste (MSW) is assumed to be the source for commercial applications. The pyrolysis process converts waste to low Btu gas which is storable and transportable and produces fewer residuals than other MSW conversion (LBL, 1978)⁽²⁾. For these reasons it is assumed to be the process used in the case study applications. System inputs and outputs are listed in Table A-5. Net energy production is 0.31 Btu/pound of MSW assuming a primary fuel to electricity conversion efficiency at 31 percent.

Table A-4 Output of Direct Solar Technologies for Industrial Process Heat Applications
Representative of Four Climatic Regions (Supplying 50% of Demand)

	10^3 BTU/ft ² of surface area/year										
	Temperature of Process Heat Demand Matched with Most Appropriate Technology										
	100°F	125°F	150°F	200°F		300°F		400°F		500°F	
	shallow ponds	shallow ponds	flat plates	concentrating (15X), tracking parabolic troughs							
				polar mounted	east-west mounted	polar	east-west	polar	east-west	polar	east-west
Minneapolis	165	145	72	62	92	60	89	55	81	49	73
Baltimore	165	145	87	71	110	71	106	64	97	58	87
Denver	217	190	105	86	130	84	127	75	113	69	103
Houston	381	304	163	133	199	130	195	117	176	107	160

Table A-5 Inputs and Outputs per 10^{12} Btu Output in a Municipal Solid Waste Conversion Technology Using a Pyrolysis Process

Inputs	Quantity per 10^{12} Btu Output per Year
Land	20.71 acres
Capital	$\$36.82 \times 10^6$
MSW	1.45×10^5 tons (1.28×10^{12} Btu)
Electricity	1.59×10^{10} Btu
(Primary Fuel)	(4.97×10^{10} Btu)
Oxygen	2.9×10^4 tons (2.83×10^{10} Btu)
<hr/>	
Outputs	
Iron	8.5×10^3 tons
Slag Aggregate	2.96×10^4 tons
Water Condensate	4.3×10^4 tons
Dry fuel gas	9.29×10^4 tons (1×10^{12} Btu)

Source: LBL (1978) ⁽²⁾

WIND ENERGY CONVERSION SYSTEMS

Wind energy conversion systems (WECSs) are likely to be located outside of the community with power delivered through the grid in order to maximize wind velocity and minimize impacts. Since the grid is available as a distribution mechanism, it makes sense to use relatively open, available and inexpensive land beyond the periphery of the city. (Malver and Overom, 1976)

There are definite disadvantages of using WECSs in urban settings. Many of them result from the spatial constraints of the urban environment on WECSs operation:

- The disruption of wind flow by structures which hinder optimum power production;
- Spatial requirements for buffers against noise or accidents (There was one case of structural failure at a 1,250 Kw wind machine in 1945);
- Concern regarding "aesthetic impacts" especially in urban locations.
- Engineering limitations on the location of WECS on buildings, especially already existing buildings.

(It is usually necessary to mount the roter at least 30'-40' above the ground in an exposed area to achieve good results. It is not very satisfactory to mount the windmill on a rooftop since the flow of wind immediately above the roof's surface is turbulent; and there may also be dangerous stresses imposed on the roof structure by the machine in high winds.) (Steadman, 1977).

On the other hand, increased turbulence in urban areas can be exploited. Wind tunneled between structures or into volume near the top of a structure could increase wind velocity through a turbine (Coonley, 1976).

It is assumed, for the sake of this analysis, that some WECSs will be located within the community. In the high rise commercial and high density residential sectors, turbines might be placed within the new structures. In the other land use sectors, and as an alternative in the above sectors, vertical or horizontal blade machines might be located on towers fixed to the ground. An existing 200 kw is depicted in Figure A-10. Two scales of WECSs are evaluated in this study: a 100 kw machine, comparable in appearance to the machine in Figure A-10, which would be sited away from the community, and a 20 kw machine which would be used for on-site energy production. The performance of these two WECSs is described in Table A-6.

Figure A-10.

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75 ft. wind turbine at Gedser, Denmark,
in operation since 1957. The 200 kW
machine generates about 400,000 kWh/year.

Table A-6
Comparison of WECSs Performance (MWh/yr)

<u>Large Scale</u>	<u>10 mph</u>	<u>12.5 mph</u>	<u>15 mph</u>
- ERDA/NASA Model 0 100 Kw output at 18 mph rotor: 125 ft. diameter, 2 blades cut-in speed: 8 mph 40,000 sq. ft.	191	309	414
- F.L. Schmidt Gedser (Denmark) 200 Kw at 38 mph rotor: 70.75 ft. diameter, 3 blades cut-in speed: 11 mph 20,000 sq. ft.	148	208	426

Source: R.M.R. Higgin & C.K. Brown, "Preliminary Assessment of the Potential for Medium and Large Capacity Wind Generators Used as Fuel Savers for AC Diesel Based Power Systems in Ontario," Proceedings of ISES Conference, Aug., 1976.

<u>Small Scale</u>	<u>12 mph</u>
- Grumman 15 Kw at 26 mph	30

Source: Office of Energy Programs, George Washington University, Social Assessment of On-Site Solar Energy Technologies, June, 1978.

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Appendix B

Community Characteristics Influencing Solar Energy Use

INTRODUCTION

The characteristics and morphology of the city largely determine the type and severity of impacts from implementation of solar technologies. While governmental policies, legislative measures and implementation plans can be used to manipulate impacts, the present morphology of the city provides the physical context which will both encourage and discourage the use of solar technologies and shape the resulting impacts. Many of the potential impacts of decentralized solar technologies are inherent in the way solar energy is distributed inequally across the globe and captured with varying efficiencies by the different technologies. Community characteristics are expected to be important to both the feasibility and impact of solar technologies. These characteristics, organized into three categories, are listed below:

1. Natural Environment Characteristics

- Latitude
- Topography
- Climate
- Vegetation

2. Built Environment Characteristics

- Street Patterns
- Open Space Patterns
- Characteristics of the Structure
- Architectural Style
- Combination of Built Environment Characteristics

3. Social Environment Characteristics

- Community Identity
- Community Interaction
- Activity Patterns

Natural environment characteristics primarily affect the determination of energy demand but also enter the discussion of impacts with the presence of tree shading; these characteristics are implicit in the case study site selection. Built environment characteristics are incorporated into the definition of land use types used in the case study analysis. Building use, density, and construction materials affect energy demand while impacts result from conflicts with architectural style. Social environment characteristics significantly influence implementation policies and therefore influence physical impacts resulting from those policies.

NATURAL ENVIRONMENT CHARACTERISTICS

Latitude

The effects of latitude on solar feasibility are that as distance from the equator increases winter heat gain decreases, and as the altitude angle decreases, the shading effects of adjacent structures or natural features increases. The first of these effects directly influences solar insolation, endowing the more southerly latitudes with higher total insolation rates. The second effect is indirect but more significant to the kinds of impacts that will result from community form. Where the altitude of the sun is lower, the shadows are elongated and the potential shadows from nearby structures and trees will rob a particular parcel or roof collector of solar energy. Consequently, the importance of the relative density of land use, height of structures, or spacing and location of trees to solar feasibility varies with latitude. The significance of latitude to solar feasibility depends on the kind of direct solar technology employed.

The direct result of reduced insolation in the more northerly latitudes cannot be mitigated. When direct solar technologies employ long-term heat storage rather than short-term storage (usually two to three days) the significance of shading during the winter season may be largely ameliorated.

Topography

Topography affects solar feasibility in two ways: by restricting building and collector orientation and by directly blocking insolation. If solar collectors are placed on structures or independently on a slope greater than 15° , the orientation of the collectors is likely to be restricted by that of the slope. Buildings on slopes are generally oriented with the slope, (parallel to the topographic lines). Consequently, if the slope is facing south, the house will face south; if the slope faces north, so does the house. For passively designed structures, this is a significant limitation. If the slope is oriented more than 20° or 30° east or west of south, it may be difficult to construct large south-facing windows and with sufficiently large thermal masses. While it is possible to orient the structure south on a slope that is oriented east or west, it is likely to be considerably more costly due to the increased amount of grading and/or design adaptations of the building.

Topography can also affect solar potential by obstructing insolation in the same way a tree or structure would. This constraint is most severe

on north facing slopes and in canyons running east-west (having north and south-facing slopes).

Active solar systems are less likely to be constrained by slope aspect. Even if the house is fitted against a north-facing slope, a portion of its roof can still be oriented south. Only if the slope above the house is steep enough to cast a shadow on the roof top will the solar potential be affected by topography. However, trees on the slope above the house will be more likely to block insolation onto the collector surface than a tree of the same height on level ground.

Climate is the basic determinant of energy demand for space heating and cooling and of the solar energy supply. A basic tenet of solar design in architecture is that a different combination of climatic conditions require different design solutions.

One way to categorize the effects of climate on solar suitability is to determine the relative extremes in energy requirements for both heating and cooling. The combinations of these extremes (as well as their relative value) establish the connection between climate and the appropriate technological response.

A community with a small cooling demand and a moderate heating demand may:

1. Eliminate most of its energy demand through conservation measures and simple passive design adaptations;
2. Locate collectors to maximize winter energy gain.

A community with an extreme cooling demand and a small heating demand may:

1. Maximize passive techniques which remove heat from a structure (of current passive design techniques roof top solar ponds appear to be most effective for this climate), take advantage of natural ventilation, and use trees for summer shade, especially in residential neighborhoods;
2. Install collectors horizontally to maximize the summer energy gain for solar air-conditioning.

A community with no cooling demand but a substantial heating demand may:

1. Maximize conservation measures to eliminate heat loss;
2. Orient buildings south to permit winter heat gain using passive design strategies;
3. Locate collectors to maximize winter energy gain;
4. Resort to long-term heat storage.

A community with temperature extremes in both the summer and winter may:

1. Maximize the effective thermal mass of exterior walls to both prevent over-heating in the summer and retain heat gain in the winter;
2. Orient buildings due south for winter heat gain;
3. Provide shading of south walls in the summer;
4. Tilt collectors to latitude to maximize year-round energy collection.

Each locality will resort to a particular set of responses to mitigate its own climatic extreme. From the example it is clear that regulations intended to permit solar applications but control their potential impacts are likely to vary as well. Finally the resulting impacts themselves will not be the same in every community but will reflect climatic variation.

Davis, California, for example, has enacted an energy conservation and solar utilization ordinance that attempts to ameliorate the extremes in climate. In addition to measures aimed at improving energy conservation within individual residences, the ordinance controls the street widths, tree canopy, amount of paved area, and to some extent the orientation of streets and lots. Such controls will not be appropriate everywhere.

Another climatic characteristic influencing solar feasibility results from modifications to climate, particularly changes in the transparency of the atmosphere. A reduction in air quality can result in a reduction in the amount of radiation available to a solar collector. For example, in the Monomonee Industrial Valley where most of Milwaukee's industries are located direct beam radiation was 20 to 30 percent lower than at a nearby rural field station. Shorter wavelength (less than 525 mm) were affected most with direct beam loss exceeding 50 percent in many cases (Bridgman, 1978).

Vegetation

Vegetation can reduce solar potential by blocking insolation onto the site and/or structure. This is a difficult problem since trees constitute an amenity and can be used to reduce energy consumption. They can serve as windbreaks to reduce heat loss from buildings and can provide shade during the summer months. While deciduous trees only partially obstruct insolation in the winter when it is needed for heating, they could still present a problem if located on the south side of a building. Depending on the branching structure of the species, a deciduous tree without foliage

will reduce insolation 40 to 60 percent (McClenon, 1977).

Even if deciduous trees permit winter insolation on to a structure they may obstruct summer insolation. This is a beneficial passive design technique. However, it does eliminate the opportunity to use solar energy for air conditioning. A quantitative comparison of heat load reduction and consequent conventional fuel savings due to shading versus fuel savings due to use of solar air conditioning is needed to assess the trade-offs between these two techniques.¹

Similarly, more research is required to provide a quantitative basis for evaluating trade-offs between energy savings from windbreaks and solar heating or air conditioning. If winds from the south have to be buffered, the windbreak trees may cast shadows on the site in the winter; if winds from the east or west are buffered, the trees may produce summer shadows.

Vegetation constraints on solar energy use can be evaluated in terms of the period of time during which trees obstruct the solar skyspace. The constraint is most severe if insolation is obstructed through the middle of the day when insolation is greatest. If the collector cannot be relocated, trees would have to be removed or severely pruned. If solar access is obstructed for only a short period of time, the consequence will be less severe. In that case the effect of vegetation could be mitigated more easily by increasing collector area or by less severe tree pruning.

¹A forest of conifers or hardwoods will reduce the monthly maximum air temperature in the summer by about 10°F below that in the open. At the same time, temperatures are higher in urban areas than in the surrounding countryside due in part to the relative absence of vegetation and consequent lack of evaporative cooling. "Mean monthly temperature differences between city and country in summer are about 2°F" (Kratzer, 1956, in McClenon, 1977). However, much greater differences occur in hot calm weather. . . ." Kratzer (1956), in McClenon, 1977) showed diurnal temperature variations for the locations in Vienna: an avenue with trees, a large square without trees and a narrow street (surrounded by tall buildings). A study of San Francisco on March 26, showed that Golden Gate Park was 15° cooler than the surrounding city (Federer, 1971, in McClenon, 1977).

BUILT ENVIRONMENT CHARACTERISTICS

The man-made environment imposes limitations on solar feasibility and determines the nature and extent of the impacts resulting from implementation of solar technologies. Large parcels of land which have not been subdivided provide maximum flexibility, while the typical street pattern and arrangement of buildings and parcels in already subdivided areas of cities reduces flexibility.

Street Patterns and Resulting Lot Orientation

One of the most important characteristics of the built environment is the street pattern or gridiron. Two features of the street pattern in any city determine the effectiveness of solar energy technologies: the shape of the gridiron and street and lot orientation. The grid provides the basic arrangement, size and shape of parcels by defining the streets. As the number of streets per unit area increases, the parcel must decrease and the grid becomes more finely dissected. This often corresponds with an increased intensity of land use; the increased demand for floor space on the small parcels lead to taller buildings on the same site, a case well illustrated by Manhattan. A finely dissected grid is clearly less useful for utilizing solar technologies for several reasons. First, the typically taller buildings produce more severe shadow problems. Secondly, the ratio of roof area--i.e., solar collector area--to the building volume is low. The tall narrow buildings have more floor space with correspondingly greater demands for space heating and cooling and hot water and insufficient roof area to meet the demand. Given these problems, it is important to note how changing the street pattern can permit significant changes in the shape of the built environment with no loss of floor space. As an example (Martin, 1972):

Consider an area of the city. Seen on plan there is an absolutely even pattern of rectangular sites. Now assume that every one of those sites is completely occupied by a building, and that all of these buildings have the same tower form and are twenty-one stories in height. That would undoubtedly look like a pretty full occupation of the land. But if the size of the road net were to be enlarged by omitting some of the cross streets, a new building form is possible. Exactly the same amount of floor space that was contained in the towers can be arranged around the edges of our enlarged grid then the same quantity of floor space that was contained in the 21-story towers now needs only 7-story buildings. And large open spaces are left in the center.

This example demonstrates the role of the grids in relationship to sun rights and the land use intensity. Larger blocks can result in more solar energy collection and result in fewer impacts if they are used in conjunction with more uniform building heights (to reduce shading) and a net reduction in street area (to increase available roof top collector sites).

Street and lot orientation is the second aspect of the gridiron of interest. An east-west orientation in the street pattern is more effective for utilizing insolation because it increases the amount of south-facing building area. Insolation onto a vertical surface (passive solar window and wall) or a tilted surface (active solar collector panel) decreases as orientation deviates from due south. To maximize efficiency and minimize cost, collectors or passive walls should be oriented as close to due south as possible. If the parcel is oriented within 25° of north, south, east or west, the structure will probably be well oriented for roof top solar utilization, even if solar orientation was not a planning or design consideration.

Urban tracts subdivided subsequent to the United States Land Survey and prior to the 1960's largely consist of parcels oriented north-south or east-west. These lots and the houses on them are ideally oriented to take advantage of solar energy. With the advent of curvilinear street designs in the late 1950's and its continued use to the present, the large number of single family units that were constructed during that period have no "typical orientation." Consequently, most new tracts of single family detached units consist of houses oriented in a range of directions. The suitability of retrofitting such tracts may be reduced by the poor orientation of many of the houses, though the generally larger size of these post-1960 single family dwellings does permit a larger roof area on which to locate collectors.

It is important to emphasize that although orientation does affect the amount of collector area required to collect a given amount of heat, poor orientation does not prohibit use of solar technology. Rather, it increases the collector area needed, and therefore, the cost of achieving a desired level of solar reliance.

Other Constraints on Structure Orientation

Zoning for detached single family developments defines relatively inflexible relationships between structures by establishing restrictions. Subsequent subdivision mapping establishes the orientation and dimensions

of parcels which are characteristic of many suburban communities. Construction of streets and utilities finalizes that form. Once these commitments have been made, maximization of energy conservation and solar energy use is more difficult.

On the other hand, if a parcel of land is zoned for construction of a planned unit development (P.U.D.) or for clustered residential development,² energy conservation and reliance on solar energy can be optimized through site planning and design. Structures can be oriented to maximize insolation, attached and/or clustered to minimize heat loss, or sited in a configuration that minimizes the obstruction of solar access.

In situations other than PUDs the potential for adjusting the orientation of a structure away from that of the lot is limited by the dimensions of the lot and by zoning restrictions. For example, new residential subdivision parcels in California are typically at a net density of 6-8 dwelling units (d.u.) per acre and have dimensions of approximately 50' x 80' to 50' x 100'. In older urban areas, lots may be smaller, with net densities of 8 d.u./acre to 14 d.u./acre. A density of 14 d.u./acre results in parcels with dimensions of about 30' x 70'. Parcels in outlying areas are frequently larger, ranging from one to four dwelling units per net acre.

Common combined sideyard setback restrictions on a 6-8 d.u./acre parcel are as much as 15 feet, with a minimum of 3 or 4 feet on either side depending upon the community and the age of the development. On a 50' wide lot, this leaves a width of 35' for one dimension of the house. The addition of an attached garage and a front yard setback of 15 or 20 feet provides little flexibility for reorienting a typical tract house. A custom designed house could be adapted to achieve optimal orientation, even on a 50' x 100' parcel, particularly if it were a two-story structure. In general, flexibility increases as lot size increases.

Open Space

Just as the grid of the city streets determine parcel size and arrangement, it also bounds the open space. Large areas of open space are in fact interruptions to the finely dissected grid pattern (for example Golden Gate Park in San Francisco) but more of the open space in cities is in

² A cluster development is one in which a number of dwelling units are grouped, leaving some land undivided for common use. It may mean grouping the same number of units in a given area on smaller than usual lots. The cluster approach increases design flexibility. The total project is evaluated and approved by the local permitting agency rather than requiring compliance with zoning or subdivision regulations. Planned Unit Developments are similar to cluster development but at a larger scale and include commercial and industrial as well as residential land use (DeChiara, 1975).

smaller units of one to several blocks such as neighborhood parks or cemeteries. Finally, a significant amount of open space in cities falls into a category of "left-over" spaces: under-utilized land between structures and narrow strips of often unkempt, forgotten rights-of-way, alleys or parkways. A substantial portion of the areal surface of cities is claimed by the setback. The sideyard setbacks alone can account for differences in gross suburban densities of several dwellings per acre.

There appears to be substantial opportunities for utilizing open space in cities for the collection of solar energy. Two important determinations in the feasibility of using open space for energy collection are: 1) the pre-emption of an existing use; and 2) the spatial proximity of the open space and energy-deficient activity. In the first case, the potential economic return of solar collectors must be balanced against other uses, and in general, large areas within an urban area will generally have land values that preclude their use as energy collectors. It will likely be the smaller, left-over spaces that have little economic value that will offer the greatest opportunity for the collection of energy.

However, if energy collection can be integrated with other land uses, there exists the possibility for utilizing open space resources. A large flood plain that is protected from urbanization and is unused or developed as recreational space may also be fitted with wind generating towers, or if structural costs can be kept low, solar collectors can reasonably be integrated into large parking lots by attaching them to light, space-frame structures.

The second determination of the feasibility of open-space pre-emption will result from the proximity of energy deficient activities. Since most low temperature energy technologies are limited by the distance over which energy can be efficiently transported, the flexibility of pre-empting open space for energy collection will result from a proximal need. It may be in a community's interest to locate solar collectors on a portion of a neighborhood park to provide heated water for the adjacent recreation facility.

Characteristics of the Structure

Characteristics of the structure itself impose direct constraints on the use of solar technologies. This is particularly true for passive design since structure and technology are one and the same. The characteristics discussed thus far can be directly manipulated to increase the feasibility

of passive and active solar reliance in new developments. Once a structure is built without incorporating conservation or solar energy use as a design consideration, it has to be retrofitted with solar technologies. At that point in time, its established form and orientation determine the extent to which it can be retrofitted and the cost of doing so.

Retrofit with passive elements would be fairly costly, at least for those techniques currently used, unless substantial renovation were being undertaken. Each situation is likely to require a unique design solution. In the case of active systems the easiest place to locate a set of collectors is on a rooftop. Therefore the suitability of an existing structure for retrofit is constrained by the adaptability of the roof: its orientation, area and slope. For example, if a single family detached dwelling unit has 1600 square feet of floor area, a gabled roof would result in somewhat more than 800 square feet of area oriented in each direction. A hipped roof would have roughly 500 square feet in each section. Some roofs are flat, although this is less common for single family detached units than for any other building type. If a house with a flat roof were oriented within 25° of the cardinal directions, fully 100 percent of its roof area would be available as a site for collector banks. Even in these cases, though, only 40 to 50 percent of that roof area can be utilized as collector surface since the tilted banks of collectors must be spaced apart to prevent shading of one another.

Architectural Style

The constraints on solar feasibility imposed by architectural style and construction bridge the gap between physical and social impacts. Many authors have noted the structural problems of refitting an existing roof with a heavy collector panel (Westinghouse, 1974). But added to this are the problems of integrating collectors into the architectural style of a building. Skeptics have been eager to point out that the same conservationists who argue for government subsidy of solar technology will be the first to "preserve" their own residential neighborhoods from the visual "impacts" of a disagreeable super-structure insensitively applied to a facade or roofline. This assertion, though intriguing, has little evidence to support it. A recent assessment of social acceptability of direct solar technologies observes that, "On the whole, (environmentalists) found few problems associated with the model design from an environmental point of view. Several felt that the aesthetic qualities of the collectors could be improved, and that solutions to the constraints placed on the positioning

of the house should be sought" (Westinghouse, 1974). But the recommendations made by these authors to improve social acceptability are mostly confined to economic breakeven points or convenience and reliability issues. Only one directly addresses the connection to aesthetics, i.e., "solar collectors should be located on the roof of the building."

Most states have already encountered the conflict between the values of architectural preservation and the health and safety requirements of emergency egress or access for the disabled. California has endeavored to adapt its building code to reconcile these values. Architectural preservation codes, though a specific case, illustrate the need to anticipate the potential conflicts between neighborhood renovation and the implementation of solar technology in order to avoid impacts on architectural style. Few communities investing in neighborhood restoration will want to see solar collectors disfigure the architectural integrity of a roofline or corniceline.

Neighborhood preservation has intrinsic energy conservation potential. The reuse of existing structures eases the demand on new construction materials. And where the renovation occurs in older, more densely built environments, the opportunities for transportation savings also increase. In order to promote these efforts at neighborhood renewal, HUD has developed several programs designed to funnel money into rehabilitation. One of these programs involves the designation of historic districts. And even where these "historical" values are not explicit, they are often presented to help justify the suitability of a particular neighborhood for rehabilitation. Refitting densely built urban neighborhoods with roof-top collectors may in many cases prove to be a conflict between energy conservation values and neighborhood aesthetics complicated by the energy savings that result from reusing sunk investments in construction.

Where rehabilitation involves substantial structural modifications, or where the individual structures have large flat roofs several floors above the street level and behind sight lines from the street, new technologies can be more easily integrated into a structure with the minimum visual impact. Indeed, where the scope of the rehabilitation presupposes the involvement of trained professional designers rather than the home-repair market, more attention will likely be directed toward a successful visual integration of the new technology.

Ultimately, the effect of solar technologies may be to change the society's aesthetic consciousness. Thayer (1978) has proposed that innovations in landscape design for energy conservation acquire symbolic aesthetic

meaning, and in doing so, function as cultural symbols to influence resource-conservation behavior. He has coined the term "conspicuous non-consumption" to convey a shift in value as much as a changing aesthetic in response to energy conservation consciousness.

Combination of Built Environment Characteristics

As the previous discussion indicates, several types of environmental characteristics influence the feasibility and the impacts of using solar technologies. The presence of some of these characteristics by themselves pose limitations but the coincidence of characteristics may also make the use of solar technologies more difficult.

For example, shadows cast on a site by trees, other structures, or by topographic forms always constrain solar feasibility. However, poor slope aspect is only a problem where lot orientation is also less than optimal or where lots are narrow. In such cases, it may be particularly difficult to shift the structure from parallel alignment with the lot lines and still maintain sideyard setbacks. On a typical 50 foot wide lot, a detached single family structure 35 feet wide has little flexibility in orientation.

SOCIAL ENVIRONMENT CHARACTERISTICS

The social environment is perhaps less visible as a constraint on solar energy reliance but may ultimately be more potent than either the natural environment or the built form. Patterns of social interaction are both culturally based and highly personal. Adaptability to certain technological changes will often be unpredictable. Still, certain culturally imbued patterns necessary for community identity, community interaction, and the pursuit of social and economic activities will respond to a decentralized solar energy technology.

Community Identity

Several salient points can be made about the role of community identity and its implications for using solar energy technologies. Part of a community's identity is tied to the image that the residents have of the city and of themselves (Lynch, 1962). The image of the city deserves attention in that those physical features of the city which are well known and relied upon by residents, e.g. landmarks and nodal centers, are not likely to be radically changed in order to implement solar technologies. In particular, any features bound into the historic identity of the city should be preserved in planning the strategies for implementation. Any site that is registered as a national or state historic landmark site as well as locally famous places that may not

be explicitly set aside as historic, e.g., People's Park in Berkeley, might be excluded as sites for solar technologies in order to avoid impacts on community identity.

The image that the residents have of themselves as a community as well as individually will determine if there will be "conspicuous non-consumption," (blatant use of solar apparatus as a status symbol). The questions arise, will residents want to display or conceal their solar equipment? And which residents are likely to adopt solar first? That is, who will be the innovators? This will probably vary from city to city. Thus community self-identity is likely to be a factor in determining which implementation strategies are the best and which rates of penetration are likely to occur. Finally, established, standardized formats of community change in the built structure--such as urban redevelopment projects, commercial revitalization projects, housing projects and campaigns to bring buildings up to code--could be tied into the planning strategies for solar technologies. These aspects of community identity will in the long run, affect the rate and success of implementation strategies and determine many of the impacts.

Community Interaction

The role of community interaction in the use of solar energy may be crucial if shared systems are needed to meet the energy demand. In conceptualizing community interaction, the types of community arrangements include cooperation and the willingness of subsets of the population to make a commitment to accomplishing the required goals. These interactions might result in local organizations of people with common interests as well as neighborhood groups of individuals who are spatially bound to each other.

In addition to this obvious aspect of community interaction, there are two others which may be required. First, education and information dissemination become important. Members of the community who are aware of benefits or negative impacts of solar technologies will need to use some type of community interaction--city-wide meetings, block groups, etc.--to convey their ideas and information. This relates to the second important aspect of community interaction, the physical and time resources necessary to accomplish the interaction (Hagerstrand, 1975, and Pred, 1973). In the case of neighborhood cooperation, it means needing people who have the time to meet and the financial resources to back cooperative efforts as well as individual ones. Having meaningful interaction necessitates

coordination of resources and people. The questions of which people, how many, and where they are spatially located are important. An unanswered question involves what segment of the population will invest the time required to achieve a consensus among individuals to establish a cooperative district system. Will that segment be a unique age/income group or an institutionally defined service industry? It is valuable to recognize these issues for community interaction will be crucial to any implementation scheme.

Activity Patterns

The activity patterns of the city describe the flows of people and goods over space, and these patterns are reflected against the background of the land-use patterns. In a city where land uses are segregated, there is likely to be more movement over space to accomplish business--for example, a household member must leave the residential area for shopping trips and the journey to work, whereas areas of mixed land use would make a different set of activity patterns. The physical resources, especially transportation choices which are available to an individual, in conjunction with the needs and desires of the population for goods and services will set the patterns for activities (Hagerstrand, 1975). A series of questions about the influence of these patterns may be raised: How do activity patterns predetermine energy use? How might these patterns particularly influence the cities' adaptability to solar technologies? And how might those patterns be adjusted to increase solar reliance.

Investigations into "flexible scheduling" of city functions have been conducted to determine whether accessibility can be increased by avoiding peak traffic congestion. But flexible scheduling will affect on-site as well as transportation energy demands (Burns, 1977). The trade offs between these two types of energy consumption have to be weighed in comprehensive calculations of energy consumption.

Whether or not contemporary cities would effectively mix land uses within the same structures will depend on the kind of activity, the scale of operation, and the social setting. Developers of large structures have become so specialized that it is currently difficult to mix residential and commercial development in the same building.

Finally, several innovators have shown that substantial energy conservation as well as passive solar design can be achieved in underground structures. The benefits of building "down" rather than up are generating very strong adherents. South facing glass-walled structures insulated by earth

on three sides as well as on top have been constructed to house individual families as well as offices. Williamson Hall of the University of Minnesota (Minneapolis campus) provides an excellent example of the practical changes in form that are the consequences of solar energy utilization. The potential modifications in activity patterns in a community gone "underground" are not yet widely discussed but changes in pedestrian circulation patterns, in indoor-to-outdoor functional relationships, as well as image could all be important. Passive solar design has the potential, particularly in residential architecture, of altering the life patterns of the house's inhabitants. Those portions of the home that function as energy collectors will take on the dynamic properties of the diurnal passage of the sun. Heated core areas will acquire attributes different from perimeter spaces that automatically "zone" the interior for suitable activities.

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Appendix C

Generic Impacts of Decentralized Energy Technologies

ENVIRONMENTAL ASSESSMENT AND ENERGY PLANNING

Environmental impact assessment generally includes three essential steps:

1. description of the "host" environment;
2. description of the project and its physical requirements; and
3. identification (either by measurement, literature review, or speculation) of direct changes in the environment likely to result from the project.

An optional fourth step, neglected in many assessments, is identification of secondary and tertiary changes resulting from the first order impacts.

A broader perspective has been adopted by Holdren in his work for Distributed Energy Technologies in California's Future (1978). Holdren's approach has been to synthesize existing quantitative information and more speculative assessments of energy technologies. Eleven categories of impacts were established, and the severity of impacts for each technology and category of impacts was tentatively ranked on a scale of 1 to 5 (see Table C-1). Holdren does not provide a total score for each technology, nor does he contend that his rankings are absolute. He notes that "identical numbers should not be taken to mean an exactly identical magnitude of impacts." (Holdren, 1978). Despite this caveat, several conclusions can be derived from his analysis.

One can readily infer that coal-based technologies have the most disruptive ecosystem effects, while nuclear technologies pose the most severe threats from sabotage and direct links to war. Of the renewable, solar-based technologies, biomass farming would require the most significant land and water use, wind generators would intrude most into the visual landscape, while direct and passive solar technologies could result in low order safety risks, land use pre-emption and visual intrusion.

As an overview of the classes of impacts expected to result from energy generation technologies, Holdren's discussion represents an appropriate framework for a more detailed analysis of specific impacts. His work is also useful in that, unlike most traditional assessments, it extends beyond the consequences of an individual project. From the standpoint

Table C-1

Tentative Rankings of Environmental Impacts of Alternative Energy Technologies for California*

	LAND USE	WATER USE	USE OF NONFUEL MATERIALS	OCCUPATIONAL HEALTH	SMALL ACCIDENTS (PUBLIC)	LARGE ACCIDENTS/ SABOTAGE	EMISSIONS/PUBLIC HEALTH	EFFECTS ON CLIMATE	EFFECTS ON ECOSYSTEMS	AESTHETIC EFFECTS	DIRECT LINKS TO WAR
PASSIVE SOLAR HEAT/COOL	1	1	2	1	1	0	0	0	1	1	0
ACTIVE SOLAR HEAT	2	1	4	2	2	0	1	1	1	2	0
ACTIVE SOLAR COOL	2	2	4	2	2	0	1	1	1	2	0
SOLAR THERMAL ELECTRIC	4	3	5	2	1	0	1	2	2	3	0
ON-SITE WIND	2	0	2	1	3	1	0	1	2	4	0
CENTRAL WIND	4	1	3	2	2	1	1	2	3	5	0
LARGE HYDRO	4	5	3	1	1	5	1	2	4	5	0
SMALL HYDRO	3	4	3	1	1	3	1	2	3	3	0
BIOMASS WASTE	1	1	1	3	3	1	2	1	2	1	0
BIOMASS FARM	5	5	1	3	3	2	3	2	4	3	0
GEO THERMAL HEAT	3	1	2	2	1	1	2	2	3	2	0
GEO THERMAL ELECTRIC	3	4	3	2	1	1	3	3	3	3	0
COAL CENT. ELECTRIC	4	3	3	4	4	1	5	5	5	4	0
COAL FLUID BED	4	3	2	4	5	1	4	5	4	4	0
COAL GASIFICATION	4	3	2	5	4	3	2	5	4	3	0
COAL LIQUEFACTION	4	3	2	5	4	3	3	5	4	3	0
GAS DOMESTIC	2	1	2	2	2	3	2	4	2	2	0
GAS IMPORTED LNG	3	1	3	2	2	4	2	4	3	3	3
OIL DOMESTIC	3	2	2	3	3	3	3	5	4	3	0
OIL IMPORTED	3	2	2	3	3	4	3	5	4	3	5
OIL SHALE	4	3	2	4	3	3	4	5	5	4	0
NUCLEAR LWR	2	3	3	3	2	5	2	2	2	2	5

* In each category, 5 denotes the most severe impact in this category, of the technologies considered. Thus there is always at least one 5, and the other values are scaled to it. 0 = negligible, 1 = small, 2 = moderate, 3 = considerable, 4 = large, 5 = worst. The divisions are necessarily coarse; identical numbers should not be taken to mean exactly identical magnitude of impact.

Source: (Holdren, 1978).

of community level impacts, however, Holdren's work like that of Amory Lovins is somewhat general.

This analysis attempts to link specific, documented impacts, broad generalizations about the consequences of using decentralized solar technologies, and the implications of these findings at the community level. Potential impacts identified in the literature are described in this section. These provide a framework within which to evaluate impacts in the case study settings.

Eight categories of impacts are used here to structure the assessment. In many respects they mirror Holdren's categories, but they have been revised to capture the consequences of the "softer" technologies: passive solar design, flat plate and concentrating solar collectors, photovoltaic cells, wind generators, and biomass conversion facilities. Small hydropower systems are excluded, as are biomass farms, and all the harder technologies. The eight categories of physical impacts are:

1. land use pre-emption and conflict;
2. water consumption;
3. water quality degradation;
4. air quality degradation;
5. infrastructure disruption;
6. safety hazards due to working fluids; and other hazards;
7. visual intrusion;
8. resource consumption.

The general approach taken in this review is to highlight those areas where the most significant community level conclusions can be drawn. Where possible, quantitative data were derived to illustrate the severity and significance of possible impacts. One section is devoted to each impact category. Not all technologies will be discussed, only those posing the most significant problems. A set of matrices organized by impact category, type of technology, and scale of implementation is included in the main body of the report. These matrices are intended to summarize and extrapolate the more specific discussions that follow in this appendix.

LAND USE PREEMPTION AND CONFLICT

Land use preemption or conflict with existing uses could occur to some extent for all technologies considered. The severity of the impact varies both with technology and with the land-use sector in which it is used.

Direct Solar Technologies

Possible impacts of roof mounted collectors in single family development include interference with optimum siting of TV antennae, loss of opportunities for water collection systems, and constraints on expansion or renovation of the structure by increasing system or construction costs.

If roof space proves insufficient to meet area requirements, collectors can be expected to be installed in frontyards, sideyards or backyards on raised structures. Although collectors may consume only a small portion of a development parcel, it must be a sunny portion. Therefore, collectors have the potential to pre-empt a wide range of sun-dependent uses including ornamental and edible garden crops, sunning and play areas, and clothes drying. Furthermore, pre-emption of opportunities for planting shade trees must be weighed against the energy savings due to their cooling effects.

Roof tops of multiple family structures, which are often flat, accommodate more outdoor activities than those of detached units. Conflicts would therefore increase as roof-top gardens and patios were pre-empted. If roof area is insufficient to meet energy needs in a multiple family case, then landscaped and parking areas could be used for an on-site installation but will require design adaptation. A space frame structure could alleviate interference with the existing uses by raising collectors above an existing use, but would result in shading of the ground area. Should combined roof and site area prove insufficient in a shared system the potential for off-site land use pre-emption arises. A broad range of public and commercial open space uses could potentially be impacted by an aggressive program of solar installation. In the multiple family row house case study the nearest open space available is a cemetery. There is also the possibility of appropriating a vacant parcel in an already developed area for collector banks. Such a strategy could have the combined effect of imposing considerable opportunity costs on the owner of the parcel and interfering with local planning efforts to encourage infilling as an alternative to sprawl.

Land use preemption in commercial strip applications could be expected to include parking and landscaped areas. Roof tops in commercial strips are seldom used for activities which would be restricted by collectors. In some cases physical elements such as signs or billboards may restrict collector location. Roof top mechanical equipment could restrict collector location but this conflict could be avoided by mounting collectors on space frames.

Potential land-use conflicts increase in the central business district. Only a small portion of the total energy demand can be met on-site. If sun-gathering space in neighboring land-use sectors were appropriated, impacts due to land use preemption would be shifted from the downtown properties to warehousing, industrial, or commercial areas that typically border central business districts.

Industries vary considerably in their process heat requirements, corresponding collector area, and available site area. In many cases, roof areas alone would prove insufficient, so a portion of the developed parcel would have to be allocated for the provision of low temperature process heat. Industrial sites near the core of older cities have to impose on adjacent parcels more often than industries on typically larger suburban sites. Newer industrial parks, whether in the suburbs or not, often feature large areas that are now devoted to parking and landscaping. These amenities could be impacted by an aggressive program of solar installation.

Wind Generator Interference with Television and FM Radio Reception

The observation that overflying aircraft can interfere with TV and FM radio reception has led to fears that wind generators might pose the same problem. Wind generators have indeed been shown to interfere with television reception in both theoretical calculations and experimental tests carried out under the auspices of ERDA (Senior, 1977). However, since the Federal Communication Commission (FCC) maintains records of home viewer complaints by type of interference (e.g., electrical) rather than source of interference (e.g., C.B. radios, power tools) there is no way to verify how important generator interference is in practice (Senior, 1977).

Television and radio signals vary in two respects: amplitude modulation (AM) and phase (frequency) modulation (FM). Tests have been conducted with phase and amplitude modulation devices to simulate modulations for a wind generator. FM broadcasts rely essentially on frequency modification; no distortion or interference has been documented from this source. (Senior, 1977). Audio portions of a television broadcast were interrupted by "clicking" only at the highest levels of modulation.

Amplitude modulation produced by wind generators, however, represents a potentially significant source of interference with the video portion of television broadcasts. Several levels of interference were identified, corresponding to the level of amplitude modulation. Subtle gray bands encroach on the image. As the amplitude increases, gray bands obscure reception to an unacceptable level and finally produce "snow" so dense that the image is

Table C-2

APPLICATIONS FOR CONSTRUCTION
OF NEW UHF TELEVISION STATIONS

	<u>On Hand</u>	<u>Received</u>	<u>Granted</u>	<u>Dismissed</u>	<u>Total</u>
December, 1977					
Commercial	76	8	2	3	89
Educational	<u>17</u>	<u>3</u>	<u>0</u>	<u>-</u>	<u>20</u>
Total	93	11	2	3	109
December, 1978				<u>Hearing</u>	
Commercial	153	11	0	2	166
Educational	<u>21</u>	<u>2</u>	<u>0</u>	<u>0</u>	<u>23</u>
Total	174	13	0	2	189

Source: Federal Communications Commission, Public Inquiries Office.
Interview, March 5, 1979 (Excerpts from the FCC Report).

Table C-3

STATUS OF UHF TELEVISION STATIONS

	<u>Licensed</u>	<u>Construction Permits</u>			<u>Grand</u>
		<u>On-Air</u>	<u>Interim</u>	<u>Off-Air</u>	<u>Total</u>
December, 1978					
Commercial	211	1	-	52	264
Educational	<u>151</u>	<u>5</u>	<u>2</u>	<u>4</u>	<u>162</u>
Total	362	6	2	56	426
December, 1977					
Commercial	209	2	-	45	256
Educational	<u>149</u>	<u>7</u>	<u>2</u>	<u>2</u>	<u>161</u>
Total	358	9	2	47	417
December, 1976					
Commercial	206	3	-	32	241
Educational	<u>148</u>	<u>5</u>	<u>2</u>	<u>6</u>	<u>161</u>
Total	354	8	2	38	402

Source: Federal Communications Commission, Public Inquiries Office.
Interview, March 5, 1979. (Excerpts from the FCC Report).

obliterated. Interpretive ratings of test viewers indicate that the modulation level at which reception became unacceptable stayed constant at about 20 percent and did not vary significantly with signal strength.

Modulation was found generally to decrease as a function of distance from a transmitter, so interference zones can be defined as areas where AM exceeds the .2 threshold level. Zones of interference are not actually circular, but vary with diffraction of blade-scattered signals as a result of topographic features as well as the natural curvature of the earth. In worst cases, interference over an area several miles from a wind generator could be expected.

More specifically, the formalized version of a zone of interference has been shown to vary as a function of the following variables¹ (FCC, 1979):

- TV channel frequency
- transmitter location
- transmitter-wind generator great circle distance
- transmitter power
- receiver location
- geometric area of generator blades
- wind mill tower height.

TV interference will be mitigated to some extent simply by divergent siting of the two types of facilities. In some medium sized communities, transmitters are located on the outskirts of cities. If they are located on windy ridgetops, the use of those sites for energy generation will be pre-empted. Such a condition prevails in Napa, California, a community of 45,000 that recently built its own UHF television station. This suggests that in the future, siting of television transmitters and wind generators will have to be coordinated because ultra high frequency transmissions are particularly vulnerable to interference.²

Data provided by the Federal Communication Commission's (FCC) Public Inquiries Office indicates that broadcasting on UHF stations is an increasing important form of media communication. Table C-2 illustrates that in

¹Senior, Sengupta, and Ferris have developed a series of linear equations to calculate interference zones based on these seven variables. In a sample calculation for a TV channel broadcasting 1 kilowatt at a frequency of 647 MHz, a receiver and transmitter located only 290 meters apart, a windmill tower height of 30 meters, and a blade area of 50 m², the zone of interference extends between 2.7 and 4.9 kilometers from the wind generator. pp. 153-154.

²The television broadcast band consists of 68 channels: very high frequency (VHF), 2 through 13 (54-72), 76-88, and 174-216 MHz) and ultra high frequency (UHF), 14 through 69 (470-806 MHz). (FCC 1976). Since experimental viewing and mathematical simulations demonstrated clearly that video distortion increases with frequency, it follows that the upper UHF channels can expect the worst interference. (Senior 1977)

December of 1977 the FCC had 76 applications on hand for new commercial facilities and 17 for new educational stations, while in December 1978, the number of commercial applications had nearly doubled to 153 (Griffith, 1979). Even if only a small portion of these new stations were constructed and subsequently licensed for operation, this would represent a considerable increase over the 211 licensed commercial stations and 151 educational stations now operating on UHF frequencies (Table C-3) (Senior, 1977).³

In light of the demonstrated ability of wind generators to interfere with UHF programming, and the emphasis on making these frequencies accessible to local communities, it appears that wind machines could have isolated but important community level impacts. Although it is difficult to project just how many stations or viewers might be inconvenienced, it does seem appropriate for communities to manage siting of wind generators in a planning process that also considers siting and construction of new UHF stations. In this way, locational conflicts which preempt siting of wind generators could be mitigated before they become serious.

Interference can also be reduced or eliminated through the use of a high performance directional antennae or through a connection with a cable service (Senior, 1977). Should a community make the decision to site one or several wind generating systems, consideration may have to be given to relocating television transmitters, compensating affected citizens, or encouraging or subsidizing cable transmissions.

³ During the 1960s and 1970s the FCC has consistently sought to emphasize control of programming on UHF stations by community based and/or educational organizations. In 1966, the FCC adopted a Table of Assignments, reserving 508 of 1089 allocated UHF stations for educational groups. (FTC 1979). In 1970 and 1975 the agency took action to limit regional concentration of ownership of UHF, VHF, and newspapers in order to bring about a diversity of voices and programming. Finally, the FCC administered a policy from 1960 to 1977 which required VHF applicants to demonstrate that they would not adversely impact UHF broadcasting. Recently this rule has been revised, in the case of a VHF station that demonstrated that it could increase public service by broadcasting on unused UHF frequencies.

WATER CONSUMPTION

Direct Solar Technologies

Table C-4 compares water demands of direct solar collectors in residential applications with typical household per capita water demands. Water demands vary with the technology employed, the type of storage incorporated in the overall design, and the climate of the area (which in turn determines heat demand). Another variable influencing residential water demand, structure size, is held constant at 1600 square feet in the example characterized in Table C-4. Thermal collectors with only short-term storage require about two gallons per square foot of collector area (Besant and Winn, 1976). This translated into 1200 gallons in a moderate climate enjoyed by cities such as Denver or Baltimore. Assuming an average daily per capita water consumption of 85-100 gallons (Dickert and Sorensen, 1976), and 3 people per dwelling unit, the water demand for the collector system on the single family house would be equivalent to only 4-5 days of water use. Significantly greater water demands occur with long-term storage. Depending on the size of the storage component, water requirements increase by a factor of 5 to 10, with a corresponding increase in water use (Besant and Winn, 1976). In an extreme case, assuming 20 gallons storage per square foot of collector area and average water consumption of 85 gallons per capita per day, the demands of the solar system would be equivalent to 47 days of water use. Similarly, demands increase in a very cold climate with a high heating demand. Since the collector area required to meet 70 per cent of home heating demand in cold climates increases from 600 to 960 square feet in the example, the equivalent demand rises to 7 days for the short-term storage system and 75 days for long-term storage.

These calculations have several implications at the community scale. While water demands for long term storage may seem large, they are essentially one-time requirements, or at most, requirements that must be fulfilled when collector systems are drained for maintenance or repair. In this respect, collector systems require less water than backyard swimming pools. The cumulative nature of these water demands would be felt most strongly if solar installation programs were carried out in such a way that all collector/storage systems were filled simultaneously. In communities where limited water is a constraint on new development, the timing of construction could be influenced, but the eventual density or extent of development would not necessarily be affected since collector demands are not continuous. A more

Table C-4: CHARACTERIZATION OF WATER DEMAND FOR DIRECT SOLAR COLLECTORS IN RESIDENTIAL APPLICATIONS

Technology	Water Requirements	Typical Collector Size, Denver/Baltimore Climate for 70% ² Reliance	Total Water Demand in Gals. Denver or Baltimore Climate/Equivalent No. of Person Days ⁵		Typical Collector Size, Minneapolis Climate, for 70% Reliance. ¹	Total Water Demand in Gals. Minneapolis Climate/Equivalent No. of Person Days.	
Flat Plate + Short Term Storage	2 gallons/ft. ² of collector area	600	1,200	12-14	960	1,920	19-23
Flat Plate + Long Term Storage	10-20 gallons/ft. ² of collector area	600	6,000	60-71	960	9,600	96-113
			12,000	120-141		19,200	192-226
Evacuated ³ Tubes with Seasonal Storage	10-15 gallons/ft. ² of collector area	600	6,000	60-71	960	9,600	19-113
			9,000	90-106		14,400	144-169
Evacuated Tubes Alone ⁴	2 gallons/ft. ² of collector area.	600	1,200	12- 14	960	1,920	19-23
		300	600	6- 7	480	960	10-11

¹Assuming 1600 square foot single family home.

²After meeting 70% of heating needs with flat plate collectors, the collector area required to provide each addition increment of heating demand is much greater, so 70% is used as a reasonable target.

³Typically can meet 100% demand.

⁴Can meet 70% demand with half as much collector area.

⁵First figure assumes a daily per capita water consumption of 100 gallons (100 gpcpd) (Dickert, Sorenson), the second figure assumes 85 gpcpd (Ritschard).

reasonable expectation is that the installation of systems will be phased to smooth or avoid peak water demands. The availability of a reliable backup source would mitigate the need for extensive long term storage.

Biomass Technologies

Water consumption requirements and resulting demand on community water supplies are potentially significant impacts of biomass conversion technologies. Of three technologies considered to be promising suppliers of energy from municipal solid waste (MSW), two will demand substantial and continuous quantities of water. In the waterwall incineration method of direct combustion, heat from burning refuse is converted to steam by circulating water in steel tubes which jacket the interior of the incinerator. This steam in turn is used for district heating or converted to electricity in a steam generator. Energy production from refuse-derived fuel (RDF) involves collection, shredding, sorting, and co-combustion of MSW with coal or oil in a boiler to produce steam electricity. The third system considered, PUROX pyrolysis, involves decomposition of organic material at high temperatures in either a low or oxygen-free environment. Unlike the first two systems, pyrolysis produces oil or gas, so that water is not required as a heat transfer medium.

Table C-5 displays a series of calculations that compare water consumption in biomass conversion facilities with that used in the individual collector panel systems required to supply equivalent amounts of energy. The key assumptions that go into these calculations are:

- All biomass conversion facilities have an operating energy requirement, so the net energy output is expressed as the base figure of 10^{12} Btu minus operating energy outputs.
- Calculations are based on heating demands of single family homes of 52,000 Btu/square foot/year; roughly equivalent to Denver and Baltimore climates.
- Typical house size is 1600 square feet.
- Water requirements of an individual collector system without long term storage are about two gallons per square foot of collector area.
- Water requirements for biomass facilities are continual, while properly maintained collectors should theoretically only have to be flushed once every four or five years.
- Collector systems and biomass conversion facilities are both being used to meet space heating needs only; electricity is not included.

As suggested by Tables C-4 and C-5 the relative impacts a community will sustain will vary significantly with the flexibility it has in selecting the mix and phasing of solar technologies. As with a large-scale program of collector installation, adverse impacts on community water supplies can be

Table C-5 Water Consumption Of Biomass Conversion Facilities

Technology	Net energy output	No. of homes served ^d	Total water consumption	Water consumption in equivalent use days	No. of homes served with collector panels with same water consumption ^g	Ratio biomass water consumption: solar panel water consumption with short-term heat storage for same energy supply ^h	Ratio biomass water consumption to solar panel w/10 gallons/square ft long term storage for same energy supply
Direct combustion (waterwall incineration)	90.82 ₁₀ ^a x 10 ¹⁰ Btu ^a	10,916	2.41 ₇ x 10 ⁷ gallons ^e	108	18,828	7.74	1.53
Refuse derived fuel	91.54 ₁₀ ^b x 10 ¹⁰ Btu ^b	11,002	8.87 ₇ x 10 ⁷ gallons ^f	397	69,297	28.35	25.15
PUROX Pyrolysis System	87.24 ₁₀ ^c x 10 ¹⁰ Btu ^c	10,486	None	0	---	---	---

Notes to Table C-5

- a. An operational input of 2.94×10^{10} Btu delivered energy is required (LBL, 1979). Since the conversion efficiency is .32, the primary energy input is $2.94/.32 \times 10^{10} = 9.187 \times 10^{10}$ Btu. Therefore, net energy output is 10^{12} Btu - 9.187×10^{10} Btu or 90.82×10^{10} Btu.
- b. An operational input of 2.71×10^{10} Btu delivered energy is required (LBL, 1979). Primary energy output is $2.71/.32 \times 10^{10}$ Btu, or 8.46×10^{10} Btu. Therefore, net energy output is $10^{12} - 8.46 \times 10^{10}$ Btu or 91.54×10^{10} Btu.
- c. An operational input of 1.59×10^{10} Btu delivered energy is required (LBL, 1979). Primary energy output is $1.59/.32 \times 10^{10} = 4.97 \times 10^{10}$ Btu. In addition 2.83×10^{10} Btu are required to pressurize oxygen gas. Therefore, total energy output is 12.76×10^{10} Btu or 87.24×10^{10} Btu.
- d. Assuming a heating load of 10 Btu/square foot/degree-day, total heating demand for an area with 5200 heating degree-days per year is 52,000 Btu/square foot/year. A typical house has 1600 square feet. Therefore, annual demand is $52,000 \text{ Btu/square foot/year} \times 1600 \text{ square feet} = 8.32 \times 10^7$ Btu/year.
- e. LBL (1979) gives the water consumption for a direct combustion facility as 1.008×10^5 tons for 10^{12} Btu output. 10.08×10^4 tons $\times$ 2000 lbs/ton $\times$ 1 gallon/8.35 lbs = 2.41×10^7 gallons.
- f. LBL (1979) gives water consumption as 169 gallons/minute. 169 gallons/minute $\times$ 525,600 minutes/year = 8.87×10^7 gallons/year.
- g. Assuming house size of 1600 square feet and a required collector area to floor area ratio of .4, the collector area requirement is $1600 \times .4 = 640$ square feet. The water requirements for an on-site system without long term storage are typically 2 gallons/square foot of collector area. Therefore, the total water requirements for an on-site system are 1280 gallons.
- h. Ratio is derived by dividing the number of homes served by collector panels by the number of homes served by the biomass facility with the same energy production. Assuming collector systems are flushed every four to five years (bosson, 1978).

mitigated to some extent by thoughtful timing of water consumption to avoid peak demands. From the standpoint of water consumption alone, the PUROX pyrolysis system would solve a lot of problems, since it requires no water for energy generation. Water consumption is of course only one consideration to be weighed, along with preemption of recycling opportunities, air and water pollution, land preemption, mechanisms for capitalizing new technologies, and relative maintenance problems.

WATER QUALITY DEGRADATION

Direct Solar Technologies

Potential water pollution impacts of thermal and cogenerating photovoltaic collector systems have been discussed briefly in the section on hazards of working fluids. Collector working fluids are generally esters or chlorinated hydrocarbons--substances not usually a part of the normal chemical makeup of streams or groundwater. Since the literature is sparse with regard to the aquatic toxicity of these materials, impacts are difficult to predict with certainty. However it is clear that water soluble working fluids are potential pollutants. The range of problems could include outright lethal impacts to aquatic life, contamination of potable water or edible fish, biological magnification of materials, increases in mutation rates, and impairment of reproductive, sensory, and other organ functions.

There are essentially two pathways through which a chemical could reach a water system. Perhaps the most likely sequence would involve flushing working fluids into a sewage system and subsequent discharge into receiving waters. Municipal sewage systems are not equipped to effectively treat what are basically industrial chemicals, so the materials could be expected to pass through a secondary or even tertiary treatment plant with no perceptible changes in toxicity or persistence. Moreover, the bacterial decomposer populations used to break sewage into more basic nutrients could be impacted by concentrations of collector working fluids.

A less probable route for surface and groundwater pollution would involve draining collector fluid directly onto the soil, followed by percolation or runoff. In addition to contaminating water systems, such an activity could impact backyard septic systems.

An alternative for disposal is house by house flushing and removal of working fluids using vehicles with pump storage tanks. This would eliminate

the threat to water quality from on-site disposal, but would still not resolve the ultimate disposal of working fluids and the effects of the possible mixing of several kinds of fluids.

Impacts on water quality may result from the effects of site preparation and construction of large-scale shared systems, causing erosion, sedimentation, and increased turbidity.

Centralized solar conversion technologies are expected to be located in areas with high insolation rates and low precipitation rates. These ecosystems are fragile and more susceptible to soil compaction, severe erosion, habitat destruction and reduction of wildlife diversity.

Thermal pollution is another possible threat to existing water quality regimes posed by both shared and centralized systems. Should the heat distribution system rupture as the result of poor construction, a drilling accident, or geologic instability, very warm water could be diverted into a stream or groundwater supply. If such leaks went undiscovered for some time, substantial changes in the aquatic ecology of an area could conceivably result.

Wind Generation

The site alteration and construction impacts described for large scale thermal collector and photovoltaic systems may result from wind generating facilities and their associated transmission lines. A first step towards mitigating these impacts is to integrate site suitability analyses into the process of solar siting. Geologic hazards, slope, characteristics of surficial materials and location of streams could be considered. Proper attention to the timing and configuration of grading can also eliminate erosion problems, as can reseeding and mulching.

Biomass Conversion Technologies

Of the decentralized solar technologies considered, the most severe water pollution impacts can be expected from biomass conversion technologies. There are two principal factors which increase the potential for water pollution significantly beyond those of other technologies: the sheer volume of water required and the composition of the waste that is converted into fuel. A technology characterization of a direct combustion MSW facility indicated that 2.41×10^7 gallons of water and an equivalent waste water flow can be anticipated from a facility that produces a net output of 10^{12} Btu/yr (LBL, 1978). That report notes that "while scrubber waste flow is acidic, high in dissolved solids and hardness, the

quench waste has a pH of 9.9, is high in suspended solids and 90°F at the outlet". This effluent could clearly be expected to prompt shifts in the aquatic ecology of receiving waters.

The waste water from a similar scaled refuse derived fuel facility amounts to 2.78×10^4 tons annually. Therefore the impacts would be substantially reduced. Water borne contaminants from this technology fuel conversion process are less noxious than those from direct combustion. They include sluice water used to hydraulically convey boiler residue to the ash disposal impoundment. Secondary sources of water pollution would include water leaching through disposal sites.

The PUROX pyrolysis process, offers several benefits over the preceeding technologies in terms of both residual characteristics and energy conversion efficiency. However, the following waterborne residuals are produced: mercury, zinc, nickel, lead, cadmium, waste heat, solubles, and sludges (LBL, 1978). Heavy metals, including the above, may be linked to organ disfunction in a variety of aquatic and marine life. They are difficult to isolate in waste treatment systems and often persist for long periods of time in the aquatic environment. Ammonia or methanol conversion in pyrolysis systems results in additional CO_1 , sulfur, NO_x nitrogen oxides, cobalt, and methanol.

AIR QUALITY DEGRADATION

Direct Solar

Improvement of existing air quality is one of the most significant benefits that accrue from a major commitment to solar reliance by reducing reliance on fossil fuel and coal-fired plants. However the manufacturing emissions of glass, copper and other collector components could be locally significant. Since these fabrication activities are likely to be somewhat centralized, there will be no real correspondence with impacts due to installation at the community level. One potential minor pollution problem is release of the vapors of organic chemicals as collectors are "outgassed" during maintenance and replenishment of collector working fluids. If the most benign are used, effects will be confined to minor odor problems. More volatile or toxic materials, if released to the atmosphere, could conceivably cause eye or skin irritation to those in the immediate area.

High ambient levels of air pollution can reduce collector efficiency. This could precipitate a decision not to site a large scale shared or centralized system in very smoggy areas.

The case study analysis indicates that to maximize solar reliance a community will need to prune, remove or restrict planting of large trees in single family neighborhoods. Large trees contribute to the purification of air in smoggy areas, (McClennon, 1976) and their absence would exacerbate air quality problems.

Wind Generators

Although wind generators contribute no pollutants directly to the air, the action of generator blades will affect localized wind regimes. In addition, large generators contribute to the suspension and dispersion of air-borne dust or spores. In very dry, dusty areas, wind generators could create or exacerbate a nuisance and/or health problem.

Biomass Conversion Facilities

Air quality concerns are more significant for biomass conversion facilities than other solar technologies. Even with the integration of the best available technology for electrostatic precipitators, direct combustion of municipal solid waste is expected to produce nitrogen/nitrous oxides, carbon monoxide, hydrochloric acid, ammonia, particulates from shredders.

Unlike direct conversion and refuse derived fuel systems, pyrolysis involves the high temperature oxidation of wastes to form an oil or gas product, and produces almost no stack emissions. This characteristic is one of the most notable features of the pyrolysis process making it less environmentally damaging than the other biomass conversion facilities considered.

Were a direct conversion or refuse derived fuel system's contribution of one or more pollutants to cause a community to exceed prevailing air quality standards, a number of different outcomes could result: 1. construction of the facility, may be delayed or halted; 2. siting of a polluting industry will be precluded where air quality standards ration a community's pollution; or 3. a polluting industry could help a community finance construction of a "clean" pyrolysis plant.

INFRASTRUCTURE DISRUPTION

Any of the solar technologies implemented on a shared or community scale have the potential to temporarily disrupt the service of underground utilities. Among the utilities now sited underground are gas lines, district steam lines (mainly in central cities), electric lines, sewer systems, water supply, telephone lines, cable television, and electrical connections for traffic lights, cable television, and electrical connections for traffic lights. The trend toward siting utilities underground is most predominant in new neighborhoods

and is likely to continue in order to upgrade aesthetic qualities of neighborhoods.

Shared thermal or cogenerating photovoltaic systems use water as a heat exchange medium and therefore require underground plumbing and excavation. If long-term storage is used additional excavation would be required.

Due to efficiencies of scale, biomass conversion facilities are likely to be more centralized than wind and direct solar technologies. Therefore, infrastructure connections for these installations might produce a single, large-scale disruption rather than many small interruptions in the performance of underground utilities. Waterwall incineration and refuse derived fuel processes both require substantial amounts of water, to produce electricity, so connections are needed to both utility networks.

Additional demands on road capacity could be initiated by a biomass conversion facility requiring large and frequent deposits of municipal solid waste. MSW facilities located to reduce long hauls to remove disposal sites, will reduce truck traffic. On the other hand truck traffic and contributions to congestion, waste, air pollution, and road wear, are all important considerations in MSW facility siting.

SAFETY HAZARDS

Toxic Impacts of Working Fluids

The safety hazards resulting from use of collector working fluids could pose a serious community scale impact. Working fluids have been employed to perform four essential functions in collector systems:

1. exchange heat from collector panels
2. prevent freezing of pipes
3. inhibit rust
4. control algal growth

Since each working fluid has different chemical properties, and since no "standard" group of chemicals has been adopted for household or commercial applications, it is difficult to forecast the consequences of use of these fluids with any certainty. However, the toxicological and environmental characteristics of specific chemicals used as working fluids have been identified.

Perhaps the most comprehensive review of liquids proposed for use as heat-exchange fluids has been carried out by Buchan, Majestic, and Bilau (1976). The findings of the report, which evaluates the toxicological properties of thirty-four fluids, is summarized in Table C-7 at the end of this appendix. Of the thirty-four fluids investigated, only nine were

recommended without reservation, another nine were recommended with some reservations due to the limited data available, three were found to have safety problems other than toxicological hazards, one was recommended only if extreme caution is used, and two were implicated as having unreasonably high toxicity and were therefore rejected.⁴

The Chemicals most recommended are, in order of preference:

1. Dibutyl phthalate
2. Butyl benzyl phthalate
3. O-dimethyl phthalate
4. Dimethyl-O-phthalate
5. Piperonyl butoxide
6. Di (2-ethylhexyl) adipate (DEHA)
7. Di (2-ethylhexyl) sebacate
8. Dibutyl sebacate
9. Petroleum.

The consequences of using moderately toxic compounds could be expected to vary widely with the concentrations employed and the nature of the work environment. At worst, the most toxic compounds have been shown to produce a diversity of ailments, ranging from eye irritation to kidney and liver disfunction, interference with oxygen-carrying properties of the blood, and even paralysis. A few have documented carcinogenic or teratogenic (mutation-causing) properties. If only the least toxic substances are used, hazards to human health should be limited to short-term irritation due to inhalation or contact with skin.

While human safety can be ensured if reasonable precautions are taken, the consequences of these chemicals in the environment are not well understood. Only two of the thirty-four substances, 1-1-2 trichloroethane and ONT, have been tested for their toxicity in aquatic ecosystems. Again, while generalizations are difficult to make, soluble chemicals are potential aquatic pollutants. Virtually no data have been compiled on the biodegradability or ability to be concentrated or "biomagnified" in food webs. These issues merit further investigation, especially in light of the prevailing lack of standards controlling discharge of collector fluids into waterways or onto landfill dumpsites.

4

In most cases, toxicity was evaluated from experimental data involving application of increasingly concentrated doses to laboratory animals, but in a few instances data from tests on human subjects or reports of industrial accidents were included in the assessments. Although it is difficult to make general statements about the toxicity of groups of chemicals, it is accurate to say that the esters (compounds formed by replacing a hydrogen molecule with an organic grouping containing two oxygen molecules) are generally less toxic than either chloriated hydrocarbons (chemicals containing carbon and chlorine) or aromatic amines (ring compounds that contain nitrogen).

Two additional hazards, flammability and explosive potential, have been documented for working fluids. Among the chemicals that have a flash point below the expected temperature of collector systems are methyl benzoate, divinyl benzene, isobutyl isobutrate, and creosote. Ethyl benzoate poses a fire hazard if heated to decomposition, and benzyl chloride could explode or produce toxic gas if employed in collectors. Cresyl diphenyl phosphate also represents a slight fire danger if heated. It is anticipated that these materials will be excluded from consideration as collector working fluids.

Community and State Regulation of Working Fluid Safety

Ken Bossong, Coordinator of the Washington D.C.-based Citizens Energy Project, has noted that California is currently the only state explicitly looking into the environmental and health hazards of working fluids (Bossong, 1979). According to staff of the Solar Division of the California State Energy Commission (Springer, 1979), the agency is "extremely interested" in safety issues surrounding deployment of solar technologies. But the only current studies of collector performance are focusing on collector integrity and efficiency rather than personal safety or environmental impact (Smith, 1979).

The agency is actively monitoring a controversy emerging in Los Angeles County over the safety of single-walled heat exchangers in thermal collector systems. Organizations that set and revise standards for new construction, such as the International Association of Plumbing and Mechanical Officials, have joined local manufacturers in their contention that single-walled construction is safe when used in conjunction with nontoxic fluids (Springer, 1979). The County Health Department has countered that even if single-walled heat exchangers are permitted in conjunction with nontoxic fluids, the fluid could be replaced with a more toxic substance later in the life of the system. Should the plumbing rupture, home-owners would be subjected to substantial risks from contamination of potable water supplies. In light of these risks the Health Department is seeking to restrict implementation of single-walled heat exchangers in the county. The City of Los Angeles has been the first to confront the issue of collector safety. The Los Angeles City Energy Coordinator is seeking to mediate the dispute and arrive at some compromise that will enable local manufacturers to continue their business (Brady, 1979).

⁵It is important to point out that no fluids are explicitly banned from use under the ASME proposal, even though the ERDA report cited earlier identified many fluids that are clearly unsuitable due to excessive toxicity or flammability.

One possible avenue for resolving this debate is a set of standards that has been unanimously adopted by the National Solar Heating and Cooling Subcommittee of the American Society of Mechanical Engineers (ASME). These standards call for:

1. system certification,
2. fluid certification,
3. installer certification, and
4. failure detection.

Four classes of toxicity were recognized, each requiring different plumbing precautions. The most toxic fluids, Class III, require double-walled heat exchangers with a feature that causes leaking fluid to flow to a location where it will be visible. These standards have received favorable reviews by HUD but the County Health Department has stood firm in its opposition.

The State Water Quality Control Board, the other California agency with a compelling interest in waste safety and discharge into waterways, does not currently intend to draft new regulations controlling collector fluids (Schuler, 1978).

The Los Angeles experience in seeking to ensure collector safety may provide a glimpse of a future that many other counties will have to manage. Disputes between agencies are likely to arise as attempts are made to balance public safety against the goals of energy self-sufficiency and the legitimate complaints of collector manufacturers. Caution seems the appropriate strategy until collector fluids and heat exchange units have been certified. As human safety issues are being resolved, greater emphasis should be placed on tracing the fate of decomposing collector fluids in the environment.

OTHER SAFETY HAZARDS

Direct Solar Technologies

In addition to the potential hazards associated with collector working fluids, other community level impacts may result from installation and maintenance of direct solar technologies. Two of the most common household accidents, falls and minor burns, may increase. In the United States falls accounted for 46 percent of household accidents in 1940 and 43 percent of fatal domestic accidents in 1940 and 1.3 percent of fatal accidents in 1963 (Backett, 1960). However, these statistics do not provide much insight as to the nature of accidents. Three factors essential to meaningful risk assessment are:

1. condition of exposure
2. adverse effects
3. relationship between exposure and effect.

It is likely that a person with training in the building trades would perform the initial installation, but a homeowner may choose to take responsibility for routine cleaning and maintenance--activities that are likely to take place only two or three times annually depending on climate and locale. The severity of cuts, falls, and burns varies to some extent, but most accidents would probably be of a low order, requiring minor medical care. However, it is likely that many accidents could be averted by attention to minimal safety precautions.

A secondary risk from direct solar systems is the glare hazard from collector panels. This could affect drivers, pedestrians, bicyclists, and pilots of light aircraft. Again, design features such as dark, matte paints can reduce or eliminate these hazards from the collector frames.

There may be additional community level hazards associated with photovoltaic cells due to the chemical content and electrical conductivity of the cells. The stability of chemical compounds over the life of a photovoltaic system has not been demonstrated conclusively. Additionally, the storage batteries for photovoltaic cells pose minor risk to unsupervised children, but these could be mitigated with design features.

Wind Generators

Wind generators are typically mounted out of reach, but could be a hazard if children climb the towers. Minor falls and cuts are possible hazards from routine maintenance. Holdren addressed the potential risks from blade throw, observing that such risks are possible but that a detailed assessment would keep the devotees of probability analysis occupied for quite some time. Logical mitigation measures for these problems are pre-market testing, preventive maintenance, and shielding from vandalism. Because of siting requirements including wind regime, broadcasting interference, noise as well as safety, district or centralized installations are expected to be remote from population centers. Large numbers of people are unlikely to be exposed to the improbable but dangerous event of blade throw.

Biomass Facilities

At the household level, use of wood-burning stoves will increase the risk of fire and burns. A household fire could result in neighborhood and community-level risks if the fire spreads. Techniques used to reduce fire hazards in residential fireplaces can be used to mitigate community impacts.

Workers in the biomass conversion industry would be subject to the same minor cuts and sprains that sanitation workers new experience. Jobs that involve operation of shredding and crushing equipment entail risk from more serious cuts and lacerations. A facility using the pyrolysis conversion process, which produces gas, could subject the population in the service area to the risks associated with gas leaks. Similarly, the steam and hot water produced by waterwall incineration and refuse derived fuel systems could subject a service population to the risks associated with hot water or steam release. Because these facilities are comparable to industrial facilities in common use the magnitude and character of accidents are expected to be correspondingly comparable. However, a single accident could trigger a strong backlash in public opinion against the new technology.

Mitigation for both centralized wind generators and biomass conversion facilities would include a program of worker training, ample in-plant monitoring devices, and routine inspection and maintenance of distribution systems.

A strategy of community solar safety can be envisioned which combined public education, worker training in vocational courses, and inspection and maintenance functions. The latter tasks could be shared by a municipal fire department and either a municipally owned solar-based utility or a semi-private utility.

VISUAL INTRUSION

It is possible to identify some aspects of potential visual intrusion of solar based technologies. Whether situated in a natural landscape or a neighborhood of a large city, objects have been characterized according to scale, bulk, form, color, and texture.

There is ample evidence to suggest that communities are very concerned about the scale, bulk, and form of new structures. An excellent example is the controversy sparked in San Francisco over the construction of the Trans-america pyramid, a structure that transformed the skyline of the city. This building is particularly notable in that its design was developed partly in response to existing restrictions on height and bulk, expressed as the floor area ratio. Similarly, the Mount Sutro tower, a television transmitter intended to improve reception to San Francisco neighborhoods, provoked extensive debate.

Of the solar technologies considered in this study, wind generators and biomass conversion facilities are likely to impose substantial changes in existing scale and bulk in a community. Because wind generators are expected to be sited remotely from the communities they serve, they will impact the appearance of the rural setting or natural environment. The profile of a biomass conversion facility would scarcely be recognized in an industrial sector but would probably be inordinately conspicuous in a residential neighborhood or commercial strip development.

Two other important elements of visual intrusion are color and texture. These qualities are less frequently regulated than height and bulk, but they do appear in the design review criteria of agencies such as the San Francisco Bay Conservation and Development Commission and the California Coastal Commission. Similarly at the local level, the Sea Ranch (Mendocino, California), Palos Verdes (Los Angeles County California), and Santa Barbara include the color and texture of building materials within their design review.

Thermal collectors represent a significant departure from the color and texture of more traditional roof coverings such as shingles or tiles. Siting of these technologies in front yards significantly alter the appearance of the community. The single family dwelling case study indicates that there is substantial flexibility in siting collectors. The choice among roofs and yards will be made locally and will be influenced by a variety of conditions including: conflicts with trees, neighborhood character, and community values.

In a commercial strip setting, roof-mounted solar collectors might well go unnoticed in an environment rich in neon lights and revolving signs, and banks of collectors could blend easily into the labyrinth of heating ducts and air conditioning vents that characterize many industrial buildings. However, in more subdued commercial settings where sign control and height limitations are already in force, the addition of flat plate collectors may be intrusive. Developers of newer industrial parks commonly stress landscaping and compatible building materials, and may not welcome banks of collectors. However, the scale of new developments will permit the aesthetic integration of collectors at the time of construction.

Solar collectors are notable for one other visual quality, namely, reflectivity. Reflectivity is a very dynamic characteristic, and can be expected to vary throughout the day and with the seasons. Excessive reflectivity has actually been used by the Coastal Commission to deny an

application for a solar home in the Sea Ranch community.

Historic Districts and Unique Architectural Styles

Perhaps the most universally recognized criterion for maintaining the visual character of an area is the addition of a neighborhood building to the National Register of Historic Places.⁶

The National Register of Historic Places is the nation's official list of cultural property worthy of preservation, as expanded in 1966 under the National Historic Preservation Act. It includes districts, sites, structures and objects significant in U. S. history, architecture, archaeology and culture. Properties of local, state, regional and national significance are included. Under the terms of the legislation, funds could actually be used to design solar solutions in keeping with the cultural heritage.

At the community level, many cities have embarked on their own efforts to preserve and restore buildings and neighborhoods. Baltimore's emphasis on row house restoration is particularly notable in this regard, because it actually allocated a portion of the city's capital improvements program for building restoration--an almost unprecedented move by a municipality. San Francisco woodframe Victorians are experiencing a renaissance with very little municipal backing as private individuals restore and repaint the run-down properties of gentrifying neighborhoods. Integrating solar collectors into restored neighborhood districts will require careful design to avoid distortion of the architectural character. The row-house case study demonstrates that collectors can be added to flat roofed structures without affecting the form of the structure. Integration into gabled roofs will prove to be more difficult.

Solar Technologies as Visual Symbols

Much of a community's attitude toward a potentially intrusive object is tied to the notion of that object as a symbol. Factory smokestacks

⁶The procedures for preparing, initiating and approving nominations to the National Register differ considerably by state, but nominations must be approved by an official state review board. Nominations approved by the review board are certified by the state historic preservation officer before being forwarded to the National Register. The 1966 legislation authorized the Secretary of Interior to grant funds to states for the purpose of preparing comprehensive statewide historic surveys and plans, in accordance with criteria established by the Secretary, for the preservation, acquisition, and development of such properties.

spewing smoke were once the symbol of prosperity, but with the rising consciousness of the environmental movement, they became a symbol of environmental destruction. Television antennae on roofs were a status symbol for homeowners in the 1950s, but by the 1960s they became a badge of middle class uniformity. Solar collectors were unknown sights in most American cities as recently as three or four years ago, but in 1979 most people would recognize a smooth, reflecting bank of solar panels as a device intended to provide heating and hot water. Wind machines, once a revered symbol of the farmer's independence in the arid west and midwest, are once again gaining recognition as the symbol for a new kind of self-sufficiency.

In short, the techniques chosen to emphasize or disguise evidence of solar reliance should reasonably reflect (and perhaps help shape) a community's attitude toward various energy technologies. The community of Boulder, Colorado now has a Post Office heated with solar panels--a feature that represents, in effect, an institutionalized commitment to solar reliance. Similar design solutions that find appeal in a small New England community may be totally inappropriate for metropolitan areas.

RESOURCE CONSUMPTION IMPACT OF BIOMASS TECHNOLOGIES

The derivation of gas or steam in "biomass" conversion technologies represents an irreversible allocation of resources that could be used for different purposes. The materials used for fuels include waste wood, agricultural by-products, lumber by-products, municipal solid waste, and sewage sludge. Several studies have documented that the availability of these fuels varies considerably. A data base consisting of a county-by-county inventory of agricultural and forest residues illustrated that these materials are most abundant in the "corn belt" states and the Pacific Northwest, with a few areas of high residue production occurring in Georgia and Florida. As would be expected, population centers on the eastern seaboard, in the eastern Great Lakes area, and the arid west are not proximate to existing supplies of agriculture or forest residues. Even in the "waste rich" areas, continuity of supply varies considerably with the season (Alich et. al., 1976).

Opportunity costs of using agricultural wastes for fuel include (Roller, 1975):

- Most food or feed crop residues are more valuable as animal feed than for fuel.

- Crop and forest residues are often not sufficiently concentrated to be brought efficiently to a conversion plant; hence the fuel expended for collection might actually exceed the energy derived.
- Only a small proportion of arable and forest lands can sustain continuous stripping of above ground vegetation without severe impacts on soil stability and fertility. In other words, substantial opportunity costs result from removal of crop residues formerly used as field mulch or as an agent to improve soil tilth.

Calculations performed on the data base illustrate that only one percent of agricultural residue is disposed at cost, while 75 percent returns to the soil and 19 percent is fed to livestock. Similarly, only 25 percent of forestry mill waste goes unused, while half is sold and another 25 percent is already used as fuel without sale. Of the 36 tons of manure identified in the inventory, 69 percent is returned to the soil and 14 percent is sold for other purposes. From this analysis, the overall conclusion can be drawn: only 14 percent of the nation's forest and agricultural wastes are presently wasted.

Table C-6
National Residue Dispositions
(10⁶ Dry Tons)

	<u>Crop</u>	<u>Manure</u>	<u>Forestry</u>	<u>Total</u>
Returned to soil	237	25	---	262
Fed without sale	61	---	---	61
Sold	13	5	38	56
Fuel	9	---	19	38
Wasted	<u>2</u>	<u>6</u>	<u>59</u>	<u>67</u>
Total	322	36	119	474

Source: Alich and Witner, 1977.

Of the major fuel types listed in Table C-6, municipal solid waste (MSW) is the most widely available. Rates of production have been characterized as ranging from 2.75 or 3 pounds (Alich and Witner, 1977) per person per day to a high of 4.5 or 5 pounds. While some studies have indicated that per capita MSW consumption rates have increased over time (Quimby, 1975) there is no substantial evidence that MSW varies by region of the country. In fact, MSW plants have been identified in at least 26 states (LBL, 1978). However, it is clear that when commercial waste are included in the calculus of determining average production of wastes, larger

commercial and manufacturing centers will show a higher rate of waste production. A recent report suggests that 4 pounds per person day is a good "ballpark" average.⁷ (LBL, 1978).

There is substantial evidence to suggest that recycling of paper, glass aluminum and ferrous metals used in the home can be accomplished successfully. Many communities in California and other states have "recycling centers" which serve as depots for depositing household wastes. Some of these centers require source separation of recyclables, while others will sort "donations." The California cities of Modesto, Davis, Berkeley, and El Cerrito offer curbside pickup of one or more recyclable materials. The Ecology Center in Berkeley, California, a non-profit organization, has offered curbside pickup of newspapers for five years. The total volume of newspapers collected has stabilized in the last five years at about 800 tons, representing approximately 20 percent of the newspapers consumed in the city and roughly 10 percent of all Berkeley households. A survey of El Cerrito residents revealed that over 50 percent had participated in the curbside pickup of newspaper, glass, and aluminum.

A program operated by the City of Berkeley under a grant from the State Solid Waste Management Board has converted donations of yard wastes to compost. This waste recycling project was established adjacent to a city dump in an effort to divert and reuse material that would otherwise wind up as landfill in San Francisco Bay. Some of the composted material has been used in community parks and gardens. In a similar project, the City of Piedmont has collected and composted street sweepings for over 25 years. Vegetative material in all stages of decomposition is available to anyone willing to haul it away.

Resource recovery can be accomplished to a lesser extent after combustion or other conversion to energy. Char resulting from direct combustion can be removed to a resource recovery system (LBL, 1978). Processes

⁷ A characterization of municipal solid waste identified thirteen constituents of MSW of which seven can be recycled or composted (LBL, 1978). Recyclable materials include paper, glass, ferrous metal, aluminum, and wood. Food and other household wastes can be composted. The report reviewed and compared fourteen other documents as to the proportion of MSW in each constituent category by weight (LBL, 1978). By summing the average proportions of MSW in recyclable categories, a figure of 91 percent is derived for the average proportion of waste that could be recycled. Only plastics, rubber and leather, and textiles cannot be readily recycled.

used to remove recoverable materials from MSW and produce a useable fuel fraction include wet processing (hydropulping) and dry processing (shredding) (LBL, 1978).

In refuse derived fuel (RDF) systems, bulky items are removed or sheared to a size shredders can handle. Refuse is fed into a hammermill and is then air classified to separate the light, primarily combustible materials from the heavy-ion combustible fraction. The heavy fraction is sent to a magnetic separator, where ferrous materials are cleaned and separated, while the rest normally winds up in landfill. It is possible to process this inert fraction through a series of steps to recover useable materials such as glass, aluminum, and other metals. As an example the RDF process employed in a plant operated by the City of St. Louis included separation and marketing of ferrous metals, glass, and aluminum (LBL, 1978).

Despite this positive example, several problems are inherent in efforts to recover recyclable wastes and generate energy from MSW. Both wet pumping and dry shredding/air classifying result in combustion of paper that could otherwise be recycled separately into high quality clear or colored glass.⁸

It seems apparent that large scale "energy recovery" facilities that rely on agricultural refuse or municipal solid waste will compromise other productive efforts to utilize waste resources such as those now underway in many California communities. Combustion or other conversion of recyclable materials would require more primary resource extraction and manufacturing of these goods, which would in turn exacerbate current levels of residuals loaded into the air and water. It could be argued that since recycling efforts in many communities are still embryonic, participation in these programs could be easily diverted to conversion of wastes into

⁸The LBL report observes:

A critical aspect of the feasibility of any resource recovery system is the quality of the products. This is true for both the secondary materials (ferrous metals, aluminum, glass) and the processed fuel. Claims to recover materials from mixed waste have not been borne out. Only ferrous metals separation, which is a long established technology, has proven itself in practice. The high degree of purity required by markets for use of secondary materials has been difficult to achieve once materials are contaminated with mixed garbage. (LBL, 1978).

energy as part of any overall community energy plan. Even though recycling may be considered more "environmentally sound" than energy conversion, proponents of decentralized government might argue that the social benefits of local biomass conversion outweigh environmental consequences that would be shared by the larger American society and by resource exporting regions.

CHEMICAL NAME/ GENERAL GROUPS OF CHEMICALS	CURRENT USES/ 1976 COST PER GALLON	RECOMMENDATION RE: USES AS A HEAT TRANSFER MEDIUM	CHRONIC IMPACTS	ACUTE IMPACTS
<u>Dibutyl phthalate</u> Phthalic acid esters	Plasticizers, insect repellent \$15.42	I	Low order; very high prolonged doses needed to produce carcinogenicity (2,3).	Low order; very high doses needed to produce lethal response (4,5,6).
<u>Butyl benzyl phthalate</u> Phthalic acid esters	Plasticizers \$2.98	I	Low order; no signifi- cant responses in laboratory animals (8).	Probably negligible; minor irritation in laboratory animals (9,10).
<u>O-dimethyl phthalate</u> Aromatic dicarboxylic	Insect repellent \$3.67	I	Some phthlate esters were lethal when injected in chick embryos (13). Morphological deformities at prolonged exposures (14). Tetato-genic in other tests. High dose inhalation may cause central nervous system depression (15).	Lethal to test animals only at very high oral doses (16,17).
<u>Dimethyl-0-phthalate</u> (DEP) Phthalate acid esters	Plasticizers, defoaming agents \$3.46	I	Low order; irritation of nasal membranes may result from prolonged inhalation. Embryo toxicity and tetato- genicity has been demon- strated in lab animals at very high doses (19,20).	Low order; very high doses needed to cause irritation of skin (21) and death in test animals (22,23,23).
<u>Piperonyl butoxide</u> Methylene-dioxphenyl derivatives	Insect repellent \$39.81	I	Extremely low order; only a mediocre insecticide (26).	Acute toxicity by either oral or dermal routes is extremely low order
<u>Di (2-ethylhexyl)</u> <u>adipate (DEHA)</u> Adipic acid esters	Plasticizer \$3.79	I	Low order; slight irritation of eye skin and respiratory tract (30,31).	Extremely low order (32,33).
<u>Di (2-ethylhexyl)</u> <u>sebacate, or Dioctyl</u> <u>sebacate (DOS)</u> Aliphatic acid esters	Plasticizer, lubricant \$9.80	I	Extremely low order; at most minor degree of irritation (34).	Extremely low order (35).

Table C-7 : Toxicological and Safety Hazards of Proposed Collector Working Fluids

APPENDIX C

CHEMICAL NAME/ GENERAL GROUPS OF CHEMICALS	ENVIRONMENTAL IMPACTS	OTHER HAZARDS/ COMMENTS	EXISTING TOXICOLOGY STANDARDS
<u>Dibutyl phthalate</u> Phthalic acid esters	Possible persistence and magnification in food chain, especially in marine organisms (7).		
<u>Butyl benzyl phthalate</u> Phthalic acid esters	Possible persistence and magnification in food chains (11).	More research needed on persistence and chronic toxicity.	Threshold limit value 2ppm or 12 mg/m ³ (12).
<u>O-dimethyl phthalate</u> Aromatic dicarboxylic	Some evidence of toxic effects on marine life (18).	No studies on biodegradability.	
<u>Dimethyl-O-phthalate (DEP)</u> Phthalate acid esters	The biodegradability of this compound is not known, but similar substances here found to be comparable to a biodegradable detergent (25). No immediate hazards are foreseen, but additional study may be appropriate.		
<u>Piperonyl butoxide</u> Methylene-dioxphenyl derivatives	Enhances the persistence of pyrethrin insecticides (28,29). No evidence of biomagnification; no accumulation in laboratory animals.	No reports of industrial accidents, probably one of safest compounds used in insecticides.	
<u>Di (2-ethylhexyl) adipate (DEHA)</u> Adipic acid esters	No evidence on biodegradability or ability to biomagnify food chains. Other esters used as plasticizers have shown environmental persistence and ability to biomagnify.	Low order of toxicity due to very poor absorption regardless of route of exposure. Caution should be used when heated to temperature of vaporization.	
<u>Di (2-ethylhexyl) sebacate, or Dioctyl sebacate (DOS)</u> Aliphatic acid esters	Environmental toxicology is not known.	No studies have been done on biodegradability.	

Table C-7 : Toxicological and Safety Hazards of Proposed Collector Working Fluids (cont.)

CHEMICAL NAME/ GENERAL GROUPS OF CHEMICALS	CURRENT USES/ 1976 COST PER GALLON	RECOMMENDATION RE: USES AS A HEAT TRANSFER MEDIUM	CHRONIC IMPACTS	ACUTE IMPACTS
<u>Dibutyl sebacate</u> Sebacic acid ester	Plasticizer \$8.59	I	Extremely low order; at most minor degree of irritation (36).	Extremely low order (37).
<u>Petrolatum</u> Mixture of semisolid hydrocarbons derived from petroleum; related to paraffin waxes.	Drugs, cosmetics, food \$1.11	I	Very low order. Aromatic portion of compound carcinogenic in mice at 50 times concentration of starting material (38).	Innocuous at dose levels for food, drugs, cosmetics (39,40). Injurious to respiratory system at very high temperatures (41).
<u>Allyl caproate</u> Unsaturated aliphatic esters	Flavoring agent; imparts fragrance to soaps and detergents \$22.03	II	Growth suppression and minor morphological changes from prolonged exposure (43).	Moderate oral toxicity in rats (44). Conflicting reports on dermal toxicity in rats (45). Minor irritation to humans (46).
<u>Ethyl cinnamate</u> Ester of cinnamic acid	Flavoring agent; occurs naturally in cocoa \$31.40	II	Findings indicate that substance is practically non-toxic (48,49).	Findings indicate that substance is practically non-toxic (50,51)
<u>Acetyl tributyl citrate</u> Esters of citric acid	Plasticizers \$5.17	II	Low order interference with weight gain documented in rats, only at high doses (53,54).	Low toxicity for oral doses (55,56). Only effects occurred at very high levels.
<u>Tributyl citrate</u> Esters of citric acid	Plasticizers \$6.65	II	Low order interference with weight gain documented in rats, only at high doses (59,60).	Low toxicity. Stimulatory effect on central nervous system in small animals. Very high doses needed to reach lethal dose (61).

Table C-7: (cont.)

APPENDIX C

CHEMICAL NAME/ GENERAL GROUPS OF CHEMICALS	ENVIRONMENTAL IMPACTS	OTHER HAZARDS/ COMMENTS	EXISTING TOXICOLOGY STANDARDS
<u>Dibutyl sebacate</u> Sebacic acid ester	Environmental toxicology is not known.	No studies have been done on biodegradability.	
<u>Petrolatum</u> Mixture of semisolid hydrocarbons derived from petroleum; related to paraffin waxes.	No data available, but not water soluble, so aquatic transport of little consequence.		TLV of related substance 2mg/m ³ (OSHA standard 1910.93) (42).
<u>Allyl caproate</u> Unsaturated aliphatic esters	No available data.		Accepted by FDA (21 CFR 121.1164) granted "Generally Recognized as Safe" (GRAS) status by Flavoring Mfg. Assoc. (1965) (47).
<u>Ethyl cinnamate</u> Ester of cinnamic acid	Very little available data. Insoluble in water; therefore not a likely aquatic pollutant. Is an effective herbicide against species in legume and sagebrush family (52).		
<u>Acetyl tributyl citrate</u> Esters of citric acid	No available data. No ill effects reported in plastics industry (57).	Low toxicity may be due to insolubility, which interferes with absorption (58).	
<u>Tributyl citrate</u> Esters of citric acid	No available data. Insoluble in water; therefore not a likely aquatic pollutant. Capable of being biodegraded by a test organism (62). Slight fire hazard when heated.		

Table C-7 : (cont.)

APPENDIX C

CHEMICAL NAME/ GENERAL GROUPS OF CHEMICALS	CURRENT USES/ 1976 COST PER GALLON	RECOMMENDATION RE: USES AS A HEAT TRANSFER MEDIUM	CHRONIC IMPACTS	ACUTE IMPACTS
<u>Methyl heptenone</u> Ketones	Flavoring agent; used in fragrances \$34.81	II	No toxicology data.	No toxicology data. Dermal effects: chapping of skin. Vapors have narcotic effect but high boiling point makes this route of exposure unlikely (63).
<u>Isobutyl salicylate</u> Salicylates	Analgesics and antipyretics \$11.11	II	No specific data for this substance.	No specific data for this substance. Salicylates generally stimulate the central nervous system when applied in toxic doses (64).
<u>Butyl oleate</u> Esters	Plasticizer and emulsifier \$1.89	II	No toxicology data for this specific substance. Low order toxicology for family of substances (65).	No toxicology data for specific substance. Low order toxicology for family of substances (66).
<u>Methyl Phenylacetate</u> Esters of acetic acid, acetates	Flavoring agent/ fragrance material \$9.82	II	No available data (58).	At high concentrations irritation results in both humans and animals. Narcosis follows, with recovery after exposure ends (69).
<u>Benzyl formate</u> Ester of formic acid	Flavoring agent \$16.30	II	No data available.	Probably low order (73).
<u>Methyl benzoate</u> Aromatic monocarboxylic acid esters.	Flavoring agent; used to impart fragrance to soaps,	III	Probably low order; chronic high doses damaged central nervous system in test animals (76,77).	Low order (78,79).

Table C-7 : (cont.)

APPENDIX C

CHEMICAL NAME/ GENERAL GROUPS OF CHEMICALS	ENVIRONMENTAL IMPACTS	OTHER HAZARDS/ COMMENTS	EXISTING TOXICOLOGY STANDARDS
<u>Methyl heptenone</u> Ketones	No data on consequences in the environment. Insolubility suggests aquatic transport would be unlikely.		
<u>Isobutyl salicylate</u> Salicylates	No data on consequences in the environment. Insolubility suggests that aquatic transport is unlikely.		
<u>Butyl oleate</u> Esters	No data on consequences in environment. A test organism is capable of degrading the substance (67).		
<u>Methyl Phenylacetate</u> Esters of acetic acid acetates	No available data. No research on biodegradability or ability to bio-magnify in food chains. Does not occur naturally (70).	None of the "fragrance acetates" has caused health problems in manufacturing or end use (71).	Granted "Generally Recognized as Safe" (GRAS) status by Flavor Extract Mfg. Assoc. Approved by Food and Drug Administration for food use (21 CFR 121.1164) (72).
<u>Benzyl formate</u> Ester of formic acid	No available data. No research on biodegradability or ability to bio-magnify in food chains. General group of chemicals considered least toxic industrial solvents in use (74).		Granted GRAS status; approved by FDA (21 CFR 121.1164) (75).
<u>Methyl benzoate</u> Aromatic monocarboxylic acid esters.	Very little data. No research on biodegradability or ability to bio-magnify in food chains. Low threshold values for odor and taste reported.	Chemical has flash point below expected operating temperature of solar units (81).	

Table C-7 : (cont.)

APPENDIX C

CHEMICAL NAME/ GENERAL GROUPS OF CHEMICALS	CURRENT USES/ 1976 COST PER GALLON	RECOMMENDATION RE: USES AS A HEAT TRANSFER MEDIUM	CHRONIC IMPACTS	ACUTE IMPACTS
<u>Ethyl benzoate</u> Aromatic monocarboxylic acid esters	Solvents, flavorings, fragrances \$10.45	III	No irritation observed in tests on humans (82).	Low order (83,84).
<u>Isobutyl isobutrate</u> Esters of isobutyric acid	Perfumes, flavorings, solvents \$1.35	III		Low order; toxic to animals only at extremely high doses (86,87).
<u>Perchloroethylene</u> Aliphatic chlorinated hydrocarbons	Solvent; treats hookworms \$2.24	IV	Liver and kidneys show patho- logical changes in laboratory animals at prolonged high levels of exposure. Irritating vapors are readily absorbed through the lungs, nose, and throat (90,91).	Low order (92,93, 94,95). Central nervous system depression at high levels.
<u>1,1,2-Trichloroethane (TCE)</u> Halogenated aliphatic hydrocarbons	\$3.27	V	No long term toxicity tests on animals or humans have been conducted, but responses are suspected to be similar to carbon tetrachloride, which causes liver and kidney damage at subacute levels (100,101).	Relatively high order. TCE can irritate the eyes, skin, respiratory membranes, intestinal tract, potentiate adre- nalin, cause severe liver and kidney disfunction, and damage and cause death (102,103,104,105).
<u>Benzyl chloride</u> Halogenated hydrocarbons	Photography, chemical synthesis, pharmaceutical pre- paration. \$2.94	V	Extremely irritating to skin, eyes, and mucous membranes (107,108). May cause lung edema (109) and skin burns (110).	Extremely irritating to skin, eyes, and mucous membranes (111). May cause lung edema (112) and skin burns (113).

Table C-7 : (cont.)

CHEMICAL NAME/ GENERAL GROUPS OF CHEMICALS	ENVIRONMENTAL IMPACTS	OTHER HAZARDS/ COMMENTS	EXISTING TOXICOLOGY STANDARDS
<u>Ethyl benzoate</u> Aromatic monocarboxylic acid esters	Very little data. No research on biodegrada- bility or ability to bio- magnify in food chains.	Chemical may react with oxidizing agents and become a fire hazard when exposed to heat or flame (85).	
<u>Isobutyl isobutrate</u> Esters of isobutyric acid	No existing data, but slight solubility of this chemical indicates potential problem as an aquatic pollutant (88).	Flash point is 150° F., lower than operating temperature of solar heating units (89).	
<u>Perchloroethylene</u> Aliphatic chlorinated hydrocarbons	Material has been used as a fungicide (96,97) but no data exists on environ- mental accumulation, bio- degradation, or ecosystem effects.	Chemical is non-explosive and non-toxic, but if heated to decomposition it will produce highly toxic chloride gases (98,99). A closely related substance, trichloro- ethylene, is a suspected carcinogen.	
<u>1,1,2-Trichloroethane (TCE)</u> Halogenated aliphatic hydrocarbons	No data on biodegrada- bility or accumulation in food chains is available. Tests with aquatic organisms indicate that TCE is slightly toxic in the aquatic environment (106).	Work places where TCE is used should be well ventilated, exposed personnel should receive examinations.	TLV: Air 10ppm (Approximately 45 mg/m ³) (OSHA Standard 1910. 93).
<u>Benzyl chloride</u> Halogenated hydrocarbons	Moderately toxic to aquatic life (114).	May explode if used in association with hot metals such as iron (115). Produces toxic fumes in the presence of steam (116).	Threshold value of 1ppm, accepted by OSHA (117).

Table C-7: (cont.)

CHEMICAL NAME/ GENERAL GROUPS OF CHEMICALS	CURRENT USES/ 1976 COST PER GALLON	RECOMMENDATION RE: USES AS A HEAT TRANSFER MEDIUM	CHRONIC IMPACTS	ACUTE IMPACTS
<u>Therminol 55 (Monsanto Chemical)</u> Akybenzenes	Solvent \$2.80	V	Oral exposure to rats showed no ill effects at highest concentrations. Other routes of exposure were not tested (118).	Data provided by Monsanto indicates extremely low order of acute toxicity (119).
<u>O-Dichlorobenzene (ODCB)</u> Cyclic halogenated hydrocarbons	Solvent for engine deposits, rust-proofing, heat exchange medium, leather degreaser, and insecticide. \$3.25	V	Low order; both oral and respiratory exposure failed to produce a lethal response in animals, but slight morphological changes were documented (121).	Low to moderate. Low concentrations cause irritation but extremely high doses were required to induce lethal responses in laboratory animals (122,123). Liver and kidney damage are a possibility (124, 125,126).
<u>Ortho-phenetidine</u> Aromatic amines	Production of dyes, rubber and rubber antioxidants, in the operation of and production of drugs. \$8.05	V	No data available on specific substance. Other aromatic amines have been shown to cause liver damage and some are recognized as or suspected of being carcinogens (130, 131, 132, 133). One of a group of compounds noted for methemoglobin forming properties.	No data available on specific substance. Other aromatic amines have been shown to cause liver damage and some are recognized as or suspected of being carcinogens (134, 135,136,137).
<u>Divinyl benzene</u> Aromatic hydrocarbons	Solvent material \$6.89	V	Moderately toxic through inhalation (140).	Moderately toxic through inhalation; moderately to slightly toxic by oral and dermal acute exposure (141, 142).
<u>Meta-chloroaniline</u> Aromatic amines	Production of dyes, rubber and rubber antioxidants, in the production of drugs, paints, polishes, and resins.	V	Liver and kidney damage and methemoglobinemia may be induced by any of the exposure routes (143,144).	Liver and kidney damage and methemoglobinemia may be induced by any of the exposure routes (145,146).

Table C-7 : (cont.)

APPENDIX C

CHEMICAL NAME/ GENERAL GROUPS OF CHEMICALS	ENVIRONMENTAL IMPACTS	OTHER HAZARDS/ COMMENTS	EXISTING TOXICOLOGY STANDARDS
<u>Therminol 55 (Monsanto Chemical)</u> Akybenzenes	No data available on effects of material on the environment.	The irritant potential of alkylated benzenes to both eyes and skin has been well docu- mented (120). The toxic potential of alkylated benzenes decreases with water solubility and complexity of chemical structure.	
<u>O-Dichlorobenzene (ODCB)</u> Cyclic halogenated hydro- carbons	Limited data available, but some evidence indi- cates environmental persistence (127,128).	The irritant properties of ODCB are of most concern.	Threshold limit of 50ppm esta- blished (4).
<u>Ortho-phenetidine</u> Aromatic amines	No available data. Only slightly water soluble; aquatic transport is therefore unlikely (138).	When heated to decom- position, chemical will form noxious gases of nitrogen oxides (139).	
<u>Divinyl benzene</u> Aromatic hydrocarbons	No data available on specific compounds, but it may exhibit properties of environmental persistence.	Flash point is below operating temperatures of solar units. The toxic potential of alkylated ben- zenes varies with chemical structure and relative solubility. Divinyl benzene is a simple, water insoluble compound and could be expected to have a lower toxicity than related materials.	
<u>Meta-chloroaniline</u> Aromatic amines	Aquatic toxicity of this material is slight (147).		

Table C-7 : (cont.)

CHEMICAL NAME/ GENERAL GROUPS OF CHEMICALS	CURRENT USES/ 1976 COST PER GALLON	RECOMMENDATION RE: USES AS A HEAT TRANSFER MEDIUM	CHRONIC IMPACTS	ACUTE IMPACTS
<u>Ortho nitrotoluene (ONT)</u> Aromatic nitro compounds	Synthesis of dyes and explosives \$1.36	V	Almost all compounds in this group are powerful skin sensitizers, and some have shown a toxic potential for the liver (153,154).	General group of compounds forms methemoglobin in humans, a condition which makes oxygen in the blood unavailable to tissues. Vapors are readily absorbed through the lungs; most compounds pass readily through intact skin (149,150,151,152).
<u>Creosote coal tar</u> Chemical conglomerate resulting from distillation of coal tar.	\$5.18	V	Creosote is a recognized carcinogen of the skin and a suspected carcinogen of the lung (156, 157, 158). Chronic exposure is suspected to cause hypertension and general cardiovascular collapse (159).	Acute toxicity is generally moderate. Acute exposure can cause eye damage, irritation to skin and mucous membranes (160).
<u>Acetylene tetrabromide, or tetrabromoethane (TBE)</u> Aliphatic halogenated hydrocarbons	Ore flotation agent, gauge fluid, solvent. \$15.42	V	Toxic exposure resulting from inhalation is probable (164). At highest concentrations test animals showed morphological damage to liver and lungs (165).	Relatively high order. Most common response to exposure to this group of chemicals is central nervous system depression. Inhalation of TBE may cause liver and kidney damage (166,167).
<u>Cresyl diphenyl phosphate</u> Phosphate esters	Plasticizers \$6.91	V	Toxicity of group of chemicals varies widely. Some researchers compare cresyl diphenyl phosphate to a very toxic compound capable of causing permanent paralysis and nervous system disorders (168,169).	Toxicity of group of chemicals varies widely. Cresyl diphenyl phosphate appears to be highly toxic in test animals (170).
<u>Tri-O-cresyl phosphate (TOCP)</u> Phosphate esters	Plasticizers, fire retardants \$8.63	V	High order. Produces severe paralysis of extremities usually followed by death (172, 173, 174).	Extremely high order. Many documented cases of damage to the nervous system in humans, causing paralysis (175,176,177,178, 179).

Table C-7 : (cont.)

CHEMICAL NAME/ GENERAL GROUPS OF CHEMICALS	ENVIRONMENTAL IMPACTS	OTHER HAZARDS/ COMMENTS	EXISTING TOXICOLOGY STANDARDS
<u>Ortho nitrotoluene (ONT)</u> Aromatic nitro compounds	ONT is only slightly toxic to aquatic life (155). No data assessing biodegradability and food chain transport mechanisms is currently available.	While ONT can be used safely in a controlled industrial environment, its safe use cannot be guaranteed if it finds widespread public use.	Air 5 ppm (OSHA standard 1910.93).
<u>Creosote coal tar</u> Chemical conglomerate resulting from distillation of coal tar.	Based on observations that wood coated with creosote retains its toxicity for 25 to 30 years (161) biodegradability appears very low. Creosote is also a moderate toxin to aquatic life; a concentration of only 1 to 10 ppm (parts per million) will kill 50% of test organisms in 96 hours (162).	The flash point of creosote is well below the expected operating temperatures of solar systems (163).	
<u>Acetylene tetrabromide, or tetrabromethane (TBE)</u> Aliphatic halogenated hydrocarbons	No research on biodegradability has been conducted.		
<u>Cresyl diphenyl phosphate</u> Phosphate esters	No research of biodegradability has been conducted.	Slight danger of fire or explosion results if material is heated. If heated to decomposition, toxic phosphorus oxide vapors are emitted (171).	
<u>Tri-O-cresyl phosphate (TOCP)</u> Phosphate esters	No information on biodegradability or magnification in the food chain. Some evidence that TOCP may be persistent in animals and humans.		

Table C-7: (cont.)

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APPENDIX D

Case Study Analyses and Findings

INTRODUCTION

This section documents the analysis of physical constraints on and community-level impacts of solar reliance in each case study example of the land use types evaluated. Each case study is described using the following format:

1. Overview of the study area.
2. Characteristics influencing solar energy use.
3. Level of solar reliance achievable within the study area relative to the scenario goals and the technologies' theoretical potentials.
4. The potential for increasing solar reliance through importation of surplus energy from other areas in the community.
5. Impacts which result from meeting the scenario goals and the technologies' potential.
6. Implications of findings for changes in future urban form to achieve a higher level of solar reliance within the land use pattern evaluated.

SINGLE FAMILY RESIDENTIAL STUDY AREA

Overview of Study Area

The single family detached residential study area is an older neighborhood located three miles southeast of the central business district. The total area is 37.2 acres, within which 144 parcels comprise eight blocks in a grid pattern running north-south. (See map, Figure D-1). On the average, there are 19 parcels per block. With few exceptions, each parcel occupies approximately 6,300 square feet. The one important exception to this is a ten-parcel block with a large school that occupies 69,900 square feet.

The study area is entirely single family residential except for the school and three vacant lots. Single family dwellings comprise 91 percent, vacant parcels 2 percent, and the school 7 percent of the total parcel area. Of the total study area, parcels cover 62 percent of the land with the remaining 38 percent in streets and sidewalks.

The structures range from 400 to 3500 square feet (excluding the 14,000 square foot school building) with an average of 994 square feet. The great majority of houses are one-story so that floor area corresponds

Figure D-1

Single Family Dwelling Study Area

Scale in Feet

0 100 200 400

closely to the average roof area of 983 square feet. Open space on a parcel averages 5306 square feet. This uncovered land (free of structures) combined with the vacant parcels (18,840 square feet) and the school yard (55,900 square feet) comprises 860,073 square feet of open space, or 82 percent of the total parcel area.

Characteristics Influencing Solar Energy Use

The SFD case study area included a neighborhood school as well as 139 households. The school, because of its large, flat roof was sufficient to collect twice its space heating and hot water demand, assuming current collector performance and short-term storage. Its own independence assured, the school's energy demand and supply were excluded from the study area characterization.

Figures D-3 and Tables D-1 through D-3 illustrate the energy demand of the residences in the study area. Figure D-2 is the graph by which solar supply using thermal collectors with short-term storage is determined. Table D-4 shows the available collector area free from shading by existing structures or trees between the hours of 10:00 a.m. and 2:00 p.m. The analysis assumes a uniform tree height of 45 feet which was determined by scaling a representative sample of shadows in aerial photographs.

Tree shadows proved to be the dominant influence on solar potential in the study area. A thorough analysis of this effect is included at the conclusion of the SFD case study discussion. The tree canopy itself is quite variable from location to location, depending on many factors, including climate and age of the development.

Street orientation was not a significant influence on active solar potential, primarily because collectors were assumed to be placed on rooftops, on frames above the ground plane, and structures were of a uniform height, i.e., one story, but also because lot coverage was low.

The influence of roof orientation of the individual houses on the roof's usefulness as a collector location was taken into account in the analyses. Solar potential on roofs was calculated for a collector of 40° from horizontal. While all roof tops do not slope at this optimum angle, Appendix A has shown that variations will not significantly affect collector performance.

Figure D-2

Single family residential 70% heat load (10Btu/ft²/d.d.) +
80% hot water (100 gal./day)

2000 ft ²	250	450	650	850	1050
1500 ft ²	200	350	500	650	800
1000 ft ²	150	250	350	450	550
500 ft ²	75	125	175	225	275

27 Btu	.27	.54	.81	1.08	1.35
18 Btu	.18	.36	.54	.72	.90
15 Btu	.15	.30	.45	.60	.75
10 Btu	.10	.20	.30	.40	.50
8 Btu	.08	.16	.24	.32	.40
6 Btu	.06	.12	.18	.24	.36

Heat load per ft² of floor area

Ratio of collector area to floor area

Notes: Assumes collector tilt of 40°. See Appendix A for assumptions regarding collector performance.

Figure D-3
SINGLE FAMILY DWELLING ENERGY DEMAND AND CONSUMPTION
(Per Average Dwelling Unit)

Existing Demand
($\times 10^7$ Btu/unit)

TOTAL END-USE ENERGY
 11.03×10^7 Btu/unit

Reduced Demand
($\times 10^7$ Btu/unit)
(88% of Existing Demand)

TOTAL END-USE ENERGY
 9.71×10^7 Btu/unit

TOTAL PRIMARY FUEL CONSUMPTION
 21.23×10^7 Btu/unit

TOTAL PRIMARY FUEL CONSUMPTION
 19.35×10^7 Btu/unit

Table D-1

Total End-Use Energy Demand of Single Family Residential Study Area

Heated Floor Area 129,000 ft ²		
END USE	ENERGY DEMAND (10 ¹⁰ Btu)	
	Existing	With Conservation
Heating	.718	.539
Hot Water	.207	.207
Cooling (C.O.P. 2.5)	.158	.154
Lights & Power	.449	.449
Total	1.532	1.349

Table D-2

Climatic Conditions Affecting Solar Energy Use: Denver

	Collectible Insolation (Btu/ft ²)		Heating Degree-Days
	40° Surface	Horizontal Surface	
January	38,709	9,731	1,004
February	40,420	21,328	851
March	45,695	23,926	800
April	41,760	39,807	492
May	40,656	51,881	254
June	42,262	49,721	48
July	47,670	54,133	0
August	45,396	43,758	0
September	46,550	30,209	90
October	43,688	20,898	366
November	32,620	11,900	714
December	31,603	10,582	905
YEAR	497,029	351,625	5,524

Note: Collectable insolation consists of direct and diffuse clear day insolation, minus reductions due to cloudiness and inability of collectors to function when insolation rate is less than 100 Btu/ft² (Anderson, 1976).

Table D-3
Output from Shared Direct Solar Technology Systems with Long-Term Heat Storage
(Btus per Ft² Collector Surface): Denver

	Thermal Collectors (40° Tilt)		Cogenerating Photovoltaics (Horizontal)	
	Existing Output ¹	Improved Output ²	Electricity ³	Heat ⁴
January	12,387	24,774	934	2,491
February	12,934	25,868	2,047	5,460
March	14,622	29,244	2,297	6,125
April	13,363	26,726	3,821	10,191
May	10,408	20,816	4,981	10,626
June	10,819	21,638	4,773	10,183
July	12,204	24,407	5,197	11,086
August	11,621	23,243	4,201	8,962
September	11,917	23,834	2,900	6,187
October	13,930	27,960	2,006	5,350
November	10,438	20,876	1,142	3,046
December	10,113	20,225	1,016	2,709
YEAR	144,803	289,612	35,315	82,415
May-September	56,969	113,938	22,052	47,043
Heating Season October-April	87,837	175,674	13,263	35,372

1. Collector efficiency = .4 (ITC, 1976); distribution and storage losses for short-term use (heating season) are assumed to be .2; an additional loss of .2 is incurred for heat that is carried over, i.e., heat collected during non-heating season.
2. Collector efficiency = .6, reflector increase .33; losses as above.
3. 80% the efficiency of noncogenerating photovoltaics, i.e., $.8 \times .12 = .096$.
4. 80% the efficiency of existing thermal collectors, i.e., $.8 \times .4 = .32$. and distribution losses of .2 for short-term and .4 for long-term heat storage.

Table D-4

Availability of Collector Area:

Denver Single Family Residential Study Area

Total Study Area (ft ²)			
Location	Unshaded	Shaded	Total
Roof	52,485	89,082	141,567
Remaining Site Area	+ 47,730	+ 793,503	+ 841,233
Total parcel	100,215	882,585	982,800
Streets/Sidewalks	+ 527,518	+ 93,092	+ 620,610
Subtotal	627,733	975,677	1,603,410
Vacant parcels	+ 8,260	+ 10,580	+ 18,840
TOTALS	635,993	986,257	1,622,250

Each house was evaluated for its adaptability to passive design modifications to the south-facing wall. The east-west orientation of parcels places the south-facing wall of each parallel structure adjacent to a side yard. Only 15 percent of the households are free of shadows on their south-facing wall and, therefore, adaptable to passive design modifications. Of those that are in shadow, the neighboring structure casts the shadow in 55 percent of the cases; trees in 42 percent of the cases.

Solar Reliance Within Study Area

The total scenario goal for the single family detached dwelling (SFD) land use sector is 36.5 percent. 22.8 percent is to be provided by thermal collectors (active solar goal) and 6.2 percent by passive design. See Table D-6 for a complete breakdown of the scenario goal.

The characterization of solar potential for the SFD case considers four collector locations, and is a characterization of potential end-use energy that can be met without impacts on the existing tree canopy, i.e., pruning or removing them to provide solar access. A discussion of the potential trade-offs between an increased solar reliance, collector location, and tree impacts follows at the end of this discussion of the SFD case.

Using passive design and/or thermal collectors with current performance, the study area can supply 19.5 percent of its total energy demand with collectors on roofs and in yards without tree impacts. If system efficiency is improved (Technology 2) the total scenario goal can be achieved without tree impacts. With district systems and long-term storage, the scenario can easily be met, and, with all by Technology 1 can provide 100 percent of the hot water and space heating demand.

Figure D-4 depicts diagrammatically the increased levels of solar reliance possible using the six technology systems.

The maximum solar energy that can be produced and utilized on site without tree impacts is 79.5 percent of total end-use energy demand. This is accomplished by using long-term heat storage and cogenerating photovoltaics on roofs as well as in yards.

ENERGY PRODUCTION IN STUDY AREA WITHOUT TREE IMPACTS:
SINGLE FAMILY RESIDENTIAL STUDY AREA.

Figure D-4

The biomass energy source analyzed in the SFD case is the conversion of air-dried wood in a wood-burning stove. Figure D-5 illustrates the amount of wood necessary with both the existing thermal demand and a reduced demand due to conservation. Meeting the scenario biomass goal would require the consumption of .29 to .33 cords of air-dried wood per household per year. To provide 100 percent of the annual heat and hot water demand in a typical case study household after conservation would require nearly 4.5 cords.

Assuming an average annual wind speed of 12.5 mph, small scale wind generators rated at 15 kw could be integrated into the SFD case study to meet the scenario wind goal of 1.2 percent of total end-use energy. A single generator requiring 300 square feet of unobstructed land area would provide the wind goal for four blocks of the SFD case study area. (See Figure D-6) Installing one generator per block would produce 5.6 percent of the total end-use demand. To meet 100 percent of the total electrical demand would require eight generators per block (approximately one in every two back yards).

While there appears to be sufficient unobstructed land area to install on-site wind generators, the wind-shadow effects of the tree canopy remain unexplored.

Implications of Analysis for Selection and Regulation of Collector Location

Figure D-7 illustrates a number of possible strategies for implementing on-site solar technologies in the SFD case. In each case, the amount of solar reliance is dependent on the unshaded collector area. The shading of potential collector area in a uniform SFD area is the result of the orientation of the roof planes (a northfacing gabled roof receives no useful solar energy for example), the shadows cast by the structures themselves both on one another and on the ground plane, and the shadows cast by trees. The first two of these physical constraints on solar reliance are not easily mitigated, but the effect of tree shading can be more easily manipulated.

Collectors can be located on roofs, in back yards and in front yards. Several combinations are possible, ranging from limiting collectors to one of these possible locations to an unlimited mix.

Notes:

- Assumes an average of 20 million BTUs/cord of air-dried wood;
Source: Cambel, Coates, Hauer, Kay, & Nutt; *Social Assessment of On-Site Solar Energy Technologies*, George Washington University, Washington, D.C., June 1978.
- Assumes an average of 60% efficiency for wood-burning stoves;
Source: Sullivan, George, *Wood Burning Stoves*, Cornerstone Library, N.Y., 1978.

POTENTIAL OF WOOD BIOMASS/FUEL CONSUMPTION TO TOTAL END-USE ENERGY DEMAND, WITH AND WITHOUT CONSERVATION: SINGLE FAMILY DWELLING STUDY AREA.

Figure D-5.

XBL 797 - 2147

Figure D-6

Solar Potential of Small Scale Wind Generators Relative to Total End-Use Energy Demand with Conservation: Single Family Dwelling, Study Area

NOTES: 1. A Grumman wind generator rated at 15 kw at 26 mph producing 30 MWh/year at an average wind velocity of 12 mph.

SOURCE: Office of Energy Programs, George Washington University, *Social Assessment of On-Site Solar Energy Technologies*, June, 1978.

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The variables evaluated in each collector location combination are: scale of the technology system i.e., individual or shared, percent solar reliance, and percentage of trees removed. Cases are organized into groups in which three of these variables are held constant. For example, in cases D through G collectors can be located anywhere on site but no trees can be impacted.

In A through C, on the other hand, the goals are short-term solar sufficiency (70 percent of heating and 80 percent of hot water demand) and confinement of collectors (presumably by ordinance or local consensus) to roof tops (A) or to a single area on site, i.e., either back yards (B) or front yards (C).

The last seven cases differ from the preceding ones in that they assume sharing of energy production with the study area. One household would install more collectors than are needed for its own demand and export the hot water to a neighbor whose collector area is shared. In cases S, T, and U the sharing occurs only with adjacent neighbors. In cases V, W, and X, the sharing is not limited to adjacent neighbors, but does not exceed the limits of the city block. The last case, Y, illustrates maximum solar reliance for the block if trees were pruned or removed to provide solar access to all areas. If each household installed collectors on the roof and in both yards, the block would meet three times its required short-term solar heating and DHW demand at the cost of 77 percent of the neighborhood trees.

Cases D, G, S, and T are the ones that have been analyzed comparatively in Table D-5. These are baseline cases, i.e., individual or shared systems, on roofs alone or on roofs and sites, but with no impacts on the existing trees.

We have selected these cases for comparison with solar potential in other land-use sectors (multiple family, commercial, etc.), because they illustrate the minimum potential of the SFD case study to meet its end-use energy demand with on-site technologies without impacting the existing tree canopy. By limiting collector location to unshaded areas, community impacts are primarily confined to the visual impact of integrating the collectors into the existing structures and yards. Using shared systems, the impacts also include the transaction costs of implementing and sustaining neighborhood cooperation. But such impacts have not been

Table D-5

Solar Potential of the Single Family Dwelling Study Area

Solar Reliance per Scenario (Percentage of End-Use Energy Demand)	Thermal Collectors	22.8%
	Passive Design	6.2%
	Photovoltaics	2.6%
	Biomass	3.6%
	Wind	1.2%
	Total	36.5%

Solar Reliance Achievable (Percentage of End-Use Energy Demand)

	Roofs Only ¹		Roofs and Sites ²	
	Existing Demand	Reduced Demand	Existing Demand	Reduced Demand
ON SITE WITH SHORT TERM STORAGE				
Thermal Collection @ current performance	9% (67% of dhw)	10.1% (66% of dhw)	17.2% (13.7% of heat 80% of dhw)	19.5% (18.2% of heat 80% of dhw)
Thermal Collection @ improved performance	17.9% (15% of heat 80% of dhw)	20.2% (20% of heat 80% of dhw)	34.5% (50.5% of heat 80% of dhw)	39% (67.2% of heat 80% of dhw)
Cogenerating Photovoltaics	35.5% (25% of heat 88% of dhw 30% of elec.)	39.3% (30% of heat 90% of dhw 30.3% of elec.)	55.2% (46% of heat 91.5% of dhw 53.8% of elec.)	59.6% (53.7% of heat 91.5% of dhw 54.1% of elec.)
SHARED (STUDY AREA) WITH LONG-TERM HEAT STORAGE				
Thermal Collection @ current performance	49% (75.7% of heat 100% of dhw)	55.1% (100% of heat 100% of dhw)	60.4% (100% of heat 100% of dhw)	55.1% (100% of heat 100% of heat)
Thermal Collection @ improved performance	60.4% (100% of heat 100% of dhw)	55.1% (100% of heat 100% of dhw)	60.4% (100% of heat 100% of dhw)	55.1% (100% of heat 100% of dhw)
Cogenerating Photo-voltaics	46.6% (45% of heat 100% of dhw 30 % of elec.)	53% (60.3% of heat 100% of dhw 30.3% of elec.)	81.7% (100% of heat 100% of dhw 53.8% of elec.)	79.5% (100% of heat 100% of dhw 54.1% of elec.)
BIOMASS wood burning		SEE	TEXT	
WIND		SEE	TEXT	
Passive Design		SEE	TEXT	

- NOTES: 1. Mean collector area per household available on roofs = 377 square feet
 2. Mean collector area per household available on roofs and sides = 721 square feet

specifically explored in this analysis. The remaining cases illustrated in Figure D-7 describe a much larger range of choices for locating on-site technologies in the SFD study area; each of these choices has differing impacts on the tree canopy.

The following conclusions can be drawn from the illustrated trade-offs:

1. Greater solar reliance can be achieved than in the baseline cases but to do so always requires some sacrifice of tree canopy.
2. It appears that to both maximize solar reliance and minimize impact on tree canopy for individual on-site systems a unique solution for each block will be required.
3. Permitting flexibility in collector area location to achieve maximum reliance w/short-term storage potentially reduces tree impacts for on-site systems by as much as 25 percent to 45 percent of the total tree canopy.
4. In this particular analysis, the greatest solar reliance possible without tree impacts for on-site systems is one where collectors can be located on roofs as well as in both yards: case D, i.e., no limits on collector location.
5. Implementing blockwide shared systems rather than single location on-site systems to achieve maximum reliance w/short-term storage reduces tree impacts by as much as 88 percent to 100 percent.

1. On-site: Solar collectors and storage located within parcel limits of demand
2. District: Solar collectors and storage located within limits of a contiguous city block.
3. Solar Sufficiency: A percentage measure of the solar energy feasible goal; 70% of heating demand, 80% of DHW demand
4. Trees removed: A percentage measure of the trees interrupting the 10 AM to 2 PM solar skyspace.

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Figure D-7

MULTIPLE FAMILY RESIDENTIAL STUDY AREA

Overview of Study Area

This study area encompasses 15.7 acres of a high density residential area of Baltimore. Within the area there are 152 parcels located on five blocks that are aligned in a typical grid pattern. The parcel area comprises 63 percent of the total study area with the remaining percentage in street and sidewalk use. (See map, Figure D-8).

There are two distinct land uses: multiple-family row houses and high rise apartment buildings. The row houses cover the majority of the parcel area (148 parcels, or 87 percent). Average parcel size for the row houses is 2530 square feet. With most of these structures occupying 40 to 50 percent of the parcel, the site area (which usually serves as a parking area) averages 1169 square feet. As these are multi-story housing structures, the average floor area averages 1368 square feet. This, in turn, corresponds to an average height of three stories.

The inclusion of the high rise apartment buildings in the study area changes the overall character of the area significantly; the buildings occupy only four parcels which constitute 13 percent of the total parcel area. These structures average eight stories, 63,500 square feet in floor area, and 13,700 square feet in parcel size. On each parcel approximately 40 percent of the land or an average of 5600 square feet is used for parking.

When the two land uses are combined, the averages are: 2824 square feet for parcel area; 5871 square feet for structure floor area; 1545 square feet for roof area; and a corresponding 1286 square feet for unbuilt site area. For the entire area (parcels and public right of way), unbuilt land totals approximately 448,600 square feet (65 percent).

Characteristics Influencing Solar Energy Use

Active Solar Technologies

In the five block area considered, each block is oriented with its longer dimension running north-south so that building facades face east or west. Figure D-9 presents a sketch of the area's form. Table D-6 through D-10 and Figure D-10 characterize the area with respect to vari-

Figure D-8

Multiple Family
Residential Study Area

40 0 40 80 120 160

Scale in Feet

- Apartment structures
(average height - 8 stories)
- 2 to 4 story row houses

Figure D-9

Form of row house study area.

Perspective

Collectors on roofs and fences.

Elevation

Table D-6

Total Annual End Use Energy Demand of Row Houses in Study Area

Heated Floor Area 638,472 ft.²

END USE	(ENERGY DEMAND (10 ¹⁰ Btu))	
	Existing	With Conservation
Heating	2.17	1.56
Hot Water	0.70	0.70
Cooling (C.O.P.2.5)	0.37	0.35
Lights & Power	0.82	0.82
Total	4.06	3.43

Table D-7

Climatic Conditions Affecting Solar Energy Use: Baltimore

Collectible Insolation Per Month
(Btu/ft²)

	40° Surface	Horizontal Surface	Heating Degree Days
January	27,324	9,242	859
February	33,605	17,732	762
March	39,206	20,435	629
April	38,160	36,376	288
May	39,039	49,228	65
June	40,002	47,062	0
July	41,314	46,916	0
August	41,652	40,149	0
September	40,432	26,239	27
October	38,354	18,347	189
November	26,795	9,775	486
December	23,868	7,992	806
YEAR	429,571	329,493	4111
Heating Season (Oct. - Apr.)	227,132	119,899	4019
(May - Sept.)	202,439	209,594	

Note: Collectible insolation consists of direct and diffuse clear day insolation minus reductions due to cloudiness and mobility of collectors to function when insolation rate is less than 100 Btu/ft² (Anderson, 1976).

Table D-8

Output From Shared Direct Solar Technology
Systems With Long-Term Heat Storage
(Btus Per Ft² Collector Surface): Baltimore

MONTH	Thermal Collectors (40° Tilt)		Cogenerating Photovoltaics (Horizontal)	
	Existing Output	Doubled Output	Electricity ³	Heat ⁴
January	8744	17487	887	2366
February	10754	21507	1702	4539
March	12488	24977	1962	5231
April	12211	24422	3492	9312
May	9994	19987	4726	10082
June	10241	20481	4518	9638
July	10576	21153	4504	9608
August	10663	21326	3854	8223
September	10351	20701	2519	5374
October	12273	24546	1761	4697
November	8574	17149	938	2502
December	7638	15276	767	2046
YEAR	124,507	249,014	31,630	63,618
May-September	51,825	103,650	20,121	42,925
Heating Season (October-April)	72,682	145,364	11,509	30,693

1. Collector efficiency = .4 (ITC, 1976), distribution and storage losses for short-term use (heating season) are assumed to be .2; for long-term storage an additional loss of .2 is incurred for heat that is carried over, i.e. heat collected during the non-heating season.
2. Collector efficiency = .6; increase due to reflectors .33; losses as above.
3. 80% of the efficiency of noncogenerating photovoltaics, i.e., $.8 \times .12 = .96$.
4. 80% of the efficiency of thermal collectors, i.e. $.8 \times .4 = .32$ and distribution losses of .2 for short-term and .4 for long-term heat storage.

Table D-9
Collector Area Available

	Total Area (Horizontal Collector Area)	Collector Bank Area	Shaded Area (10 ft. above Surface)	Unshaded Equivalent Collector Bank Area	Unshaded Area	Unshaded Equivalent Collector Bank Area	Total Unshaded Collector Bank Area
Roofs-total	202,469	99,210					
Roofs-winter			13,680 all day	0	188,789	74,229	74,229
Roofs-summer			0	0	202,469	94,210	99,210
Sites-total	173,067	69,227					
Sites-winter			120,342 1/2 day	19,255	52,725	16,872	36,172
Sites-summer			86,534 1/2 day	17,307	86,534	34,614	51,921
Streets & side- walks-total	269,419	107,768					
Streets & side- walks-winter			107,768 1/2 day	17,243	101,651	32,528	49,771
Streets & side- walks-summer			134,710 1/2 day	26,942	134,710	53,884	80,826
Parking lots- total	0	0					
Parking lots- winter							
Parking lots- summer							
Vacant lots- total	0	0					
Vacant lots- winter							
Vacant lots- summer							

Table D-10
Solar Reliance Achievable For Study Area (10^{10} Btu) Using
Technologies with Short-Term Heat Storage

SCENARIO GOALS Total 36.5% Active Thermal 22.8% Photovoltaics 2.4%								
THEORETICAL POTENTIAL OF TECHNOLOGIES Passive/Active Thermal 44% (Maximum reliance possible) Photovoltaics 82%								
Collector Location and Seasonal Demand (th = thermal; el = electrical)	Thermal Collectors with existing output		Thermal Collectors with doubled output		Cogenerating Photovoltaics			
	Usable energy (surplus)	% of total demand	Usable energy (surplus)	% of total demand	Usable electricity (surplus)	Usable heat (surplus)	Total Usable energy (surplus)	% of total demand
Roofs - total		26%		38%	.63	.87	1.5	44%
th 2.58								
winter	.62	18%	1.01	30%	.22	.58		
el 0.48								
th. 0.29								
summer cooling 0.35	.29	8%	.29	8%	.41	.29		
el. 0.34								
Sites - total		19%		28%	.39	.64	1.03	30%
winter	.39	11%	.70	20%	.13	.35		
summer	.29	8%	.29	8%	.26	.29		

Notes on Table D-10:

Performance Values:

Estimates of short-term storage system output are derived from ITC, 1976 which assumes a collector efficiency of .4 and no additional system losses.

Estimates of long-term, shared storage system output assumes a collector efficiency of .4, losses due to distribution and storage of .4 for existing thermal collectors.

Estimates for systems with improved technology assume a doubling of output as a result of improved efficiencies in all components and use of planar reflectors (see Appendix A).

Surplus Estimates:

For short-term storage systems surplus reflects the amount of energy collected beyond that which is needed on site on a month-by-month basis.

Summer values for thermal collectors are expressed as end use electrical energy for air conditioning (with a C.O.P. of 2.5) that would be displaced by solar air conditioning since this is assumed to be the use to which the surplus would be put.

Surplus for short-term storage systems is calculated by determining the proportion of the seasonal thermal demand up to 70 percent of heating and air conditioning, and 80 percent of hot water which can be met on a site. For example, if the 70 percent heat/80 percent hot goal were achieved for the winter season resulting in a maximum reliance of 56 percent, any additional energy collected would be surplus. A surplus of 112 percent would indicate that the goal could be met two more times during the season. This surplus would not be usable unless it could be transported to another site for immediate use.

For long-term storage the storage capacity is assumed to be large enough to store all collected energy. Distribution and storage losses have been deducted so that this value represents usable output available throughout the year.

Air conditioning:

In the commercial sector it is assumed that for thermal collectors thermal energy would be used to run an absorption air conditioner with a C.O.P. of .5. Estimates by ITC, 1976 were used to determine collector area that would meet a proportion of the cooling load (expressed in units of electrical energy use) for a "general comfort" building. It is assumed that this percentage of the study area's cooling load (derived from A.D. Little, 1977) is met. The value recorded in the table corresponds to the A.D. Little value in order to consistently reflect end use energy displaced.

It is assumed that with cogenerating photovoltaics air conditioning would be provided by electricity so that existing systems could be retained.

The maximum reliance goal for thermal collectors with short-term storage assumes a small amount of sharing by adjacent parcels.

Baltimore Row House
Energy Demand and Fuel Consumption
(10^3 Btu/ft²)

EXISTING

WITH CONSERVATION

End Use

Primary fuel consumption
(present fuel sources) Primary fuel consumption
(all electric)

Figure D-10

ables influencing active solar potential. Figure D-11 is the graph by which solar supply using thermal collectors with short term storage was determined. The primary influences on active solar potential are:

- limited roof area relative to floor area;
- shading of adjacent site area by structures, and shading of roof tops by high-rise apartment buildings interspersed among row houses (see Figure D-12 for shadow pattern on December 21, 10:00 am to 2:00 pm.)
- The due-north-south orientation of the grid, and therefore of the buildings, which allows for maximum collector bank coverages of roof tops, i.e., an area equivalent to one-half of the roof area can be devoted to collectors.

Passive Solar Design and Conservation Potentials

The potential for modifying these structures to allow for direct solar gain is limited. Only the wall of the southernmost structure in each row has a southern exposure. Direct solar gain could be provided through the roof to heat the third story only.

While this configuration limits the opportunity for direct solar gain, it also minimizes heat loss. The annual load is presently 33.8 thousand Btu per square foot or 7.5 Btu per degree day. With the implementation of modest conservation measures, i.e. roof insulation and storm windows, the heat load could be reduced to 22.6 thousand Btu per square foot per year or 5.5 Btu per square foot per degree day.

Solar Reliance within Study Area

Meeting Scenario Goals Using Direct Solar Technologies

The active solar goal designated in the scenario (22.8 percent) can be met for the study area as a whole on roof tops alone using any one of the six technology systems (see Figure D-13 and Table D-10.) While some structures fall short of the goal others can supply more than the designated goal. Figure D-14 depicts the on-site solar potential of individual structures on a block-by-block basis for thermal collectors with existing and improved performance levels.

Figure D-11

Single family residential 70% heat load (10 Btu/ft²/d.d.) +
80% hot water (100 gal./day)

2000 ft ²	250	450	650	850	1050
1500 ft ²	200	350	500	650	800
1000 ft ²	150	250	350	450	550
500 ft ²	75	125	175	225	275

27 Btu	.27	.54	.81	1.08	1.35
18 Btu	.18	.36	.54	.72	.90
15 Btu	.15	.30	.45	.60	.75
10 Btu	.10	.20	.30	.40	.50
8 Btu	.08	.16	.24	.32	.40
6 Btu	.06	.12	.18	.24	.36

Heat load per ft² of floor area

Ratio of collector area to floor area

Notes: Assumes collector tilt of 40°. See Appendix A for assumptions regarding collector performance.

Figure D-12

Shadow patterns, 9:30 a.m. to 2:30 p.m., December 21. Rooftops are shaded by the 8-story structure located in the midst of 3-story row houses.

XBL 798-2549

ON-SITE ENERGY PRODUCTION IN STUDY AREA: MULTIPLE FAMILY RESIDENTIAL STUDY AREA.

Figure D-13

PERCENT OF HEAT LOAD SUPPLIED BY THERMAL COLLECTORS WITH SHORT-TERM HEAT STORAGE IN INDIVIDUAL BUILDINGS WITHIN THE MULTIPLE FAMILY RESIDENTIAL STUDY AREA.

Figure D-14

Structures that fall short are mainly row houses shaded by high-rise structures and the high-rise structures themselves. This is particularly apparent in Block B where seven structures have no opportunity to collect solar energy due to shading by a ten-story structure on the southern portion of the block.

The total scenario solar goal can be met for the area as a whole by all except Technology One using rooftop and site collector area.

Maximum Use of Direct Solar Technologies

Figure D-13 depicts the maximum solar reliance possible using the six technology systems. Maximum solar reliance using all available collector area on site ranges from 33 percent for thermal collectors with existing output and short term storage to 100 percent plus a thermal energy surplus of 50 percent with cogenerating photovoltaic and long-term storage. It should be noted that the actual number of collectors that can be located on a site is generally greater for technologies with long-term storage than for those with short term storage. Winter shading is not as significant a constraint when systems use long-term storage since heat can be collected during sunny months and stored for winter use. In order to identify the maximum physical limits on solar energy use, this analysis assumes that, for systems with short-term storage, collectors are located in areas receiving sunlight for only half the day. However, it is unlikely that such areas would in fact be used with short-term storage systems for economic reasons.

Figure D-13 depicts the relationship of the scenario goals to the technologies' theoretical potential which is limited by the quality of energy produced and its availability over time.

If collectors are limited to roofs and sites only, land availability becomes a limiting factor before the technology itself in four cases. Only in the cases of improved thermal collectors, using long-term storage (with a theoretical potential of 66 percent) and improved thermal collectors using short-term storage (with a theoretical potential of 44 percent) can the technologies be used to the maximum extent possible without locating collectors over public land (streets).

The level of solar reliance possible in the study area increases substantially with the use of photovoltaics. With long-term storage, thermal collectors can provide 100 percent of the domestic hot water and heat loads; this is 66 percent of the total energy demand. Although more heat can be supplied in the space available, it cannot be utilized. Cogenerating photovoltaics produce electricity as well as heat; therefore, a larger portion of the energy output can be used. About 90 percent of the total demand can be met using roofs and sites only, if long-term storage of heat is provided. The electricity supply falls short of the demand while a surplus of thermal energy is produced.

Meeting Scenario Goals Using Indirect Solar Technologies

Table D-11 indicates the requirements for meeting wind and biomass goals designated by the scenario. Wind potential is relatively low in the study area region so decentralized wind machines may not be technically feasible. However, there would be sufficient area on which to site wind machines if they proved feasible. Four 15-kw wind machines would be required, or one for every thirty-seven structures (111 dwelling units). There would be one machine on every block; it could be located in a parking area.

Less than half the power produced by an offsite 100-kw machine would be required to supply the scenario goal for wind production. The total power and lighting demand could be provided by eight centralized machines, or one for every nineteen structures (fifty-seven dwelling units).

To meet the scenario biomass goal on-site would require consumption of 1.25 cords of wood per unit, assuming a wood burning efficiency of 60 percent. 4.0 cords per unit would be required to supply 100 percent of heating and hot water demand.

Impacts of Solar Reliance

As indicated above, meeting the active solar goal (22.8 percent) would result in minimal land-use related impacts since only roof tops would be needed for all technologies. A storage capacity of 1380 gallons per structure or 460 gallons per unit would be required.

Table D-11

**WECSs Required to Meet Study Area's Electrical Energy Demand:
Multiple Family Residential Study Area**

	Number of WECSs	
	Decentralized (15 Kw) 3x10 ³ Kwh/year	Centralized (100Kw) 3.09x10 ⁴ Kwh/year
Total Lighting and Power (8.2x10 ⁷ Btu or 2.4x10 ⁶ kwh)	80	8
Wind Share per scenario, 1.2% (4.1x10 ⁸ Btu or 1.2x10 ⁵ kwh)	4	0.4

Figure 6.2-3 B(5)

Wood Required to Meet Study Area's Thermal Energy Demand

	Cords of Wood (30' x 40') Per Unit*
Total heating and hot water (4.06x10 ³ Btu/Unit/year)	3.4
Biomass Share per scenario 3.6% (0.15x10 ⁸ Btu/Unit/year)	1.25

*1438 ft²/unit

To achieve the 36.5 percent total scenario goal requires an increase in collector area. In the case of Technology One (thermal collectors with short term storage and existing performance) collectors would have to be placed on sites and over some street area. In all other cases roof tops alone are adequate.

The primary physical impacts of any of the technology/location mixes at the community level are a function of the spatial requirements of the systems. Although collectors on space frames do not pre-empt land for other uses, they do, to a certain extent, limit the range of uses. Figure D-15 summarizes the land-use requirements of each technology system.

The most obvious impact will be visual. To use Technology One to its theoretical potential would require a bank of collectors along the property line of each parcel, across the streets at 20 foot intervals as well as on roof tops. With improved efficiencies, only a portion of the sites will require collectors on the site as well as on the roof tops. Collectors on the roof will be visible only to a limited extent. Those on the ground plane will be more visible. However, they can be integrated into the elements within the space. They may be an extension of a fence or the cover of an enclosed structure, e.g. storage shed, greenhouse, or carport.

There are presently very few trees located on sites and along streets in this area. The addition of collectors on the ground would constrain the opportunity to plant trees to a limited extent. As discussed in Chapter 5, deciduous trees reduce insolation about 50 percent in the winter (depending on branch patterns) and 100 percent in the summer time. Thus, trees planted in the solar sky space of a collector would reduce insolation onto the collector to varying degrees depending on the character of the tree.

The use of long-term storage reduces the impact on tree planting potential since it reduces the collector area needed. Moreover, winter shading is less limiting since collectors are producing usable energy during the summer as well as the winter time. On the other hand, if trees are taller than 20 or 30 feet, summer shading of collectors may significantly reduce collectable energy.

TECHNOLOGY	Thermal Collectors Existing Output	Thermal Collectors Improved Output	Cogenerating Photovoltaics	Thermal Collectors Existing Output	Thermal Collectors Improved Output	Cogenerating Photovoltaics
TECHNOLOGY POTENTIAL:	44%	44%	82%	66%	66%	100%
PERCENT OF TOTAL DEMAND						
PERCENT OF END USES	70% Heat 80% DHW	70% Heat 80% DHW	70% Heat 80% DHW 100% Cooling 100% Elec.	100% Heat 100% DHW	100% Heat 100% DHW	100% of total end use

KEY	
—	Total Usable Energy Produced On Site
- - -	Total Scenario Goal
■	Corresponding land area used as collector sites.

UNSHADED SITE AREA USED TO MEET SCENARIO GOAL:
MULTIPLE FAMILY RESIDENTIAL STUDY AREA.

Figure D-15

Figures D-13 and D-15 demonstrate that, in general, as the efficiency of the system increases, the collector area needed to achieve a given level of solar reliance decreases. Consequently, land-use related impacts decrease.

However, as technology efficiency increases, other impacts appear. Long-term storage requires increased water consumption. With short-term storage, the 1.5 to 2 gallons per square foot of collector can be located in one or several tanks within the structure's basement or adjacent to it. Storage volume will vary depending on the number of units being served by it. The size of the storage volume would probably require that it be located underground on the site. There is sufficient accessible underground area available in all cases.

As the scale of the system, i.e. the number of units sharing a single storage volume, increases, the amount of additional distribution infrastructure required increases. Pipelines must be extended from the tank to each unit being served. Because structures are in close proximity in this area, distribution lines are minimized. Shared systems also carry the social cost of increased cooperation among neighbors.

These analyses of existing residential sites indicate that the magnitude and types of impacts from increased solar reliance are a function of the technology performance and system organization within the physical context. Because of the range of choices among implementation strategies in an existing urban context the selection of one system and collector location scheme over another will have to be based on an assessment of the physical, economic and social impacts in each situation.

Implications of Findings for the Modification of Future Urban Form

The potential of active on-site technologies to reduce reliance on nonrenewable fuel sources in existing settings after conservation measures have been employed is limited by the availability of roof and site area as collector locations and the adaptability of structures to passive design. The potential can be increased by increasing conservation measures or by using technologies with increased output per unit of field

area. The level of solar reliance identified in the scenario can be met on-site with existing technologies and using short-term storage. However, it cannot approach 100 percent of the thermal energy demand, (i.e. space heating and hot water load), without the use of long-term storage, reflectors and collectors with increased efficiencies, and/or the location of collectors off-site, i.e. over streets and publicly owned land.

Even if thermal collectors are used to meet the entire heating and hot water demand, that demand represents only 58 percent of the total energy demand. A substantial portion of the remaining demand for power, lighting and air conditioning could be met on site by cogenerating photovoltaics if and when they become economically feasible.

This analysis suggests that to retrofit an existing multiple family structure with a passive or active solar energy system that will provide more than the hot water demand will be, in many cases, a substantial undertaking. Systems requiring the use of public land or at a scale larger than the individual site will entail even greater complexities. The integration of solar technologies into existing urban areas is likely to be more practical, i.e. economical, for an individual, a neighborhood, or a community in some situations than in others. The following discussion briefly explores some of the variables that will influence the use of solar energy design and technologies in existing urban contexts.

Existing Structures

Active and passive techniques are likely to be implemented only when the life-cycle cost of the improvements can be amortized within the life expectancy of the structure. The probable time at which to make such improvements is when the existing heating system "wears out" or when the structure is being renovated for other reasons, e.g. when an area undergoes "gentrification".

New Structures

It is expected to be more convenient and more effective to integrate solar design and technology into *new* structures. Thus, the use of solar systems would appear to be a more attractive proposition in situations where a building or an entire block is being redeveloped or where infilling occurs.

Based on projections to 1995, and assuming the same number of replacements per year until 2025, 17.4 percent of the housing stock active in 1975 will have been removed by 2025. (A. D. Little, 1977) Infilling of vacant parcels or parcels developed at a low density is an on-going

process. How and when solar energy is used and, therefore, the types and magnitude of impacts incurred in a particular redevelopment or in-fill context is a function of the following variables.

Time Frame:

Individual on-site retrofit to achieve a less-than-complete solar reliance for heat requirement can be viewed as an effective action in and of itself, and also as one step toward an even greater level of solar reliance. Individual rooftop and site collectors can be integrated at a future time into a shared system in which the thermodynamic economies of scale for storage could increase output per unit of collector area. Eventually, thermal collectors could be replaced by cogenerating photovoltaic arrays which, together with the large scale storage capacity, could provide close to 100 percent of the total energy demand. Thus, the level of solar reliance achievable in any situation is not static. New structures can be designed to maximize passive design and active thermal collection at the time of construction and to accommodate future modifications such as long-term and/or shared storage and distribution.

Social Organization:

If solar energy systems are installed on an individual basis, the level of organization corresponds to ownership patterns. At a larger-than-individual scale, however, installation would require coordination among individual owners or by a larger organization, e.g. neighborhood, city, or utility. There is a lack of precedent for long-term cooperative action by individuals in a previously unstructured setting. Cooperative agreements are commonplace, however, in new planned unit developments and condominiums.

Scale of Implementation:

In the case of redevelopment, the size of the project is critical. The passive potential of individual urban parcels, in particular, is limited by adjacent structures, parcel orientation, parcel size and the pattern of the existing street grid. However, when a sufficient number of adjacent parcels are redeveloped simultaneously, the opportunities for passive design increase dramatically.

The smallest development in which passive design techniques can be employed will vary by individual case. In the land use patterns from which this multiple family residential case study was drawn, it varies as a function of block orientation.

When the long axis of the block runs east-west, a portion of the block as small as one-fourth could be redeveloped to the same density using passive design. Figure D-16 depicts the change in spatial relationship between structures and in structural dimensions necessary to increase passive solar design in east-west blocks potential. To meet these requirements in the study area, building height would have to be reduced and an additional row of units installed in order to maintain the existing density, because of the pattern established by street widths.

Criteria for increased passive solar potential:

1. A distance 25 times the height of the structure must be maintained to avoid shading of south walls from 10 a.m. until 2 p.m. on Dec. 21.

2. The dimensions of existing structures need to be altered to increase south-facing collector area.

Plan no scale

Existing

Increased passive potential

Figure D-16

Constraints on the development of only a few parcels at a time to increase passive design potential include shading by adjacent structures, property lines and rights-of-way. If three parcels were vacant as in Plan A, they could not be replaced by the configuration shown in Plan B which would improve the south-facing surface to volume ratio because of these constraints.

Plan no scale

Figure D-17

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Figure D-17 demonstrates the difficulties encountered in redeveloping a single parcel or a few parcels. Shading by adjacent structures remains as a constraint. Furthermore, existing property lines and rights-of-way prevent the new development from achieving similar densities. Only if a portion running the entire width of the block is redeveloped as a unit can shading by adjacent structures and relocation of rights-of-way be accommodated (see Figure 18).

As the size of the development increases, design flexibility increases. Consequently, a greater level of solar reliance can be achieved with fewer impacts. At the block level, the form could deviate significantly from the basic row house pattern and still achieve comparable densities.

Figure D-19 depicts the existing block configuration and two modified patterns which would provide for solar access and maintain existing densities.

For blocks running north-south a more dramatic change in the existing pattern is required to accommodate passive design criteria. In essence, the structures must be reoriented to face south rather than east or west. At a minimum, the southern one-third of the block could be redeveloped within passive design constraints (see Figure D-18). If two adjacent blocks were redeveloped simultaneously, they could be redesigned as a south facing block. Figure D-20 depicts the existing form and alternatives providing increased passive solar reliance at the single and two-block levels.

Redesign of one block or consolidation of two would result in a selective closure of streets or alleys and abandonment of rights of way together with the provision of some new streets and alleys and utility infrastructure.

COMPARISON OF RESIDENTIAL LAND USE TYPES

In this section the active solar potential of five different residential land use types located in Baltimore, which has a climate typical of the national average, is compared using energy demand values from a detailed analysis (Hittman Associates, 1972, 1974), land use data from

REDEVELOPMENT OF A PORTION OF A BLOCK WITHIN PASSIVE DESIGN
CONSTRAINTS: AN EAST-WEST ORIENTATION

REDEVELOPMENT OF A PORTION OF A BLOCK WITHIN PASSIVE DESIGN
CONSTRAINTS: NORTH-SOUTH ORIENTATION

Existing development

Proposed development

Figure D-18

XBL 799-2563

Figure D-19

REDEVELOPMENT OF AN ENTIRE EAST-WEST ORIENTED BLOCK TO INCREASE
PASSIVE DESIGN POTENTIAL

EXISTING FORM

Density:
35 d.u./net acre
120 units/block
Height:
3-story (two rows)
Unit Dimensions:
20' x 55'-70'
(approximately 1200 ft²)

Section A-A

MODERATE INCREASE IN
PASSIVE POTENTIAL

Same Density:
38 d.u./net acre maximum
128 units/block maximum
Increased Height:
4-story (two rows)
Unit Dimensions:
25' x 50'
(1200 ft²)

Section B-B

SIGNIFICANT INCREASE IN
PASSIVE POTENTIAL

Reduced Density:
27 d.u./net acre maximum
90 units/block maximum
Same Height:
3-story (three rows)
Unit Dimensions:
40' x 30'
(1200 ft²)

Section C-C

XBL 799-2561

Figure D-20

REDEVELOPMENT OF AN ENTIRE NORTH-SOUTH ORIENTED BLOCK TO
INCREASE PASSIVE DESIGN POTENTIAL

INCREASED PASSIVE POTENTIAL

EXISTING FORM
NO PASSIVE POTENTIAL

Density:
35 d.u./net acre
120 units/block
Height
3-story (two rows)
Unit Dimensions:
20' x 55' -70'
(approximately 1200 ft²)

ONE BLOCK

Density:
27 d.u./net acre maximum
90 units/block maximum
Height:
3-story (two rows) and
2-story (two rows)
Unit Dimensions:
40' x 30'
(1200 ft²)

TWO BLOCKS

Density:
27 d.u./net acre maximum
72 units/block maximum
Height:
same as for one block
Unit Dimensions:
same as for one block

Section A-A

XBL 799-2560

the city planning department and collector area availability from our analyses.

In order to make this generalized comparison, several influential characteristics of urban form are held constant: blocks are assumed to be oriented with their long axes running north-south and multiple family structures on the blocks are located as in Figure D-21. The majority of blocks in the case study city are oriented in this way. Furthermore, this configuration appears to result in a collector area availability fairly representative of the average. Figure D-21 demonstrates why: of the four primary orientation/building location configurations, these configurations comprise one half of the cases; of the other two configurations one results in a smaller collection potential (Case 3) and one a larger potential (Case 4).

It is assumed that no shading from outside the block occurs, that a single land use type occurs on each block and that all structures' energy demand values reflect the reductions achieved with conservation measures. Assumed energy consumption and energy conservation measures are listed in Tables D-12 through D-16.

The comparison is summarized in Table D-17. Using thermal collectors with existing efficiencies and short term storage, only the SFD unit can achieve the maximum level of reliance possible with that technology, i.e., 70 percent of heating and 80 percent of domestic hot water loads. The others have insufficient collector area available. In the case of the townhouse, rowhouse and low rise apartment buildings, there is adequate area but that area is shaded by the structures during part of the day. In the case of the high rise apartments there is simply insufficient area; much of that area is shaded as well. However, if the units are compared with respect to *remaining energy consumption* after the thermal load has been displaced by the on-site solar energy, the SFD still consumes substantially more energy than the other units. Of the four other units, the high rise consumes the least and the townhouse the most.

When thermal collection with improved performance is assumed, all units except the high rise unit can meet the technology's theoretical potential on-site. The gap between the remaining energy demand of the SFD and that of the other units increases. The ranking of residential types in terms of energy consumption remains the same.

Using systems with long term storage and improved performance, the entire thermal load can be met by all units except the high rise unit.

Figure D-21

Shadows cast by prototypic structure in four primary orientation/location configurations.

Cases 1 and 2

Unshaded area as percent of surface area:

	roof	site
winter	100%	25%
summer	100%	50%

Collector area as percent of surface area (equivalent unshaded collector area):

	roof	site
winter	49(39)	10(8)
summer: above + summer only	49(39)	34(32)

Case 3

Unshaded area as percent of surface area:

	roof	site
winter	100%	0%
summer	100%	83%

Collector area as percent of surface (equivalent unshaded collector area):

	roof	site
winter	49(39)	0%
summer: above + summer only	49(39)	51(49)

1.07% of
Case 1

Figure D-21 page 2

Winter

Summer

Case 4

Unshaded area as percent of surface area:

	roof	site
winter	100%	100%
summer	100%	100%

Collector area as percent of surface area
(equivalent unshaded collector area):

	roof	site
winter	49(39)	40(38)
summer: above +summer only	49(39)	40(38)

Average of 4 Cases

Unshaded area
as percent of surface

	roof	site
winter	100	38
summer	100	71

Collector area
as percent of surface:

	roof	site
winter	49(39)	15(12)
summer: above + summer only	49(39)	40(38)

108% of
Case 1

XBL 799-2559

Table D-12

Energy Consumption In A Prototypical Single Family
Detached Dwelling Located in Baltimore
(Derived from Hittman, 1973)

Characterization:

2 stories, basement
1695 ft²/dwelling unit
exterior walls woodshiplap, R-7 insulation
heating system: 1970s, forced air; 1920s, hot water.
fuel: 1970s, gas; 1920s, gas.

	End use (10 ⁷ Btu/yr)	% of total	% of total w/conservation	Assumed delivered fuel to end-use efficiency	Natural gas consumption (10 ⁷ Btu/yr)	Primary fuel consumption for electric- ity (10 ⁷ Btu/yr)
Space heat	7.10	48.4	-	.68	10.44	
W/conservation	4.76	-	42.9	.68	7.00	
Hot water	1.49	10.2	11.6	.55	2.71	
Cooking	.40	2.7	3.1	.80	.50	
Clothes drying	.33	2.3	2.6	.825	.40	
Lighting & appliances	2.52	17.2	19.6	1.00		8.14
Cooling	1.25	19.2	-	1.00		8.88
W/conservation	1.08	-	20.2	1.00		8.09
Total	13.09	100.0	-			
W/conservation	10.58	-	100.2			

Notes: Assuming 4500 degree days per heating season, heat load without conservation = 9.3 Btu/ft²/D.D.;
with conservation = 6.2 Btu/ft²/D.D.

- Derived from figures for primary fuel consumption of an all electric home, assuming a conversion efficiency of 10,910 Btu/Kwh consumed in the house.
- Conservation measures consisting of:
 - a 12% increase in insulation value.
 - storm windows and storm doors (resulting in a 50% reduction in infiltration and U-value reduction of 50%).
 - forced air attic ventilation when attic temperature exceeds 100° F.
- Primary fuel consumption plus distribution loss is assumed to be 0.11 therm/Kwh or a conversion efficiency of 32%.

Table D-13

Energy Consumption In A Prototypical Townhouse Located in Baltimore
(Derived from Hittman, 1974)

Characterization:

2 stories, no basement, 8 units/row
1300 ft²/unit
exterior walls 4" brick, 4" concrete block w/ air space
roof: asphalt shingles
heating system: forced air
fuel: gas

	End use (10 ⁷ Btu/yr)	% of total	W/conservation % of total	Assumed natural gas to end-use efficiency	Natural gas consumption (10 ⁷ Btu/yr)	Primary fuel*1 consumption for electric- ity (10 ⁷ Btu/yr)
Space heat	6.32	56.4	-	.68	9.30	
W/conservation*2	4.55	-	48.4	.68	6.69	
Hot water	1.49*4	13.3	15.8	.55	2.71	
Cooking	.58	5.2	6.2	.80	.72	
Clothes drying	.40	3.6	4.3	.825	.48	
Lighting & appliance	1.67	14.8	17.8	1.00		5.39
Cooling	.75	6.7	-	1.00		2.42
W/conservation*3	.72	-	7.7	1.00		2.32
Total	11.21	100.0	-			
W/conservation	9.41	-	100.0			

Assuming 4500 degree days per heating season, heat load w/out conservation = 11 Btu/ft²/D.D.;
w/conservation = 7.8 Btu/ft²/D.D.

Table D-13 NOTES (continued)

- *1. Primary fuel consumption plus distribution loss is assumed to be 0.11 therm/Kwh or a conversion efficiency of 32%.
- *2. Minimal conservation measures result in 28% decrease in heat load: 17% reduction w/R22 roof insulation & storm windows (R in layer = 0.8). 28% if no internal shading of windows is added.
- *3. Minimal conservation measures result in 4% decrease in cooling load: same insulation plus window shades closed. (Hittman, 1974)
- *4. Hot water consumption has been modified from the Hittman (1974) report to correspond with the consumption figures in the single family dwelling unit on the assumption that hot water demand of multiple dwellings is not substantially higher than that of single family residences and that the proportion of total residential end-use energy used for hot water in Baltimore is close to the national average, i.e. 15% (Lovins, 1976). Hittman (1974) shows consumption for hot water heating for townhouses as 432 therms (10^5 Btu) and 270 for single family residences (10.2% of the total) which corresponds to 25% of total end-use energy consumption assuming 60% primary to secondary energy conversion efficiency.

Table D-14

Energy Consumption In A Prototypical 1912 Rowhouse Located In Baltimore
(Derived from Hittman, 1974)

Characterization:

3 stories, basement

2,255 ft²/unit

exterior walls double layer brick, uninsulated 2" x 4" studding, lath and plaster

roof: slate

heating system: steam

fuel: gas

	End use (10 ⁷ Btu/yr)	% of total	W/conservation % of total	Assumed natural gas to end-use efficiency	Natural gas consumption (10 ⁷ Btu/yr)	Primary fuel* ¹ consumption for electric- ity (10 ⁷ Btu/yr)
Space heat	4.42	47.5	-	.68	6.5	
W/conservation	3.19	-	39.6	.68	4.7	
Hot water	1.49	16.0	18.5	.55	2.71	
Cooking	.58	6.2	7.2	.80	.72	
Clothes drying	.40	4.3	5.0	.825	.48	
Lighting & appliances	1.67	17.9	20.7	1.00		5.39
Cooling	.75	8.1	-	1.00		2.42
W/conservation	.72	-	8.9	1.00		2.32
Total	9.31	100.0	-	1.00		
W/conservation	8.05		100.0			

Assuming 4500-degree days per heating season, heat load without conservation = 7.5 Btu/ft²/D.D.; with conservation = 5.5 Btu/ft²/D.D.

Notes:

- *1. Primary energy consumption plus distribution loss is assumed to be 0.11 therm/Kwh or a conversion efficiency of 32%.

It is assumed that row houses consume 70% of the energy consumed by townhouses for space heating.

Table D-15
Energy Consumption In A Prototypical Low-Rise Apartment Located in Baltimore
(Derived from Hittman, 1974)

Characterization:

3 stories, no basement, 24 2-bedroom units
 floor area per unit: 1140
 exterior walls 4" concrete block, 4" brick
 roof: asphalt shingles
 heating system: 1970s, forced air; 1930s, steam
 fuel: 1970s, gas; 1930s fuel oil

	End use (10 ⁷ Btu/yr)	% of total	W/conservation % of total	Assumed natural gas to end-use efficiency	Natural gas consumption (10 ⁷ Btu/yr)	Primary fuel consumption for electricity
Space heat	4.60	50.5	-	.68	6.76	
W/conservation*1	2.39	-	35.1	.68	3.41	
Hot water	1.32	14.5	19.4	.55	2.40	
Cooking	.58	6.4	8.5	.80	.72	
Clothes drying	.40	4.4	5.8	.825	.48	
Lighting & appliances	1.51	16.6	22.2	1.00		4.73
Cooling	.69	7.6	-	1.00		2.15
W/conservation*1	.61	-	9.0	1.00		1.91
Total	9.10	100	-			
W/conservation	6.81		100			

Assuming 4500 Degree Days per heating season, heat load without conservation = 9.0 Btu/Ft²/D.D.;
 with conservation = 4.7 Btu/ft²/D.D.

Notes:

Conservation results in <u>48% reduction in heat load:</u>	<u>12% reduction in cooling load:</u>
double glazing (R=0.8)	-24%
shading in summer, no	0
shading of windows (winter)	-13%
R-20 insulation of ground	
floor	- 6%
R-21 insulation of roof	- 9%
	+ 2%
	- 3%

Table D-16

Energy Consumption In A Prototypical High-Rise Apartment Located In Baltimore
(Derived from Hittman, 1974)

(Does not include elevator & other non-unit electricity consumption)

Characterization:

10 stories, no basement, 196 units (40 2-bedroom, 156 1-bedroom)
floor area per intermediate units 850 ft²/unit and end units 950 ft²/unit.
exterior walls 4" concrete + 4" brick
heating system: 1970s, hot water; 1920s, steam.
fuel: 1970s, gas; 1920s, fuel oil.

	End use (10 ⁷ Btu/yr)	% of total	W/conservation % of total	Assumed natural gas to end-use efficiency	Natural gas consumption (10 ⁷ Btu/yr)	Primary fuel consumption for electricity
Space heat* ²	2.58	41.7	-	.68	3.79	
W/conservation* ¹	1.67	-	32.2	.68	2.45	
Hot water	0.98	15.8	18.9	.55	1.44	
Cooking	0.40	6.5	7.7	.55	.72	
Clothes drying	0.15	2.4	2.9	.80	.48	
Lighting & appliances	1.50	24.2	28.9	.825		4.69
Cooling	0.58	9.4	-	1.00		1.82
W/conservation* ¹	.49	-	9.4	1.00		1.53
Total	6.19	100	-	1.00		
W/conservation	5.19	-	100			

Assuming 4500 degree days per heating season, heat load without conservation 6.6 Btu/ft²/D.D.
an average of 875 ft²/unit; with conservation 4.2 Btu/ft²/D.D.

Notes:

- Conservation results in:

	<u>78% reduction in heat load:</u>	<u>9% reduction in cooling load:</u>
double glazing	-38%	+ 4%
no window shading (winter)		
shading (summer)	-17%	-12%
R-20 ground insulation	- 3%	+ 1%
R-22 roof insulation	-20%	- 2%
- Space heating requirements of entire building are distributed among units.

Table D-17

Comparison of The Solar Potential of Residential Types

Energy use/land use type (net density)	END USE ENERGY DEMAND ASSUMING CONSERVATION			LAND USE CHARACTERISTICS				
	Electrical demand/mo. Oct.-Apr./ May-Sept./ (10 ⁷ Btu)	Heat/ DHW demand per year (10 ⁷ Btu)	Total end-use energy (10 ⁷ Btu)	●Parcel area as percent of gross area	●Struc- ture cov- erage of parcel (percent)	●Roof area (ft ²) per unit ●Area usa- ble at 40° tilt	Site area (ft ²) per unit ●Area usa- ble at 40° tilt	●Percent of site shaded by structures (10 ft above ground plane): winter/summer
Single family detached 1695 ft ² /dwelling unit 2 stories 8 d.u./acre	.29 .94	7.00	13.09	60%	26%	(% of total) 849 400 (37%)	(% of total) 2,418 967 (40%)	W. 33% 1/2 day S. 21% 1/2 day
Townhouse 1300 ft ² /dwelling unit 2 stories 16 d.u./acre	.22 .40	6.04	9.58	60%	40%	650 325 (49%)	984 394 (40%)	W. 65% 1/2 day S. 42% 1/2 day
Row house - 5 units 1300 ft ² /dwelling unit 3 stories 31 d.u./acre	.22	4.68	8.22	60%	55%	433 210 (49%)	438 175 (40%)	W. 75% 1/2 day S. 50% 1/2 day
Low rise apartments 24 units, 1140 ft ² dwelling unit, 3 stories 32 d.u./acre	.21 .36	3.71	6.98	60%	48%	285 140 (49%)	437 175 (40%)	W. 75% 1/2 day S. 50% 1/2 day
High rise apartments 200 units, 850 ft ² / dwelling unit, 10 stories 150 d.u./acre	.17 .29	2.65	5.32	60%	60%	103 50 (49%)	68 27 (40%)	W. 100% 1/2 day S. 100% 1/2 day

Table D-17 (continued)

Comparison of The Solar Potential of Residential Types: Thermal Collectors.
and Cogenerating Photovoltaics with Long Term Heat Storage

	TECHNOLOGY FIVE: Long Term Storage/Improved Performance			TECHNOLOGY SIX: Cogenerating Photovoltaics/Long Term Storage						
	●Usable energy produced (10 ⁷ Btu) ●% of total demand	Remaining Demand ●Delivered oPrimary (10 ⁷ Btu)	Equivalent central solar land pre-emption (ft ²)	Available collector area unshaded equivalent: winter; summer	Collector area used (ft ²) (Location)	Energy produced: ●Electricity (max. less than 100%*) ●Heat	●Total usable energy produced (10 ⁷ Btu) ●Total used on-site ●% of total demand	Total energy: exportable ●Electricity ●Thermal	●Delivered ●Primary (10 ⁷ Btu)	Equivalent central solar land pre-emption (ft ²)
<u>Single Family Detached</u>	7.00 ✓ 56%	6.74 21.06	599- 1,768	3,267 W 2,712 S 3,267	1,808 (Roof + 1,408 site)	6.6 14.1	17.9 12.3 (94%)	.669 7.16	.81 2.5	58- 172
<u>Townhouse</u>	6.04 ✓ 63%	3.54 11.06	277- 817	1,634 W 1,314 S 1,477	1,292 (Roof + 642 on-site)	4.1 8.7	12.80 9.19 (96%)	.947 2.66	.39 1.22	28- 83
<u>Row house</u>	4.68 ✓ 67%	3.54 11.06	197- 582	871 W 701 S 762	871 (Roof + 338 on-site)	2.24 5.0	7.24 6.91 (84%)	0 .32	1.61 5.03	116- 341
<u>Low rise Apartment</u>	3.71 ✓ 53%	3.27 10.22	216- 637	722 W 559 S 609	722 (Roof + 437 on-site)	1.91 3.9	5.81 5.62 (81%)	0 0	1.34 4.19	96- 284
<u>High rise Apartment</u>	1.6 ✓ 30%	3.72 11.63	276 812	171 W 131 S 137	171 (Roof + 68 on-site)	0.43 0.92	1.38 1.38	0 0	3.94 12.3	284 836

*100% of February and July loads

✓ indicates that the long term storage goal of 100% space heat and 100% hot water demand is achieved.

Table D-17 (continued)

Comparison of The Solar Potential of Residential Types: Thermal Collectors
With Short Term Heat Storage

SCENARIO GOALS: Total 36.5%; Active Thermal 23.1%; Passive Thermal 6.2%

	Available collector area/unit (unshaded equivalent winter; summer)	Ratio of available winter collector area to floor area	TECHNOLOGY ONE: Short Term Storage/Existing Performance				TECHNOLOGY TWO: Short Term Storage/Improved Performance			
			•Solar share (10 ⁷ Btu)	•Collector area used (equiv. unshaded) •Location •Storage volume (gal)	Remaining Demand: Equivalent central solar land pre-emption (ft ²)	•Delivered Primary (10 ⁷ Btu)	•Solar share (10 ⁷ Btu)	•Collector area used (equiv. unshaded) (Location) ft ²	Remaining Demand: Equivalent central solar land pre-emption (ft ²)	•Delivered Primary (10 ⁷ Btu)
Single Family Detached	1,181 W 918 S 1,181	.6	4.95 ³ 37%	520 (520) Roof & site 1,120	9.17 28.65	660- 1,946	4.95 37%	350 ✓ (350) (Roof only)	9.17 28.65	660- 1,946
Townhouse	713 W 464 S 650	.36	2.82 ³	713 (463) Roof & site 928	6.76 21.13	448- 1,521	4.38 47%	280 ✓ (230) (Roof only)	5.20 16.26	374- 1,104
Row house	388 W 262 S 344	.30	2.47 ⁴ 30%	388 (262) Roof & site 412	5.75 17.97	381- 1,507	3.62 42%	275 ✓ (220) (Roof + 65 onsite)	4.60 14.36	331- 976
Low Rise Apartment	316 W 206 S 272	.18	1.90 ⁴	316 (206) Roof & site 412	5.08 15.88	365- 1,067	2.80 39%	200 ✓ (200) (Roof + 60 onsite)	4.18 13.06	301- 887
High Rise Apartment	78 W 53 S 65	.06	0.88 ⁴	78 (53) Roof & site 156	4.44 13.87	320- 942	1.40 23%	78 (78) (Roof + 28 onsite)	5.92 12.25	282- 832

1. Does not include electrical energy consumption outside of units.
2. It is assumed that reflectors are not adaptable to single family dwelling roof tops.
3. Some percentage of total demand could be provided by passive design.
4. Some percentage of total demand could be provided by passive design only for units with south facing exposure

⁴ Indicates that short term storage goal of 70% heat and 80% DHW is achieved.

Notes on Table D-17

Building characteristics and energy demand values: see Figures 4.13-2 through 4.13-6 (From Hittman Associates for HUD, Residential Energy Consumption, 1973 and 1974).

Land use and usable area values derived from case study findings and seasonal shadow pattern analysis. See Figure 4.13-7.

Central Solar Conversion values from Weingart, Jerome M.,
The Helios Strategy, 11ASA Working Paper, 1978, Table 6:

solar thermal electrical conversion technology
 direct beam radiation 7-8 Kwh/m²/day
 efficiency (from resource to secondary energy) 0.15 - 0.25
 ground cover 0.4 - 0.6
 W/m² solar machine: 44 - 83 (electrical)
 130 - 250 (thermal)
 W/m² dedicated land: 17 - 50 (electrical)
 50 - 150 (thermal)

Remaining energy demand of the SFD is almost twice that of the other units. The remaining demand of the high rise unit is now slightly higher than that of the other multiple family units.

It is only with the use of cogenerating photovoltaics that the SFD can reduce its remaining demand to less than that of the MFD units. However, collector area required is substantially greater, resulting in greater on-site impacts from achieving this high level of solar reliance.

This brief analysis suggests that, although the on-site solar potential of multiple family (higher density) units is likely to be limited by site constraints before that of single family units, a policy of maximum solar reliance to reduce energy consumption would not encourage single family development and consequent "sprawl". With the use of thermal collectors only, single family detached units consume more energy than any other residential type. With the use of cogenerating photovoltaics, the SFD demand can be reduced to less than that of the other types. However, to do so requires twice the collector area used in the other types. Consequently the impacts on the single family site would be greater than those on the multiple family sites due to the larger collector area requirement and the greater sensitivity of single family units to visual and tree shading impacts. Townhouses at twice the density of SFD units can reduce demand to the same level as the SFD units using half the photovoltaic collector area.

The comparison does not, of course, consider all energy uses in each residential type. The inclusion of construction infrastructure and transportation energy costs will reduce the attractiveness of the SFD as an energy conserver relative to the other residential types. (Harwood, 1977; Real Estate Research, 1975).

STRIP COMMERCIAL STUDY AREA

Overview of Study Area

The medium density commercial area is adjacent to two major freeways and a single family residential area. Land uses include a department store and restaurant, motel/hotel accommodations, and a railroad right-of-way which together occupy 28 percent of the parcel area. Commercial office buildings occupy 42 percent and multiple family residential units occupy 30 percent. The residential units consist of a single block of low rise apartments and a large apartment complex. Of the total parcel area only 2.6 percent remains undeveloped. (see map, Figure D-22). and other public rights-of-way, compared with 38 percent in the single family residential and CBD study areas. Blocks are larger than in the other study areas. Parcels have a mean area of 9,082 ft². for the low density multi-family residential block and 49,339 ft². for the commercial area.

Structures range in height from one to three stories. An average of 63 percent of each site is unbuilt compared with 10-20 percent in the central business district. The unbuilt area is primarily used for parking. For this analysis only the commercial sites will be evaluated.

Characteristics Influencing Solar Energy Use

Tables D-18 and D-19 and Figure D-23 characterize the area with respect to variables influencing active solar potential. The graph in Figure D-2 is used to determine short term thermal supplies. The low profile of the buildings and the large amount of open space surrounding each one provide an enormous opportunity for both passive and active design applications.

Solar Reliance Achievable Within Study Area

The scenario allocates 18.3 percent of the commercial sector's total end use demand to decentralized solar technologies, and 14 percent of the total end use demand to active solar technologies. Both of these goals can be met in the study area by any one of the direct solar technology systems evaluated using only roofs as collector locations. (See Table D-20 and Figure D-24).

Figure D-22

XBL 798-2547

Table D-18

Annual Total End-Use Energy Demand of Strip Commercial Study Area

Heated Floor Area: 563,700 ft.²

END USE	ENERGY DEMAND (10 ¹⁰ Btu)	
	Existing	With Conservation
Heating	9.887	3.078
Hot Water	0.394	0.265
Cooling (C.O.P. 2.5)	1.353	0.998
Lights and Power	3.269	2.762
Total	14.903	7.103

For insolation and collector performance values see Tables D-3 and D-4.

Table D-19
Collector Area Available

	Total Area (Horizontal Collector Area)	Collector Bank Area	Shaded Area (10 ft. Above Surface)	Unshaded Equivalent Collector Bank Area	Unshaded Area	Unshaded Equivalent Collector Bank Area	Total Unshaded Collector Bank Area
Roofs-total	352,195	172,576					
Roofs-winter			23,470 1/2 day	4,577	328,725	128,203	132,780
Roofs-summer			0	0	352,195	172,576	172,576
Sites-total	1,367,375	546,940					
Sites-winter			463,137 1/2 day	74,102	904,328	289,356	363,458
Sites-summer			0	0	1,367,375	546,940	546,940
Streets & side- walks-total	520,861	208,344					
Streets & side- walks-winter			0	0	520,861	166,676	166,676
Streets & side- walks-summer			0	0	520,861	208,344	208,344
Parking lots- total	15,500	6,200					
Parking lots- winter			0	0	15,500	4,960	4,960
Parking lots- summer			0	0	15,500	6,200	6,200
Vacant lots- total	54,940	21,976					
Vacant lots- winter			13,900 1/2 day	2,224	41,040	13,133	15,357
Vacant lots- summer					54,949	1,976	21,976

Commercial Strip Annual Energy Consumption
(10^3 Btu/ft²/year)

EXISTING

WITH CONSERVATION

Figure D-23

Table D-20

Solar Reliance Achievable for Strip Commercial Study Area Using Technologies with Short Term Heat Storage
(End Use Energy Displaced In 10^{10} Btu)

Collector Location and Seasonal Demand (th = thermal el = electrical)		SCENARIO GOALS Total 18.8%							
		THEORETICAL POTENTIAL				Active Thermal 12.89% Photovoltaics 3.87%			
		Passive/Active Thermal 43% Photovoltaics 86%							
		TECHNOLOGY ONE Thermal Collectors with existing output		TECHNOLOGY TWO Thermal Collectors with doubled output		TECHNOLOGY THREE Cogenerating photovoltaics			
		Usable energy (surplus)	% of total demand	Usable energy (surplus)	% of total demand	Usable electricity (surplus)	Usable heat (surplus)	Total Usable energy (surplus)	% of total demand
Roofs-total		7.09		2.97	43%	1.213	1.27	2.48	35%
				(1.77)	(25%)		(1.35)	(1.35)	(19%)
winter	th	3.23		2.27	33%				
	el	1.60	22%	(0.83)	(12%)	0.436	1.16		
summer	th	0.11		.70	10%		0.11		
	cooling	1.0	10%	(.94)	(13%)	0.777	(1.35)		
	el	1.15							
Sites - total		7.09		3.04	43%	3.24	2.34	5.58	79%
				(3.22)	(45%)	(1.30)	(6.93)	(8.23)	(116%)
winter	th	3.23		2.34	33%	1.09	3.20		
	el	1.60	23%	(5.63)	(79%)	(.11)			
summer	th	0.11		0.70	10%	2.15	0.11		
	cooling	1.0	22%	(2.99)	(42%)	(1.19)	(6.93)		
	el	1.15							
Roofs and Sites total		7.09		3.04	43%	3.75	2.34	6.10	86%
				(13.43)	(189%)	(2.00)	(9.95)	(11.54)	(163%)

Table D-20 (continued)
Solar Reliance Achievable For Strip Commercial Study Area Using Technologies With Shared, Long Term Heat Storage (End Use Energy Displaced in 10¹⁰ Btu)

Collector Location and Seasonal Demand (th = thermal el = electrical)		SCENARIO GOALS Total 18.8%							
		THEORETICAL POTENTIAL OF TECHNOLOGIES (Maximum reliance possible)				Active Thermal 12.89% Photovoltaics 3.97%			
		Passive/Active Thermal 61% Photovoltaics 100%							
		TECHNOLOGY FOUR Thermal Collectors with existing output		TECHNOLOGY FIVE Thermal Collectors with doubled output		TECHNOLOGY SIX Cogenerating Photovoltaics			
		Usable energy (surplus)	% of total demand	Usable energy (surplus)	% of total demand	Usable electricity (surplus)	Usable heat (surplus)	Total Usable energy (surplus)	% of total demand
Roofs - Total	7.09	1.90	27%	3.44	48%	1.213	2.82	4.033	57%
winter th	3.23	1.17	16%	2.34	33%	0.436	1.16		
el	1.6								
summer th	.11	0.11 (DHW)	11%	0.11	15%	0.777	.11		
cooling	1.0	.62 (AC)		1.00			(1.55)		
el	1.15								
Sites - total	7.09	4.34 (2.01)	61% (28)	4.34 (7.25)	61% (102%)	3.24 (1.30)	3.34 (7.93)	6.468 (9.21)	91% (130%)
winter th	3.23	3.23	45	3.23	46%	1.09	3.23		
el	1.6			(3.23)	(46%)	(.11)			
summer th	0.11	0.11 (th)	16	0.11	15%	2.15	0.11		
cooling	1.0	1.0 (cool.)	(28)	1.0	(57%)	(1.19)	(7.91)		
el	1.15	(2.01 stored surplus or		4.02 stored surplus or					
Streets/sidewalks total		1.43 summer cool. surplus		2.9 summer A.C. surplus					
Roofs and Sites total	7.09	4.34 (3.91)	61% (55%)	4.34 (10.69)	61% (151%)	3.75 (2.00)	3.34 (10.75)		100% (180%)

ON-SITE ENERGY PRODUCTION IN STUDY AREA: STRIP COMMERCIAL STUDY AREA.

Figure D-24

Figure D-25 shows the solar supply that can be achieved on-site by individual buildings and the percentage of end-use demand that can be met by increasing collector area on-site, i.e., on roofs and on on-site open space, beyond that needed to meet the total scenario goal. Values are expressed as percentages of the total demand (7.103×10^{10} Btu/year). Surplus energy collected is subdivided according to the seasons during which it is produced and according to its quality. Therefore, the usefulness of the surplus as an exportable energy source can be calculated.

The maximum amount of end-use energy that can be supplied by a given technology system, i.e., its theoretical potential, can be provided within the study area in each case. Collector area availability is not a limiting factor. This theoretical potential ranges from 43 percent of total demand for thermal collectors with short-term storage to almost 100 percent of the total demand with cogenerating photovoltaics.

Table D-21 indicates the number of 15 kw wind machines that would be required to meet the scenario wind goal. The number of large-scale (100 kw) machines that would be required is included as an alternative since it is more likely that WECSs will be located remotely to meet energy demand in urban areas.

The eleven 15 kw machines could be accommodated within the study area assuming that each requires 300 square feet as a foundation and that freedom from obstruction by other wind machines or objects of equal height can be maintained.

Use of municipal solid waste (MSW) as an energy source is evaluated in the section for the central business district (CBD). It is assumed that energy from that source would be used in the CBD, since the ability of the CBD to provide its own energy within the study area is so limited.

Impacts of Solar Reliance

Scenario Goal

To meet the scenario's total solar goal (18.3 percent of end use energy demand) after conservation would consume approximately 1.35×10^5 gallons of water (at 1.5 gallons per square foot of collector area or .25 gallons per square foot of heated floor area.)

Figure D-25

PERCENTAGE OF HEAT LOAD PLUS 80% DOMESTIC HOT WATER LOAD MET ON 28 INDIVIDUAL SITES WITH EXISTING THERMAL TECHNOLOGY AND SHORT-TERM STORAGE (SYSTEM 1) IN THE STRIP COMMERCIAL STUDY AREA.

Table D-21

Wind Energy Conversion Systems required to meet the strip commercial study area's electrical energy demand

	Number of WECSs	
	Decentralized (15 kw) 3x10 ³ kwh/year	Centralized (100 kw) 3.09x10 ⁴ kwh/year
Total Lighting & Power (8.1x10 ⁶ or 2.76x10 ¹⁰ Btu)	270	27
Wind share per scenario (3.2x10 ⁵ kw or .11x10 ¹⁰ Btu)	11	1

Figure D-26 portrays the land-use "pre-emption" which would result from meeting the scenario goal and from achieving maximum reliance. Since only rooftops are used, no alternative land use is actually pre-empted. Furthermore, visual impact is limited to an occasional glimpse of collector banks from the ground.

If wind machines were located within the study area they might be placed on the periphery of parking areas, so that a few parking spaces (two or three) might be preempted for each 15 kw wind machine. One acre of land would be preempted in a remote area to provide for the centralized WECS required.

Maximum Solar Reliance

To achieve theoretical potential on-site using thermal collectors with short-term storage (43 percent of total demand), collectors would have to be located on a portion of the ground plane (approximately 20 percent) as well as on roofs, using collectors with existing output. With improved performance, only about 10 percent of the ground plane would be used. With sharing by adjacent sites and use of collectors with improved performance the need for collectors to be located on the ground could be eliminated entirely.

A slight increase in collector area⁹ combined with large shared-storage facilities would be required to increase reliance to 61 percent of the total demand, (100 percent of thermal demand). There is abundant parking area on which to locate a storage facility either above or below grade.

To meet 100 percent of the demand, thermal as well as electric, would require the use of cogenerating photovoltaics with long-term heat storage. To produce sufficient electricity during the winter would require the placement of arrays over the entire area, on both roofs and over the ground plane. A large thermal energy surplus and a substantial summer electrical energy surplus would result.

⁹ Roofs plus 30-40 percent of the ground plane with existing performance and roofs plus less than 10 percent of the ground plane with improved performance.

UNSHADED SITE AREA USED TO MEET SCENARIO GOAL:
STRIP COMMERCIAL STUDY AREA.

Figure D-26

CENTRAL BUSINESS DISTRICT

Overview of Study Area

The 16-block Central Business District (CBD) study area represents 8 percent of the total CBD land area and 25 percent of its total floor area. Within the study area, 50 percent of the parcel area is devoted to high rise offices and hotels. Twenty percent is comprised of multiple-family residential units and another 20 percent is comprised of parking lots and structures. One percent is vacant and the remaining 9 percent is dedicated to miscellaneous uses. (See map, Figure D-27).

Buildings range in height from one to thirty-one stories. The greatest number (74 percent) are under five stories; 13 percent are from five to nine stories; 12 percent are from ten to eighteen stories. A single structure is thirty-one stories tall.

The ratio of building square footage relative to parcel area for developed parcels is 6.7, reflecting the CBD's high density compared to 0.24 for the strip commercial area.

Characteristics Influencing Solar Energy Use

The CBD study area's potential production of energy is more severely constrained than any other study area due to a combination of physical characteristics:

- structures are oriented at 45° from south, which reduces the amount of collector area that can be accommodated on existing rooftops to about one-third of the total roof area;
- density is high, resulting in a small amount of roof area relative to floor area;
- height of structures vary considerably, resulting in obstruction of solar access onto roofs and south-facing walls of a large portion of the structures.

Tables D-22 and D-23 and Figure D-28 characterize variables influencing the area's solar potential. The demand for light and power is assumed to be about the same as the demand of conventional low rise office buildings (A. D. Little, 1977). Heating demand is assumed to be somewhat lower and reducible with conservation to 5 Btu per square foot per degree day. Based on these assumptions, the demand of high rise structures after conservation measures are imposed is lower than that of low rise offices on

Figure D-27

Central Business District Study Area

Scale in feet

0 100 200 400

Table D-22

Annual Total End-Use Energy Demand
 of the CBD Study Area
 Heated Floor Area 6,041,850 ft²

END USE	ENERGY DEMAND (10 ¹⁰ Btu)	
	Existing	With Conservation
Heating	60.4	23.1
Hot Water	1.6	1.6
Cooling	13.2	4.3
Lights & power	32.6	23.1
Total	107.8	52.1

Demand/acre of Study area	2.0	1.0
---------------------------	-----	-----

For insolation and collector performance values see Tables D-3 and D-4.

Table D-23

Collector Area Available

	Total Area (Horizontal Collector Area)	Collector Bank Area	Shaded Area (10 ft. Above Surface)	Unshaded Equivalent Collector Bank Area	Unshaded Area	Unshaded Equivalent Collector Bank Area	Total Unshaded Collector Bank Area
Roofs-total	763,800						
Roofs-winter			335,987 all day		427,813	136,900	136,900
Roofs-summer							
Sites-total	194,642						
Sites-winter			165,750 all day		28,829		9,245
Sites-summer							
Streets & side- walks-total	1,076,330						
Streets & side- walks-winter			909,914 all day		166,416	53,253	53,253
Streets & side- walks-summer							
Parking lots- total	244,420						
Parking lots- winter			151,480 all day		92,940	29,741	29,741
Parking lots- summer							29,741
Vacant lots- total	23,150						
Vacant lots- winter			14,347 all day		8,803	2,817	2,817
Vacant lots- summer							2,817

Figure D-28

Central Business District Study Area

Scale in feet 0 100 200 400

a square-foot-of-floor-area basis. However, as a result of the area's density, demand per unit of study area is considerably higher, i.e. 1×10^{10} Btu/acre compared to 0.13×10^{10} Btu/acre in the strip commercial area.

Buildings range in height from 1 to 31 stories with an average floor area ratio (F.A.R.)¹⁰ of 6.67 for heated buildings. Figure D-28 shows shadows cast on December 21 between 10 A.M. and 2 P.M. Only 31 percent of the surface area available for collector location is unshaded (available area includes roofs, sites, streets and parking lots and excludes vacant parcels since it is assumed that they will eventually be developed).

Solar Reliance

Direct Solar

A simplified analysis of the CBD's potential solar reliance was conducted due to the complexity of shadow patterns. Shadow patterns were determined for the winter time and it was assumed that only that collector area unshaded during the winter would be utilized. The area of unshaded collector bank surface would be equivalent to 10 percent of the total surface area in all locations, i.e. one-third of the unshaded area. Horizontal cogenerating photovoltaics could be located on the entire unshaded area.

Table D-24 records the analysis of solar potential. Figure D-30 presents the results graphically. Only with Technology 6, cogenerating photovoltaics with long-term storage, located on all available unshaded areas can the scenario's active solar goal of 14 percent for the commercial sector be achieved. All other technology systems fall short of meeting the active solar goal.

The total scenario goal cannot be met using only direct solar technologies as it can in all other land use types.

¹⁰Floor area ratio is the ratio of floor area to total parcel area.

Table D-24

Solar Reliance Achievable For Study Area Using Technologies
 With Short Term Heat Storage
 (End Use Energy Displaced in 10^{10} Btu)

	SCENARIO GOALS				Total 18.82%		Passive/Active Thermal Photovoltaics		12.89% 3.87%
	THEORETICAL POTENTIAL OF TECHNOLOGIES (Maximum Reliance Possible)						Passive/Active Thermal Photovoltaics		39% 86%
	TECHNOLOGY ONE Thermal Collectors with existing output		TECHNOLOGY TWO Thermal Collectors with doubled output		TECHNOLOGY THREE Cogenerating Photovoltaics				
Collector Location	Usable energy (surplus)	% of total demand	Usable energy (surplus)	% of total demand	Usable electri- city (surplus)	Usable electri- city (surplus)	Total usable energy (surplus)	% of total demand	
Roofs-Total	1.87	3.6% (80%DHW)	3.64	7.2% (80%DHW)	1.51	1.74	3.25	6.2%	
winter	1.20	2.5%		5.2%		1.21			
summer	.67					.53			
Roofs & sites total	1.95	3.7% (80%DHW 2.9%heat)		7.4% (80%DHW 5.8%heat)	1.61	1.82	3.43	6.6%	
Roofs & sites & streets total	2.42	4.6% (80%DHW 4.9%heat)	4.68	9.2% (80%DHW 7.8%heat)	2.20	2.29	4.49	8.6%	
Roofs & sites & streets/ sidewalks & parking lots total	2.68	5.1% (80%DHW 9.4%heat)	5.36	10.2% (80%DHW 9.4%heat)	2.53	2.55	5.08	9.8%	

Table D-24 (continued)

Solar Reliance Achievable For Study Area Using Technologies
 With Long Term Heat Storage
 (End Use Energy Displaced in 10^{10} Btu)

		SCENARIO GOALS		Total 18.82%		Passive/Active Thermal 12.89%		Photovoltaics 3.87%	
		THEORETICAL POTENTIAL OF TECHNOLOGIES (Maximum Reliance Possible)				Passive/Active Thermal 39%		Photovoltaics 86%	
		TECHNOLOGY ONE Thermal Collectors with existing output		TECHNOLOGY TWO Thermal Collectors with doubled output		TECHNOLOGY THREE Cogenerating Photovoltaics			
Collector Location	Usable energy (surplus)	% of total demand	Usable energy (surplus)	% of total demand	Usable electri- city (surplus)	Usable electri- city (surplus)	Total usable energy (surplus)	% of total demand	
Roofs - total	1.74	3.3%	3.48%	6.7%	1.51	3.22	4.73	9.1%	
Roofs & sites total	1.86	3.6%	3.72	7.1%	1.61	3.44	5.05	9.7%	
Roofs & sites & streets total	2.54	4.9%	5.08	9.8%	2.20	4.70	6.90	13.2%	
Roofs & sites & streets/ sidewalks & parking lots total	2.92	5.6%	5.84	11.2%	2.53	5.40	7.93	15.2%	

Central Business District Annual Energy Consumption
(10^3 Btu/ft²/year)

Figure D-29

ON-SITE ENERGY PRODUCTION IN STUDY AREA: CENTRAL BUSINESS DISTRICT.

Figure D-30

XBL 797 - 2149

Biomass Conversion

Table D-25 indicates the population required to support energy production from municipal solid waste (MSW) conversion using a pyrolysis process to supply the study area's energy demands. Net energy production from the purox pyrolysis process (selected because it produces fewer environmental residuals than other processes) is 0.31 Btu/lb. of MSW (LBL, 1979) in the form of low-Btu gas. Per capita MSW output is 4 lbs./day (LBL, 1978); therefore, low-Btu gas production is 452 Btu/person-year. Land area for the facility required for facility required for that production is 4.53 ft²/person.

The population of the Denver SMSA is 1,270,529. Assuming that all of the waste produced in the SMSA were converted into usable energy* only 0.0004% of the study area's current end-use energy demand could be met. Obviously, MSW is an insignificant energy source compared with direct solar technologies. Moreover, if a substantial portion of the waste that could be recycled, i.e., 88 percent (California Solid Waste Management Board, 1977), were recycled, there would be an even smaller supply of MSW.

Wind as an Energy Source

The scenario calls for the provision of 1.6 percent of the commercial sector's total energy demand by wind. Seven 100-kw WECSs would be needed to provide 1.6 percent of the study areas demand after conservation.

If these WECSs were located outside of the urban area, the impact would be the preemption of approximately 1 acre per wind machine, or a total of 7 acres. Within the CBD, WECSs would probably be of the 10-15 kw scale, located on the roofs of existing structures, or as turbines within the upper portion of new structures. Seventy of these small scale machines would have to be located in the study area to meet the scenario goal for wind energy. (This is one 15 kw generator for every third of an acre of net development parcels in the study area.)

Energy Importation

To meet the total scenario goal within the community using any of the technology systems evaluated, energy would have to be imported from nearby

* Gas to electricity efficiency 32 percent and direct use efficiency 70 percent.

Table D-25

Population and Land Area Required to Support CBD Case Study
Using Municipal Solid Waste As Fuel Source

Proportion of Energy Demand to be Provided	POPULATION AND LAND AREA REQUIRED	
	Without Conservation	With Conservation
Total primary energy demand, (Heat and DHW-direct fuel; cooling, lights & power-electric).	4.36 billion 453,416 acres	2.50 billion 259,986 acres
Total heating demand	1.04 billion 108,154 acres	508 million 52,829 acres
Scenario goal (0.45% of total end use)	11.4 million 1,186 acres	4.5 million 468 acres

The total population of the SMSA (metropolitan area) of which this is the central city is 1.2 million. This region is not large enough to supply the solid waste needed to meet the scenario goal for biomass for the study area with net MSW energy production.

areas. Both the strip commercial and the warehousing district produce a substantial surplus of energy. Since the warehousing district receives less public use so that impacts would not be felt as heavily as in the strip commercial area, that area will be considered as a possible energy source for the CBD. Table D-26 summarizes the potential of the three technology systems with long-term storage to supply the CBD with winter thermal energy and, in the case of system 6, year-around electricity. To meet the CBD's deficit after collectors have been located on roofs and over unbuilt site area would require that there be: 3.2 acres of warehouse development for every one acre of CBD area using thermal collectors with present performance levels; and 1.5 acres for every one acre using thermal collectors with improved performance. There is sufficient warehousing district area available to meet this requirement in the city in which these case studies are located.

Impacts of Solar Reliance

The impact of reaching the active solar goal in the CBD would be placement of horizontal photovoltaic arrays in all areas receiving winter sun, i.e. on roofs, over 15 percent of parcel area adjacent to buildings, over 15 percent of streets and sidewalks and over 38 percent of parking lots. (See Figure D-31.) Distribution and heat storage infrastructure to supply the few buildings whose energy demand could be met would have to be installed.

To use land area in the warehousing district to produce exportable surplus energy for the CBD would require that collector frames be placed over the entire parcel since roof mounted collectors will be used to meet on-site energy demand.

Implication for Form of the CBD

Figure D-32 characterizes the land use and density of the CBD study area. The ratio of parcel area to street/side walk area is not representative of the rest of the CBD because the study area is bounded by a street much wider than average. For most of the CBD the proportions are: 64 percent parcel area to 36 percent street/sidewalk area. The existing street pattern, i.e. orientation, width and length, and the resulting block dimensions limit the height that structures may attain without obstructing the passive solar areas of adjacent structures. To ensure solar access during the winter time from 10:00 am to 2:00 pm, a single structure covering the entire block could be 30 feet tall on the parcel's

Table D-26

The Potential for Energy Importation
from Warehouse District to CBD

CENTRAL BUSINESS DISTRICT Study Area 53 acres		Technology Systems (Long-term Storage)	
	Thermal Collectors Existing Performance	Thermal Collectors Improved Performance	Cogenerating Photovoltaics
CBD Theoretical Potential (Maximum reliance with technology) in 10^{10} Btu	56% 29.2(th)	56% 29.2(th)	100% 52.1(th&el)
CBD potential using roof & sites & short-term storage (10^{10} Btu)	2.0	3.9	3.4
CBD Deficit (10^{10} Btu)	27.2	25.3	48.7

WAREHOUSING DISTRICT Stud- Area 53 acres			
Warehouse Surplus (10^{10} Btu)	8.5	16.9	14.6
Remaining CBD Deficit (10^{10} Btu)	18.7	8.4	34.1
Acres of Warehouse to meet Deficit of One Acre CBD	3.2	1.5	

th = thermal energy

el = electrical energy

TECHNOLOGY	SHORT TERM HEAT STORAGE			LONG TERM HEAT STORAGE		
	Thermal Collectors	Thermal Collectors	Cogenerating Photovoltaics	Thermal Collectors	Thermal Collectors	Cogenerating Photovoltaics
	Existing Output	Improved Output		Existing Output	Improved Output	
TECHNOLOGY POTENTIAL:	39%	39%	86%	56%	56%	100%
PERCENT OF TOTAL DEMAND						
PERCENT OF END USES	70% Heat 80% DHW 70% Cooling	70% Heat 80% DHW 70% Cooling	70% Heat 80% DHW 100% Cooling 100% Elec.	100% Heat 100% DHW 100% Cooling	100% Heat 100% DHW 100% Cooling	100% of total end use

UNSHADED SITE AREA USED TO MEET SCENARIO GOAL:
CENTRAL BUSINESS DISTRICT STUDY AREA.

Figure D-31

CBD Characteristics

Total CBD =
1 square mile
Study area =
8% of land
area and 25%
of floor area

Ratio of existing floor area
to gross study area (height index)
2.8 Stories

Ratio of parcel area
to street/sidewalk
54:46

Ratio of floor area to
parcel area (F.A.R.)
5.2 Stores

Study area
1 block

.87 Stories

64:36

1.3 Stories

CBD as a whole
1 block

.70 Stories

64:36

1.08 Stories

Undeveloped CBD
1 block

Figure D-32

northern perimeter and about 120 feet tall (10 stories) at its southernmost point without blocking solar access on adjacent blocks. If the block were divided into four parcels, the southernmost parcel could have a high point of 65 feet and a low point of 12 feet with a setback of 36 feet corresponding to the low point without blocking solar access of the parcels to the north. The northernmost parcel could be 85 feet tall (7 stories) at its highest point decreasing to 30 feet (2.5 stories) at the northern lot line. These volumes of space are depicted in Figure D-33.¹¹

Although a larger volume is available for development on the single parcel than in the four-parcel block, the ability of a structure filling that entire volume to maximize solar reliance may be limited by the reduced surface-to-volume ratio. Natural ventilation and day lighting, which can reduce energy consumption in a well-insulated commercial building more significantly than passive heating, require an increased surface to volume ratio to allow light and air to penetrate into the structure. The relationship among development controls such as parcel size and height limits, energy conservation and density needs to be explored through practical experience as well as research. The resulting information base can assist localities in determining the most effective means of reducing energy consumption within its particular context.

Density can be increased beyond the level established by the passive solar access envelope. The additional volume would not have solar access but the solar access of the volumes already described could be maintained. Two techniques for doing this are listed below. Because an energy demand which cannot be met with passive design is added, the proportion of the total heating and hot water load that can be met by the fixed on site energy supply decreases. The following possibilities are depicted in Figure D-34.

1. All structures could increase in height uniformly. Total energy consumption would increase by more than the additional heating, cooling, and lighting load because additional energy is required to power elevators and other mechanical equipment necessary in high-rise structures.

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For a thorough discussion of buildable volumes of space which do not obstruct solar access see Knowles, Ralph L., Energy and Form: An Ecological Approach to Urban Growth, Cambridge, Mass.: MIT Press, 1974.

Figure D-33

Solar access envelopes to maximize winter time insolation from 9:30 a.m. to 2:30 p.m. for the Denver Central Business District Study area.

XBL 798 - 2545

Figure D-34

Building all structures at a uniform height greater than five stories moved preserve passive solar/day lighting access to top five stories.

Growing down would reduce the heating and cooling load of additional stories, elevators would be required less frequently. A central atrium would increase ventilation and day lighting.

XBL 799-2556

2. An alternative to uniform upward growth is downward growth. Underground structures would increase energy demand to a lesser extent than above surface structures since heating and cooling loads are reduced and less mechanical equipment is needed. Downward growth would not have to be uniform, since the above-surface passive form would not be affected.

WAREHOUSING DISTRICT STUDY AREA

Overview of Study Area

The warehousing study area, located approximately two miles north-east of the city center, consists of eighteen blocks comprising 112 acres. The study area lies adjacent to a major river and railroad tracks on its eastern edge. The area is predominantly industrial and commercial with a small percentage of residential sites interspersed. (See map, Figure D-35).

Warehouses make up 35 percent of the entire study area's parcels. 10 percent are miscellaneous commercial uses including printing plants, hotels, a financial building, and a small market. 19 percent of the parcels are residential ranging from single-family dwellings and condominiums to eight-unit dwellings. The remaining parcels (36 percent of the total parcel area) consist of vacant land, helicopter landing pads, and parking lots.

The average parcel sizes are: warehouse sites 51,900 square feet, commercial sites 82,096 square feet, vacant parcel areas 13,372 square feet, and residential parcels 3,977 square feet.

Twenty-one percent of the gross study area consists of streets and sidewalks. Blocks vary greatly in size from 220,000 square feet to 600,000 square feet. Only one of the study area's fifty-six non-residential buildings is a three-story structure. Six buildings are two-story, and the remaining forty-nine are one-story. The average structure size for the warehouses is 23,950 square feet, and for the commercial structures it is 9,800 square feet. The average roof area (11,194 square feet) is closely in line with the average square footage of the structure (11,287 square feet) and illustrates the low rise character of the entire study area.

Only the warehousing sites will be evaluated.

Characteristics Influencing Solar Energy Use

Although on-site density of the warehousing sites is higher than that of the strip commercial area (F.A.R. of .46 relative to F.A.R. of .23 for strip commercial), the warehousing sites have two characteristics of physical form which make them well suited to solar energy use:

- little variation in building height - this minimizes shading of rooftops and of the unbuilt portions of the sites by structures.
- A low energy demand even without conservation measures.

D-93

Figure D-35

The area's primary disadvantages is the orientation of streets and, therefore, of the structures, 45° from due south. Collector bank area on the flat roofs is consequently limited to approximately one-third of the roof area. Were the structures oriented with the cardinal points, 17 percent more collector area could be accommodated on the same roof area.

Tables D-27 and D-28 and Figure D-36 characterize variables influencing the use of active solar technologies.

Passive design techniques, which employ south-facing wall areas are constrained by building orientation. However, the predominantly single-story form of the structures allows for rooftop solar access using skylights with thermal storage masses in the building interiors.

Solar Reliance Within Study Area

The total scenario goal of 18.3 percent can be met with the utilization of approximately 10 percent of the roof area on each site using thermal collectors with existing performance. With improved performance, the same goal can be met with five percent of roof area. Since shading is never a constraint on rooftops, all sites can achieve the goal independently. (See Table D-29 and Figure D-37.)

Figure D-37 depicts the increased levels of solar reliance possible with additional collector area. The theoretical potential of each system can be provided on-site. For maximum reliance on thermal collectors, only a portion of the roof area is needed. To achieve close to a 100 percent reliance with photovoltaics, a small portion of ground area must be used in order to meet the summer electrical demand.

Nine 15 kw wind machines would be required to provide the scenario wind energy goal of 1.6 percent of total end-use demand. Due to the low-rise form of the buildings and the absence of vegetation, obstruction of wind flow does not appear to be a problem in this study area. One machine would have to be located on every 5.8 acres of warehousing parcel area, or one for every nine warehouses.

Table D-27

Warehousing District Study Area
Annual Energy Consumption

Heated Floor Area 1,053,844 ft²

END USE	ENERGY DEMAND (10 ¹⁰ Btu)	
	Existing	With Conservation
Heating	2.92	none assumed
Hot Water	0.03	
Cooling (C.O.P. 2.5)	1.63	
Lights & Power	1.21	
Total	5.79	

For insulation and collector performance values see
Tables D-3 and D-4.

Table D-28

Collector Area Available

	Total Area (Horizontal Collector Area)	Collector Bank Area	Shaded Area (10 ft. Above Surface	Unshaded Equivalent Collector Bank Area	Unshaded Area	Unshaded Equivalent Collector Bank Area	Total Unshaded Collector Bank Area
Roofs-total	955,310	305,699					
Roofs-winter			0	0		955,310	305,699
Roofs-summer			0	0		955,310	305,699
Sites-total	1,329,107	425,314					
Sites-winter			278,829 1/2 day	44,613	1,050,278	366,089	380,702
Sites-summer			0		1,329,107	425,314	425,314
Streets & side- walks-total	993,640	317,965					
Streets & side- walks-winter			0	0	993,640	317,965	317,965
Streets & side- walks-summer			0	0			
Parking lots- total	97,750	31,280					
Parking lots- winter			7,382 1/2 day	1,181	90,368	28,918	30,099
Parking lots- summer					97,750	31,280	31,280
Vacant lots- total	305,750	97,840					
Vacant lot- winter			37,393 1/2 day	5983	368,557	85,874	91,857
Vacant lots- summer			0	0	305,750	97,840	97,840

Warehousing Annual Energy Consumption (10³ Btu/ft²/year)

EXISTING

Existing primary fuel consumption

All electric primary fuel consumption

Source: Jackson & Johnson, 1978

Figure D-36

Table D-29

Solar Reliance Achievable For Study Area Using
Technologies With Short-Term Heat Storage
(End Use Energy Displaced in 10^{10} Btu)

SCENARIO GOALS: Total 18.82% Passive/Active Thermal 12.89% Photovoltaics 3.87%										
THEORETICAL POTENTIAL OF TECHNOLOGIES (Maximum Reliance Possible) Passive/Active Thermal 56% Photovoltaics 85%										
TECHNOLOGY 1 Thermal Collectors with existing output			TECHNOLOGY 2 Thermal Collectors with doubled output			TECHNOLOGY 3 Cogenerating photovoltaics				
Collector Location & Seasonal Demand (th = thermal, el = electrical)			Usable energy (surplus)	% of total ann. demand	Usable energy (surplus)	% of total ann. demand	Usable electricity (surplus)	Usable heat (surplus)	Total Usable energy (surplus)	% of total ann. demand
Roofs	Total	5.79	3.21 (2.32)	56% (40%)	3.21 (9.13)	56% (158%)	2.44 (.94)	2.07 (6.92)	4.51 (7.86)	78% (136%)
winter	th	2.94	2.06	36%	2.06	36%	.71	2.06		th 36%
	el	.71	(1.49)	(26%)	(5.86)	(101%)	(.56)	(1.32)		el 12%
summer	th	.01	1.15	20%	1.15	20%	1.73	.01		th .2%
	cooling	1.63	(0.83)	(14%)	(3.27)	(57%)	(.38)	(5.60)		el 30%
Sites	Total	5.79	3.21 (3.52)	56% (61%)	3.21 (10.25)	56% (177%)	2.84 (1.46)	2.07 (7.80)	4.91 (7.26)	85% (160%)
winter	th	2.94	2.06	36%	2.06	36%	.71	2.06		th 30%
	el	.71	(2.26)	(39%)	(6.58)	(114%)	(.68)	(1.64)		el 37%
summer	th	.01	1.15	20%	1.15	20%	2.13	.01		th 6.2%
	cooling	1.63	(1.26)	(22%)	(3.67)	(63%)	(.78)	(6.16)		el 37%
	el	.50								
Roofs & sites	Total	5.79	3.21 (9.05)	56% (157%)	3.21 (22.59)	56% (391%)	2.84 (4.84)	2.07 (16.79)	4.91 (21.63)	85% (37%)

Table D-29 (continued)

Solar Reliance Achievable For Study Area Using
Technologies With Long-Term, Shared Storage
(End Use Energy Displaced in 10^{10} Btu)

			SCENARIO GOALS: Total 18.82% Passive/Active Thermal 12.89% Photovoltaics 3.87%							
			THEORETICAL POTENTIAL OF TECHNOLOGIES (Maximum Reliance Possible)						Passive/Active Thermal 79% Photovoltaics 100%	
			TECHNOLOGY 1 Thermal Collectors with existing output		TECHNOLOGY 2 Thermal Collectors with doubled output		TECHNOLOGY 3 Cogenerating photovoltaics			
Collector Location & Seasonal Demand (th = thermal, el = electrical)			Usable energy (surplus)	% of total ann. demand	Usable energy (surplus)	% of total ann. demand (surplus)	Usable electricity (surplus)	Usable heat (surplus)	Total Usable energy (surplus)	% of total ann. demand (surplus)
Roofs	Total	5.79	3.73	65%	4.58 (2.88)	79% (49%)	2.44 (.94)	2.95 (4.92)	5.39	93% (118%)
winter	th	2.94	2.69	46%	2.94 (2.44)	51% (41%)	.71 (.56)	2.94 (.44)		
summer	th cooling el	.01 1.63 .50	1.04	18%	1.64 (.44)	28% (8%)	1.73 (.38)	.01 (4.48)		
Sites	Total	5.79	4.24 (0.40)	73%	4.58 (4.70)	79% (82%)	2.84 (1.46)	2.95 (5.69)	5.79 (7.15)	100% (123%)
winter	th el	2.94 .71	2.94 (0.40)	51% (7%)	2.94 (3.74)	51% (65%)	.71 (.68)	2.94 (.76)		
summer	th cooling el	.01 1.63 .50	1.30	22%	1.64 (.96)	28% (17%)	2.13 (.78)	.01 (4.93)		
Roofs & sites	Total	5.79	4.58 (3.79)	79% (65%)	4.58 (12.16)	79% (210%)	2.84 (4.84)	2.95 (13.56)	5.79 (18.40)	100% (318%)

ON-SITE ENERGY PRODUCTION IN STUDY AREA: WAREHOUSING DISTRICT.

Figure D-37

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119 machines would be required to supply the entire lighting and power demand of the area, or an average of 2.7 machines per site (average size 1.2 acres). Twelve 100 kw machines located in non-urban areas would provide the same energy supply. They would consume about twelve acres of land, or less than one-quarter acre per warehouse.

Impacts of Solar Reliance

Only roof tops are needed to meet this scenario goal (see Figure D-38). Close to 100 percent of the total demand could be provided using rooftops only. If an increased area is used in order to produce an exportable surplus energy supply, impacts may become significant. To provide 70 percent of heat and 80 percent of water with short-term storage, about one quarter gallon of storage per square foot of floor area is required.

Impacts from wind machines at the scenario level other than those generic impacts discussed in the text are limited in this study area. Due to limited use by the public impacts on aesthetics, noise and safety are of less concern than in more heavily used areas.

TECHNOLOGY	SHORT TERM HEAT STORAGE			LONG TERM HEAT STORAGE		
	Thermal Collectors Existing Output	Thermal Collectors Improved Output	Cogenerating Photovoltaics	Thermal Collectors Existing Output	Thermal Collectors Improved Output	Cogenerating Photovoltaics
	56%	56%	87%	79%	79%	100%
TECHNOLOGY POTENTIAL:						
PERCENT OF TOTAL DEMAND						
PERCENT OF END USES	70% Heat 80% DHW 70% Cooling	70% Heat 80% DHW 70% Cooling	70% Heat 80% DHW 100% Cooling 100% Elec.	100% Heat 100% DHW 100% Cooling	100% Heat 100% DHW 100% Cooling	100% of total end use

UNSHADED SITE AREA USED TO MEET SCENARIO GOAL:
WAREHOUSING DISTRICT STUDY AREA.

Figure D-38

INDUSTRIAL STUDY AREAS

Selection and Characterization of Industrial Cases

In this initial analysis six industrial sites have been evaluated. The study areas are located in a central city area at latitude 45° North. The examples are randomly selected from among industries with a high technical potential for solar energy use based on a matching of end use energy quality with solar technologies. (ITC, 1977, and Battelle, 1977). Thus, the influence of physical constraints can be compared to that of technical constraints.

Energy demand for each industry was estimated using national average energy consumption (ITC, 1977) per employee (U.S. Census of Manufacturers 1972) and number of employees at each case study site. Potential for solar energy use was determined by mapping case study sites, estimating area available for collector siting, and applying the appropriate technology. The solar technology used was selected from the following systems as a function of process heat quality requirements: $100-125^{\circ}\text{F}$, shallow ponds; 150° flat plates $200-500^{\circ}\text{F}$ parabolic troughs (ITC, 1977).

Five of the case studies fall within the general category of food products (industrial code 2000 to 2099). This category of industry employs 22 percent of the city's total industrial employment and comprises 28 percent of the total value added; it is the third largest in size and value rank of the industries in the city from which the cases were selected. One case study is within the paper products category which represents 8 percent of employment and 11 percent of the value added for industries in this city.

Characteristics Influencing Solar Potential

Unlike thermal energy demand in the residential and commercial sectors, the demand for process heat is not seasonal but is relatively uniform through the year, allowing for more efficient use of solar energy. Demand fluctuates greatly among industries and availability of land area does not vary correspondingly. In the case study city, industrial land use is concentrated in two major areas: along the river and along the railroad tracks. Four of the six sites had undeveloped land adjacent to them, in some cases serving as a buffer between the industrial use and railroad area and adjacent residential areas.

Figures D-39 and D-44 summarize for each site: collector area on roofs, sites and in adjacent undeveloped areas; energy demand assumed by subprocess with energy quality requirements appropriate for solar energy use; solar technologies used, and the level of solar reliance possible based on collector area availability.

Solar Reliance

The total scenario goal for the industrial sector is 17.2 percent of that sector's total consumption. Of the total industrial sector's energy consumption, about 86 percent is for process heat (Lovins, 1977). For our purposes, then, the scenario goal becomes 20 percent of process heat energy consumption. Of this, 12.42 percent is solar thermal, 9.23 percent biomass, 1.03 percent synthetic fuel and wind; PVs and solar thermal electric comprise less than 1 percent.

Based on analyses of market penetration and technical feasibility, the maximum reliance on direct on-site solar energy for the U.S. industrial sector in 2000 is estimated at 35 percent (ITC, 1977 and Battelle, 1977). In order to reach this overall goal, each individual industry has its particular goal which varies regionally with climatic and economic factors. Table D-30 includes those goals for the particular industries evaluated. It is assumed that case study sites must achieve these goals in order for the U.S. as a whole to reach the 35 percent solar share.

Direct Solar Technologies

Table D-30 summarizes the level of solar reliance possible as the collector location domain increases for each case study site and Figure D-45 presents the results graphically relative both to the 35 percent goal identified by ITC and Battelle and the 20 percent goal given by the scenario.

Roof area alone is sufficient to meet the scenario goal in three cases and one of these can also achieve the level of reliance identified by ITC and Battelle. Roofs plus sites as collector area enable an additional site to meet the scenario goal. In the two remaining cases the use of adjacent undeveloped area enables the industries to meet the scenario goal.

Figure D-39

Calculation of Energy Demand	Number of Employees	175
	Btu per Employee, National Average	3.86×10^8
	Total Energy Demand	6.70×10^{10}
Subprocess Energy Consumption	Process Heat; Forms and Temperature (°F)	550 direct
	Percentage of Total	100
	Subprocess Demand (Btu)	6.70×10^{10}
Technology and Collector Requirements	Appropriate Technology	parabolic troughs
	Output per ft ² area	73
	ft ² of Area Required	9.17×10^5
Sufficiency	Percentage Area Met by Structure/ Site/ Adjacent Area	$\frac{6}{5} / \frac{51}{51}$

Figure D-40

Calculation of Energy Demand	Number of Employees	266				
	Btu per Employee, National Average	7.96×10^8				
	Total Energy Demand	2.12×10^{11}				
Subprocess Energy Consumption	Process Heat; Forms and Temperature (°F)	200 indirect	250 indirect	200 indirect	250 indirect	350 indirect
	Percentage of Total	2	5	2	13	78
	Subprocess Demand (Btu)	3.80×10^9	1.1×10^{10}	4.29×10^9	2.86×10^{10}	1.65×10^{11}
Technology and Collector Requirements	Appropriate Technology	parabolic troughs	parabolic troughs	parabolic troughs	parabolic troughs	parabolic troughs
	Output per ft ² area	92	89	92	89	81
	ft ² of Area Required	4.18×10^4	1.23×10^5	4.66×10^4	3.21×10^5	2.04×10^6
Sufficiency	Percentage Area Met by Structure/ Site/ Adjacent Area	38/86/790	10/29/269	35/77/710	5/11/103	1/2/16
TOTALS

Area	Total ft ²	Unshaded ft ²
Roof	275,400	206,600
Site	486,800	413,300
Adjacent	239,600	239,600

Figure D-41

Legend	
Structure	=====
Site	-----
Adjacent Area	-----

Calculation of Energy Demand	Number of Employees	65
	Btu per Employee, National Average	3.86×10^8
	Total Energy Demand	2.50×10^{10}
Subprocess Energy Consumption	Process Heat; Forms and Temperature (°F)	550 direct
	Percentage of Total	100 "
	Subprocess Demand (Btu)	2.50×10^{10}
Technology and Collector Requirements	Appropriate Technology	parabolic troughs
	Output per ft ² area	73
	ft ² of Area Required	3.43×10^5
Sufficiency	Percentage Area Met by Structure/ Site/ Adjacent Area	5/10/96

Area	Total ft ²	Unshaded ft ²
Roof	21,400	16,100
Site	42,300	35,900
Adjacent	331,400	331,400

Figure D-42

Calculation of Energy Demand	Number of Employees	175
	Btu per Employee, National Average	1.18×10^7
	Total Energy Demand	2.07×10^9
Subprocess Energy Consumption	Process Heat; Forms and Temperature (°F)	200 indirect
	Percentage of Total	100
	Subprocess Demand (Btu)	2.07×10^9
Technology and Collector Requirements	Appropriate Technology	parabolic troughs
	Output per ft ² area	92
	ft ² of Area Required	2.25×10^4
Sufficiency	Percentage Area Met by Structure/ Site/ Adjacent Area	290/ 1700/ --

Legend	
Structure	=====
Site	-----
Adjacent Area	-----

Area	Total ft ²	Unshaded ft ²
Roof	67,100	43,600
Site	453,600	385,500

Figure D-43

Calculation of Energy Demand	Number of Employees	15
	Btu per Employee, National Average	1.78×10^8
	Total Energy Demand	2.67×10^9
Subprocess Energy Consumption	Process Heat; Forms and Temperature (°F)	350 indirect
	Percentage of Total	100 "
	Subprocess Demand (Btu)	2.67×10^9
Technology and Collector Requirements	Appropriate Technology	parabolic troughs
	Output per ft ² area	81
	ft ² of Area Required	3.29×10^5
Sufficiency	Percentage Area Met by Structure/ Site/ Adjacent Area	$45/17/121$

Legend	
Structure	=====
Site	-----
Adjacent Area	-----

Area	Total ft ²	Unshaded ft ²
Roof	24,000	15,000
Site	7,200	5,800
Adjacent	40,000	40,000

Figure D-44

Legend	
Structure	
Site	
Adjacent Area	

Calculation of Energy Demand	Number of Employees	175		
	Btu per Employee, National Average	3.85×10^7		
	Total Energy Demand	6.72×10^9		
Subprocess Energy Consumption	Process Heat; Forms and Temperature (°F)	150 indirect	450 indirect	
	Percentage of Total	7	93	
	Subprocess Demand (Btu)	4.70×10^8	6.25×10^9	
Technology and Collector Requirements	Appropriate Technology	flat plates	parabolic troughs	
	Output per ft ² area	72	73	
	ft ² of Area Required	6.53×10^3	8.56×10^4	9.21×10^4
Sufficiency	Percentage Area Met by Structure/ Site/ Adjacent Area	460/120/_	35/6/_	33/5/_

Area	Total ft ²	Unshaded ft ²
Roof	30,200	30,200
Site	8,500	5,100

PERCENT OF ENERGY DEMAND PROVIDED BY DIRECT SOLAR TECHNOLOGIES AT CENTRAL CITY INDUSTRIAL SITES.

Figure D-45

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Table D-30

Solar Reliance Possible on Industrial Sites
Using Appropriate Direct Solar Technologies

Site	Percent Solar Reliance (Surplus)			
	Technical Feasibility Goals	Roofs only	Roofs & Sites	Roofs, Sites & Adjacent areas
1	60	33	38	-
2	55	5	15	55 (56)
3	69	69 (221)	69 (1921)	-
4	62	45	62	62 (121)
5	55	6	5	55 (7)
6	69	8	24	53

These examples are all central city sites in a relatively dense city. A study of the size of industrial sites of another dense urban area found that sites outside the central city are substantially larger than those in the central city for any given industry (Boykin, 1973). In the food processing sector (from which five of our cases were drawn) suburban sites were an average of 2.5 times larger than central city sites. If that is the case in this city, suburban industries comparable to our central city examples could meet their scenario goals on site in all cases. The technology limit could be achieved on site in all but two cases.

Biomass Conversion

Biomass derived from wood wastes is expected to be used primarily in less urban settings, closer to the supply, and therefore to have a limited impact on urban areas. However, the use of pelletized wood waste in place of coal is planned within the case study region. A pelletized plant is planned for construction in 1980 adjacent to its parent lumber company and within 30 miles of 6 other wood-using businesses that generate 50,000 tons of wood residue a year (Minnesota Department of Economic Development). If this potential is developed, wood waste could be used to replace coal at industrial sites in the city. Similarly, use of crop and feedlot waste could provide a portion of the industrial demand. Forty-six percent of the 474×10^6 tons of wood crop and feedlot wastes produced in 1976 in the U.S. (Alich and Wither, 1976) would be required to meet 9.23 percent of the total U.S. industrial energy demand called for in the scenario, assuming an energy content of 16×10^6 Btu/dry ton (LBL, 1978).

Importation

In all three of our case study cities, the CBD lies in close proximity to areas of concentrated industrial activity. This spatial relationship makes the industrial waste heat a very accessible source for the CBD. Moreover, 2 of the 3 cities are already served by steam heat, so that part of the infrastructure as well as the back-up facility are already in place. It is outside the scope of this study to evaluate the cogeneration potential of the industrial-CBD relationship, but it unquestionably represents a significant opportunity for meeting the CBD deficit.

Impacts of Solar Reliance

Use of pelletized wood wastes as an industrial energy source would produce air pollution but less than the amount produced by the coal it would be replacing (Minnesota Department of Economic Development, 1978).

If solar collectors are placed on raised frames as is assumed for the residential and commercial sectors, land use would not be preempted in our case study examples. However, if shallow ponds were used that land could clearly be unavailable for other uses.

Considering the quantity of collector surface required for industrial applications relative to that required for commercial and residential uses, placement of collectors on raised frames may be particularly unlikely. Moreover, parabolic troughs are heavier and expected to require more maintenance than evacuated tubes or flat plate collectors. Consequently, it would be more costly to mount them on structures and, subsequently, to maintain them. Industrial applications to date have located collectors on the ground.

Ground placement would greatly reduce the amount of site area that could be used. In the places where they are used, use of the land for any other purposes would be preempted.

Implication for Future Industrial Siting

Availability of collector area may be seen as one more incentive for the relocation of industry to the suburbs. On the other hand, increased energy costs also mean increased transportation costs. For industries with a centralized market, the benefits of central city location may outweigh the benefits of cheaper land as an energy source. Furthermore, co-generation, which was not addressed in this study, remains a viable alternative energy source in the city, particularly in areas of concentrated industrial activity.

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