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Project Summary

An Assessment of the Effects of Active Solar Thermal Technologies on Urban Emissions

Energy and Environmental Analysis, Inc.

This study analyzes the fuel displacement potential of solar technologies to determine the benefits of emission reduction which might result in urban areas from use of solar energy. Fuel displacement by solar energy was found to be greatest in the residential water-heating and in electric end-uses in all three cities investigated (Houston, Chicago, and Philadelphia). Fuel displacement increased from 1985 to 1995, as solar energy became more competitive with other fuels. However, emissions reductions attributable to the expanding market for solar energy were relatively small in all three urban areas; generally less than one percent.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Cincinnati, Ohio, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Solar energy systems can have a positive impact on air quality by displacement of fossil-fired energy conversion sources. The objective of this study was to analyze the fuel displacement potential of solar systems and to determine the associated emissions reductions in metropolitan areas. The study considered emissions reductions of particulates, sulfur oxides, nitrogen oxides, hydrocarbons, and carbon monoxide resulting from fossil fuel displacemnt by solar energy. Three metropolitan Air Quality Control Regions (Chicago, Houston, Philadelphia) were analyzed for two future points in time: 1985 and 1995. Analysis of solar technologies was limited to active solar thermal systems because of their commercial readiness and their widespread applicability to urban energy markets.

The study was divided into five sequential tasks: market definition, technical assessment of solar systems, economic analysis, sensitivity tests, and emissions impacts. Fuel use which could be potentially displaced by solar systems was identified and disaggregated into market segments, consisting of a matrix of end-uses and fuel types (e.g., one market segment would be gas-fired space heating in single-family detached residences). These market segments reflect both technical factors (e.g., process temperatures) and economic factors (e.g., ownership status), which affect solar competitiveness. The end-uses considered in the residential, commercial, and public sectors included space heating and cooling, and water heating. These market segments account for a large portion of energy consumption in all these sectors. In the industrial sector, market segments were restricted to space heating and process heat at less than 816°C (1500°F).

A technical assessment helped to define viable solar systems for each end-use market segment and to identify performance factors affecting end-use solar energy utilization. For example, collector land use is expected to limit the size of solar systems in a number of situations. Technically viable solar systems were compared with conventional systems on the basis of a life-cycle cost analysis. When the ratio of levelized price of displaced fossil fuel to annualized solar cost of an end-use exceeded one, the solar system was considered competitive in that market segment. When a solar system was competitive, the entire amount of energy consumed by the particular market segment, adjusted by a solar load factor, was considered displaced.

A sensitivity analysis was conducted to determine how fuel displacement would be affected by different economic assumptions and to establish a fuel displacement range. Six scenarios were constructed by pairing three solar cost estimates (low, medium, and high) with two fuel-price projections (mid-range and high). Two scenarios received particular attention: a "base-case" scenario (medium solar costs and mid-range fuel price projections) that was considered the most likely reflection of future market conditions, and a "best-case" scenario (low solar costs and high fuel prices) that was considered most favorable for solar penetration of the market place.

Findings

Fuel Displacement

Under the base-case scenario, fuel displacement in the residential, commercial, and public sectors resulted primarily from the capture of part of the oil and electric hot water heating markets in 1985. Displacement increased substantially in 1995 with the capture of certian space-heating market segments (see Figure 1). More fuel displacement occurred in the residential sector than in the commercial and public sectors, due to the size of the residential water and space heating markets and the competitiveness of residential solar systems. The fraction of total commercial and residential energy consumption displaced in 1985 was 1.43, 0.70, and 1.79 percent for Houston, Chicago, and Philadelphia, respectively. Fuel displacement was less than five percent of the total consumption for these sectors in 1995, for each AQCR investigated.

Industrial fuel displacement was not significant in the base-case scenario; industrial solar systems were not competitive with any fuel type in 1985 and only marginally attractive in 1995. The relatively low fuel displacement levels in both years are attributable to: 1) land restrictions which limit solar system size and output, 2) industrial coal use, 3) low solar load fractions, and 4) limited low-process-temperature applications where solar is competitive.

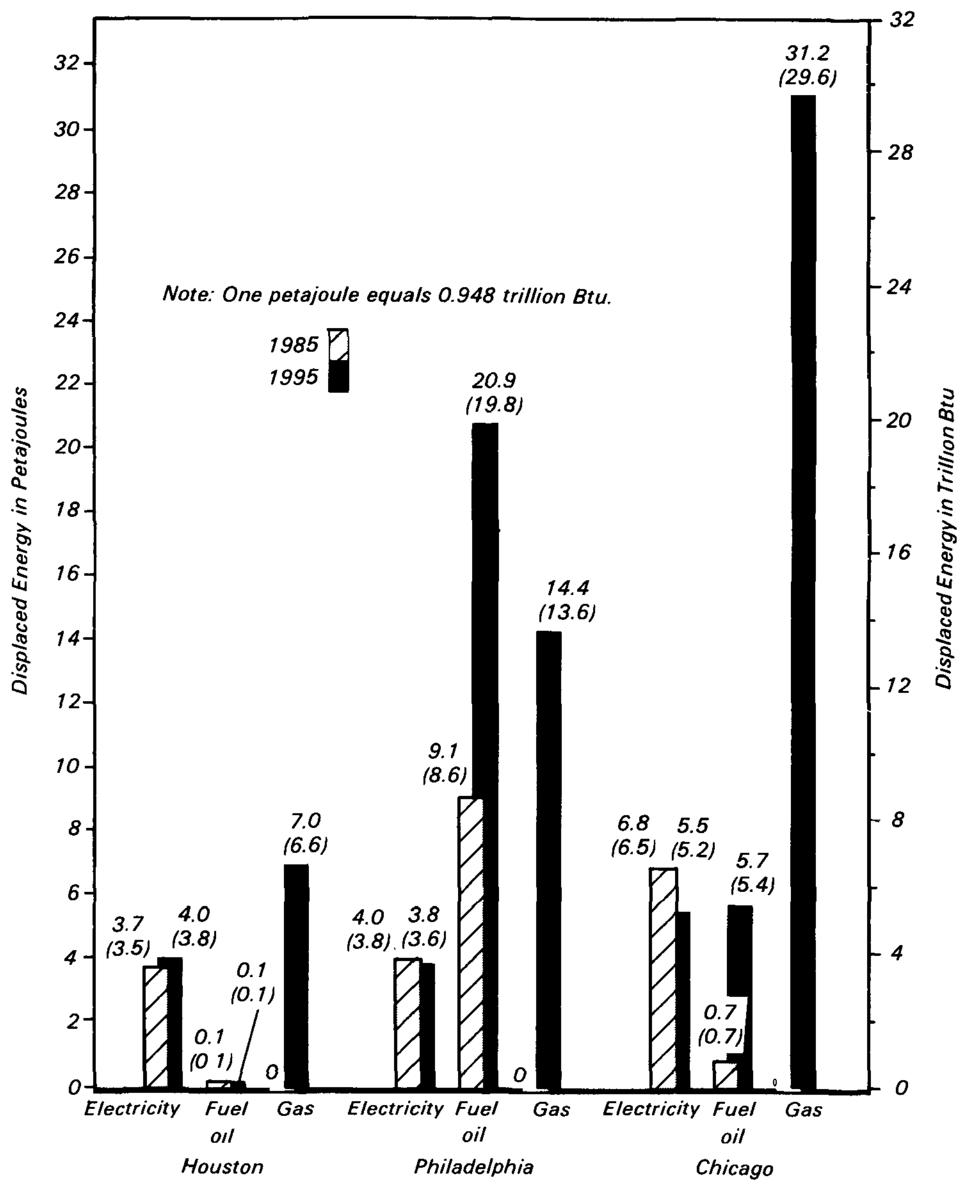

Figure 1. *Displaced energy in residential, commercial, and public sectors by air quality control regions — base-case economic and fuel-escalation scenario.*

In the sensitivity tests, fuel displacement increased substantially in all three Air Quality Control Regions (AQCR) under the more favorable solar scenarios. Gas displacement in the residential, commercial and public sectors was most noticeable, because in 1985, under the base-case scenario, no gas was displaced. The fraction of total commercial and residential energy consumption accounted for in the 1985 best-case scenario was 3.2 percent, 5.9 percent, and 6.3 percent for Houston, Chicago, and Philadelphia, respectively. Industrial fuel displacement was also larger under the more favorable solar scenarios. In these cases, solar became competitive with gas and oil space heat systems, process heat, and some steam applications. However, best-case fuel displacement in the industrial sector in 1985 amounted to less than one percent of the industrial energy consumption in any of the AQCR's.

Emissions Reductions

The emissions reductions under the base-case scenario in 1985 and 1995 are identified in Table 1, along with the percentage attributed to each fuel type. These percentages reflect the relative competitiveness of solar systems to different fuels, as well as the emissions characteristics of the displaced fuel. In most cases, electricity displacement had the largest

Table 1. Displaced Emissions, Tonnes/Year (Tons/Year)[a]

AQCR Source Category	Particulates 1985	Particulates 1995	Sulfur Oxides 1985	Sulfur Oxides 1995	Carbon Monoxide 1985	Carbon Monoxide 1995	Hydrocarbons 1985	Hydrocarbons 1995	Nitrogen Oxides 1985	Nitrogen Oxides 1995
Houston										
Total Tonnes/Year	336.1	370.6	1236.9	2555.4	44.3	128.7	10.2	51.8	1135	1760
(Tons/Year)	(370.6)	(409.6)	(1366.2)	(2821.6)	(48.8)	(141.9)	(11.2)	(57.1)	(1251)	(1940)
Percent[b]										
Electric[c]	99	76	99	96	96	44	90	35	100	72
Gas[c]	0	8	0	neg[d]	0	44	0	44	0	12
Oil[c]	1	1	1	neg	4	2	10	2	neg	neg
Industrial Gas	0	0	0	0	0	0	0	0	0	0
Industrial Oil	0	15	0	4	0	10	0	19	0	15
Chicago										
Total Tonnes/Year	78.7	365.7	1495	1700	38.6	373.9	13.6	165.7	287.8	1858
(Tons/Year)	(86.8)	(403.2)	(1648)	(1874)	(42.6)	(412.2)	(15.0)	(182.7)	(288.0)	(2049)
Percent										
Electric	100	17	100	70	100	8	100	7	100	37
Gas	0	35	0	neg	0	68	0	62	0	52
Oil	0	48	0	30	0	23	0	32	0	11
Industrial Gas	0	0	0	0	0	0	0	0	0	0
Industrial Oil	0	0	0	0	0	0	0	0	0	0
Philadelphia										
Total Tonnes/Year	200.7	346.0	1140	2191	165.2	393.9	98.2	244.7	998.7	7030
(Tons/Year)	(221.3)	(381.5)	(1257)	(2416)	(182.1)	(434.3)	(108.3)	(249.7)	(1101)	(7751)
Percent										
Electric	20	32	31	15	16	6	12	5	67	9
Gas	0	29	0	neg	0	25	0	8	0	15
Oil	80	27	69	83	84	65	88	85	33	74
Industrial Gas	0	neg	0	neg	0	2	0	1	0	1
Industrial Oil	0	9	0	2	0	1	0	2	0	1

[a]Base-case scenario.
[b]Percent of emissions by source category displaced.
[c]Residential, commercial and public sectors by fuel type.
[d]Neg = negligible.

impact on emissions because solar was most competitive with electricity, which has a higher emissions output than gas or fuel oil. The increase in emissions from 1985 to 1995, and the shift in source category shares of emission reductions reflect solar's greater capture of gas and oil market segments in 1995.

The range of displaced emissions bracketed by the base-case and best-case scenarios is shown in Table 2. The best-case scenario increased emissions displacement for a given pollutant and city from 19 percent to more than 700 percent over the base-case scenario. The best-case scenario offered the greatest emissions displacement in the 1995 time-frame, where space-heating and industrial-process applications are just marginally competitive under the base-case scenario.

In the cities investigated, the potential for reduction of emissions resulting from solar fuel displacement appears limited. As shown in Table 3, the overall impact of

Table 2. Displaced Emissions Range, Tonnes/Yr (Tons/Yr)

	Particulates Base-Case	Particulates Best-Case	Sulfur Oxides Base-Case	Sulfur Oxides Best-Case	Carbon Monoxide Base-Case	Carbon Monoxide Best-Case	Hydrocarbons Base-Case	Hydrocarbons Best-Case	Nitrogen Oxides Base-Case	Nitrogen Oxides Best-Case
Houston AQCR										
1985	336.1	441.8	1236.9	1384.6	44.3	84.6	10.2	27.5	1134.9	1511.2
	(370.6)	(487.1)	(1366.2)	(1529.1)	(48.8)	(93.3)	(11.2)	(30.3)	(1251.3)	(1666.1)
1995	371.5	665.4	2555.4	5008.1	128.7	303.8	51.8	133.2	1759.3	3640.4
	(409.6)	(733.6)	(2821.6)	(5530.8)	(141.9)	(335.0)	(57.1)	(146.9)	(1939.7)	(4013.7)
Philadelphia AQCR										
1985	200.7	1157.6	1140.1	2699.6	165.2	561.0	98.2	310.2	998.7	4028.1
	(221.3)	(1276.3)	(1257.0)	(2976.4)	(182.1)	(618.5)	(108.3)	(341.8)	(1101.1)	(4441.1)
1995	346.0	1341.2	2190.9	2933.8	393.9	731.0	226.6	389.3	7030.1	8955.1
	(381.5)	(1478.7)	(2415.6)	(3234.6)	(434.3)	(806.0)	(249.7)	(429.2)	(7750.9)	(9873.3)
Chicago AQCR										
1985	78.7	693.9	1494.7	2882.2	38.6	584.8	13.6	257.0	261.2	4164.9
	(86.8)	(765.0)	(1648.0)	(3177.7)	(42.6)	(644.8)	(15.0)	(283.3)	(288.0)	(4591.9)
1995	365.7	1435.6	1700.1	3767.5	373.9	1156.0	165.7	537.1	1853.4	7457.1
	(403.2)	(1582.8)	(1874.4)	(4153.8)	(412.2)	(1274.5)	(182.7)	(592.2)	(2048.0)	(8221.7)

NOTE: 1 Tonne = 1 metric ton = 1.102 short tons.

Table 3. Total Displaced Emissions as Percent of AQCR Total[a] 1985 (tonnes/year)

	Houston		Chicago		Philadelphia	
Pollutant	*Total Tonnes/year*	*Percent displaced of total emissions[b]*	*Total tonnes/year*	*Percent displaced of total emissions[b]*	*Total Tonnes/year*	*Percent displaced of total emissions[b]*
Particulates	*336.1*	*0.2*	*78.7*	*<0.1*	*200.7*	*0.1*
Sulfur Oxides	*1236.9*	*0.6*	*1494.7*	*0.2*	*1140.1*	*0.3*
Carbon Monoxide	*44.3*	*<0.1*	*38.6*	*<0.1*	*165.2*	*<0.1*
Hydrocarbons	*10.2*	*<0.1*	*13.6*	*<0.1*	*98.2*	*<0.1*
Nitrogen Oxides	*1134.9*	*0.3*	*261.2*	*<0.1*	*998.7*	*0.3*

[a]Base-case scenario.
[b]Based on total 1975 emissions data for each AQCR.

active solar thermal technologies on total AQCR emissions in the base-case in 1985 is less than one percent for each pollutant. Under the best-case scenario, emission reductions are never greater than two percent of total emissions of any pollutant. Emissions reductions as a percentage of total AQCR emissions are low, mainly because of the large percentage of emissions from market segments where solar is not competitive, or from other sources of emissions, such as road dust.

Conclusions

For the metropolitan areas considered in this study, emissions reductions which occur throughout the AQCR due to solar thermal energy development are likely to be relatively small. The same is expected to be true for other cities with similar fuel costs, fuel mixes, insolation and incentives for solar energy use. However, some other urban areas of the country have high insolation, which favors capture of the energy conversion market by solar systems. Also, state and local incentives for solar energy use are stronger in some regions of the country, increasing the economic attractiveness of solar systems and their potential impact on fuel consumption. The resulting emissions reductions may also be greater, but this will depend on the fuel prices, space heating and hot water fuel mix, and industrial mix.

Even in the three AQCR's considered here, solar energy has the potential to displace a small amount of fossil fuel in certain market sectors during the next ten to fifteen years. Solar energy is most competitive with water heating and electric end-uses in the residential, commercial and public sectors. Area source emissions reductions (which are typically difficult to achieve) might ead to significant reductions in urban background pollutant levels.

This Project Summary was prepared by the staff of Energy and Environmental Analysis, Inc., Arlington, VA 22209.
***Benjamin L. Blaney** is the EPA Project Officer (see below).*
The complete report, entitled "An Assessment of the Effects of Active Solar Thermal Technologies on Urban Emissions," (Order No. PB 83-156 927; Cost: $13.00, subject to change) will be available only from:
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Telephone: 703-487-4650
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