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Putting Renewable Energy to Work in Cities

June 1982

Prepared for:

U.S. Department of Energy

Assistant Secretary, Conservation
and Renewable Energy

Office of Solar Electric Technologies

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GENERAL INTRODUCTION

This book's purpose is quite specific. It is intended to supply city officials with some of the information they need to develop local policies that encourage the use of energy conservation and renewable energy technologies. Although the authors harkened to the principle of objectivity, this is not an impartial document. Indeed, it reflects the belief that conserving finite energy resources and tapping renewable sources of energy represent the country's best energy choices if weighed in terms of long-range economy, environmental benevolence, increased community control, and ultimately, strengthened national security.

This book was written primarily for local energy officials in communities that want to begin energy conservation and renewable energy development programs. Officials in such "pioneering" communities as Seattle, St. Paul, or Davis will find little here strikingly new. In fact, these cities' experiences and discoveries have been used extensively on the hope that energy planners and officials in other cities might learn from them.

Three basic assumptions have guided the preparation of this material. The first is that city energy officials need technical information. Since cities are becoming interested in energy conservation and renewable energy options for a variety of economic, social, and political reasons, much of the available literature on using these technologies in cities focusses either on how they benefit the community or on how their use can be accelerated. As valuable as such information is, it must be buttressed by information on the technologies themselves. Before launching even small-scale energy programs, cities need to be sure that the technologies they choose to support are both reliable and suitable. However, much of the technical information supporting more policy-oriented urban energy studies fails to discriminate between appropriate and inappropriate uses.

The approach taken here is to discuss both the strengths and the weaknesses of different technologies and to indicate which technologies would be most useful in which types of cities. We have also suggested how conservation or solar approaches might be combined. Accordingly, we have organized the presentations by end-use (such as water heating or space heating) rather than solely by technology (such as solar energy or wind energy). Our hope is that this document can provide city officials with a framework for organizing new information.

Our second assumption is that urban energy managers must be acutely conscious of the constraints and opportunities posed by existing conditions. The city officials we are addressing will not be designing out of nothing. Land-use patterns, building stocks, energy supply and distribution networks, and social and economic conditions are all givens, and all limit an energy planner's flexibility. Still, considerable room for productive action remains, and energy conservation and renewable energy technologies are both diverse and responsive to diverse circumstances.

So important are existing conditions that we devote the entire first portion of the book to describing the "urban energy context," indicating how its key features affect energy conservation patterns, conservation potentials, and opportunities for using renewable energy.

The final assumption is that no urban energy program can afford to overlook the links between energy and housing, employment, and economic development. While this issue deserves more attention than it gets here, some of the social and economic implications of using conservation or solar technologies are discussed.

We have left it up to cities themselves to come up with detailed plans for implementing programs to develop these resources, but we do provide examples and general suggestions wherever possible. The Center for Renewable Resources hopes to take up implementation issues in future work when the outcome of current shifts between Federal and state/local governments is clearer.

In spite of the immense publicity generated by some local energy programs, the urban or community energy management field is still embryonic. We hope that the information presented here can accelerate its maturing into an effective and responsible enterprise.

Chapter One

Incremental Planning: Making the Best Use of Scarce Resources

ENERGY AND THE CITY

As recently as late 1978, when the U.S. Department of Energy surveyed local government energy activities, local governments by and large failed to associate energy with urgent economic problems like high unemployment or a declining tax base. All that has changed. The National League of Cities reported in June, 1981, that 76 percent of City officials polled in an opinion survey identified energy as a major factor in the national economic stagnation. Sixty-seven percent felt energy costs undermining their economy as well.

On the most basic level, rising energy costs are accounting for ever larger portions of municipal budgets. Consequently, cities must spend more to deliver the same or even reduced services. Testifying before Congress in 1977 during the relative calm before the most precipitous oil price rises, former Hartford City Councilman Nick Carbone put things this way:

"(W)e must understand how rising energy costs over the past few years have affected local budgets and the delivery of services. Hartford's experience with inflation is relatively typical. Since fiscal year 1971-2, Hartford's budget has increased from \$84 million to \$130 million...(But) (e)ven though our budget has increased by 28 percent, we have been forced to cut back on services by 31.6 percent...at the heart of these inflationary price increases is the rising cost of energy. Since 1971, the cost of fuel oil has gone from 12 cents a gallon to 40 cents--a 228 percent increase. The price of gasoline has increased by 168 percent and electricity has gone up by 71 percent."

Of course, more recent gasoline and fuel price hikes, which represent a 150 percent increase just since this testimony was given, mean that still more is being spent to deliver less. And Hartford's plight is, as Carbone said, typical: many other cities are reporting price increases and cutbacks.

A Drain on the Local Economy

However, spiralling energy costs are beginning to mean more to cities than simply higher figures on municipal budget sheets. Cities' overall economic health, measured by the size of the tax base, the amount of available decent housing, and the number of jobs provided by business and industry is also being threatened. While it would be foolish to blame all or most of urban economic woes on energy problems, it is certainly true that these problems have made bad economic situations worse.

For one thing, energy expenditures can represent a significant drain on a local economy, especially in energy-poor regions like the Northeast and Midwest. A study of the energy situation in Washington, D.C., conducted by the Institute for Local Self Reliance in 1979 showed that for every dollar city residents spent on energy, only 13 cents stayed in the city. Even in more energy-self-sufficient Louisiana, planners lament the economic consequences of energy price increases on New Orleans: "The result of this monetary drain is less local capital for investment, less purchasing power for consumers and, consequently, a slower economic growth than could be possible in the absence of such a cash outflow. Additionally...less tax revenue is generated for the city. So, in essence, increased energy costs contribute to whatever problems a city may have with an already declining tax base."

Dire as the overall outlook appears, some groups and interests within the city are worse off than the big picture suggests. Struggling industries must endure energy price rises even as they face the threat of energy cutoffs or curtailments--serious threats even without heavy reliance on a vulnerable energy source. In Philadelphia, for instance, industries use relatively little natural gas and yet the instability of gas supplies has been a driving force behind the city's recent energy-management efforts. Minneapolis, St. Paul, and other cities located at the far--and thus wrong end of regional gas pipelines are comensurately more vulnerable to shortfalls.

When energy shortages or curtailments within the industry are severe or lasting, industries are forced to fold or relocate, costing workers jobs in either case. Indeed, hard on the heels of the energy price rises and shortages of 1977 came the loss of 11,000 jobs in Philadelphia, twice the number of the previous year's loss.

Substandard housing is also hard hit by energy price inflation. While energy price hikes are not the sole causes of housing abandonment, they can contribute to the premature demise of the marginal units that constitute a large portion of inner city housing. In Rochester, for example, the number of abandoned buildings jumped from under 400 in 1970 to 1900 at the end of 1978. At the same time fuel oil prices rose 153

percent, natural gas 105 percent, and electricity 108 percent.

The Plight of the Urban Poor

Housing abandonment and growing unemployment are only the most dramatic examples of the steady and severe pressure energy costs exert upon the urban poor. Nor can the particularly regressive nature of these negative impacts be questioned. Recent figures suggest that percentages of income devoted to energy expenditures are three to five times higher for families with annual incomes under \$5,000 than for those that are better off.

This national figure may dilute the substantially more severe burdens in colder areas with high-priced fuels. For example, a study in Hartford showed that families with an average yearly income of \$3,800 or less spent 30 to 46 percent of their total income on energy alone. The same study revealed that people who cannot afford to fill their oil tanks at each delivery pay a 10 to 15 percent premium as a delivery charge. While the regressive character of energy-induced employment impacts is harder to document, the same people who cannot spare another dollar for energy or afford to buy heating oil by the tankful will most likely be the first to lose their jobs when businesses or industries cut back. For them, each price increase is a matter of double jeopardy.

Ultimately, the combined effects of energy, economic, and social problems erupt in city politics. In the short term, the upshot may be virulent but manageable. Yet, even that is not to be taken for granted. As Hans Tanzler, former mayor of Jacksonville, Florida, saw the situation a few years ago:

"Like all cities in America during the past four years, our problems have been almost totally related to the energy crisis...(I)n January of 1974, the price of oil skyrocketed from \$2.69 a barrel to \$13.00 a barrel in less than ninety days. That 500 percent increase almost caused a taxpayers' revolution in my city...(B)ecause of the understandable citizen hostility to the utility company and to the government, it was becoming increasingly difficult to govern. To put it bluntly, we had a credibility problem, a public relations problem, a political problem."

In the longer run, the political implications of the energy crisis for cities and city governments are even less sanguine since many of the problems Tanzler cites are mutually reinforcing and, in the absence of strong leadership, perpetuating.

THE BEGINNINGS OF LOCAL ACTION

The bright side of what otherwise looks like a negative syndrome is that local governments are beginning to perceive themselves as proper focal points for dealing with local energy problems and to convince their constituents to view them as such. Several large cities (as well as some smaller communities) are responding to this challenge by developing policies to tap "local sources of energy via energy conservation and renewable energy technologies. Indeed, every city that has studied its own energy future has identified a vast conservation potential. In a landmark study, Portland, Oregon, discovered it could reduce energy consumption to 34 percent below predicted levels by 1995 if the city adopted a broad range of conservation policies. Davis, California, has cut residential, commercial and transportation energy use radically. It has adopted energy-conserving building codes and zoning ordinances, developed land-use controls to encourage the use of solar energy, and officially discouraged automobile traffic and encouraged bicycling. A nine-week campaign in Fitchburg, Massachusetts, paid off handsomely by motivating over 3,000 homeowners to take low-cost or no-cost conservation measures that reduced their heating bills an average of 14 percent.

Urban Solar Projects

Developing incentives to encourage alternative energy technologies is less commonplace than launching conservation programs, but urban solar projects have proven successful. Solar water-heating systems in multifamily structures dot cities from Boston to Honolulu. New infill housing using passive solar energy is planned for neighborhoods in Denver and Buffalo. St. Paul may use a community-scale solar energy system to provide heat and hot water in a developing industrial park that will house mostly energy firms.

Just as energy problems interlock and take their toll in many sectors, the benefits of developing widespread programs to employ conservation and renewable energy in cities would reverberate through the urban economy. Far fewer dollars would leave the local economy if money being spent for foreign oil or out-of-state natural gas were instead spent on the manufacture and installation of conservation or solar energy materials and equipment. Besides assisting businesses and creating jobs, investments in local energy

would indirectly improve housing and reduce energy costs.

The Need for Good Planning

Its great promise notwithstanding, local energy development based on conservation and renewable resources will be neither automatic nor simple. While the pioneering efforts of a few cities serve as precedents and inspiration, few local governments have any experience in community energy management. To develop local energy resources, particularly in a way that uses conservation and renewable energy as cornerstones, cities will need integrated energy plans. Good planning is essential to combine energy-supply and conservation options in the most economical way and to make sure that beneficial, long-term energy options are selected over attractive, but ultimately damaging, "quick fixes." Moreover, the intimate connection between energy problems and other urban problems dictates that energy planners consider the consequences of different energy strategies for the larger urban picture. The right kind of energy planning requires a broader focus than that employed in many current programs, quite a few of which seem narrowly focused on one technology or approach and exclusive of important urban participants. To get a clearer idea of how this kind of planning effort might differ from some of those in place now, we should consider some of the broad strategies available to cities.

STRATEGIES FOR DEVELOPING LOCAL ENERGY

Reliance on Federal and State Programs

One strategy, of course, is to implement Federal and state conservation programs in a vigorous way. The Portland study referred to earlier identified this option as being central to its energy conservation projections. According to the analysis, fully 27 percent of the city's projected 34 percent energy savings in 1995 would derive from the local implementation of state- and Federally-sponsored conservation programs. To get such results, a city would have to do far more than respond passively to Federal or state pressure. Not only would legislatures and agencies have to be lobbied to adopt energy conservation policies, but local initiatives would be needed to turn Federal or state "paper policies" into real programs. State weatherization requirements, for instance mean little in the absence of local capacity to conduct energy audits, install energy equipment, and provide financing.

However, looking to national and state leaders for much guidance and support appears futile as the Federal government retrenches on its energy conservation and renewable energy initiatives. Not only are regulatory programs like the Building Energy Performance Standards being curtailed or abandoned, but support for state and local programs has been reduced and/or diluted in state block grants.

While this change in Federal policy direction has serious consequences, it may also compel cities to be more responsible and creative in undertaking energy-saving programs. Cities can work more speedily than the Federal bureaucracy, and municipal regulatory or incentive programs can be designed to fit the particular circumstances facing a particular city.

Contingency Planning

Another approach favored by cities is to concentrate on programs that can help in meeting energy emergencies. The list of cities that have adopted some form of emergency energy management system is too long to repeat. Good contingency plans are far from random responses to the crises of the moment: they incorporate carefully thought-through measures to prevent disruptions in the event of an acute energy shortage, and often require the coordination of several city departments. But while contingency planning is necessary, it does nothing to assure ongoing, effective community energy management. In the absence of baseline planning for long-term, non-crisis energy management, actions prescribed by emergency planning bear all the earmarks of the typical crisis decision: narrowly focused, short-term, unavoidably reactive, and incapable of alleviating the underlying problems that caused the energy shortage in the first place. Thus, in giving contingency planning first place among its energy priorities, the city of Los Angeles does so within the context of a general plan to reduce future energy consumption under non-emergency circumstances. It also notes that lasting benefits accrue when energy reductions under emergency circumstances are carried over to periods of normalcy.

Cities sometimes try to meet energy emergencies by stepping up their lobbying for guaranteed, continuing conventional energy supplies. This kind of effort is clearly less feasible for cities like those in New England that must import nearly all their energy supplies than for others with supply sources near at hand. For example, Orleans parish, which includes the city of New Orleans, has oil and gas deposits within its boundaries. To assure continuing supplies it need do little more than address legal or environmental obstacles that could threaten fuel production. However, unless supported by more far reaching energy policies, such actions fall short. Securing additional oil and gas does nothing to reduce vulnerability to continued price escalations, and it may act to delay

the search for energy sources that will not be continually growing more scarce.

Use of Market Barriers and Incentives

Still another energy policy option available to cities and one that is increasingly more frequently exercised depends on interacting with the private market forces which determine energy use in various sectors of the urban economy. The city can affect the kinds of transactions that normally occur in that market by removing barriers and providing incentives or by creating barriers that will encourage or discourage various private decisions. Rather than rely on mandatory or regulatory powers to compel energy efficiency, this approach is based on changing the pattern or mix of opportunities and constraints that the private energy user faces.

Some common adjustments of energy barriers and incentives include reserving certain roadways exclusively for carpools, providing density bonuses for developers who include energy conservation features in new or renovated buildings, and providing tax incentives to encourage the use of solar energy equipment. Probably the classic example, though, is adoption of an energy-related pricing policy that encourages a reduction in consumption. This could involve increasing local gasoline taxes and charges for public parking while holding mass transit fares down.

Despite significant strengths, the barriers-and-incentives approach fails to qualify as a complete community energy management strategy. One problem is lack of breadth. Comprehensive city-wide energy management cannot be based solely on efforts to get people to take actions such as riding the bus, installing a solar water heater, or converting from oil to gas water heating. As John Alschuler, City Manager of Santa Monica, California, notes:

"(The) use of municipal regulatory power and fiscal resources is not...an alternative to the market approach. Successful local programs depend on the present price structure and on the anticipation of continued price increases. However, market strategies without local government support will not yield the anticipated or necessary benefits. Local initiatives increase the amount of conservation derived from any given price level. Or, to rephrase the argument, equal amounts of savings can be achieved with less price-induced hardship if local government action is coupled with price signals."

Second, there is no guarantee that simply changing the constraints on private decisions will have the desired public effects. As a city tackles energy problems, it is interested in preserving its tax base, reducing the flow of dollars from the local economy, and minimizing adverse impacts on city residents. Any policy that accomplishes these objectives without costing more than it saves is, from the city's point of view, economical. But the private consumer, in decided contrast, is concerned with his own cash flow or his rate of return on investment. Thus, what is most economical for the city over time may be unappealing in the short term for the consumer. Of course, the purpose of the barriers-and-incentives approach is to make some publicly beneficial choices more privately appealing. But the degree to which this can be done without some form of regulatory support is questionable. The most rationally-constructed incentive program may be short-circuited if one market actor can simply shift the costs of energy consumption to others. As Nick Carbone points out in relation to encouraging energy conservation by landlords:

"(Proposals) to give tax credits to owners who make their living units more energy efficient (are) no doubt well intentioned. It would seem, after all, that poor people would be helped indirectly...that a tax credit would offer an incentive for the owners of apartment buildings to insulate and retrofit their structures. But that won't happen in many cases in Hartford. Landlords began shifting the cost of energy to their tenants as inflation pushed up prices. Across the city 75 percent of the tenants now bear responsibility of providing their own heat and hot water."

A final limitation of the barriers-and-incentives approach is the difficulty of ensuring that its costs and benefits are distributed equitably. Incentive levels may, for instance, be inadequate or inappropriate to encourage poor people to conserve energy.

Conversely, imposing barriers or constraints (including taxing to raise prices or installing individual utility meters in rental units) may regressively affect those whose ability to pay is lowest and whose demand for energy is least elastic.

Mandating Energy Efficiency

The drawbacks to approaches that rely on voluntary compliance may suggest that mandatory programs are the best solution. Local governments already perform a number of health- and safety-related regulatory functions to which energy efficiency could easily be added. Used alone, however mandatory energy policies have some serious deficiencies.

First, political battles over mandatory requirements will be difficult in the best of cases. Even when successful, protracted political struggles may stifle private initiatives until they are resolved. In Wisconsin, for example, several owners of multifamily buildings reported deciding against installing energy conservation measures because these might fall short of mandatory standards then being considered by the legislature.

Second, political squabbles over the coverage and precise technical detail of energy standards can lead to the adoption of the least controversial, i.e., the weakest, standard. For example, energy conservation practices mandated for multifamily buildings in Minnesota do not extend to heating systems, arguably the most important component in energy consumption in larger buildings. Moreover, "light" standards can often become a maximum, rather than a minimum, tending to stifle the innovative conservation practices of those who would otherwise do more.

Third, mandatory requirements will limp without the supporting mechanisms and broad sweep of a comprehensive community energy management effort. For example, it would be pointless to require efficiency improvements in lower-income homes or apartments without providing some means of helping lower-income people finance them. Moreover, though some end-use efficiency improvements may occur without a broad program, larger improvements in thermal or electrical distribution cannot be expected.

Finally, the overall effects of mandatory standards on other urban problem areas are poorly understood. Will mandatory improvements in marginal apartment buildings result in better and less costly housing or more abandonments and condominium conversions?

A "Shotgun Approach"

As we have seen, each strategy or policy option described thus far--reliance on Federal and state programs, contingency planning, use of market barriers and incentives, and mandating--has its limitations as a total approach. In recognition of this, some cities are gambling on still a fifth strategy--a "shotgun" approach designed to attack energy problems from many vantages. The Portland study, for example, identifies ninety separate policy options. Numerous others are spelled out in the reports produced by 16 communities whose planning efforts have been supported by the U.S. Department of Energy's Comprehensive Community Energy Management Planning (CCEMP) program. In St. Paul, five separate citizen subcommittees devised lists of options. Some of the most frequently endorsed have been:

- Encouraging end-use conservation in buildings through incentives and regulation;
- Developing more efficient energy-distribution systems, including cogeneration facilities and district heating systems;
- Managing municipally-controlled energy use more efficiently;
- Using land-use controls to encourage energy efficiency in buildings and transportation;
- Requiring energy impact statements for large new urban projects; and
- Encouraging the use of renewable resources.

Describing and analyzing a set of potential actions can be first steps toward formulating a city energy plan. However, something more is needed to complete the transformation. Turning lists into plans and programs requires making choices about priorities, timetables, and resource commitments. Lacking these choices, community energy efforts will continue to reflect only the energies and initiatives of committed individuals, some of whom may be duplicating or even countering the efforts of others. For this reason, it is useful to see integrated energy planning as a sixth option--one that presupposes but differs from the collection, analysis, and evaluation of scattered energy strategies.

INTEGRATED URBAN ENERGY PLANNING

Good urban energy planning cannot be boiled down into a few specifics. The right strategy for a particular community will depend on its own problems, resources, and political situation. What can be laid out here are some general guidelines or perspectives to be borne in mind as cities begin to grapple with energy policy development.

Couple Conservation and Production Planning

First, planners should not view end-use conservation and improvements in energy distribution efficiencies as unrelated to the quest for more reliable, less expensive energy supplies. Installing simple conservation measures in buildings is, dollar for dollar, the cheapest way to reduce conventional energy consumption. The amounts saved, study after study suggests, can be very substantial. But efforts to reduce consumption can often be markedly more effective if teamed with the use of renewable energy and/or low temperature, community-scale thermal distribution systems. A good example is supplementing conservation measures with the use of solar water heating. On a somewhat grander scale, the Swedes are successfully combining strict end-use conservation in buildings with small centralized community or district-heating systems that draw on coal-fired boilers or waste heat to meet the reduced load.

Once the wisdom of wedding efforts to save energy to efforts to produce energy becomes plain, so do the hazards of focusing too narrowly on end-use conservation in a total community energy-planning effort. Portland's energy-use study illustrates this point. Among the many substantive end-use efficiency improvements expected by 1995 in Portland is the wide-scale conversion of gas- and oil-fired heating units to electrical units. Within a building, electric heat is more efficient than gas or oil furnaces, and uses fewer BTUs of energy. But this calculation ignores the staggering loss of energy that occurs in the process of electrical generation. If relatively cheap and more efficient hydropower were available, the error would not be grievous. But given the political battle in the Northwest over costly new nuclear generating facilities, it is misleading to stress building-line efficiency while relying on a large-scale and expensive energy source.

Another area where the failure to relate conservation and production planning can cause missteps is in the improvement of energy distribution techniques. Efforts to conserve electricity are often hampered by the fact that initial investments in centralized power-generation plants cannot be recouped unless energy demand is sustained at predicted levels. If demand drops significantly, some way must be found to compensate for lost revenues. Whether unit costs go up, or the rates of customers who will not or cannot conserve are increased, end-use conservation efforts are being frustrated by the need to pay for a community system that is larger than is now necessary.

By the same token, if large-scale community thermal systems like district heating are sized and financed on the assumption that end-use conservation will be minimal, any subsequent energy improvements to buildings could reduce demand enough to adversely affect the community system's financial position. The lesson is clear. Improvements in distribution need to be planned with the community's total energy situation in mind. What is needed, quite simply, is to take first things first: take or at least plan building-conservation measures before planning community energy-distribution systems. Swedish district heating systems have shown that with this kind of planning end-use conservation techniques and improved distribution efficiencies combine to yield high energy and economic benefits.

Make Realistic Projections

Second, cities should be as realistic as possible in anticipating future feasibility of different energy supply options. Mistakes in the first area can lead to oversizing systems and, in the second, to underestimating the cost-effectiveness of various energy conservation measures. For example, it is most unlikely that past patterns of growth in electrical demand will be repeated in the future, even in fast-growing areas, due to the dampening effect of price increases and to the growing market in more efficient appliances. Nor should it be assumed that large-scale nuclear or coal-fired plants will ever be built any faster or at lower cost than is possible right now. Their construction will in all likelihood become even more time consuming and costly.

Be Politically Realistic

Third, the successful implementation of energy programs will necessarily involve cooperation among a variety of local individuals and groups. In developing local energy programs, city officials need to consider how the cooperation or opposition of affected groups will influence the success of the program. A less stringent or comprehensive program relying on voluntary compliance may be widely acceptable where a stricter program could succumb to heavy opposition. The more controversial regulatory proposals are bound to encounter time-consuming political debates and maneuverings.

Compare and Evaluate Multiple Options

Fourth, in assessing the feasibility of a large-scale project, city officials should compare its economics not only to a "business as usual" scenario, but also to alternative actions whose energy-saving benefits could be in the same range. For example, energy savings that could be realized with large-scale, high-temperature district heating, as applied to leaky buildings and inefficient heating systems, should be compared to the

savings achievable through extensive building and heating-system improvements. Similarly, the costs and benefits of passive solar retrofits requiring substantial building alterations should be compared with the costs and benefits of more conventional energy conservation approaches. Multiple comparisons in different combinations are essential if the city is to make decisions leading to the greatest possible savings.

Choose a Flexible Mix

Fifth, good energy planning involves finding the right mix of complementary technologies for the city's particular situation. Jumping on a single technology bandwagon, and pinning all hopes there, seems foolhardy whether that technology is the fashion of the moment or one whose promise is yet to be demonstrated. Getting locked in to a single approach is particularly dangerous if it forecloses the exercise of attractive energy options that could present themselves in the future. Decentralized sources of heat and power tend to be compatible with this goal of flexibility, and their economics are highly competitive with conventional plants. The substantial economies of scale once enjoyed by centralized facilities no longer pertain today, as the capital costs of construction and equipment spiral upward, the price and availability of conventional fuels are less certain, and the demand for energy grows less rapidly.

Consider Links to Other Issues

Finally, the planning process should acknowledge the obvious links between energy and problems in service-delivery, housing, employment, economic development, and public welfare. The appropriateness of different energy solutions depends to a major degree on their potential impacts in non-energy areas. A good way to ensure that the necessary cross-checking goes on is to open urban energy planning and program efforts to the scrutiny of all vitally affected groups.

MAKING THE BEST USE OF SCARCE RESOURCES

Given the financial and staff limitations under which most cities operate, officials are forced to limit their attention to energy difficulties that exacerbate existing problems. However, even with scant resources, cities can make headway against longer-term energy problems by delving into both the context and the impacts of narrowly-defined projects. The importance of context can be illustrated in terms of a program to finance furnace improvements in low income housing. If planning for the program fails to take account of the existing condition of the targeted buildings--and if those buildings are drafty and uninsulated--projected energy savings could fall miserably flat. Major indirect impacts of short-term projects are equally germane. For example, a city that decides to improve street lighting efficiency ought to be investigating how the electric utility will react to reductions in demand. By the same token, initiatives to protect the access of solar water heaters to sunlight should be developed only after the tradeoffs between energy-saving and development goals have been thoroughly examined.

"Visualizing" the City

Formal "rules" are of little use in posing questions about context and impacts. What is needed is a broad understanding of how specific energy applications and programs are influenced by a few basic factors that vary from city to city. An older, densely populated city, for instance, is likely to have a considerable stock of multifamily housing and a well-developed mass-transit system. Just as likely, many of its buildings will be poorly insulated. A newer city with better-insulated buildings could still require more energy per dwelling and more transportation energy per person because of its sprawling character. Obviously, the conservation and renewable energy strategies best suited to one city would ill suit the other. The older city would have relatively little leeway for making development patterns more compact, but much to gain from promoting energy conservation in existing buildings. The newer city, on the other hand, might gain most from revising land-use controls both to reduce conventional energy use by encouraging denser development and to increase renewable energy use by protecting access to sunlight.

The basic factors that influence energy-conservation and renewable energy potentials in a given city--specifically, climate and resources, land use, building characteristics, existing energy supply and distribution systems, and socio-economic factors--are the subject of the next several chapters. For the moment it is sufficient to note that learning to "visualize" the city in terms of these factors is crucial in beginning the process that can lead to long-term urban energy redevelopment.

Targeting Data Collection

To get started on energy planning, officials will obviously need some facts about their city's energy usage. But, since information needs are determined by the problems

being addressed, the logical first step is to identify where those problems lie and see how they relate to some of the city's broader housing, employment, and economic development problems. Planning efforts that rigidly follow a methodology calling for extensive, across-the-board data collection could be inundated by an ocean of details of dubious validity and usefulness. A methodology is only a tool; data become useful information only if collected in the right form, quantity, and level of detail. Is energy consumption data needed in BTU or in some other measure? Does the city really need to know how many laundries, restaurants, hospitals, and food stores lie within its boundaries? How important is precise information on materials used in building exteriors? Such questions are best answered after energy problems have been delineated.

Perhaps the best known of the energy planning methodologies that concentrate on extensive, a priori data collection is the methodology developed for DOE's 16 "CCEMP" communities. That approach not only overemphasizes data collection, but is inconsistent with comprehensive urban energy planning in several other particulars. First, it advises extrapolating current levels of energy consumption to some future target year to help anticipate energy shortfalls. Making such unwarranted assumptions could lock a local energy management program into an energy future predicated upon today's mistakes. For, as the CCEMP Committee of Los Angeles has commented,

"If energy management goals and objectives are defined solely as a process of advance identification of shortages of conventional energy sources and appropriate planning to deal with them, this implies that the present ways in which community energy needs are met are optimal...this will not be our approach in Los Angeles...We will attempt to identify specifically to what extent any given energy management tactic should replace a conventional energy source if it meets the test of yielding superior benefits."

Secondly, because data collection is exclusively focused on end-use consumption, opportunities to distribute conventional energy supplies more efficiently or to substitute renewable energy for conventional fuels are slighted. Finally, socio-economic characteristics are virtually ignored. Yet these factors greatly affect the urgency and frequency of energy problems in various parts of the city, as well as the ease or difficulty with which conservation and renewable energy technologies can be introduced.

Advantages of Incremental Planning

A city government with the perspective outlined in this chapter has a realistic chance of coping with both short- and long-term energy problems and of pursuing both short- and long-term energy saving opportunities. By subjecting proposed activities and programs to a careful review of their potential city-wide impacts and of the context to which they would be applied, cities will be integrating many non-technical factors critical to the development of sound local energy policy. This approach, being fluid and impressionistic is perhaps too tolerant of tangents and false starts. But it is also self-correcting: as city staff gain experience and citizen involvement broadens, relationships among separate projects can be clarified. If the approach lacks a certain academic rigor, its compatibility with practical problem-solving and gradual improvement more than compensates. As John Alschuler notes, "(F)requently, communities have begun planning for a particular project, then, when energy management has gained some legitimacy, broadened their activities into a comprehensive review."

There are at least four other distinct advantages to an adaptable, incremental planning approach.

First is economy. This kind of planning is not likely to lead to a financial commitment to oversized and overpriced energy projects that the city will be stuck with for years. In fact, Seattle's recent decision and moves to rely less on nuclear power plants and to pursue a broad public energy-conservation program grew out of such planning.

Second is sensitivity to other urban concerns. The energy-planning approach recommended here calls for integrating energy programs with other urban programs. Where integration is absent, the full range of potential impacts is likely to be ignored. For example, some large-scale energy supply or distribution systems have received local government endorsements simply because they would create large numbers of jobs--no matter that the jobs might be temporary or go to out-of-city workers, much less that other strategies for creating urban jobs could be more cost-effective or socially beneficial. Clearly, the need is to evaluate the jobs-creation potential of any energy program in light of its impacts on the short- and long-term energy and employment pictures of the city as a whole.

Third is accountability. Nothing would be more foolish than to exclude energy suppliers from community energy management efforts. But recognizing the deep connections

between energy problems and other urban policy areas means that city energy policies cannot be developed by energy supply firms alone. A balanced approach would bring public energy suppliers into a position of greater public responsibility.

Last is political stability. The right kind of community energy management can help put the politics of energy on an even keel. Political upheavals like those feared by Jacksonville's Mayor Tanzler would not occur if the city exerted more control over energy problems and solutions. What would happen could be economically and politically invigorating. In St. Paul, Mayor George Latimer mobilized more than one hundred citizen representatives, of a broad cross-section of city interests to help develop a comprehensive community energy plan. A letter sent to each participant from Latimer and Councilwoman Joann Showalter may have expressed the community perspective most concisely:

"The key to our becoming an energy-conserving, self-reliant city is community technology--all of us bringing our ideas to the table and melding our ideas together to find the solutions. By working together we can help one another to avoid obstacles which would waste many years of precious time that we no longer have. Our society is vastly complex and energy is the common denominator."

Chapter Two

The Promise of Conservation and Renewable Energy Resources

To appreciate how well energy conservation and renewable energy production fit together with sound urban energy planning requires looking cursorily at the resources in question and the technologies available to put those resources to work.

TECHNOLOGIES: APPLYING RESOURCES TO END USES

Resources

First, conservation. In heating, cooling, lighting, and the operation of appliances, the potential for increasing the amount of "energy out" while reducing the total "energy in" is staggering. Room for efficiency improvements is so great because energy waste is so rampant. Much of the heat and electricity now used in poorly insulated buildings, oversized heating systems, and inefficient appliances accomplishes nothing. Reducing the amount of energy needed to supply heat and power or tapping supplies of waste heat can be viewed as creating a new energy resource or supply and thus extending the non-renewable energy sources used now.

Next, renewables. The tendency to identify "renewable energy" with "solar energy" is understandable and in a sense accurate. Renewable energy does come directly or indirectly from the sun's light and heat. But renewable energy is certainly more than just sunlight. Energy produced in the movement of winds, tides, and fresh water flows is "solar energy," since the movement occurs because the sun heats air and water over different geographic locations and formations unevenly. Because they are continually renewed, these kinds of natural resources cannot be depleted. By this same token, biomass or plant matter, organic wastes, and geothermal energy are usually considered nearly renewable since they are available in large quantities and will last indefinitely.

Overall, then, three types of energy resources are at issue here: renewable resources (sunlight, wind energy, and water flows), abundant finite resources (wood, organic wastes, and geothermal energy), and resources supplied by energy conservation.

End Uses

Energy is defined by physicists as simply the ability to do work, be it growing food or powering 747s. The ancient Greeks, too, used the word *energeia* in reference to activities of all sorts. Although the word "energy" has taken on a more specialized meaning in modern industrial societies, the commodity energy is nevertheless still used for a variety of different jobs--as heat for buildings and industrial processes, as fuel in engines, and as power for lighting and appliances.

Thermal, mechanical, and electrical energy can in turn be used in various applications or end uses. Thermal energy can heat water and buildings and provide heat for use in industrial processes. Electrical energy can power home appliances, lighting and public transit systems. In some applications, different kinds of energy can be combined. For example, heat produced by burning garbage or wood chips or by concentrating solar energy can run a turbine to help generate electricity, which can then be used to heat a building.

Matching Resources to End Uses

The success with which conservation and renewable energy are brought to bear on energy problems depends upon how well energy resources are matched to end uses. Making this match is a matter of assessing available energy sources, suitable applications, and the existing technologies that can reliably capture or apply available energy in a specific form.

Failure to match technologies to end uses properly leads to severe energy waste. For example, the temperatures reached at the power plant in generating electricity far exceed the operating range of on-site boilers, furnaces, or solar collectors, meaning that the latter are clearly much better suited to the end use of home heating than is electricity.

When the true energy demands imposed by various end uses are recognized, the advantages of many smaller-scale, lower temperature energy sources become more apparent.

Table One suggests the range of technologies available to capture or control the different energy resources mentioned earlier for various end uses. As the table shows, these renewable energy technologies are remarkably numerous. Strictly speaking, a few are not "technologies." Passive solar design elements, for instance, are simply conventional building features (windows, wall, floors, overhangs) modified so as to increase the building's natural heat gain or reduce its natural heat loss. Solar thermal-electric systems, on the other hand, are highly sophisticated technologies.

Size varies, as well as degree of sophistication. Renewable energy technologies can be decentralized, matched one to one with individual buildings. But, potentially at least, they can also be centralized to provide power to thousands of people. Moreover, the same technology can in some cases be used in applications at both ends of this scale.

A few flat-plate solar collectors on the roof of a small house can provide most of its hot water, while the same kind of solar collectors multiplied over several thousand square feet as a part of a community thermal energy system can heat several buildings or

TABLE ONE

MATCHING RESOURCES AND END USES BY TECHNOLOGY

<u>Renewable Resources</u>	<u>Technologies</u>	<u>End Uses</u>
Sunlight	flat-plate solar collectors	low-temperature heat
	passive solar design	
	solar-assisted heat pumps	
	ground-coupled heat pumps	
	concentrating solar collectors	medium-, high- temperature heat
	flat-plate solar collectors, concentrating solar collectors	
	passive solar design	electricity
	photovoltaics solar thermal-electric systems	
Water	solar ponds	low, medium-temperature heat
	passive solar design (roof ponds)	cooling
	low-head hydro production	electricity
	solar ponds	
	ocean thermal-electric production	
Wind	mechanical friction	low-temperature heat
	wind energy conversion systems	electricity
Wood/	wood stoves	low-temperature heat
Agricultural Crops	central wood combustion	low-to-high temperature heat
	wood-fired electrical generation	electricity
	methanol, ethanol production	liquid fuels
Organic Wastes	central waste combustion	low-to-high-temperature heat
	waste fired electrical generation	electricity
	methane, biogas production	gaseous fuels
	pyrolysis	liquid fuels
	bioconversion	
	refuse-derived fuel production	solid fuels

supply enough hot water for an industrial process. Likewise, photovoltaic (solar electric) systems can be sized for use on a single residence, a shopping center, or in a public utility grid. Small wind machines have been installed on apartment buildings in Manhattan, while large wind turbines require hundreds of acres of open space. The point is that this flexibility in the potential size of renewable-energy systems affords energy planners great latitude in matching resources to tasks.

The renewable energy technologies listed so far also vary by levels of technical and economic feasibility. Solar water-heating systems can be purchased now in confidence that they will perform about as predicted. High-temperature solar collectors, on the other hand, need more research and development. Active solar water heating and passive solar design can be economical choices in many situations. But photovoltaics and solar pond technologies are still prohibitively expensive.

A quick glance at how these technologies are applied also reveals that some of them serve identical end uses. Thus, potentially anyway, a given end use has more than one technological option. This is important since particular buildings or cities may be prevented from using one renewable energy technology, but not all. For example, a community-scale solar energy system serving several buildings could be used in built-up areas where not enough unshaded space was available to accommodate separate systems on each roof or property lot.

PRACTICAL BENEFITS OF CONSERVATION AND RENEWABLE ENERGY TECHNOLOGIES

Energy conservation investments are, dollar-for dollar, the most effective of any energy purchase. Beyond immediate economic sense, there are a number of additional reasons why intelligent energy planning with a conservation and renewable energy base is beneficial from a community energy management perspective.

Sensitivity to Individual Situations

Because they require "appropriate" matching to end uses, conservation and renewable energy technologies can be particularly responsive to the specific energy needs of different cities and even of different city neighborhoods. This kind of matching means that it is less likely that "high level" energy (e.g., electricity generated in nuclear power plants) will be used for "low level" jobs (e.g., space heating).

Long-Range Flexibility

Urban energy redevelopment that is planned and built on increments of energy conservation and renewable energy retains a large degree of flexibility. A first initiative might be to retrofit existing housing with basic conservation measures, adding passive solar energy features where practicable, and ensure that new infill housing be energy-conserving and properly oriented to make use of solar heat. This approach would allow the city substantial freedom in choosing how to cut thermal energy needs still further in the future, ranging from additional on-site conservation to development of a small-scale, low-temperature community heating system, and beyond. However, flexibility would be sacrificed if, for example, the initial decision were to ignore the leaky condition of existing buildings and construct a large-scale district heating system to pipe waste heat to them from a power plant. We have already seen that incentive to conserve can be stifled when curtailment of energy use forces a utility to raise unit prices simply because of the need to maintain power plant capacity that exceeds current demand. There is good reason for a city to be cautious about closing off its future conservation options by committing a stated portion of its heating needs to a large, centralized thermal grid.

Incremental Energy Development

Drawing on energy conservation and renewable resources, a city can build an urban energy system "from ground up," allowing for incremental growth and the gradual, rational, replacement of outdated technologies. For example, the addition of energy-conservation and passive solar features to a house today in no way restricts the addition of a renewable electric system a few years hence. In fact, protecting the solar access of south-facing walls for the sake of passive solar features that are incorporated there simultaneously preserves the solar access of the south-facing rooftops to which photovoltaic electric cells might someday be attached.

Conversely, a city loses flexibility when it becomes reliant on an electric power plant to supply waste heat to a large district heating grid. Because of that dependency, the city may have to ensure the plant's continued viability even though future reductions in use of electricity or opportunities to generate electricity from renewable energy sources might dictate otherwise.

Potential for Greater Community Control

Decentralized conservation and renewable energy technologies are at least potentially more open to public inspection than most larger scale energy technologies. This is not

because renewable energy technologies are less complicated (most are not) or because they need not interrelate with conventional energy sources (all must). One reason is that their development is coinciding with greater public interest in community energy planning. Moreover, their use may be subject to a greater degree of local control--a key factor given the increasing public demand for greater self-reliance. Of course, no one can guarantee the quality or equity of "self-reliant" decisions. But insofar as all members of the community participate in energy-related decisions, the chances of these decisions resulting in serious social or economic inequities are diminished.

THE ENERGY PLANNING CONTEXT

The right kind of energy planning involves finding the right technologies to match available energy resources to end uses; that is, the tasks that need doing. Before those technologies can be identified, both components in the match need to be well understood. In other words, planners will need two kinds of information or the answers to two important contextual questions.

First, what kinds of conservation potentials and renewable energy resources are available in the area? Ann Cline, an energy planner in Richmond, Indiana, waxes enthusiastic about "discovering" renewable resources there. Says Cline:

A search for local energy resources can be one of the most fascinating projects any city can undertake. In general, it is a new look at the city which produces maps the likes of which no one has heretofore seen. Visually representing the geography of the city's energy uses and potentialities has opened our imaginations. The location of prime wind sites, prime solar sites and aquifers for water-to-air heat pumps brings to public and planning attention potentials for local energy production which were not previously known.

Of course, nobody needs an expanded imagination to identify sunshine in Phoenix or wind in Chicago. But for most cities even a crude inventory of local renewable energy supplies will require new information, some of it gathered using new or unfamiliar techniques.

Second, how is energy being used at present? Patterns of consumption and the need for energy in specific forms vary enormously from city to city, but the variations are closely linked to a few basic factors: climate, land use, building characteristics, energy supply and distribution systems, and socio-economic factors. Each factor deserves some consideration prior to any assessment of the suitability of particular energy technologies.

These two questions relate to the context--both natural and built--within which urban energy redevelopment can occur. The next five chapters provide background information that will be useful to planners and community leaders in defining that context as it exists in their own city.

Chapter Three

The Natural Context: Climate and Resources

Climate and geographical characteristics influence both urban energy demands and the amount of renewable energy available.

Temperature is the most obvious climatic influence on energy demand. (See Table Two) Heating and cooling can account for 60 to 80 percent of the energy used in a city's homes and commercial buildings. (1)

Besides temperature, the key climatic factors affecting energy demand are humidity and wind. In local energy planning, all three factors must be assessed in terms of both the general region and the city's own microclimate. For example, often average temperatures in a city are several degrees above those prevailing in nearby suburbs. As so-called "heat islands," cities require less heating but more cooling energy than their suburban neighbors.

Climate and topographical features also help determine how much renewable energy is available in an area. Yet tapping local resources is difficult without detailed information on their energy production potential. Accordingly, this chapter specifies different types of renewable resources, indicates in broad terms where they can be found, and tells how to assess their potential. Once cities have located and assessed general resource potentials, they can use the more specific information resources provided in later chapters.

Sunshine

The most basic renewable energy resource is sunlight itself. The amount available in any spot depends upon latitude, topography, and microclimatic influences. Also important are seasonal differences, which occur because regions receive varying amounts of sunshine as the earth rotates on its tilted axis around the sun.

Since the most readily available solar energy technology is solar heating, it is unfortunate that most U.S. cities are sunniest in summer. Even so, substantial amounts of winter sunshine fall nearly everywhere in the country. From November through April, for example, Cleveland averages about 675 BTU of sunshine per square foot of horizontal space per day, almost six times as much energy as a single-family home there needs for space heating, cooling and water heating. Even in a dwelling unit with five times more living space than roof area, the sunshine falling on a horizontal roof is more than enough to meet those same three needs. Of course, no matter how much solar energy is potentially available, how much is usable will depend upon how efficiently it is collected. The point here is that the potential is enormous. Moreover, prospects will improve even more once photovoltaic cells (which can produce electricity for cooling) become affordable and inter-seasonal thermal storage techniques are perfected, since the larger amounts of sunshine available in summer can be tapped then.

Differences in solar intensity, which occur because the sun strikes the northern latitudes at steeper angles than it does the more southerly ones, can be a key determinant of solar potential. (See Table Three.) While, for example, Philadelphia and Houston receive approximately the same number of sunny hours yearly, Houston gets about 20 percent more BTU per square foot per year.

How much sunshine an area receives also depends upon how rainy and cloudy it is. Cleveland gets sunshine only 52 percent of daytime hours, while 70 percent of Denver's daylight hours are sunny. Still, even when cloud cover impedes direct sunlight, diffuse solar radiation reaches the earth's surface, and many solar collection techniques (such as passive solar designs) can make efficient use of diffuse radiation.

How much available sunshine is usable sunshine also depends on an area's topography and the nature of the built environment. On south-sloping land, incident sunlight is more intense than that on adjacent flatlands; on north slopes, it is less. Where hills, vegetation, and buildings are numerous, shading occurs. (See Chapter Four, Land Use and Energy--Shading.) And shading problems are exacerbated by seasonal changes, especially in northern cities, where the low winter sun casts long shadows.

A final influence on the amount and intensity of solar radiation available in cities is air quality. Fog, smog, and pollution tend to absorb or scatter the sun's rays, diffusing solar radiation. The impacts of air quality upon solar availability vary over the course of the day. In San Francisco, for instance, once morning fog dissipates, sunlight becomes more intense and direct. By the same token, it becomes more diffuse as industrial pollution and auto exhausts increase. This means that peak periods for solar energy collection in San Francisco extend from mid- to late-morning to mid-afternoon.

OTHER RENEWABLE ENERGY RESOURCES

Wind, water, biomass, geothermal energy, and other renewable resources are less widely available than direct sunlight, and some regions are better endowed than others. Then too, the built environment also poses constraints. In the central city, for instance, large-scale wind energy conversion systems (WECS), are too big and potentially dangerous to be practical.

TABLE TWO

HEATING AND COOLING DEGREE DAYS IN SELECTED CITIES

<u>City</u>	<u>Heating Degree Days</u> ¹	<u>Cooling Degree Days</u> ²
Boston	5621	668
Providence	5972	610
New York	4848	919
Rochester	6719	531
Buffalo	6927	540
Newark	5034	1024
Pittsburgh	5278	836
Philadelphia	4865	1247
Baltimore	4729	1274
Washington	4211	1732
Norfolk	3488	1535
Charlotte	3218	1696
Atlanta	3095	1773
Jacksonville	1327	2559
Miami	206	4183
Birmingham	2510	1975
New Orleans	1465	3059
Memphis	3227	2357
Louisville	4640	1539
Cincinnati	4844	1070
Cleveland	6154	896
Detroit	6228	894
Fort Wayne	6209	748
Indianapolis	5577	1300
Chicago	6127	982
Milwaukee	7444	548
Minneapolis/St. Paul	8159	811
St. Louis	4750	1519
Kansas City	4711	1535
Omaha	6049	1321
Dallas	2382	2965
Austin	1737	2908
Houston	1434	2866
San Antonio	1570	2994
Oklahoma City	3695	2418
Denver	6016	748
Salt Lake City	5983	1018
Albuquerque	4292	1398
Phoenix	1552	4343
Los Angeles	1819	827
San Diego	1507	722
San Francisco	3080	144
Oakland	2909	128
Sacramento	2843	1132
Portland	4792	343
Seattle	4727	161
Anchorage	10911	0

Source: U.S. National Oceanic and Atmospheric Administration,
Comparative Climatic Data

1. A heating degree day measures how much the average daily outside temperature falls below 65°F. Figures here are annual (sums of heating degree days for each day) averaged over 30 years.
2. Measures how much the average daily temperature exceeds 65°F. Annual data averaged over thirty years.

TABLE THREE

AVAILABILITY OF SUNSHINE - SELECTED CITIES

<u>City</u>	<u>% Sunny Hours of Annual Daylight Hours</u>	<u>Intensity of Sunshine on Horizontal Surface, Nov-April (Btu/ft²/Day)</u>
Boston	60	738.9
Providence	57	767.7
New York	59	759.9
Rochester	45	641.9
Buffalo	52	630.9
Newark	n/a	825.4
Pittsburgh	49	693.4
Philadelphia	58	830.3
Baltimore	57	872.8
Washington, D.C.	58	850.5
Norfolk	63	1000.5
Charlotte	66	1040.1
Atlanta	61	1038.9
Jacksonville	61	1209.2
Miami	67	1161.9
Birmingham	58	1027.1
New Orleans	59	1148.9
Memphis	65	998.3
Louisville	57	840.7
Cincinnati	57	781.0
Cleveland	52	674.2
Detroit	54	719.71
Fort Wayne	59	730.2
Indianapolis	58	779.0
Chicago	57	799.9
Milwaukee	56	775.0
Minneapolis	58	767.8
St. Louis	59	921.8
Kansas City	67	936.6
Omaha	62	910.4
Dallas	n/a	1114.6
Austin	61	1139.2
Houston	57	1046.7
San Antonio	61	1161.3
Oklahoma City	67	1101.8
Denver	70	1165.4
Salt Lake City	70	1055.7
Albuquerque	77	1402.7
Phoenix	86	1441.1
Los Angeles	73	1260.4
San Diego	67	1296.1
San Francisco	67	1092.6
Oakland	n/a	1095.5
Sacramento	79	1053.1
Portland	48	619.0
Seattle	49	574.7
Anchorage	56	n/a

Source: U.S. National Oceanic and Atmospheric Administration,
Comparative Climatic Data.

Still, nearly all U.S. cities can make use of some renewable resources other than sunlight. If they cannot find applications within their own borders, they can "import" renewable supplies from outside the city limits. As the following guidelines indicate, the availability of these resources varies considerably by city.

Wind

The winds flow because the earth's surface is not heated evenly. Solar radiation striking the earth at various angles is absorbed and reradiated at different rates, depending on latitude, vegetation, topography, and geology. As a result, the air near the earth's surface warms up at different rates. These masses of relatively warm and cool air interact as high and low pressure systems. Cold, dense air from low-pressure systems tends to flow under the "lighter" air of high-pressure systems, producing winds as a result of convection. The rotation of the earth combines with these factors to create prevailing winds, which in North America generally blow from the West or Northwest.

Winds of different speeds embody different amounts of potential kinetic energy. Ordinary windmills can convert this energy into mechanical energy, and more elaborate wind energy conversion systems (WECS) can transform it into electricity.

Regional Availability of Wind Resources

Average wind speed and wind distribution (the number of hours the wind blows at speeds higher and lower than average) determines the availability of usable wind in any area. Most large open areas, junctions of land and large bodies of water, and areas where higher land meets relatively flat land have persistent high-speed winds. But since cool air tends to settle in and remain in valleys and other low-lying areas, most of these sites are ill suited for the use of wind energy.

Within densely settled cities or neighborhoods, the generation of electricity from wind energy will be minimal. Spatial and safety considerations interfere, and large buildings tend to create excessive and potentially damaging turbulence. But many cities can import wind power produced outside the city,(5) and some cities do have unpopulated and unobstructed tracts of land suitable for wind energy collection. In general, if a city is within a region with average wind speeds of 10 miles per hour or more, wind energy is available. (See Table Four.) If the city includes relatively large flat and open areas near bodies of water or higher land masses, it can tap wind resources on the spot.

Available Wind Resources in Cities

If the region is windy enough, the availability of wind energy in particular city neighborhoods depends heavily on natural topography. The built environment is even more important since turbulence caused by the presence of tall buildings can damage a wind machine's blades.

Given these potential problems, windpower assessments must be thorough. In general, though, the prime sites for larger wind systems are lake fronts, land abutting water, and open areas. For small wind energy conversion systems, the flat roofs of relatively low apartment or commercial buildings are suitable if neighborhood building heights are more or less uniform. In New York City, for example, the Energy Task Force found that wind speeds were sufficiently constant on the roof of a five-story apartment building surrounded by apartment houses of similar height to justify installing a wind machine.(6) (See Chapter Twelve, Electricity.)

Water Resources

Both ground water and surface water can be tapped as energy resources. Ground water is most commonly used to supply and store heat energy. Surface water can do both and also generate electricity in hydropower facilities or solar ponds.

Few large cities will be able to use natural water resources within city limits to meet much of their total energy demands. But in some areas within such cities, water resources may be able to supply relatively large amounts of energy. Smaller cities have more opportunity to use intra-city water resources on a larger scale. For example, many Northeast cities with populations under 100,000 are finding that existing dams on adjacent rivers can be used as hydro-electric facilities.(7) In addition, large cities can buy hydroelectricity produced outside the city, as is common practice now in the Northwest and South.

Water and Thermal Energy

With its high specific heat, water can store large amounts of thermal energy. Ground water in particular, which is more isolated than surface water from climatic changes and stays between 40 degrees F and 60 degrees F in most of the United States,(8) makes a good heat source in winter and heat store (or heat sink) in summer.

Ground water is found in various geological formations--confined aquifers, underground reservoirs, and subterranean channels.(9) Heat can be transferred to and from ground water in these by any of numerous technologies, including ground-coupled heat

TABLE FOUR
AVERAGE WIND SPEEDS FOR SELECTED CITIES

<u>City</u>	<u>Average Annual Wind Speed</u> (Miles Per Hour)
Boston	12.6
Providence	10.7
New York	12.2
Rochester	9.8
Buffalo	12.3
Newark	10.1
Pittsburgh	9.4
Philadelphia	9.7
Baltimore	9.4
Washington, D.C.	9.3
Norfolk	10.6
Charlotte	7.5
Atlanta	9.0
Jacksonville	8.4
Miami	9.2
Birmingham	7.3
New Orleans	8.3
Memphis	9.1
Louisville	8.4
Cincinnati	9.1
Cleveland	10.8
Detroit	10.2
Fort Wayne	10.3
Indianapolis	9.7
Chicago	10.4
Milwaukee	11.8
Minneapolis	10.5
St. Louis	9.5
Kansas City	10.3
Omaha	10.8
Dallas	10.9
Austin	9.3
Houston	7.6
San Antonio	9.4
Oklahoma City	12.8
Denver	9.0
Salt Lake City	8.8
Albuquerque	9.0
Phoenix	6.3
Los Angeles	6.2
San Diego	6.7
San Francisco	10.5
Oakland	8.2
Sacramento	8.2
Portland	7.8
Seattle	9.2
Anchorage	6.7

Source: U.S. National Oceanic and Atmospheric Administration,
Comparative Climatic Data.

pumps that move heat to and from ground water either directly or through heat exchangers.(10)

Whether it is technically feasible to use ground water to supply or store heat depends primarily on where the ground water is found. Two rules of thumb are that aquifers are larger than subterranean channels and that underground reservoirs experience greater temperature swings than confined aquifers because the former are connected to surface water sources. However, confined aquifers also have drawbacks. Located beneath tons of soil and rocks, they are relatively inaccessible and can be thermally polluted if ground water is used for heat storage.

Most large cities lie above ground water resources. The questions are whether those resources are worth developing, whether ground water reserves are readily available, and whether local environmental constraints limit their use for supplying and storing heat. In general, though, there is increasing evidence that useful aquifers are far more prevalent under large cities than hunch would allow.(11)

Surface water resources can also be used to obtain or store heat though this may prove tricky in some climates since surface water temperatures vary more by season than ground water temperatures do. Then too, many of the same environmental questions surrounding the use of aquifers apply equally to surface water's use.

Like natural water resources, artificial bodies of water can be used to collect and store heat or to store cold.(12) These solar and ice ponds can be constructed to supply heating or cooling to many smaller buildings, a few bigger ones, or a single large structure. They will enjoy only limited use inside central cities, however, since they require relatively large areas of land. However, just how much land is required depends upon the application. More land is needed for electricity-producing ponds (see below) than for those that provide heat only.(13)

Hydroelectricity

A more common way to produce energy from surface water is to use flowing water to rotate turbines and thereby generate hydroelectricity. How much electricity can be produced this way depends on such site characteristics as the size of the vertical drop (the "head") and the consistency and rate of stream flow.

All but the smallest of hydroelectric projects (less than 100 kw) require one of two types of dams to direct the flow of water. Storage dams are best suited to large-scale (or "high-head") sites, where flow rates usually vary. Quite tall, they work best in deep valleys, where they can form large, deep reservoirs. They have no place in the city.

In contrast, run-of-the-river dams do occur within city boundaries where they are used to control the flow of a river, rather than to create a reservoir. These dams--which could be used in low-head hydro projects--abound in many cities (some of them large) in the Northeast, upper Midwest, and the Northwest. (See Table Five.) Lowell, Massachusetts, is renovating the Pautucket Dam in the Lowell Canal System off the Merrimack River to produce about 80 million kilowatt-hours (Kwh) per year. Paterson, New Jersey, is rehabilitating its Great Falls hydro plant to obtain some 30 million kwh annually; and Idaho Falls, Idaho, is redeveloping three existing hydroelectric plants on the Snake River to obtain 170 million kwh yearly (about three times the electricity currently produced by the city's municipal utility).(14)

Since it is cheaper to renovate than to build run-of-the-river dams, cities with existing dams can make more economical use of hydropower. In addition, the economic feasibility of developing a low-head hydro site depends on the condition of the existing dam, the area's electricity demand, and the local utility's policies. (For details, see Chapter Twelve, Electricity.)

Natural or man-made bodies of still water can produce enough heat to generate electricity if they contain natural or implanted layers of salt that increase in density with the pond's depth. (Another requirement is fairly high and constant levels of sunshine, so electricity-producing solar ponds may be most feasible in southern regions.)(15) As the salt absorbs heat, higher temperatures concentrate toward the bottom while the less dense salt solution moves upward, preventing the convection of concentrated heat throughout the pond. Even more than solar thermal ponds, ponds producing electricity have water, land, and climatic requirements that are almost impossible to meet in urban areas. However, cities could obtain electricity produced by solar ponds in outlying areas.

Biomass Resources

The solar energy stored in biological material--primarily wood, crops, and organic wastes--can be turned into heat or steam (for electricity generation) or into solid, liquid, or gaseous fuels. Wood and crop "biomass" resources include harvest residues, other waste by-products, and resources grown specifically as energy sources. Most organic wastes are found in the community's solid waste stream.

Most large cities have easier access to municipal solid wastes than to agricultural or forest resources. Still, nothing prevents large cities from importing liquid or solid

TABLE FIVE
NEW HYDROPOWER POTENTIAL BY REGION (1978-2000)

	<u>Sites</u>	<u>Capacity Megawatts</u>	<u>Annual Energy Production Gigawatt Hours</u>
<u>Totals, Nation</u>	2,100	57,000	149,000
<u>By Electric Reliability Council</u>	%	%	%
Northeast Power Coordinating Council (NPCC)	32	8	11
Western Systems Coordinating Council (WSCC)	30	55	50
Southeastern Electric Reliability Council (SERC)	9	12	9
East Central Area Reliability Coordinating Agreement (ECAR)	9	8	9
Mid-American Interpool Network (MAIN)	4	2	2
Alaska	3	6	10
Electric Reliability Council of Texas (ERCOT)	2	1	1
Mid-Atlantic Area Council (MAAC)	2	2	1
Mid-Continent Area Reliability Coordinating Agreement (MARCA)	2	2	1
Puerto Rico and Hawaii	2	1	1
Southwest Power Pool (SWPP)	5	4	5

Source: U.S. Army Corps of Engineers.

fuels or electricity from wood-fired power plants. Then too, many smaller or middle-sized cities may be close enough to forests, wastewood industries, or crop-growing areas to use biofuels to generate electricity in intra-city power plants or to convert wood or crops into fuel in urban facilities economically.

Any use of biomass for energy needs to be evaluated in light of environmental constraints. In municipal solid waste operations, cities must distinguish between wastes that have no other uses (and, thus, must be disposed of) and wastes whose contents can be recycled, saving scarce materials and the energy used to extract them. Using crops and wood carries additional caveats since some crops would otherwise be used for food or animal feed and since both crops and tree cover add vital nutrients to the soil.

Wood

Wood can be used to heat buildings or to fuel power plants of up to fifty-megawatt capacity.(16) Alternatively, wood can be converted into liquid or gaseous fuels for space heating or transportation uses.

Wood resources are available from several sources. In New England, lumber and paper mills and furniture-manufacturing plants all produce a fairly steady flow of wood and bark wastes that these industries convert into energy.(17) Lewiston, Maine, may use surplus wood wastes from nearby paper mills to fuel a small cogeneration and district-heating system that serves its factory district and the surrounding residential areas.(18) Logging residues also make good fuel. Each year, millions of tons of diseased, damaged, or undersized trees left over from logging operations are burned off or left to decay.

A third wood source for biofuels is wood grown or harvested specifically for energy. For large-scale harvesting, overgrown woodlots that need extensive thinning to improve yields of marketable timber hold promise. So do wood-energy plantations on which rapidly growing trees would be harvested every four to seven years.

The expense of hauling wood will probably limit its intra-city use for electricity generation or production of wood-derived fuels. Even where wood is plentiful close to cities, hauling requirements would influence the maximum size of plants or operations. For example, fueling a 50-megawatt electric generating plant in Burlington, Vermont, will require the equivalent of 105 truck trips a day to haul 1500 tons of wood chips from within a fifty-mile radius of the city.(19) Distances much in excess of this would be uneconomical.

Environmental factors do limit the number of trees that can be harvested for energy. If erosion is to be controlled, trees on steep land or close to stream beds cannot be harvested.(20) The possibility that using wood for energy could sap nutrients from the soil also warrants more research. Greater concern has arisen over "whole tree chipping," which is quite profitable, but involves removing nitrogen-rich branches and leaves.(21) Fortunately, nitrogen depletion is likely to become serious only after several generations of harvesting, so with careful monitoring, harvesters can modify their management practices as needed.

Crops

Crops, crop surpluses, and crop residues can be put to many of the same energy uses as wood. In the Midwest, numerous plants are already turning crops into liquid fuels, and permits for other conversion facilities of all sizes are being sought. According to recent studies, dried and treated crop residues can be used alone to fuel small-scale, on-farm electric generators or used with coal in larger power plants.(22)

Surplus crops--those stocks not used for food, animal feed, or export--and crops grown specifically for energy can be channeled to energy uses. Which surpluses are used under which circumstances depends partly on natural or climatic factors (such as crop-production levels) and partly on regulatory or administrative factors (such as how the Department of Agriculture's acreage set-aside and grain-reserve programs, which discourage excess crop production are used).(23) In addition, the long-term impact on food supplies of growing energy crops on a large scale remains to be established.(24)

Harvesting residues are most plentiful where corn, soybeans, wheat, and other grains are produced.(25) But, agricultural studies suggest, between one-third and three-fourths of all crop residues must be left on the soil to prevent nutrient depletion.(26)

In general, cities will be hard-pressed to make direct use of agricultural energy resources if large crop-growing areas are more than fifty miles away. Such cities may be able to purchase crop-based liquid fuels from rural producers, but (along with regional utilities) they may also have to compete with farmers for these fuels. In any event, numerous food-related questions need to be answered before crops can be widely used for energy purposes.

Municipal Solid Waste

Few big cities have easy access to large wood or crop resources, but all have only too ready access to municipal solid wastes. Indeed, disposing of mountains of solid waste poses severe environmental and land-use problems for some cities. "Clean air"

statutes limit burning, and land for waste disposal is growing scarcer.

On average, cities process three to five pounds of solid wastes per person per day.(27) To help offset the costs and headaches of waste control, some cities now produce a salable energy as a by-product of waste disposal, either by using solid waste as fuel in "garbage to energy" operations or by obtaining methane gas from landfills.(28) While getting energy from garbage is no justification for abandoning environmental or land-use controls, it does in cases where, say, solid wastes can be turned into refuse-derived fuel, reduce the amount of trash that must be burned or else buried in landfills.(29)

All cities have access to a solid waste stream that contains some combination of food, glass, plastic, metal, and yard wastes. Whether the energy in that waste stream can be used depends on the answers to several questions. How predictable is the waste stream's size and composition? How much of the waste can be recycled? And how reliable are the markets for recycled energy products?

The amount and composition of a city's waste varies by day and season. Waste flow may be higher on weekdays than on weekends because industrial activity is heightened then. In summer, when carbonated beverage sales peak, the waste stream may contain more glass and metal.

Both the size and composition of the waste stream must be known before any resource-recovery system can be properly sized. Particularly important is accurately estimating the amount of available recyclables (paper, ferrous metals, aluminum, and glass) since building oversized plants may actually stifle some recycling programs by providing an incentive to keep the volume of waste high. Equally important is finding reliable markets for the plant's products.(30)

Geothermal Resources

Heat stored within the earth can be used to provide thermal energy to run electric generators. In some geological formations, large (though ultimately exhaustible) quantities of the earth's heat are concentrated close enough to the surface to be extracted economically.

While geothermal wealth is not equally distributed, a surprising number of locations throughout the country have usable stores of heat. The West is better endowed geothermally, but the Atlantic coast and other parts of the East have potential too.(31) In fact, as part of its East Coast Drilling Program, the Department of Energy drilled an exploratory well on penninsular Maryland and thereby confirmed the presence of geothermal hot water under the Atlantic Coastal Plain.(32) Also, the geothermal potential of the Eastern U.S. may be underestimated since most of the geothermal "prospecting" which has occurred has looked for high temperature reserves only. Including the lower temperature hot water available in current geothermal inventories could reveal a number of additional stores in the Eastern U.S.

Most of the higher-temperature (over 200 degrees F) reserves are in the West. Cities there may be able to produce electricity and feed it into the local utility grid. In contrast, the moderate and low-temperature reserves found in Eastern cities are suitable primarily for heating clusters of buildings.

Geothermal energy is stored in hydrothermal (hot water) resource, geopressed resources (water and dissolved methane stored at high temperatures and high pressure), and dry hot rock.(33) It can be tapped by drilling and then used to provide heat or to run electric generators. Hydrothermal resources are easiest to recover, and hydrothermal technologies are closest to commercial readiness.

Hydrothermal resources are now being used to heat clusters of buildings (as in Boise, Idaho, and Klamath Falls, Oregon) and to provide electricity (as in the Geysers in Sonoma, California, and Raft River, Idaho). Technologies for using geopressurized reserves (mainly, the methane they contain) are expected to become operational in the mid-1980s. Meantime, questions related to the amount of methane that a given well can produce and other economic factors, await answers. As for using heat from hot dry rocks, the technologies for drilling, fracturing, and recovering heat from dry rocks are still under development.(34)

Besides resource availability and technological readiness, cities interested in geothermal resources also have negative environmental impacts to consider. Some geothermal recovery systems produce large quantities of brine, the disposal of which could be environmentally menacing. Likewise, since most geothermal reserves (particularly high-temperature ones) are located where earthquakes are possible, the withdrawal of hydrothermal fluids needs to be monitored carefully.

Finally, institutional considerations are also important. Questions over the definition of ownership may hamper development of geothermal resources. So might the state laws precluding the development of geothermal resources.(35)

Where to Find Local Information

To assess the local potential of any renewable energy resource, city officials should first consider resource availability. The need for progressively more detailed and site-specific analyses will depend on the resource, its likely applications, and the projected city role. For example, assessing availability of sunshine is relatively easy on a broad scale. If the city is considering using solar equipment in city buildings or launching a solar financing program supported by, say, a general-obligation bond issue, it should extensively analyze the solar access of representative buildings and neighborhoods. For purposes of publicity or information programs, on solar applications, the more general analysis is probably sufficient. However, in the case of wind resources, variations in topography and the built environment are so influential that at least some site-specific analysis is always indicated. Likewise, because tapping resources with such larger-scale technologies as geothermal recovery or hydropower may require capital expenditures by the city, resource assessments and feasibility analyses are absolutely essential.

Unfortunately, few ready sources of information on climate and renewable energy resources can provide the detailed data needed for more elaborate site-specific studies. Most general sources of information merely help city energy offices decide whether more detailed studies would be fruitful. Here, some general sources of information are described and sources of more detailed evaluations are suggested.

One general point first. Before undertaking any type of analyses, a city should check likely sources to see if such assessments have been done already. In particular, it should contact the State Energy Office. What the city wants the state may have already have done. At the very least, State Energy Office staff can sometimes provide guidelines or short cuts that can ease the workloads and reduce the costs of analyses considerably. Also, many utilities are collecting data on sunshine, wind, and other resources for their own projects. (Cities located in the marketing areas of the Tennessee Valley Authority (TVA) or the Bonneville Power Administration (BPA) will, for example, very likely find detailed resource assessments of solar, wind, or hydropower.) Other possible sources of completed resource analyses are state colleges and universities, some of which are beginning energy programs while others have specialized schools in agriculture, forestry, or natural resources. Finally, state solar energy associations may know of available resource assessments.

Sunshine and Wind Resources

Primary sources of information on sunshine and wind are the nearest weather station and airport. To interpret such information as intensity of sunshine, the average annual percent of sunny hours, and average wind speeds, city officials need to know how the weather station's microclimate differs from that of the city. Keep in mind that the effects of air pollution on direct solar radiation in densely developed areas will not show up fully in weather station reports.

Topographical variations can create fairly substantial differences in wind speeds for sites that are close geographically. Airport sites tend to be selected for their moderate winds, so wind speeds are likely to be greater elsewhere, say, on the heights above a river valley.

Information more detailed than weather-station data will be required to evaluate different neighborhoods' potentials for using solar energy systems or wind energy conversion systems. For any system using sunshine as a resource, information on shading patterns is needed. (See Chapter Four, Land Use and Energy.) For wind energy systems, information on average wind speeds and wind-distribution patterns is essential. A wind data compiler (which records wind speeds each second so that average wind speeds per hour can be calculated) can in two months or so provide the data needed to compare average speeds measured at weather station sites so the wind speed distribution can be calculated.⁽³⁶⁾ The time required to collect data at a site depends largely on how closely site data correlate with weather-station data. If the correlation is high, then weather-station data can be used to predict wind speed distributions at the site. If not, site data may have to be collected for up to a year.

A few states (Alabama, California, Connecticut, and New Jersey) have established wind energy offices, and ninety-one utilities around the country had some kind of wind program as of 1980.⁽³⁷⁾ California loans anemometers for assessing the wind potential of a given site.

Water Resources

General information on an area's surface water resources will be available from state or regional departments of environmental or natural resources, bureaus of water or land management, or public interest or education groups that focus on water issues. To gauge the potential of a body of surface water to supply or store heat, cities will have to consider such factors as the size of their heating and/or cooling needs, the size of water resource, average seasonal temperatures, proximity of surface water to end-uses, and such potential environmental problems as thermal pollution.

To assess hydropower production potential, cities also need to know the average steam heads and the rates and consistencies of flow at existing dams. Information on stream flow should be obtainable from the state agency responsible for water resources or the U.S. Geological Survey. Both maintain gauging stations on rivers. Topographical maps may also help city officials estimate an area's general potential, though specific sites should be analyzed by qualified engineers. Among other things, engineers must determine the maximum and minimum flow rates of a stream in order to calculate its maximum and minimum electrical output potential.(38) Cities interested in recommissioning an abandoned hydro-electric plant may be able to obtain data on stream flows from the plant's old records.

General information on the location and size of ground water heat sources or stores can be obtained from many of the same organizations that supply information on surface water. But since this information is so general, water-resource assessment experts will be needed to determine a ground water reserve's capacity and to assess the environmental consequences of heat removal or heat storage on both the ground water source and connected water resources.

Wood

General information on how much and which type of wood resources are available can be obtained from state offices of natural resources, environmental resources, or forestry. They can also be secured from universities with forestry departments. This information is site specific enough to allow the city official to determine whether wood resources warrant further study. If they do, the city will need to commission experts on energy, forestry, and environmental issues to determine the energy potential of available wood stocks, the transportation costs of housing the wood, and the maximum level of tree harvesting that is environmentally safe.

Crops

General data on the availability of crops and crop surpluses for energy use can be obtained from state or regional agricultural offices. In addition, the Stanford Research Institute has published a report, An Evaluation of the Use of Agricultural Residues as an Energy Feedstock, that estimates county-by-county availability of agricultural wastes. However, more detailed studies will be needed to assess local possibilities for converting crops to biofuels. The location of existing or proposed processing plants, transportation costs, and the effects of crops-to-energy projects on food supplies and soil quality--all must be considered. In the case of energy plantations, one consideration is whether land used for energy farms would be used more profitably for food production.

Municipal Solid Waste

Before a city commits itself to a major resource-recovery study, it should roughly gauge local conditions to determine if resource recovery is technically, economically, and environmentally feasible. A quick survey of the city's goals (for example, to use resource recovery to generate revenue or to solve a waste-disposal problem, an energy problem or both) together with analyses of its existing disposal options, the cost of resource recovery versus other options, and the existence of markets for products (electricity, steam, and recycled materials) should be made to see if further study is warranted.

Many relatively quick techniques can be used to estimate the size and composition of a community's municipal solid waste stream. Some communities maintain weight records of the refuse they dispose. Those that do not can estimate total weight by recording the weights of a sample of disposal trucks and multiplying the average by the number of truckloads of waste generated per day. The key, of course, is making the sample representative of weekly, seasonal, and geographic differences and finding a way to estimate the recycling potential of the waste stream.(39)

Where preliminary assessments are favorable, cities should commission a qualified firm to determine the precise composition of the waste stream on a seasonal and annual basis. While the study may cost upward of \$25,000 for larger communities, the benefits are substantial. In many cases, it can enable a community to develop a resource-recovery operation that makes maximum use of both recycled products and energy from the waste stream.

City officials wishing to make preliminary feasibility assessments of resource-recovery plants should turn to the Environmental Protection Agency's Office of Waste Management guidebooks, which are designed to assist city officials plan and implement resource-recovery plants. They also should examine the U.S. Conference of Mayors' case study reports on cities using resource-recovery plants. Also of note, the International City Management Association keeps up-to-date files on resource-recovery projects around the country, and the American Consulting Engineering Council publishes a directory of engineering firms engaged in resource recovery.

Geothermal

For the near term, most practical applications of geothermal energy will make use of hydrothermal (hot water) resources.

General information on geothermal resources is available from the U.S. Geological Survey. "An Assessment of Geothermal Resources of the U.S.--1978" (U.S. Geological Circular 790) tells the location of known geothermal resources, gives estimated average temperatures, and estimates the amount of energy that can be extracted. Also, many states are compiling geothermal data under DOE sponsorship through the state bureau of geology, water resources department, bureau of mines, or state energy office. Where this information indicates that geothermal potential exists, a more detailed study of possible sites will be needed. Since different applications require different temperatures, the physical characteristics required for the particular application called for must first be defined. These include flow rate, the water temperature, and the water quality. Such a resource analysis of hydrothermal potential (as distinct from a narrower technical or economical feasibility study) must also take into account the expected duration of the recoverable hydrothermal reserves under different usage patterns, probable losses of heat during transmission, and the environmental effects of geothermal recovery and transport, brine removal, and brine disposal. A competent engineering firm, preferably with experience in geothermal applications is needed to perform such analyses. (See Appendix I.)

Chapter Four

Land Use and Energy

Undertaking even the most modest energy-conservation or renewable energy program raises land-use issues, and these issues cannot be resolved without accurate information. For example, conservation strategies must take housing density into account, and provisions to encourage solar water heating cannot be developed without knowledge of solar access potentials. Thus, Boulder is basing its residential energy-conservation plans in part on projected increases in the number of single-family attached homes built. Los Angeles considered requiring the installation of solar water heaters in new construction only after first analyzing land-use impacts of solar access protection.

Most community energy analyses classify energy uses and develop policy options according to four major land-use sectors: residential, commercial, industrial, and transportation. Knowing how much and what types of energy are used in each helps the city determine its "energy profile." However, the numbers alone mean little. Also needed is a keen awareness of building density, the nature of the industrial/commercial mix factors in the local economy, and other factors that influence each sector's consumption patterns and conservation potential.

Building Density

The population densities of different cities or neighborhoods can be compared by determining the number of residents per square mile in each. Typically, relatively "dense" areas have many different types of built environments, including high- and mid-rise apartment buildings and shopping complexes, and lower-rise garden apartments or attached townhouses interspersed with commercial strips.

In terms of reducing energy use, building density can be a plus. In construction of comparable size and quality most research shows multi-family buildings use less energy per unit than single-family houses do because the common walls and ceilings in apartments reduce their surface-to-volume area. Studies of residential energy consumption in San Francisco, Minneapolis, and Atlanta showed that single-family detached housing units account for 74 percent of the city's residential consumption but comprise only 54 percent of the city's housing stock.

Buildings also benefit from proximity to other buildings. Neighboring structures block the wind in the heating season and unwanted sun in the summer. This is offset somewhat by the so-called "heat island" effect, which keeps cities hotter than outlying suburbs and adds to urban cooling loads in the summer.(3) (See Chapter Three.)

Denser development also tends to include mixed land uses. In dense zones, residents can walk to workplaces, stores, and entertainment. But in suburbs and rangier settlements, the distances between home, work, and other hubs of activity can be substantial.

Most cities' General Plans and zoning or subdivision ordinances encourage particular degrees of housing and commercial building density as well as mixed uses. In Los Angeles, for example, the General Plan explicitly fosters low-density residential development and limits high-rise apartments, offices, and commercial complexes to specially designated "centers." (5) The District of Columbia limits the height of new residential and commercial buildings to twelve stories. Boulder controls housing density in part by restricting the number of building permits issued each year.(6)

The move toward encouraging greater building density for energy conservation is catching on, at least in theory. In Portland and Los Angeles, energy analysts have recommended zoning for denser and more mixed-use development to reduce urban energy use.(7) Yet, the policy options open to cities will vary according to the existing levels of density, the city's development goals, the growth-management tools at hand, and, sometimes most importantly, the political feasibility of changing density patterns.(8)

No single pattern of "dense" development characterizes a "typical" city; therefore no "typical" compact development program suits all cities. In general, though, older cities in the Northeast and Midwest are relatively denser than newer cities in the South and West, although even these denser cities often include substantial numbers of single-family homes.(9) (See Tables Six and Seven.) Moreover, building density varies by neighborhood--an important consideration since energy-conservation and renewable energy technologies can be neighborhood- and building-specific. Mapping those variations is easy enough in most cases, though older neighborhoods that have weathered redevelopment more than once can have an unpredictable mix of housing types. A recent analyses of a "typical" multi-family neighborhood in Baltimore found that single-family detached homes, row houses, and mid-rise apartment buildings coexisted within a relatively small geographic area.(10)

Since building density varies widely among cities and neighborhoods, cities' "density goals" must vary too. Constructing massive high-rise buildings in the name of energy efficiency should not be the general rule. As a recent Urban Institute study shows, increasing building heights will reduce per capita energy use only up to a point. Beyond it, per capita consumption begins to rise with the increased need for electricity for elevators and other services.(11) Then too, high-rise structures may violate the scale

TABLE SIX
URBAN POPULATION DENSITIES
(Selected Cities)

<u>City</u>	<u>Population Density</u> (Persons per Square Mile)
Boston	13,842
Providence	8,874
New York	24,964
Rochester	7,280
Buffalo	9,859
Newark	14,450
Pittsburgh	8,309
Philadelphia	14,131
Baltimore	10,877
Washington, D.C.	11,588
Norfolk	5,450
Charlotte	2,596
Atlanta	3,316
Jacksonville	734
Miami	10,644
Birmingham	3,345
New Orleans	2,840
Memphis	2,401
Louisville	5,599
Cincinnati	5,283
Cleveland	8,416
Detroit	9,675
Fort Wayne	3,351
Indianapolis	1,995
Chicago	13,911
Milwaukee	7,008
Minneapolis	6,813
St. Louis	8,578
Kansas City	1,494
Omaha	4,586
Dallas	3,006

TABLE SIX
(Continued)

<u>CITY</u>	<u>Population Density</u> (Persons per Square Mile)
Austin	3,147
Houston	2,744
San Antonio	2,935
Oklahoma City	576
Denver	5,090
Salt Lake City	2,445
Albuquerque	3,150
Phoenix	2,467
Los Angeles	5,879
San Diego	2,397
San Francisco	14,637
Oakland	6,192
Sacramento	2,229
Portland	4,495
Seattle	4,470
Anchorage	3,170

Source: The City/County Data Book

TABLE SEVEN

SINGLE FAMILY HOMES PER THOUSAND POPULATION
(Selected Cities)

<u>City</u>	<u>Population</u>	<u>Number of Single Family Homes</u>	<u>Single Family Homes/Thousand Population</u>
<u>Under 100</u>			
Boston	636,725	33,300	52
New York	7,481,613	341,700	46
Newark	339,568	9,400	28
Chicago	3,099,391	277,800	90
<u>100-200</u>			
Buffalo	407,160	43,600	107
Washington, D.C.	711,518	46,300	135
Atlanta	436,057	73,300	168
Cleveland	638,793	104,800	164
St. Louis	524,964	74,600	142
<u>200-300</u>			
Pittsburgh	458,651	98,500	215
Philadelphia	1,815,808	415,600	229
Baltimore	851,698	172,000	202
Birmingham	276,273	62,400	226
Memphis	661,319	139,700	211
Louisville	335,954	75,400	224
Detroit	1,335,085	271,100	203
Indianapolis	782,139	173,900	222
Omaha	371,455	79,700	215
Houston	1,326,809	271,200	204
Oklahoma City	365,916	107,100	293
Denver	484,531	112,300	232
Salt Lake	169,917	36,300	214
Phoenix	664,721	175,100	263
Los Angeles	2,727,399	601,500	221
Sacramento	260,822	66,200	254
Seattle	487,091	138,600	285
<u>Over 300</u>			
Providence	167,724	98,500	587
Minneapolis	378,112	132,900	352

Sources: Population: City/County Data Book
Homes: Annual Housing Survey

of the urban landscape or otherwise impair livability.

Thus, the Boulder study predicts, housing density will increase primarily as a function of the shift from single-family detached houses to single-family townhouses.(12)

In Bridgeport, Connecticut, city planners expect housing density to increase along with the increased construction of multi-family buildings.(13)

Taking an eclectic (or neighborhood-specific) approach to zoning can allow selected small businesses into neighborhoods that were once exclusively residential, reducing some work or shopping-related travel.(14) In older, central cities a complementary step would be to allow higher residential or commercial densities in redeveloped warehouse districts or low-rise commercial areas bordering higher density residential or business areas.(15) In a city such as Los Angeles, density could be increased by using "step down" techniques--from the centers outward, building progressively lower story multi-family or commercial structures.(16)

The administrative means of implementing compact zoning programs will also vary from city to city, depending upon the growth-management tools available. In most cases, city energy officials should work with city planning or building departments to incorporate energy elements in General Plan revisions, in zoning or subdivision regulations, and in procedures for granting variances and zoning-code exceptions.(17)

Commercial/Industrial Mix

Besides knowing how their city is laid out, city officials also need to know how the local economy uses energy. Without this knowledge, they can neither anticipate energy-related economic problems nor identify where conservation or renewable energy would make the most difference. Yet, understanding local energy use is more than simply knowing how much energy the city's businesses and industries consume.

Industry-based economies have different energy needs than more commercially based ones. Businesses use energy mainly for space conditioning, service lighting, and appliance operation. Industries use it primarily to fuel industrial processes--many of which require extremely high temperatures. As a result, industry tends to consume more energy per employee or per dollar invested than most commercial enterprises. Even though Portland's industrial sector employs only 50 percent of the city's workforce, it consumes 67 percent of the total energy that industry and businesses use.(18) In Bridgeport, energy use per industrial employee is almost 250 percent higher than per commercial employee.(19) (See Table Eight.)

Businesses consume different types as well as different amounts of energy than industry does. Commercial or service concerns use relatively large amounts of electricity for air conditioning, lighting, appliances, or refrigeration. (Philadelphia's commercial sector, for instance, uses about 34 percent of the electricity the city consumes, even though business accounts for only 17 percent of the city's total energy use.)(20) In industry, the type of energy used depends more on the fuel sources available and the temperature level required. Philadelphia's industries run primarily on oil,(21) while Cambridge's high-technology industrial sector uses mostly electricity. (See Table Nine.)

The type and amount of energy used also varies within each sector. Food-processing industries are less energy-intensive than primary metal producers (See Table Ten), retail hardware stores less so than retail food stores. Yet, some commercial establishments are more energy-intensive than some industries.

Knowing what economic factors influence local energy consumption can help city officials develop more responsive and effective policies. One option recommended by the Portland Study Group is to persuade businesses and industries that are not energy-intensive to locate in the city.(22) Another is to encourage or require the most energy-intensive businesses and industries to improve their energy efficiency. Here, some perspective is needed since commercial users may be able to upgrade the building shell and the heating, cooling, and lighting systems without spending much money, while industrial investments in improving the energy efficiency of production processes may be much more expensive and harder to make. Accordingly, cities may need to do little more for businesses than provide information and remove unnecessary barriers to energy-conservation improvements. For industry, however, low-interest loans, city tax breaks on energy-saving investments, or other stronger incentives may be needed.

Land Use and Availability of Renewable Energy

A city's physical dimensions help determine its potential for using renewable energy in two ways. First, the types and levels of energy demand depend in part on land-use considerations so different renewable energy technologies can be used to meet different demands. (See Parts Two and Three of this book.) Second, land-use factors influence the amount of properly oriented and unshaded space available for solar energy collection in dense areas. Specifically, three separate factors are involved: the availability of adequate physical space, the proper orientation of that space, and the availability of solar access.

TABLE EIGHT

EMPLOYMENT DISTRIBUTION BY CITY, JULY, 1981

<u>City</u>	<u>Percent of Payroll</u> ¹		<u>Percent of</u> <u>Energy Use</u> ²	
	<u>Goods</u>	<u>Services</u>	<u>Commercial</u>	<u>Industrial</u>
Denver-Boulder	24	76	14.0	8.9
Dayton	32	68		49.4
Lawrence-Haverhill	42	58		37.2
Knoxville	32	68	17.7	15.3
Bridgeport	42	58	13.4	21.3
Miami	19	81		6.3
Los Angeles-Long Beach	28	72	13.3	12.4
Portland	24	76	10.0	39.0
Philadelphia	19	81		20.0

Sources: 1. U.S. DOL, Bureau of Labor Statistics, Employment & Earnings
Sept., 1981 (Table B-8)

2. Portland: Energy Conservation Choices for the City of
Portland, Oregon (1977).

Lawrence/Haverhill: The Lawrence Economic Development/
Energy Program (1981)

Other cities: Comprehensive Community Energy Management
Planning (CCEMP) Audits.

TABLE NINE

PRINCIPAL INDUSTRIES AND INDUSTRIAL MIX BY CITY

		Fuel Mix (Percent Industrial Energy Use)							
<u>City</u>	<u>Principal Industries</u>	<u>Total Industrial Energy Use (10⁹ Btu)</u>	<u>Electricity</u>	<u>Fuel Oil</u>	<u>Natural Gas</u>	<u>Propane</u>	<u>Coke & Coal</u>	<u>Steam</u>	<u>Other</u>
Boulder	Computers, paving & gravel, aircraft	1838	23		77				
Dayton	Transportation Equip- ment, machinery, food		24.7	8.7	45		16.9	4.7	
Greenville	Light manufacturing & assembly food processing, agri- business, pharmaceuticals	827	41	42	18				0.2
Wayne County, MI	Motor vehicles, steel machinery, fabricated metals		19.9	10.3	40.8		23.5		5.5
Knoxville	Apparel, textile mills food processing, machinery		28.7	11.1	46.3	1.4	11.2		1.3
Bridgeport.	Fabricated metals, transportation equip- ment electrical equipment	11900	20.9	54.9	24.5				
South Florida	Food processing; stone, clay & glass	13682	66	.03	30				

TABLE NINE

PRINCIPAL INDUSTRIES AND INDUSTRIAL FUEL MIX BY CITY
(Continued)

<u>City</u>	<u>Principal Industries</u>	<u>Total Industrial Energy Use (10⁹ Btu)</u>	<u>Electricity</u>	<u>Fuel Oil</u>	<u>Natural Gas</u>	<u>Propane</u>	<u>Coke & Coal</u>	<u>Steam</u>	<u>Other</u>
Los Angeles	Petroleum refining; food processing; stone, clay & glass transportation equip- ment	44,700	29.5	24.6	45.6				
Portland	Paper & allied products; primary metals (aluminum) construction; lumber & wood; food processing	98,821	28.4	17.4	43.9				10.3
Philadelphia	Food processing; apparels & textile products; printing & publishing; textile mills	47,900	17.1	65.9	15.4			1.5	

Sources: Portland: Energy Conservation Choices for The City of Portland, Oregon (1977).

Other Cities: Comprehensive Community Energy Management Planning (CCEMP) Audits.

TABLE TEN

ENERGY INTENSITY BY INDUSTRY, 1978

<u>Industry</u>	<u>Energy Consumption (Btu x 10¹²)</u>	<u>Employees (x 10³)</u>	<u>Energy Intensity (Btu x 10⁶/Employee)</u>
Food and kindred products	980.5	1,665.6	588.67
Tobacco products	20.8	73.0	284.93
Textile mill products	326.6	898.7	363.41
Apparel and other textile mill products	69.1	1,356.0	50.95
Lumber and wood products	231.1	739.3	312.59
Furniture and fixtures	55.3	491.4	112.53
Paper and allied products	1,301.1	689.0	1,888.38
Printing and publishing	91.5	1,186.2	77.13
Chemicals and allied products	2,905.3	1,108.9	2,619.98
Petroleum and coal products	1,122.7	218.9	5,128.82
Rubber and miscellaneous plastics	261.0	770.9	338.56
Leather and leather products	21.6	255.4	84.57
Stone, clay, and glass products	1,299.8	688.7	1,887.32
Primary metal industries	2,710.9	1,213.2	2,234.50
Fabricated metal products	400.2	1,684.5	237.57
Machinery, except electrical	350.7	2,345.3	149.53
Electric and electronic equipment	254.9	2,021.5	126.09
Transportation equipment	397.7	1,991.0	199.74
Instruments and related products	79.0	644.2	122.63
Miscellaneous Manufacturing Industries	49.0	467.1	104.90

Source: Bureau of the Census, 1978 Annual Survey of Manufacturers.

Physical Space

All renewable energy systems require certain minimum collector areas to perform satisfactorily. How much space depends in part on system type, system scale (on-site or community), and climate. Thus, for example, most active domestic water-heating systems require far less collector area than combined space- and water-heating systems do. An active system designed to supply about 50 percent of the water heating needs in a single-family home requires about 60 square feet of collectors in Boston. Add space heating to the load, however, and the requisite collector area could jump to over 500 square feet. Minimum collector areas for space heating or combined systems are correspondingly reduced where loads are smaller or insolation higher. For multi-family buildings or community energy systems, less collector space per household is needed. (To obtain half the domestic hot water needed for a 50-unit apartment building in Boston, about 1500 square feet of collectors may be enough.)(23)

Establishing typical collector areas for passive systems is particularly difficult since these systems are highly individualized. In general, though, a fair proportion of the building's south-facing walls must be unshaded and properly oriented if the passive retrofit is to be effective.

Orientation

Because of the tilt of the earth's axis, the earth's rotation around the sun, and other climatic factors, sunlight falling on the continental United States is more intense on south-facing areas--which is why solar energy collectors need to be oriented in a general south-facing direction. (See Chapter Three, The Natural Context, pp. xx-xx) A system's precise orientation can vary with the system's purposes and the climatic or geographic context. For example, a water-heating system can be oriented further east or west of south, depending on when most hot water is needed. A collector with an easterly orientation will collect heat sooner for use a mid-day, but evening demands for hot water might be met by a collector with a more westerly orientation since it would heat water later in the day and thus reduce standby losses in the water tank.

The orientation of most solar retrofits is largely, if not totally, determined by the buildings's orientation, which in turn depends upon street direction, the lot's position on the street, and the building's position on the lot.(24) All three factors are in most cities controlled by zoning ordinances.

A building is ideally suited for solar collection when one of its longest sides (axes) faces south. In cities, most zoning requirements specify that lot and building axes be perpendicular to streets. Accordingly, the urban solar ideal is to have streets run north to south and to have the long sides of buildings run east to west and face south. However, this arrangement has a fatal flaw in cities, since south-facing walls of most houses will be shaded by their next-door neighbors. In rowhouse neighborhoods only the unit at the row's southernmost end even has a chance for adequate solar access. Thus, it might be preferable to have the short side of the house facing south so that solar collectors can be placed on front or rear roofs or walls. In practice, this means, that east-to-west streets are most accommodating to solar access requirements.

While this general rule is worth remembering, streets running due east-to-west are by no means the only streets that provide acceptable solar orientation in cities. Many other arrangements can afford adequate solar access, and the rule has exceptions (in some cases, north-south street directions are better). Then to, other factors can sometimes offset the disadvantages of poor street directions.

First, the ranges. Some solar collectors have performed well with orientations of 45 degrees east or west of due south.(25) Thus, streets running diagonally (say, southeast to northwest) or curvilinearly in a general east to west direction may well prove adequate. Moreover, in cities or neighborhoods where the ratio of building area to total lot area (lot coverage) is low, so are the chances that a building's south-facing roof or wall will be shaded. And where lot coverage is low, more open space is available for ground-mounting active solar collectors. For example, a study of a typical single-family neighborhood in Denver revealed that even with streets running north to south, lots were only 18 percent covered. So south-facing solar collectors would be feasible.(26)

North-to-south street patterns in densely built areas may also prove acceptable where buildings have flat roofs. This proved true in a study of a low-rise rowhouse neighborhood in Baltimore.(27) The key is having enough space between collectors so that those to the south do not shade those immediate to the north. In warehouse districts, where most roofs are flat, street directions should not pose problems for collector orientation.

Where lots and buildings run parallel rather than perpendicular to streets, buildings on streets running east to west may have a long side facing south. This means that most buildings can be assumed to be properly oriented for solar access if they are on streets that run generally east to west. Where streets run north to south, energy officials will need more information about building- and lot-orientation to evaluate solar access.

Shading

Even the most well-oriented solar collector will be useless if it is shaded. To operate properly, most collectors require exposure to sunlight from about 9:30 p.m. to 3:00 p.m. on December 21st, when the sun is lowest in the sky and casts the longest shadows.(28) Meeting this access requirement can be difficult in densely populated, built-up areas. (In lower-density residential neighborhoods, vegetation is likely to pose greater problems than buildings.(29) In a typical Denver neighborhood studied, about half of all shading was caused by trees,(30) and several California cities well-endowed with shade trees have proposed or passed "solar shade control" ordinances.)(31)

Even in denser areas, solar access for roofs may be good if building heights are uniform.(32) Building shading is more severe where taller buildings to the south border lower ones to the north, or where buildings of different heights are mixed. A study of a Baltimore neighborhood with varying building heights showed that an eight-story apartment house located south of a block of row-houses shaded half of the houses during critical solar collection hours.(33) The problem is most serious in central business districts and areas where residential and commercial uses are mixed.(34)

Policy Considerations

City policies can directly affect solar access and orientation. To some degree, they can even affect the space available for solar energy collectors. While city officials undoubtedly have more leeway in developing policies for new subdivisions, their focus must be on established areas if substantial urban solar energy use is to be encouraged.(35)

The space available for on-site solar collectors is mostly fixed by the building's and property lot's dimensions. But cities can increase the amount of space that can be used for solar collection, chiefly by enforcing setback, sideyard, rearyard, and bulk limitations in the zoning code. Often, these limiting provisions require that a certain percentage of or certain locations on the property lot be kept clear of permanent structures. Seattle and some other cities now exempt solar collectors from these restrictions.(36)

In developed areas, city governments have some control over street patterns and lot- and building-orientation wherever settled land is redeveloped, vacant land developed, new subdivisions planned, or new areas incorporated. Taking care not to confuse traffic as a result, they can exempt new subdivisions from the requirement that all city streets follow the same directional patterns.(37) For redeveloped areas closer to inner cities, they can allow greater latitude in lot positions relative to streets and building positions relative to lots to allow for better solar orientation.(38) Cities can also encourage developers to maximize solar collection potential. (Los Angeles already requires builders of new developments to file solar access reports with the city planning office.(39) Alternatively, cities can give builders density bonuses or quick service on building permits if they optimize solar orientation in new tracts.(40)

Probably cities' greatest opportunity to help existing neighborhoods is to develop policies that protect existing collector areas from shading since the de facto availability of solar access is no guarantee for the future.(41) Many lots in both residential and commercial neighborhoods are not built to their height limitations, so further development is legal, and few cities require permits to plant shade trees.

In view of these facts, states and localities are increasing their efforts to develop formal guarantees or protections for solar access. Methods for doing so in newer subdivisions are well established and relatively straightforward. But in established areas guaranteeing solar access is much more difficult, particularly if development is dense. Still, though few municipal solar access ordinances are on the books, the number of proposed ordinances or moves toward proposed ordinances is increasing.

Area-Wide and Lot-by-Lot Approaches

Generally, the two main approaches to protecting solar access are area-wide and lot-by-lot.(42) Area-wide approaches are uniform, predictable, and relatively easy to administer. In contrast, lot-by-lot approaches have none of these advantages, but their impact on normal development patterns is minimal so they may be politically more acceptable.

The simplest area-wide strategy is to use conventional zoning techniques (height limitations, setback, sideyard, and lot-coverage requirements, etc.) to guarantee access to sunlight. Simply stating that the protection of solar access is one intended benefit from existing zoning provisions may be adequate where existing solar access is good and most buildings are already as high as the law allows.

In other cases, zoning for solar access may require amending zoning provisions. If for example, single-family detached homes in a neighborhood were subject to a height limitation of three stories even though nearly all houses were only one story high, the limitation could be reduced to one story expressly to protect solar access. If the

needed adjustments were relatively minor or the city wished to target solar access protection to where solar potential was greatest, it could impose a "solar overlay zone," allowing traditional requirements to coexist with solar zoning additions. Such an approach would not interfere with zoning provisions and the development rights of property owners could be preserved in zones where widespread solar use is unlikely.

A more innovative approach would be to redefine height, setback, and other restrictions to draw theoretical "solar envelopes" around parcels of land.(43) The envelope would circumscribe the shape of a building according to the solar access needs of surrounding parcels. New construction, development, redevelopment, or modifications on "enveloped" properties would not be permitted to penetrate the envelope's boundaries. Envelopes could be designed to afford varying levels of protection--to roofs, walls, or entire lots and to properties to the south only or to all surrounding properties. As a form of "performance zoning," a solar envelope approach does not need traditional uniform height, setback, or bulk requirements. Moreover, it could be applied as an overlay zone, depending on how much or how little the envelope's dimensions affected traditional zoning controls. In any event, the solar envelope approach can be made consistent with any density regulations.(44)

In lot-by-lot protection techniques, restrictions on shading sources are tailored more closely to the requirements of particular collector sites than in area-wide approaches. One approach (enacted into law in New Mexico amid deserved controversy) simply prohibits shading of solar collectors installed after a certain date.(45) A more reasonable mechanism (proposed in Massachusetts, Rhode Island, and some other states) is to require owners of built or planned solar installations to apply for formal recordations from the building department. (Whether applicants received such recordations would depend on whether the collectors can deliver a certain minimum amount of energy and on whether the solar energy system owners can demonstrate that adverse impacts on surrounding solar access protection would be minimal.) At the same time, the building department would deny building permits for structures that would shade recorded collectors beyond a certain minimal level. This "recordation" approach can be further refined by confining its applications (to, for example, areas where most structures are as high as the law allows) and by establishing procedures for settling disputes (for example, binding arbitration).

In a modified form, the solar envelope concept could also be used on lot-by-lot basis. Questions of fairness (Should a building that conforms to a solar envelope and lies in the shadows of a larger building have its own density reduced without receiving the benefits of solar access itself?), administrative complexity (Is the city prepared to use the interactive computer programs needed to construct each envelope on the basis of site-specific data?), and predictability (What happens when the envelope changes with surrounding construction?) will no doubt come into play. Accordingly most experts conclude that solar envelopes are best applied on an area-wide basis where residential or commercial development is moderately dense.(46) Of course, even the best of the lot-by-lot approach is inherently limited by laboriousness and the likelihood that affected parties will squabble in court.

Cities should probably not adopt any solar access protection techniques until they weigh the solar access problem. No single protection device will avail in all city neighborhoods. Surveys of buildings in Boston, Philadelphia, and Baltimore indicate that substantial rooftop access is available in neighborhoods with homogenous construction (all rowhouses, all small apartment buildings, etc).(47) In these areas, simply acknowledging a formal intent to protect solar access through existing zoning might be enough. In other neighborhoods in the same cities, particularly where new mid-rise buildings could be positioned so as not to shade each other's south facing walls, the solar envelope technique could be usefully applied. Envelope zoning could also be used in areas where newer, taller buildings are interspersed with older, smaller ones. For some purposes--say, protecting the solar access of community solar energy systems--a combination of approaches might work best.

Where to Find Local Information

Since cities have long regulated land use, land-use information is readily available. The key to using these sources effectively for energy planning is to define information needs clearly so that long and expensive data-collection exercises are not undertaken unnecessarily. For example, to encourage the use of solar water heating, a city may need only general information on solar access potential in different neighborhoods; but to offer financial incentives to low-income groups, it may need more detailed and precise data on solar access.

As it finds and interprets data and develops policies, city energy officials should stay in constant contact with the City Planning Office, the Community Development Office, or whichever city department develops and implements land-use controls to simplify information gathering and policy development. (Solar access surveys were conducted in Los Angeles by the City Planning Commission and in Seattle by the Department of Community

Development.)

The most comprehensive source of general land-use information is probably the city and (in some cases) neighborhood maps the city or county planning departments maintain. Generally, these provide an overview of the location of different land uses within the city. They show street directions, the contiguity of different land uses, building densities, and the location of commercial and industrial concentrations. Most such maps are coded by letters, numerical designations, or colors that indicate the location of different land uses. Sometimes City Planning Offices maintain Sanborn Maps, which show in great detail the dimensions, types of construction, and orientations of buildings.

Detailed data on each land-use sector can also be obtained from property-tax records. Where tax records are computerized, the data on lot sizes, ages, and types of buildings, and lot coverage ratios can be summarized for all city buildings if the computer files allow counts and sorts. If not, officials should base their calculations on data describing a representative cross-section of buildings.

Since solar access considerations are so novel, few standard techniques for measuring land uses provide reliable information on them. Data from Sanborn Maps and from land-use maps on zoning classifications, street directions, building densities, and height limitations are of help in assessing solar access potential on a neighborhood-, block-, or even single-building- basis. Indeed, they proved to be the most important tools used in a survey of solar access in Boston.(48) Unfortunately, neither conventional city planning maps nor Sanborn Maps show the extent of vegetation shading, and general land-use maps are of limited help in evaluating solar access in mixed-use areas or in border zones. To get more detailed information, some cities in California, Colorado, and elsewhere have commissioned aerial photographs. Such photographs may also be available from some city or state offices. In Boston, for example, the Massachusetts Department of Public Works has aerial photographs of the city on file.

Using land-use information to discover patterns of urban energy use in the city can be done in various ways. One is simply to rely on some rules of thumb. Where single-family housing predominates, for example, residential heating energy consumption will be relatively high so that on-site conservation and renewable energy technologies that reduce heating loads will probably reduce overall energy consumption levels greatly.

A second option is to examine the results of community energy audits conducted in other similar cities and to treat these findings as general indicators of energy consumption patterns. (See Appendix I.) For the residential sector, the city would have to select audits in communities with similar housing stock and a similar climate. But for the industrial sector, a city can get a reasonable idea of the relative energy intensities of its own industries from data on similar industries in any climate. (See Appendix I.)

Third, the city could use state or regional data to estimate the amounts and kinds of energy consumed in different land-use sectors. Obviously, the usefulness of this approach depends upon how detailed the available data and how similar the land-use characteristics are. If data is available only at the state level, city uses may differ significantly. Cambridge, for example, found that it differed significantly from Massachusetts as a whole in terms of the amounts and types of energy it used in both the commercial and industrial sectors.(49)

A fourth strategy requires the city to obtain consumption data for different sectors from energy suppliers, either for all consumers or for a representative sample. This strategy could be straight-forward and simple indeed if utilities and oil dealers cooperated. Supplier data can, however, be hard to get and hard to decipher for policy purposes.

Finally, the city could survey selected typical residential and industrial users and generalize from the results. (For commercial facilities, this approach is thorny since "typical users" are difficult to pinpoint unless a local economy is dominated by one type of business.)

Chapter Five

City Buildings

Land-use information can help city officials discern how much energy neighborhoods and sectors use and how much they can save. But to develop effective energy conservation policies and programs, city governments also need information on the city's building stock. For example, a rowhouse neighborhood composed of structurally sound but poorly insulated fifty-year old housing requires energy-conservation measures quite different from those suited to new and better-insulated townhouses. Substandard housing with significant structural flaws will profit most from still other measures. Policy options for encouraging these measures might also differ. For example, an effective financing program for energy improvements to substandard housing would have to cover structural improvements.

Many state building codes set at least a minimal standard for energy efficiency in new buildings.(1) Even in the absence of codes, some builders are applying stricter conservation measures on their own. Consequently, it is much easier to find information on energy-conservation measures in newer buildings than to estimate their extent in older structures. To compensate, the emphasis here is on what kinds of information city officials need about existing buildings and where they can obtain it.

Effects of Building Stock Quality

The greatest influences on energy use in a building are the character of its shell (walls, roof, foundation) and the design and condition of the heating (and cooling) system. Energy-efficiency requires that both be properly designed and maintained.

In terms of energy use and conservation, a shell's most important features are the thermal integrity of its walls, windows, ceilings, and joints, its surface-to-volume ratio, and the materials (brick, wood frame, steel with brick cladding, etc.) that make up its structure.

Thermal Integrity of Building Shell

Both shell design and structural characteristics determine whether a building uses energy efficiently or wastefully. In most climates, south-facing windows add to the amount of heat a building gains. Conversely, keeping north-side windows to a minimum reduces heat loss. The loss of heat through doorways can be cut with air-lock vestibules. In hot climates, vegetation helps cool buildings naturally, as do proper ventilation, overhangs, and shutters.(2)

Whatever its design, to use the energy efficiently a building must be well insulated and well-sealed. Depending on the climate, it must also have adequate storm windows and doors. Because steep energy-price increases are relatively recent, few buildings that are not brand new are weathertight. Indeed, before 1975 fuel savings did not seem to justify front-end expenditures for energy-saving techniques.

While builders are responding to higher prices and stricter regulations by building homes that are more energy efficient,(3) in cities with older housing stock, particularly in the Northeast and Midwest, many buildings have little or no insulation. According to a recent Annual Housing Survey, proportionately fewer single-family houses in older northeastern and midwestern cities had attic or roof insulation than did housing in more recently urbanized areas with comparable climates. (See Table Eleven.) For example, only 39 percent of single-family housing in Baltimore has attic insulation and only 53 percent in Buffalo and 59 percent in St. Louis. By contrast, 78 percent of Denver's single-family homes had insulated attics or roofs and 87 percent of Omaha's. Even though buildings in colder climates tend to have more insulation than their counterparts in warmer places, higher heating loads and fuel prices in cold areas mean that the gap between existing and cost-effective insulation is greater where it is colder.(4)

Differences between the thermal integrity of central city versus suburban housing are also much greater in eastern and midwestern cities where older buildings predominate (See Table Twelve.) According to a HUD report, roughly two thirds of all single-family inner city houses lack storm windows and storm doors, while only about half of suburban homes lack these devices.(5)

Basic energy improvements in older buildings tend to be offset by the buildings' poor structural conditions. In a project aimed at insulating low-income housing, Princeton University and the Tennessee Valley Authority (TVA) found it nearly pointless to insulate some buildings until they were structurally upgraded.(6) The extent of this problem in cities can be inferred from the number of urban households reporting structural deficiencies. By the latest HUD figures, 21.5 percent of city households reported at least one structural deficiency in 1976, as compared with 17.9 percent in the suburbs.(7) (Over 31 percent of black low-income households in inner cities reported one or more structural problems.)

Although older commercial buildings suffer from some of the same structural problems older houses do, overall, occupied commercial buildings are probably sounder structurally. Still, most lack energy-saving design features. A whole generation of "glass box" structures have large single-glazed windows on all sides and no provisions

TABLE ELEVEN

PERCENTAGE OF SINGLE FAMILY DWELLING UNITS WITH ATTIC INSULATION
(SELECTED CITIES WITH 4,000 or MORE ANNUAL HEATING DEGREE DAYS)

<u>City</u>	<u>HDD</u>	<u>% of SF Homes With Attic Insulation</u>
Boston	5621	59
Providence	5972	78
New York	4848	76
Rochester	6748	81*
Buffalo	6927	54
Newark	4589	73
Pittsburgh	5930	38
Philadelphia	4865	55
Baltimore	4729	39
Washington, D.C.	4211	52
Louisville	4645	63
Cincinnati	5070	78*
Cleveland	6154	53
Detroit	6228	67
Indianapolis	5577	80
Chicago	6497	73
Minneapolis/St. Paul	8159	88
St. Louis	4750	57
Kansas City	5161	80*
Omaha	6049	86
Denver	6016	78
Salt Lake City	5983	75
Portland	4792	78*
Seattle	5185	72*

* Figures for SMSA only.

Source: Annual Housing Survey

TABLE TWELVE

PREVALENCE OF ENERGY CONSERVATION MEASURES IN SINGLE FAMILY HOMES - CENTRAL
CITY vs. SUBURB (SELECTED CITIES WITH 4000 OR MORE ANNUAL HEATING DEGREE DAYS)

City	% Homes with Attic Insulation		% Homes Completely Storm doored		% Homes Completely Storm-Windowed	
	Central City	SMSA	Central City	SMSA	Central City	SMSA
Boston	59	79	77	84	73	80
Providence	78	81	84	85	91	91
New York	76	86	73	82	75	82
Rochester	n/a	81	n/a	82	n/a	87
Buffalo	54	78	83	86	77	88
Newark	73	85	50	77	67	81
Pittsburgh	38	67	21	79	44	58
Philadelphia	55	63	65	73	66	72
Baltimore	39	67	56	61	47	56
Washington, D.C.	52	82	46	50	43	50
Louisville	63	79	72	75	61	64
Cincinnati	n/a	78	n/a	70	n/a	51
Cleveland	53	78	84	87	71	83
Detroit	67	84	87	89	82	87
Indianapolis	80	83	79	80	77	79
Chicago	73	87	77	84	78	88
Milwaukee	n/a	87	n/a	93	n/a	95
Minneapolis/St. Paul	88	93	95	92	97	98
St. Louis	57	81	72	70	67	70
Kansas City	n/a	80	n/a	71	n/a	72
Omaha	86	86	88	88	89	91
Denver	78	83	44	43	29	33
Salt Lake City	75	84	56	50	20	20
Portland	n/a	78	n/a	22	n/a	20
Seattle	72	80	20	15	10	10

Source: Annual Housing Survey

for retaining heat in winter or for minimizing overheating in summer.(8)

Surface-to-Volume Ratio

Buildings lose heat primarily by conduction or infiltration through the surface. The larger the surface-to-volume ratio, the more heat per square foot of living space lost. Put simply, smaller single-family residential and commercial buildings lose proportionally more heat than do larger multifamily and commercial structures. Shared floors/ceilings and walls in apartments and party walls in rowhomes reduce exposure of each dwelling unit's surface to the outdoors. In many office or manufacturing buildings too, many work areas are far from outside walls.

Differences of surface-to-volume ratios in buildings influence the relative importance of shell-conservation improvements versus heating-system adjustments. In most single-family residences and other buildings with large surface-to-volume ratios, shell conditions greatly influence energy use. As such, they should be a primary target for energy-conservation initiatives. Where buildings have a smaller surface-to-volume ratio and more complex heating and cooling needs, the shell's condition influences energy use somewhat less than the design and condition of the heating systems does.(9)

Building Materials

Neither wood nor masonry--two of the materials most commonly used for building exteriors--has high insulating properties.(10) Accordingly, the energy efficiency of both wood frame and masonry buildings depends primarily on how much insulation and weatherstripping is used. However, the choice of structural materials does affect the ease and the economy with which buildings can be retrofitted with various energy-conservation measures. For example, most uninsulated wood-frame houses usually have behind-the-wall cavities that can accommodate blown-in insulation, while few masonry structures do. Insulating masonry structures is thus much more difficult and costly. Consequently, buildings in Philadelphia, where over 90 percent of single-family homes are made of masonry, need a different approach to wall retrofitting than buildings in Dayton, where two-thirds of the single-family houses are made of wood (See Table Thirteen and Chapter Nine, Heating Buildings.)

Heating and Cooling Systems

While a building's shell influences the amount of heating or cooling energy it needs, the amount of energy it uses to meet that demand is determined by its heating and cooling system. If the system's components are adequately sized and configured, well maintained, and properly controlled, a high percentage of the energy in the fuel that goes in comes out as useful heat.

Gauging the effectiveness of a buildings's heating system requires a thorough and systematic audit. Short of that, however, city officials can assume that older buildings' heating systems are both oversized and poorly maintained. Many older oil furnaces and gas furnaces are only 50 to 60 percent efficient, and most heating systems installed when fossil fuels were cheap are oversized--gauged to meet temperature extremes that seldom if ever occur. When the Institute for Human Development in Philadelphia conducted a program to repair oil burners in low-income houses, it found that fully 25 percent of purchased fuel was being needlessly wasted in some houses by oversized or badly maintained furnaces.(11)

In commercial and other large buildings, heating and cooling system efficiencies are affected not only by system size, but also by the system's configuration, operation, and control. Because many work areas accumulate heat cast off by people and machines, some zones actually need cooling energy year-round. Many systems, however, cool forced air to meet the needs of these "hot spots" only to reheat it for use elsewhere.(12) Also, some systems are left on too late at night or started too early in the morning. Another problem is that many control systems do not distinguish between building zones that require heating or cooling constantly and those whose demands fluctuate. In addition, the heating systems in many commercial buildings are poorly maintained: few boilers and furnaces get cleaned periodically; and much of the heat-distribution piping and ductwork is uninsulated or sagging.

Compact Development

Encouraging building owners or renters to improve energy efficiency and encouraging more energy-efficient development patterns are complementary, not competing, means of reducing energy use. Densely built housing is not necessarily structurally and mechanically energy-conserving; per capita energy use will not drop automatically with an increase in multifamily buildings. Similarly, existing multifamily buildings may need strenuous energy-conservation measures. The Philadelphia Solar Planning Project discovered that substantial energy savings would result from basic shell- and heating-system improvements even in mid-block rowhouses.(13)

Opportunities to conserve energy in buildings and to make development more compact exist in most cities, but the relative emphasis placed on each will vary by city. The

TABLE THIRTEEN

EXTERIOR STRUCTURAL MATERIALS COMMON
IN RESIDENTIAL CONSTRUCTION
(By Region)

<u>Region</u>	<u>Common Exterior Materials</u>
Northeast	Wood frame
Mid-Atlantic	Masonry
Southeast	Wood frame
East North Central	Wood frame
West North Central	Wood frame
East South Central	Wood frame
West South Central	Wood frame
Southwest	Masonry
West	Wood frame
Northwest	Wood frame

compact-zoning or development strategy makes most sense in cities that expect a boom in new housing; stressing improvements to existing buildings is more appropriate for other cities.

Buildings and the Availability of Sunlight

While land-use considerations influence building orientation and sources of shading, features like roof space, walls, and materials determine a structure's ability to use available sunlight. Since many active solar energy systems use roof-mounted solar collectors, the quality, size, and shape of a building's roof determine the system's feasibility. Also important is the system's weight--active solar collector panels can weigh from 75 to 200 pounds.(14) Most new roofs can support that additional weight, but some building inspectors contend that the older roofs of inner city buildings should be reinforced before they are retrofitted. Nearly any roof will require structural bolstering before a small wind energy conversion system can be installed.

As for space, active solar water-heating systems require far less collector area than combined water- and space-heating systems do, and many city rooftops can accommodate collectors for active water-heating systems. But finding enough space for active space-heating systems may be difficult. In a typical single-family neighborhood of detached houses studied in Denver, an average of only 377 square feet of roof per house was found available for solar collectors,(16) and typical rowhouses have even less roof space. Flat roofs provide the most usable space since they allow roof-mounted collectors to be oriented due south.

Collectors can, of course, be mounted on the ground, but few inner city lots have room for on-site collectors for space heating. Then too, even low-rise buildings can shade ground-level structures.

For passive solar retrofits, the building's materials matter greatly. Buildings with large amounts of south-facing glass have built-in collectors already--though modifications for storing, distributing, and controlling collected heat and for preventing heat loss will certainly be necessary.(17) If painted and glazed, buildings with south facing brick or masonry walls can both collect and store solar heat.(18) (See Chapter Nine, Heating Buildings.) In three Philadelphia neighborhoods assessed for solar potential, from 28 percent to 54 percent of the houses had wall materials and orientations suitable for passive solar retrofits.(19) In many urban warehouse or factory districts, flat roofs and expansive brick walls are commonplace--an auspicious combination for active solar water heating and for passive solar space heating.

Policies to encourage the use of solar designs and materials in new buildings could be combined with solar access policies. One possibility in cold climates is altering building codes to allow or encourage the increased use of glass on the south sides of buildings and the decreased use on north-facing walls. Where cooling loads are greater, the opposite approach could be used.(20) Another option is smoothing the way for building code certification of innovative building materials used in passive designs.

Knowing the potential of each area and each building type for collecting and using renewable energy enables city officials to create effective incentives and regulations. To protect solar access, for instance, a city might protect south-wall access in neighborhoods with properly oriented brick or masonry housing. City governments might also think twice about allowing the removal of buildings whose design and construction make them good candidates for solar retrofits.

Where To Find Local Information

Officials developing building energy policy can profit from an early and close relationship with city housing departments. For some programs, general information on city buildings is enough. To initiate policy development or to marshal data for general needs assessment, city officials can use HUD's Annual Housing Survey, which shows what percentage of a city's residential buildings have attic insulation, storm windows, or storm doors. However, this survey does not indicate insulation levels, and--a more serious limitation--it provides information only on occupied, single-family homes. DOE now collects data on insulation thickness (for ceilings, floors and walls) in one-to-four family homes, but not for larger buildings.(21) Another drawback is that the DOE information is regional, not city-specific.

City energy and housing officials can estimate energy-conservation potential in many ways. Portland, St. Paul, and some other cities have used information on the age ranges of city buildings to substitute for more exact data.(22) In general, building age correlates with the energy efficiency of the building shell. According to an Urban Institute study for HUD, about 65 percent of all single-family homes without attic insulation, storm windows, and storm doors were built before 1950.(23) Houses built between 1950 and 1974 are likely to have some, although minimal, conservation features. Building age does not indicate the adequacy of a building's heating system since heating equipment can be upgraded or replaced, but most houses built after 1950 probably still

have their original furnaces.

General data on building age can be obtained from numerous sources. The best is the local building department or the state building code authority. Records of subdivision plats for newer areas or tax records for older buildings in inner cities may also help city officials collect information on a relatively small number of buildings and extrapolate from it.

Information on the suitability of buildings for solar applications (including that on a house's size, style, and building materials) can be obtained from Sanborn Maps or from tax records. Details on the structural strength of roofs should be obtained from estimates made by local or state building inspectors.

Ultimately, of course, understanding how and why buildings consume energy requires auditing a representative sample of buildings. Experience indicates conclusively that on-site energy audits are essential if precise reliable information is needed. Audit forms filled out by home owners and mailed back to energy auditors all too often turn out to be inaccurate.(24) Moreover, homeowners cannot be expected to answer even semi-technical questions accurately, much less to be able to assess their home's directional orientation and solar access.

Energy audits can be expensive and time-consuming, but often they are necessary and worthwhile. Indeed, a city would be foolish to target a revolving loan program for energy-conservation improvements on low-income neighborhoods without first gauging the soundness of the building stock. The audits will tell the city if energy improvement funds should be devoted in part to structural repairs.

Although city energy planners may have to conduct their own energy audits in some cases, they should also make use of results from the growing number of energy audit programs. They should draw on the energy audits HUD now encourages (or requires) in some housing-production or housing-assistance programs.(25) Similarly, they can study the findings of energy audits conducted in conjunction with housing-modernization projects controlled by the city housing authority, under the auspices of the Residential Conservation Service (RCS) program, or by urban community groups (such as the Anacostia Energy Alliance in Washington, D.C., the Energy Task Force in New York City, and Mass Fair Share in Boston). (See Appendix I.)

Chapter Six

Energy Supply and Distribution

Along with land-use patterns and building characteristics, sources of energy supply and energy distribution patterns help determine the technical and economic feasibility of using conservation or renewable energy in cities. For example, the substitution of energy-conserving or renewable energy technologies will be more attractive to consumers currently using electricity for water heating than to those using natural gas. Electricity costs so much more than price-regulated natural gas that defraying the up-front costs of a replacement takes much less time. Where electric water-heating is common, city government may need to do little more to stimulate a switch to solar energy than to provide information. Where natural gas is used for water heating, public financing or other incentives may be needed.(1)

Other elements of the energy supply-and-distribution picture also bear upon a city's options for reducing energy use. The rate structures, capacity factors, type of fuel the public utilities use, and other supply and delivery factors all affect the economics of many conservation and renewable energy approaches.

Types of Energy Used

The types of energy a city uses greatly influence the the technical and economic ease with which conservation and renewable energy technologies can be put to work. Cities with heavy needs for cooling will have different technical options than colder cities with huge heating demands. And how economical each option is depends partly on how much competing fuels cost.

Thermal vs. Electric Demand

Two factors determine the types of energy a city uses--what kind of energy demand it has and where it gets its energy supplies. As for demand, the most basic distinction is between thermal and electric needs. Theoretically, any end use (including cooling, since absorption or Rankine-cycle cooling equipment can run on low-heat energy) requiring relatively low-temperature heat represents a demand for thermal energy that can be supplied by any of a number of means. In contrast, end uses that require very high temperatures or power translate into demands for electricity. In practice, however, thermal energy is usually used for space heating and water heating, while electricity is used for cooling, lighting, and appliances. (Hereafter, "heating energy demand" refers solely to water- and space-heating needs, and "electricity demand" to energy needed for cooling, lighting, and appliance operation.)

In most residential and commercial buildings, the relative sizes of thermal and electric demands depend largely on building type and climate. In all but the hottest climates, needs for space heating and water heating predominate in single-family homes, small apartments, and commercial buildings. Where temperatures are extremely high, demands for cooling (and thus electricity) are proportionately higher.(2) Regardless of climate, most high-rise multifamily or commercial buildings demand more electricity (for services, appliances, and lighting) than other buildings do.(3)

In industry, energy needs depend primarily upon the temperature level the industry's processes require. A Solar Energy Research Institute survey of industries using relatively low-temperature processes indicates that natural gas or oil is most often the primary energy source.(4) But in a high-technology industrial area (such as Cambridge, Massachusetts) or in cities with large concentrations of metal processing industries that use electrolysis (such as Portland, Oregon), electricity demands are higher.(5)

Practice does differ considerably from theory, of course, and heating and electrical energy needs do not always break down so neatly or, more to the point, efficiently. Electric-resistance heat is often used to meet space- and water-heating needs that low-temperature thermal energy could meet, and because electricity generation and transmission are inefficient, the owners of all-electric homes pay high utility bills. In some cases, electric bills outstrip mortgage payments.(6)

To evaluate the technical feasibility of different energy conservation and renewable energy technologies, cities should first identify their true levels of demand for heating versus electric energy. The key here is remembering that space heating and water heating loads require heat, not electricity. For example, while both Seattle and Miami rely primarily on electricity, Seattle uses most of it to heat space and water, while Miami's demands are primarily for cooling. This difference means that the two cities have different technical and policy options. Seattle can replace much of the energy it now gets from electric resistance space heaters with building-shell conservation measures, electric heat pumps, or solar energy technologies. In Miami, the greater emphasis should be on the use of more efficient air conditioners, better planning, and the integration of energy-generating facilities. Miami might also consider renewable sources of electric energy.(7)

Sources of Energy Supply

The energy supplies available for heat and electricity vary by region. In general, few larger, older cities use much electricity for space heating. Most Northeastern

cities use oil; most Midwestern cities and a few Northeastern cities, natural gas. But electricity is being used increasingly for space heating in fast-growing cities in the South, Southwest, and Northwest.(8) (See Table Fourteen and Electric Utilities.)

Differences in Energy Prices

Efficiency, availability, and Federal pricing regulations influence the price of each energy source. These prices also vary from city to city, depending on the primary fuels used for heat and electrical generation, and on how the local utility's rates are structured. In general, on a delivered BTU basis, natural gas is cheaper than oil, which is cheaper than electricity. (See Table Fifteen.) Energy prices in the Northwest stand as an exception to this rule since relatively cheap hydro-electricity is abundant and natural gas costs more there than in other regions. Elsewhere, conservation and renewable energy techniques will be far more cost-effective if they displace fuel oil or electric resistance heat instead of natural gas. However, with accelerated natural gas deregulation relatively cheap heat will soon be only a memory for gas users.(9)

Of course, economics is not the only spur to energy-saving investments. The threat of oil cutoffs or natural gas shortfalls has already prompted such cities as Minneapolis and St. Paul to initiate energy-saving strategies. Both cities depend primarily on natural gas for thermal energy, so their position at the end of a national pipeline leaves them particularly vulnerable to natural gas shortfalls like the one experienced in 1977.(10)

Energy Use Patterns

While less important than energy types and prices, energy-use patterns also determine the ease with which conservation and renewable energy techniques can be put to use in cities. When energy demand peaks and whether that demand is primarily for low- or high-temperature heat are particularly key factors.

Times of Use

Different types of buildings use energy at different times of day. In most homes, heating needs peak on winter evenings, cooling needs on late-summer afternoons. In offices and most commercial buildings, relatively little heat is needed at night. Restaurants, laundries and many other commercial facilities need large quantities of energy for heating water throughout the day.

The most economical conservation and renewable energy options meet variable demands without oversupplying energy during slack periods. In some cases, this is a matter of choosing the right technology; in others, of adjusting energy use to coincide with the availability of renewable energy. If, for example, restaurants wash dishes mostly in the evening, solar energy collected each day could be expended then, minimizing overnight storage losses.

Temperature Levels

The temperature level each energy user needs also bears on technology choices and conservation policies. Here, the key is reducing the temperature level of each application to the lowest point at which it is effective. This can be as simple as turning down a residential thermostat or as ambitious as installing industrial heat-recovery systems or new industrial equipment that operates at low temperatures.(11)

City officials should learn how different energy-use patterns can help or hinder particular renewable energy options, and then educate energy consumers too. For instance, if demand for hot water peaks in early evening, the city could encourage solar energy use by letting energy consumers know how well supply matches demand peaks. Where usage patterns make it difficult to use solar technologies effectively, the city could focus instead on changing energy-use habits, much as some utilities now encourage customers to use major appliances primarily during off-peak periods.

Existing/Proposed Community Heating Systems

Both electricity and thermal energy can be distributed to end uses in various ways. Which distribution system is in use affects how swiftly and economically cities can implement new conservation measures. Then too, developing more efficient distribution techniques can itself be energy conserving.

The utility grids that supply most electrical energy serve an urban district, a whole city, or a larger region. Most thermal energy for heating space and water comes from furnaces, boilers, heat pumps, or other equipment in the building. But some center-city business districts are served instead by community or ("district) heating systems that move centrally generated heat through underground piping to densely clustered groups of buildings.

District Heating

New York, Boston, Philadelphia, Rochester, Minneapolis, and several other old Northwestern and Midwestern cities have such district heating systems, many of which use

TABLE FOURTEEN

DOMINANT HEATING ENERGY SOURCE - SELECTED CITIES

Principal Source(s) of Energy for Heating				Principal Source(s) of Energy for Heating			
City	Fuel Oil	Natural Gas	Electricity	City	Fuel Oil	Natural Gas	Electricity
Boston	X			Chicago		X	
Providence	X			Milwaukee		X	
New York City	X			Minneapolis		X	
Rochester		X		St. Louis		X	
Buffalo	X	X		Kansas City, MO		X	
Newark	X	X		Omaha		X	
Pittsburgh		X		Dallas		X	
Philadelphia		X		Austin		X	
Baltimore	X	X		Houston		X	
Washington, D.C.		X		San Antonio		X	
Norfolk		X		Oklahoma City		X	
Charlotte		X		Denver		X	
Atlanta		X		Salt Lake City		X	
Jacksonville			X	Albuquerque		X	
Miami			X	Phoenix		X	
Birmingham		X		Los Angeles		X	
New Orleans		X	X	San Diego		X	
Memphis			X	San Francisco		X	
Louisville		X		Oakland		X	
Cincinnati		X		Sacramento		X	
Cleveland		X		Portland	X		
Detroit		X		Seattle			X
Fort Wayne		X		Anchorage	X	X	
Indianapolis		X					

Source: Derived from information collected by the U.S. Office of Technology Assessment.

TABLE FIFTEEN

CURRENT ENERGY COSTS BY FUEL TYPE
(SELECTED CITIES)

<u>City</u>	<u>Natural Gas</u>		<u>Fuel Oil</u>		<u>Electricity</u>	
	<u>¢/Therm</u>	<u>\$/MMBtu</u>	<u>\$/Gallon</u>	<u>\$/MMBtu</u>	<u>¢/Kwh</u>	<u>\$/MMBtu</u>
Boston	.61	6.10	1.28	9.13	.083	24.44
New York City	.74	7.40	1.28	9.14	.127	37.08
Buffalo	.51	5.10	1.29	9.22	.067	19.63
Newark	.74	7.40	1.28	9.14	.127	37.08
Pittsburgh	.41	4.10	n/a	n/a	.063	18.32
Philadelphia	.60	6.00	1.24	8.82	.077	22.63
Baltimore	.53	5.30	1.24	8.82	.068	19.91
Washington, D.C.	.57	5.70	1.28	9.12	.068	19.82
Atlanta	.48	4.80	n/a	n/a	.051	14.89
Miami	.55	5.50	n/a	n/a	.075	22.10
Cincinnati/KY	.43	4.30	1.23	8.76	.054	15.76
Cleveland	.41	4.10	n/a	n/a	.082	24.15
Detroit	.50	5.00	1.27	9.05	.068	19.83
Chicago/N.W. IN	.46	4.60	1.24	8.83	.082	24.17
Milwaukee	.55	5.50	1.19	8.48	.055	16.10
Minneapolis/St. Paul	.47	4.70	1.18	8.44	.059	17.30
St. Louis	.49	4.90	1.19	8.48	.056	16.37
Kansas City, MO	.38	3.80	n/a	n/a	.069	20.17
Dallas/Fort Worth	.46	4.60	n/a	n/a	.065	19.04
Houston	.47	4.70	n/a	n/a	.064	18.81
Denver	.45	4.50	n/a	n/a	.065	19.15
Los Angeles	.37	4.1	n/a	n/a	.071	20.76
San Diego	.41	4.1	n/a	n/a	.098	28.59
San Francisco/Oakland	.39	3.9	n/a	n/a	.053	19.43
Portland, OR	.59	5.9	1.17	8.36	.042	12.40
Seattle	.68	6.8	1.27	9.06	.024	6.94
Anchorage	.25	2.5	1.23	8.80	.054	15.72

Source: Bureau of Labor Statistics (1981)

waste heat from nearby power plants. (See Table Sixteen.) When these systems were built, they could deliver cheaper heat than individual on-site systems. But as energy costs declined, they became less competitive and fell into disrepair.(12) Now, as heating-fuel prices rise these systems again hold appeal. While most older district heating systems are steam-based and less economical and efficient than modern water-based systems,(13) these older systems could be upgraded substantially. In fact, Philadelphia, Minneapolis, Detroit, and Baltimore are now considering upgrading and expanding their existing systems.(14)

District-heating projects--whether new construction or retrofits--represent major capital investments requiring careful evaluation. In many cases, on-site conservation technologies will emerge as the more economical alternatives, but new or upgraded district-heating systems could provide energy and economic benefits to some cities. The keys are using existing lower-cost sources of waste heat, keeping piping and building connection costs low, and weatherizing the buildings being heated.

Existing Heat sources

District-heating systems can run on waste heat from power plants or industrial facilities or on heat from such renewable energy resources as geothermal energy or surface water. Boie plans to employ geothermal resources in an upgraded version of its turn-of-the-century district-heating facilities, while Hartford is looking at ways to use nearby surface water for district cooling.(15) Lawrence, Massachusetts, is considering utilizing extra industrial boiler capacity to supply heat to five mini-heating districts that include commercial or institutional buildings.(16)

Existing Piping Options and Building Distribution Systems

Once existing heat sources have been identified, cities need to determine whether a distribution system can be economically installed and whether it will be compatible with the distribution system inside the buildings being served. Piping costs generally constitute the single most expensive part of a district-heating system. Retrofitting conventional distribution technologies into city streets in dense urban areas may be prohibitively expensive in many cases.(17) But the use of low temperature heat coupled with innovative distribution technologies could in some cases reduce distribution costs significantly. City officials should also be aware of any urban features that could reduce the costs of distribution systems. For example, digging up pipe-free streets costs less than excavating streets under wired by utility or water lines. So too, planning the construction of district-heating distribution systems to coincide with major sewer repairs, or subway construction, or the like can keep down total excavation costs.(18)

As for whether individual buildings can be served by a district-heating system, city officials need to be aware of the kind of fuel each building uses--important since district heating is more competitive with fuel than with natural gas-fired systems--and the kind of distribution system it has. If the building distribution system is hydronic, hook-ups with district heating can be easy and relatively cheap. Where forced air is used, hook-ups require adding a liquid-to-air heat exchanger. Where one-way steam or electric resistance heat is used, interconnection costs are likely to be prohibitively expensive.(19) (See Chapter Eleven, Community Heating and Cooling Systems.)

Policy Considerations

From a policy standpoint, the city's basic challenge is to compare the economics of new or improved district-heating systems with those of upgraded building-conservation measures. District-heating systems are economical only where heating demand is high, but oversizing the systems to accommodate buildings that use energy inefficiently is false economy indeed. Then too, in some cases, installing a district heating system could actually discourage conservation if buildings that did conserve were charged higher rates to offset the energy suppliers' revenue losses. In any event, policies aimed at encouraging district heating have to be evaluated in terms of how economical they are compared to policies aimed at encouraging end-use conservation and how compatible they are with conservation efforts.

Electric Utilities

The economic appeal of energy conservation depends partly on how much energy is saved, and partly on how much these savings affect consumer prices. While reducing consumption of natural gas or fuel oil has reasonable predictable economic impacts, cutting electricity use often does not. The question, is how utilities react to widespread conservation, which depends on their primary fuel sources, capacity pictures, daily and seasonal peaking patterns, and rate structures.

As noted, few large cities heat many buildings with electricity. But for numerous reasons, city officials must watch electric utilities' reactions to widespread conservation and renewable energy use. First, many cities are annexing newly developed

TABLE SIXTEEN

EXAMPLES OF URBAN DISTRICT HEATING SYSTEMS

<u>City</u>	<u>System Capacity (10³ lbs. Steam/hr)</u>	<u># Customers</u>	<u>Fuels Used</u>	<u>Average Price of System (\$/10³ lbs.) (1978\$)</u>
New York ¹	14,983	2,285	Residential oil	\$ 6.76
Philadelphia ¹	3,857	670	Residential oil	5.84
Detroit ¹	2,931	843	Natural gas	5.26
Boston ¹	2,340	465	Residential oil	
			natural gas	7.05
Baltimore ¹	990	720	Natural gas	
			residential oil	5.47
Rochester ²	7,986	271	Residential oil	
			natural gas	6.00 (1980 \$)
Indianapolis ¹	1,722	703	Coal	4.21

Sources: 1. U.S. Office of Technology Assessment (1981)
 2. Robert Botsford, "The Rochester Steam Story" (1981)

areas that contain high proportions of electrically heated homes. In some other cities, electric space-heating is becoming more popular as gas supplies grow less reliable or more expensive--a trend that may accelerate with gas deregulation.

Second, opportunities abound for conserving the electric energy used for cooling, lighting, and appliance operation. California's appliance efficiency standards and Florida's new energy building code are both aimed at cutting electric energy uses--the one by improving efficiency, the other by reducing demand. Oakland saved tax-payers over \$1.5 million dollars a year on its electric bills by installing more efficient street lights.(20)

Third, under the rules of section 210 of the Public Utility Act (PURPA), cities and individuals producing their own electricity now have the guarantee that the area utility will purchase it.(21) Lowell, Massachusetts; Paterson, New Jersey; and Idaho Falls, Idaho--these and other cities are now refurbishing old hydroelectric facilities to create revenue. Others (such as Lewiston, Maine) are thinking about developing cogeneration systems. As photovoltaic cells and other decentralized renewable sources of electricity become more readily available, this trend should accelerate.(25)

Finally, utilities themselves are beginning to invest in end-use conservation improvements to curtail demand and in renewable electricity sources to improve the economy and flexibility of supply. (See Chapter Twelve. The effects of such conservation programs could be amplified if cities cooperated with utilities.

But even though public utilities can make or break urban energy conservation efforts, most cities have little influence over utility policy. A few utilities are municipally owned, but investor-owned utilities regulated by state Public Utility Commissions (PUCs) or Public Service Commissions (PSCs) supply most cities with power. Given this ownership pattern, cities' best hope is to work with local utilities to make sure that conservation and strategies developed by either benefit both. Where relationships are less cordial, cities can try to initiate state-level PUC reviews of utility policies that work against municipal or individual energy-conservation efforts. City energy officials can also advocate state regulatory policies that compel public utilities to pursue energy-conservation options more vigorously.

To cooperate with a utility or challenge its policies, city officials need to understand the utility's situation. While none of the factors discussed here operates in isolation, and while none will alone commit utilities to pursuing or opposing conservation, together they do influence a utility's posture toward the widespread use of energy conservation and renewable energy technologies.

Utility Fuel Sources

As a good rule of thumb, a utility that relies on expensive or unreliable fuel sources will be more positive about energy conservation and renewable energy use than one whose fuel sources are secure and cheap. Such Northeastern cities as New York, Boston, and Providence and such Southeastern cities as Jacksonville and New Orleans are served by utilities heavily dependent upon oil. Cities closer to coal-producing regions rely more on that resource. In the Southwest, natural gas is an important primary electric fuel for cities, while most utilities servicing Northwestern cities rely on hydropower. Substantial reliance on nuclear power is less regional: New England, Philadelphia, Minneapolis, Chicago, Birmingham, and Oakland all get relatively large baseload contributions from nuclear power. (See Table Seventeen.)

In practice, few utilities rely on a single primary fuel source. For example, Philadelphia's mix includes nuclear power, oil, coal, and hydropower; Minneapolis' electricity supply depends about equally on coal and nuclear power; and Fort Worth's comes from gas and coal. In some cases, utilities cover their baseloads with one fuel and use others to meet intermediate or peak loads. Increasingly, coal- or nuclear-fired plants serve as baseload facilities, while oil and gas generators are employed for intermediate- or peak-load generation. (See Table Eighteen.) A technique gaining popularity is using baseload power to pump water behind dams and then using the pumped-water-storage to run hydroelectric turbines when usage peaks.

With the price and availability of some fuels uncertain, many utilities now expect to switch from one primary fuel to another. New York currently uses oil to generate about two thirds of its electricity, but its plans are to burn relatively more coal. In the Northwest, some utilities faced by predicted demand increases are shifting from hydropower to nuclear power for baseload generation and hoping to use nuclear-pumped storage for peak power.(23)

How a utility's fuel sources affect the economics of energy conservation depends on two key variables--fuel price and fuel availability. Hydroelectricity costs far less than electricity produced from oil. Consequently, conservation or renewable energy options that save or displace electricity hold more appeal in the Northeast than in the Northwest. Then too, most oil-based utilities are increasingly worried about foreign supply cutoffs, which makes domestic coal and nuclear power more attractive. Still, coal production strikes, transportation hazards, and nuclear safety can pose problems as severe as supply cutoffs.(24)

TABLE SEVENTEEN

PRIMARY FUELS FOR ELECTRIC-GENERATION
(Selected Cities)

<u>City</u>	<u>Principal Primary Fuel(s)</u> <u>For Electricity Generation</u>					<u>Hydropower</u>
	<u>Oil</u>	<u>Gas</u>	<u>Coal</u>	<u>Nuclear</u>		
Boston	X			X		
Providence	X					
New York	X			X		
Rochester			X	X		
Buffalo	X					
Newark	X		X	X		
Pittsburg			X			
Philadelphia		X	X	X		
Baltimore			X	X		
Washington, D.C.			X	X		
Norfolk	X		X	X		
Charlotte			X	X		
Atlanta			X			
Jacksonville	X			X		
Miami	X			X		
Birmingham				X		X
New Orleans	X					
Memphis			X			
Louisville			X			
Cincinnati			X			
Cleveland			X			

TABLE SEVENTEEN

PRIMARY FUELS FOR ELECTRIC-GENERATION (continued)
(Selected Cities)

<u>City</u>	<u>Principal Primary Fuel(s)</u> <u>For Electricity Generation</u>				
	<u>Oil</u>	<u>Gas</u>	<u>Coal</u>	<u>Nuclear</u>	<u>Hydropower</u>
Detroit			X		
Fort Wayne			X		
Indianapolis			X	X	
Chicago			X		
Milwaukee			X	X	
Minneapolis/St. Paul			X	X	
St. Louis			X		
Kansas City			X		
Dallas/Fort Worth		X	X		
Austin		X	X		
Houston		X	X		
San Antonio		X	X		
Oklahoma City		X	X		
Denver			X		
Salt Lake City			X		
Albuquerque			X		
Phoenix			X		
Los Angeles	X	X			
San Diego	X	X			
San Francisco	X	X			
Oakland	X	X			
Sacramento	X	X			
Portland				X	X
Seattle					X
Anchorage	X	X			

Source: Derived from information collected by the U.S. office of technology assessment.

TABLE EIGHTEEN

COMPARISON OF FOSSIL-FUEL* INPUTS TO STEAM-ELECTRIC
VS. PEAKING FACILITIES BY REGION

<u>Region</u>	<u>Total Fossil-Fuel Btu Input to Steam-Electric Units (Btu)</u>	<u>% Coal</u>	<u>% Oil</u>	<u>% Gas</u>	<u>Total Fossil-Fuel Btu Input to Steam-Electric Peaking Facilities (Btu)</u>	<u>% Oil</u>	<u>% Gas</u>
New England	513,062.8	6.4	92.4	1.2	1160.0	88.1	11.9
Mid-Atlantic	1,892,813.9	58.8	31.4	9.7	54803.4	47.3	92.7
East North Central	3,209,263.1	95.0	4.1	10.9	28376.6	25.9	73.0
West North Central	1,450,751.1	92.1	0.5	7.1	7276.4	49.4	50.6
South Atlantic	3,116,342.7	74.3	20.4	5.3	48802.9	49.8	50.2
East South Central	1,527,726.7	91.8	2.3	5.9	5342.9	27.3	72.7
West South Central	3,324,294.1	30.4	2.2	67.4	65510.2	2.1	97.9
Mountain	1,379,495.8	88.1	1.2	10.8	14903.9	1.5	98.5
Pacific	1,041,031.5	8.5	31.4	60.4	20086.0	54.3	45.7

*Excludes nuclear and hydropower

Source: Energy Information Administration, Cost & Quality of Fuels for Electric Utility Plants, June, 1981.

Utility Capacity

Simply stated, an electric utility's capacity is the maximum amount of power it can generate at any one time. In principal, utility capacity should cover the maximum expected customer demand and a "reserve margin" designed to accommodate unpredicted demand surges or to offset power outages. More precisely, the utility's base capacity meets regular year-round demands (such as annual lighting and appliance demands); its intermediate capacity meets regular predictable increases over baseload (such as normal air-conditioning demands on average summer days); and its peak capacity meets the highest predictable demand (such as air conditioning on the hottest summer days). A utility's current capacity was determined by demand projections and investment decisions made years ago. By the same token, demand projections and investment decisions made now will determine a utility's future capacity.

How well a utility's capacity matches its demands depends upon how accurate its demand projections are. When demands outstrip predictions, a utility must operate continuously at or near peak capacity, which is the most expensive form of operation.(25)

Most utilities forced to operate at peak capacity for long either build new baseload plants or purchase additional power from another grid. But when regular demand falls below predicted levels, the utility must maintain unneeded facilities. The risk is serious. Given recent declines in demand, increased conservation initiatives, and the years it takes to bring a power plant on line, some utilities are now finishing plants that are no longer needed.

While the concept of utility capacity is simple enough, setting and maintaining capacity is complicated. One problem is infrequent peaking. If demand peaks only once or twice a year, the utility and its customers end up paying for "peak insurance" since prices must cover the costs of maintaining rarely used peak facilities. Then too, older plants in the utility's grid must at intervals be retired or refurbished, while others may need to be converted so they can make use of a different primary fuel. As the utility's mix of generating facilities changes in terms of age, size, and efficiency, the utility may have to replace outmoded or worn-out facilities even if demand or growth in demands shrinks. Luckily, these two drawbacks can be offset by a third factor. A utility may be able to buy extra capacity from or sell it to a larger regional grid, reducing the need to construct new power plants or to charge customers for idle excess capacity. (For example, from time to time, Los Angeles draws on electricity generated from hydropower in the Northwest.(26)) In any case, all three factors have to be weighed and balanced.

In terms of capacity utilization, the utilities serving large U.S. cities vary tremendously. In many older Northeastern and Midwestern cities, excess capacity (i.e., capacity over reasonable reserve margins) is developing as populations decline and higher prices force demand down. In the Southwest and West, demand increases stemming from regional growth are outstripping capacity. (See Table Nineteen.)

Capacity factors can encourage or impede energy-conservation efforts irrespective of the availability or cost of primary fuels. In Philadelphia, recent efforts to use more energy-efficient heat pump systems in a redeveloped downtown area were stymied when the local utility--which has substantial excess capacity--offered the complex a very low rate for electric resistance heating.(27) On the other hand, both Seattle and Portland have launched major energy-conservation efforts, even though they now rely on relatively inexpensive hydropower. Each is trying to avoid building the nuclear plant it would need if demand increases as projected. Similarly, Southern California Edison is developing some renewable sources of electricity to reduce the need to invest heavily in new coal or nuclear power plants, which now typically take about ten years to build and can cost over \$2,000 per KW of capacity--about twice the cost of oil-fired plants.(28)

As this brief review suggests, city officials must have information on the capacity of the utilities that serve them. In particular, they need to know about long-range demand forecasts and the utility's potential for connecting with other utilities through power grids. While few cities can spend time or money investigating utility capacity, all should be familiar with utilities' assessments of their own capacity situations, utilities' plans to expand or reduce capacity, and the opinions of state PUC staff on all plans and assessments.

Peaking Patterns

Closely related to capacity is another factor that affects local opportunities to implement conservation and renewable energy programs--usage peaks in the utility's service area. Electricity use peaks both daily and seasonally, and law requires the utility to meet those demand peaks

Usually, the highest daily peaks occur during peak seasons--typically, say, the hottest hour on the hottest day of the year. But in some areas, the year's highest daily peak occurs in an off-peak season. For example, in Southern Florida, the highest daily peak is in winter because the highest hourly demand for electricity occurs there on unusually cold winter mornings. (29) Since peak load determines the capacity the utility maintains, the utility serving South Florida has idle peak capacity even in mid-July

TABLE NINETEEN

UTILITY CAPACITY SITUATIONS
(Regional Power Pools)

<u>Regional Reliability Council</u>	<u>Reserve Margin July 1980</u>	<u>Capacity Over 20% R.M.</u>	<u>Reserve Margin Feb. 1981</u>	<u>Capacity Over 20% R.M.</u>
Northeast Power	43%	23%	37%	14%
Mid Atlantic Area	28%	8%	48%	28%
East Central Area	27%	7%	35%	15%
Southeastern	27%	7%	28%	8%
Mid America (MO, WI, IL)	21%	1%	34%	14%
Southwest	26%	6%	65%	45%
Mid-Continent Area (ND, SD, MN, IO, NE)	21%	1%	51%	31%
Texas	36%	16%	50%	30%
Western Systems	21%	1%	27%	7%

Source: Derived from OTA (1981) data.

because its highest daily peak occurs in winter.

It is to the advantage of both the utility and the energy consumer to keep peak electricity consumption down. Conservation and new energy supplies make the most impact if peak energy is saved. Replacing peak electricity reduces the need for new peak power plants, while curbing off-peak power use does not. Similarly, if conservation or renewable energy measures merely reduce the load factor (electricity used divided by peak capacity), the utility's fuel costs will decline while the operation and maintenance costs of existing peaking facilities or the capital costs for new peaking facilities remain the same. When this happens, utilities have an incentive to make up their revenue losses by charging customers who reduce off-peak energy use a higher rate or by increasing all rates.

Effects of Seasonal Peaks

As they try to predict and respond to utility reactions to widespread conservation or renewable energy use, cities must bear in mind the differences between daily and seasonal peaks. In most utility service areas, daily peaks represent a higher increase over baseload capacity than do seasonal peaks.(30) (See Table Twenty.) In practice, though, mismatches between conservation and renewable technologies and seasonal peaks can cause greater problems. As for imbalances between conservation techniques and daily peaks, they exacerbate the effects of a seasonal mismatch but they will not cause it.

Poor seasonal matches can occur when a conservation or renewable energy technology is used mostly or solely in a single season (as, for example, solar space heating often is). Moreover, changing consumers' energy-use habits or utilities' load-management practices cannot offset poor seasonal matches as they can mismatches between year-round technologies and daily peaks. (See next section.)

Utility seasonal peaks vary by region and by type of electricity end use. Of prime importance is whether demands for electric heat within the utility's service area is large. For example, since few homes in older cities use electricity for space heating, utilities serving those areas will likely peak in summer when cooling needs are greatest.

But in growing, sprawling cities, and in smaller cities within large utility service areas, the utility may serve proportionately more homes with electric space heating. If it does, the usage peak occurs in winter. For instance, while Philadelphia's electric utility is summer-peaking, the demand of the utility serving Allentown and Bethlehem (smaller cities only thirty miles north of Philadelphia) peaks in winter.(31) In newer sun-belt cities, seasonal peaks usually occur in summer too, even though most utilities there serve relatively more electrically heated homes. Utilities serving cities such as Portland that have low cooling loads will certainly be winter-peaking if the number of homes with electric heating grows as predicted.(32)

Put briefly, poor seasonal matches between an energy conservation or renewable energy technology and the peaking patterns of a utility do not occur unless the technology replaces substantial amounts of electricity during the utility's off-peak season. For example, solar heating would mismatch with a utility's seasonal peak only if the utility was summer peaking and if it served large numbers of electrically heated homes. Conversely, a photovoltaic (solar electric) system, which provides its peak output in the summer, could be "out of step" with winter-peaking utilities.

Daily Peaks and Load-Management Techniques

Many utilities try to cut operating costs by helping customers better manage energy use. In particular, these utilities are improving load management to offset the rising costs of construction, operation, and primary fuels.

One load-management strategy is to use a computer to match supplies to demand more efficiently. Another is to offer "interruptible" rates to certain classes of customers. (See next section.) A third is to encourage the use of off-peak energy storage (in, for example, water-heating systems).(33) How on-site energy conservation and renewable energy technologies combine with different utility load-management strategies influences how economical any given approach is. Using off-peak electricity to charge hot water tanks could complement the use of solar water heaters during peak periods. However, off-peak storage could also lower total water-heating costs for customers with conventional systems so much that solar energy becomes less economically attractive.

In short, the most effective urban energy policies are those that fit or match consumers' energy-conservation efforts with utility load-management strategies. Where the two are already compatible, publicizing appropriate energy-conservation approaches or helping low-income people finance energy-saving measures may be all the city need do. Where individual and utility approaches work at cross purposes, the city should let consumers know which conservation practices best complement utility load-management efforts or urge utilities to adopt load-management practices that enhance the results of household conservation measures.

TABLE TWENTY

RATIO OF DAILY PEAK AND SEASONAL PEAK LOADS TO BASE LOAD

(By Region)

<u>Region</u>	<u>Daily Peak As % of Base Load</u>	<u>Seasonal Peak As % of Base Load</u>
New England	8%	7%
New York/New Jersey	17%	6%
Mid-Atlantic	17%	9%
South Atlantic	17%	11%
Midwest	14%	10%
Southwest	44%	15%
Central	28%	8%
North Central	13%	9%
West	23%	14%
Northwest	16%	9%

Source: Energy Information Agency -- Report to Congress (1978)

Policy Options

Where widespread on-site conservation measures would adversely affect the local utility's capacity situation and load factor, setting urban energy policy will be difficult at best. If the utility is municipally owned, the city can prevent it from encouraging inefficient uses of electricity, but the utility can still ask to raise the unit prices of delivered electricity to compensate for idled capacity or reduced load factors resulting from conservation. If price increases are unavoidable, the city could help the needy offset utilities raised rates. Alternatively, the city could help defray the maintenance costs of idled capacity until an older plant is retired and overall capacity falls. In the case of privately owned utilities with excess capacity, the city will probably have to work with the Public Utility Commission or the utility's other customers to encourage energy conservation efforts. Here, experimentation is the key since both local problems and local resources vary so much.

At the other end of the spectrum are cities whose predicted demands exceed current utility capacity. Perfect candidates for using conservation and renewable energy in lieu of building new power plants, utilities can cooperate with cities in long-range planning. Cities could become qualified power producers under the provisions of PURPA 210 or follow the Los Angeles municipal utility's lead in providing consumers with no-interest loans for the purchase of solar water heaters.(34)

Rate Structures

Since utilities charge different unit prices for electricity consumed in different quantities and at different times, rate structures greatly influence how much money consumers can save by taking conservation or renewable measures.

Accordingly, city energy planners need to understand how rate structures work and to know which rate structures are in effect.

Along with rate structures, city officials must understand three caveats. One is that the issue of rate structuring is related but not identical to the larger issue of energy pricing-- whether utilities should charge average or marginal prices for energy. Average prices combine the higher costs of more expensive fuels (say, foreign oil or nuclear power) and new generating equipment with the lower costs of less expensive fuels (say, hydropower) and existing equipment.(35) In contrast, marginal pricing reflects the unit costs of producing additional energy from the utility's most expensive sources. While most utilities theoretically charge "averaged" prices, in fact some are closer to average and others to marginal pricing. (Here only different rate structures will be discussed.) Second, few utilities employ a single rate structure. Instead, most apply different structures to different classes of customers or to the same class of customers under different seasonal conditions or usage-patterns. (Different structures are discussed here as though they are alternatives, but they can be combined.) Finally, the relation between energy conservation and rate structures can change since the use of energy conservation or renewable energy techniques can alter the demand peaks that a utility must meet. (Nevertheless, here the discussion focuses only on how existing structures affect energy conservation strategies.)

Types of Rate Structures

Some of the more common types of utility structures include:

- Flat Rates - The same unit price is charged for every unit of energy consumed, regardless of time of day or peak periods.
- Declining Block Rates - Per unit costs fall as energy use increases. This structure was developed as a marketing device when utilities wanted to encourage increased use--especially by large users such as industries--and obtain higher load factors.
- Inverted Rates - Per unit costs increase as consumption increases.
- Lifeline Rates - Relatively low unit prices are charged until a given level of consumption is reached; then, rates increase at steeper levels as demand rises. The structure is theoretically designed to provide basic utility services at prices the poor can afford.
- Time-of-Day Rates - Higher unit prices are charged for daily peak energy.
- Interruptible Rates - The utility has the option of cutting back service during extraordinarily heavy peak periods while the user (usually a business or industry) is charged lower unit prices overall in return for its willingness to accept cuts in the heaviest period.
- Demand Rates - Higher unit prices are charged to customers whose demands are unpredictable. A utility's justification for this rate structure is that a customer with unpredictable demand may decrease the utility's load factor without eliminating its need to maintain capacity. (See Peak and Off-Peak Usage Patterns,

Effects on Energy Conservation

Plainly, some rate structures will support energy conservation while others hinder it. For example, the declining block rate penalizes energy conservers. In contrast, the inverted rate rewards those who conserve energy.

More specifically, however, how rate structures affect conservers depends on how particular conservation measures "fit" with particular rate structures. For example, if such a measure reduced peak demand, time-of-day pricing could reward attempts to conserve. But if it saved only off-peak energy, the consumer's cost savings would be less substantial. In this second case, either the rate structure or the use of the conservation technology would have to be adjusted to maximize cost savings. (For example, solar energy could be stored for use in peak periods, rather than used immediately.)

Lifeline rates require less careful coordination between energy conservation technology and rate structure. However, this rate structure, like the inverted rate, does nothing to encourage the use of off-peak power because unit prices depend upon how much, not when, energy is consumed.(36) How lifeline rates affect energy conservation also depends on which type of rate structure is imposed on the amounts of energy used in excess of lifeline consumption levels.

Where energy-conservation measures save the most expensive energy, the city's role may be limited to making sure that its information, incentive, or financing programs reinforce that match. For example, the city could help the utility promote and even finance off-peak storage devices. But where utility rate structures discourage energy conservation, the city can ask utilities or (if the utility refuses) PUCs to rework the offensive rate structures--a request perfectly consistent with the provisions of Title One of the Public Utility Regulatory Policies Act (PURPA) of 1978, which requires PUCs to determine whether current rate structures foster or hinder energy-saving activities.

Where To Find Local Information

Extensive information on how the city uses energy in its municipal operations is usually available from either local centralized sources (such as an office of municipal, general, or emergency services) or from city departments (such as those for schools or police). In many cases, however, obtaining any but the most general information--total gallons of oil or gasoline purchased, for example--will be impossible.

General information on the amounts and types of energy consumed by different classes of residential, commercial, or industrial customers can be obtained most directly from energy suppliers, including electric and gas utilities, fuel oil dealers, or gasoline suppliers. However, as noted suppliers' data will be hard to get, difficult to interpret, and too general for some uses. In some cases, city or state agencies charged with monitoring air pollution can provide some information on the types of fuel large residential, commercial or industrial facilities use.

City officials can, of course, use land-use information on housing types and densities, commercial/industrial mixes, and sectoral relationships to estimate general energy-use patterns--including the amounts, types, and levels of energy used. Where more precise and better organized information is needed, state Public Utility Commissions or Energy Offices may be more valuable sources.

To get more detailed information on energy consumption (including times of use and temperature levels), cities will probably have to survey or audit a cross-section of residential, commercial, and industrial energy consumers. Before releasing consumption figures, most utilities have to obtain permission from individual customers, and few utilities supply more than general figures on times of use. A better strategy for the city might be to conduct a small survey of its own, the details of which will vary with the city's policy interests. Where information from low-income residents (especially renters) proves hard to get, city officials can hire neighborhood or community groups to conduct energy-consumption surveys, perhaps in combination with energy audits.

Information on the utility's fuel sources, capacity, peak patterns, rate structures, and load-management programs can be complex. The best approach is to synthesize information from several sources: the utility, the state PUC, and state or local utility activist groups. Each source will raise utility-related issues that the city should consider as it develops conservation or renewable energy programs, and each can direct the city to additional information.

Chapter Seven

Socio-Economic Factors

Energy problems are not just technical problems, so energy programs cannot be exclusively technical. For at least three reasons, the causes and effects of urban energy problems--and their solutions--cannot be isolated from the city's social structure or its economy.

First, understanding the city's vulnerability to energy shortages and price increases can enable the city to anticipate and counter particularly severe blows. Some cities have developed emergency rationing or assistance plans to protect critical industries or particularly vulnerable citizens. In Hartford, for example, the emergency housing assistance program helps poor families in substandard housing.

Second, socio-economic characteristics affect the speed with which individuals and businesses adopt energy-conservation technologies. If renters make up most of the population, for instance, the city cannot expect residents to invest heavily in energy-conservation improvements. Nor can it expect low-income homeowners to make such investments or all upper income-residents concerned enough about fuel costs increases to install renewable energy technologies. Clearly, policies aimed at encouraging conservation and renewable energy will have to be tailored to the separate needs of each class of residents.

Finally, if they first assess a city's social and economic conditions, city officials can gear energy programs to address larger urban problems. For example, creating job-training and business-development programs for a new urban energy-conservation industry helps cut energy consumption while addressing employment problems.

While each city faces different social and economic problems, some generalizations do hold true. One is that while much has been written in the past ten years about the rebirth of cities, little empirical evidence supports those impressionistic accounts of urban revival. Many cities designated as distressed ten years ago have since lost more inhabitants, jobs, and businesses⁽¹⁾ (see Tables Twenty-One and Twenty-Two.) Recent HUD assessments of housing quality, demographics, and job- and business-development all show cities' plight worsening over time in relation to surrounding suburbs. A second generalization is that inner cities are socially and economically worst off. In particular, older Northeastern and Midwestern inner cities have lost people, jobs, and businesses even as their infrastructures deteriorated and their housing stock declined.⁽²⁾ Even in Western cities, economic growth may be confined primarily to newly annexed areas, the equivalent to close-in suburbs in older cities.⁽³⁾

For these reasons, urban energy planning, especially in large central cities, must take social and economic problems, as well as narrower technical factors, into account. It would be impossible here to mention every social and economic consideration relevant to urban energy planning. However, it is possible to sketch some major factors and to indicate how they can help or hinder conservation or renewable energy strategies.

Tenure and Income of Residents

Encouraging household energy conservation will be difficult if residents do not have the money or incentive to adopt the measures recommended. Yet, energy improvements may be needed most in poor areas, where rising energy costs take their greatest toll, or in rental housing, most of which is less energy efficient than owner-occupied dwellings.⁽⁴⁾ Thus, besides knowing about the energy conservation characteristics of city buildings, officials need to know something about the tenure and income of building occupants.

The most recent edition of Annual Housing Survey indicated that an average of 51 percent of all urban dwelling units are rented, as compared with about 33 percent in the suburbs and 22 percent in exurban or rural areas.⁽⁵⁾ (See Table Twenty-Three.) In many large central cities, especially in the Northeast and Midwest, the percentage of rentals is higher still. In Boston, for example, 73 percent of all housing is rented; in New York, 71 percent. Most likely, urban rental units differ from rental housing in the suburbs or in new developments. For one thing, they are probably older.⁽⁶⁾ (See Table Twenty-Four.) For another, while most of the nation's renters live in two-to-four family (owner-occupied) dwellings, more of the central-city rental stock probably consists of larger apartment buildings controlled by absentee landlords. In 1976, 71 percent of all buildings with more than fifty dwelling units were located in central cities.⁽⁷⁾

In rental units, energy inefficiency is difficult to combat because control over energy use and energy costs is divided between building owners and residents. Of the many arrangements for splitting energy payments between the two parties, none provides a clear financial incentive for either to conserve by improving the building or making voluntary lifestyle changes. For example, if tenants pay for all energy costs, the landlord has no incentive to upgrade or weatherproof the building. Tenants have an incentive to reduce their energy consumption, but they may need the landlord's permission to make energy efficiency improvements and they will not profit from the increased property value of major conservation retrofits. Consequently, few can do more than set back their thermostats, turn off lights, and make other minor behavioral changes.

TABLE TWENTY ONE

PERCENTAGE CHANGES IN POPULATION 1960 - 1977
(Selected Cities - Five Classes)

<u>City Class</u>	<u>Pop. Change 1960-1970 (%)</u>	<u>Pop. Change 1970-1980 (%)</u>
First ¹ (Most Distressed)	-10.1	-12.2
Second ²	- 1.1	- 8.9
Third	7.7	0.9
Fourth	15.2	10.2
Fifth ² (Least Distressed)	28.6	20.2

Codes:

1. First Class (Most Distressed): St. Louis, Boston, Newark
Buffalo, Pittsburgh, Cleveland, Philadelphia, Rochester,
Detroit, Cincinnati, Minneapolis
2. Second Class: Baltimore, Birmingham, Toledo, Louisville,
Chicago, New Orleans, St. Paul, New York, Kansas City,
Oakland, Akron
3. Third Class: Portland, San Francisco, Milwaukee, Omaha,
Columbus, Miami, Memphis, San Antonio, Seattle, Denver
4. Fourth Class: Oklahoma City, Atlanta, Norfolk, Ft. Worth,
Baton Rouge, Los Angeles, Austin, Sacramento, Tulsa,
Wichita
5. Fifth Class (Least distressed): Charlotte, Long Beach,
El Paso, Tampa, Houston, Dallas, San Diego, San Jose,
Albuquerque, Phoenix, Tucson

Source: Fossett and Nathan (1980)

TABLE TWENTY-TWO

PERCENTAGES CHANGE IN EMPLOYMENT (1958-72)
(Selected Cities - Five Classes)

<u>City Class¹</u>	<u>% Change in Employment 1958 - 1972</u>
First	-17.3
Second	- 1.1
Third	+16.3
Fourth	+50.4
Fifth	77.4

Source: Fossett & Nathan (1980)

1. See Table Twenty-One.

TABLE TWENTY-THREE

TENURE OF OCCUPIED HOUSING BY LOCATION

<u>Tenure</u>	<u>U.S. Total</u>	<u>Central City</u>	<u>SMSA Suburb</u>	<u>Outside SMSA</u>
Owned (%)	65	51	67	78
Rented (%)	35	49	33	22

Source: Boynton, ed., Occasional Papers in Housing and
Community Affairs (1979)

TABLE TWENTY-FOUR

AGE OF OCCUPIED DWELLINGS BY LOCATION AND TENURE STATUS
(1976)

<u>Tenure</u>	<u>Median Age Inside Central Cities (Years)</u>	<u>Median Age In Suburbs (Years)</u>
Owned	26	18
Rented	35	17

Source: Boynton (1979)

At the opposite extreme, landlords who pay all energy bills would seem to be motivated to improve the building's energy efficiency. Yet, many building owners simply raise rents to cover increased energy costs. Even where rent controls prevent building owners from passing on fuel costs, the same restrictions can also discourage banks from loaning them capital for conservation improvements.(9) In either case, tenants whose rent payments cover energy costs have no incentive to curb their energy use.

Besides tenure, the income levels of city residents should influence urban energy policy strategies. Energy price increases obviously hurt poor people most.(10) Yet, whether they own or rent housing, few people on low incomes can afford to make energy conservation purchases.

Many poor people are drawn to larger central cities and get stuck there. As a recent HUD paper concluded "the larger a city is, the more likely it is to have a large percentage of its residents in poverty."(11) Because the poor spend proportionately more on food, fuel, housing and other basics, they have little left over for making longer-term energy-saving purchases. Even low-cost or no-cost conservation measures address only a sliver of the housing problem many low-income urbanites who live in structurally unsound buildings face. As an Urban Institute study conducted for HUD indicates, about 60 percent of energy-inefficient single-family homes are occupied by people who earn less than \$8,000 per year, and a larger percentage of this housing is substandard compared with more energy-efficient homes.(12)

City programs aimed at helping homeowners or renters on low incomes must provide financing or subsidies for conservation investments and make energy-saving improvements part of larger efforts to upgrade low-income housing. One such dual action strategy is to make energy-conservation improvements part of public housing modernization, a move now specifically encouraged by HUD.(13) All efforts to improve privately owned low-income housing, of course, must also be directed and controlled so that low-income people benefit. Too often, inner city buildings are rehabilitated for new, more affluent occupants, and poorer city residents are left homeless.(14) Needless to say, such "energy eviction" is no solution to the energy problems of the poor.

Policies

Effective policies addressing the "renter's dilemma" must influence both building owners and tenants. After all, the building owner has a longer-term interest in energy savings and more freedom to make structural or mechanical improvements. Conversely, tenants can make important lifestyle adjustments that can multiply the benefits of building shell or heating-system retrofits. Evidence of tenants' willingness to conserve can spur landlords to invest more in energy-efficiency improvements and banks to finance them.

Numerous policy strategies have been proposed for improving the energy efficiency of rental buildings.(15) Some states (Oregon and Minnesota, for example) now include energy-conservation measures among items eligible for funding under low-interest loan programs for financing housing rehabilitation. Other states or cities are using Federal or locally raised money to develop targeted energy-conservation financing programs aimed at rental buildings. Portland is using a \$3 million Urban Development Action Grant (UDAG) from HUD to subsidize 8-percent bank loans for energy improvements in homes, apartment buildings, and businesses. Rochester, Springfield (MA), and St. Paul plan to use their UDAG money for similar purposes.

Pittsburgh is using direct grants, rather than low-interest loans, to encourage its rental property owners to take conservation action. Two rental housing programs, both funded by the city's share of community development block grants (CDBG) from HUD, are aimed at housing occupied by low- and moderate-income tenants.

The first program provides up to 45 percent of the funds needed to rehabilitate multifamily buildings. The rehab work, averaging \$15,000-\$20,000 per building, often includes boiler replacement or repair and other major energy-conservation improvements. Pittsburgh bankers are more willing to finance the remainder of the rehab costs if the city approves the project and awards a grant.(16) For the past two years, the city has helped about 300 rental units annually through this program.

The second Pittsburgh Program--"Rent Break"--is operated by a non-profit housing rehabilitation corporation, Action Housing. This program provides up to \$2,000 per unit specifically for energy-conservation improvements in rental housing. To date, about 1200 rental units--most of them rented single-family homes and duplexes--have been retrofitted. In exchange for the grant, the building owner must agree to freeze rents for one or two years, depending on the amount received.(17)

Local tax breaks can also serve as conservation incentives. Since 1955, New York City has offered a flexible and effective tax abatement program, titled "J-51." Under this program, owners of rental property, condominiums, and cooperative apartments can write 8.33 percent of the cost of building improvements off of their city taxes each year for up to 20 years. If they take this option, they are also exempted from increased property tax assessments during the period of the tax abatement. The advantage to the city is that all improved rental properties stay under the city's rent stabilization

program while taxes are abated. Like Pittsburgh's direct grant program, New York's tax abatement helps landlords obtain bank financing for rehabilitation. Banks are more willing to make property improvement loans, knowing that the city will require property owners to offer proof of construction expenditures. Many rental property owners use J-51 to help finance boiler conversions or replacement, building shell improvements, and other energy-conserving retrofits.(18)

Much as they provide tax incentives, cities can use their rent-regulating authority to encourage energy conservation. The Cambridge (MA) rent-control board is using a two-pronged approach. First, landlords may increase rents at the rate of the finance charge on loans for energy-conservation improvements, which speeds up amortization. Second, not all landlords can pass through the full costs of fuel to tenants. (After analyzing fuel consumption in all of its rent-controlled buildings, the city decided not to allow owners of buildings falling in the top 25 percent to pass all fuel costs on to the tenants.)(19)

Other states and localities are also considering mandating energy-efficiency improvements in rental buildings. In 1978, Minnesota began requiring all rental buildings constructed before 1976 to comply with one set of conservation standards by 1980 and another, more stringent, set by 1983. Beginning in December 1980, all buildings in Davis California, were required to meet city energy-conservation standards at the time of resale. Under an ordinance recently passed in Eugene, Oregon, owners of 1-4 unit buildings must meet specified energy-efficiency standards by 1985.(21)

Recognizing that energy retrofitting rental buildings should save tenants money, some cities now systematically encourage tenant involvement in energy-saving practices. Some conduct or sponsor tenant-education programs or do-it-yourself audit programs for tenants. In New York, ever more buildings acquired by the city under tax foreclosure are being leased back to tenant-managers, who are provided with energy conservation information. New York is also cooperating with a small non-profit group, the Urban Homesteading Assistance Board, to help finance a small energy-conservation demonstration program in tenant-managed buildings.(25)

Other cities or states have programs for helping ensure that tenants benefit from structural improvements to buildings. Through its "Rent Break" program, Pittsburgh will underwrite improvements in rental buildings if landlords agree to hold down rents for a specified period.

The obvious benefits of approaching both landlords and tenants have led some states, localities, and community groups (some with Federal or foundation support) to launch programs involving both landlords and tenants in energy-improvement decisions. Sometimes these involve negotiations between landlords and tenants. Sometimes the thrust is toward providing energy-conservation funding and information assistance to landlords who sign rent-stabilization agreements. For example, the Urban Coalition of Minneapolis (UCM) brought rental housing under the DOE low-income weatherization housing program it administers: it made energy-improvement subsidies contingent upon temporary rent freezes.(23) The Massachusetts Executive Office of Communities and Development has successfully included rental properties in its low-income weatherization program too. For stabilizing rents for one year, the property owner receives free weatherization improvements. If the tenant pays for heat, the building owner must agree to neither raise the rent nor evict the tenant for one year, and both parties must agree to make heating bills available for three years following the weatherization work. Where the landlord pays for heat, the rent may not be increased for one year (except to compensate for tax increases and the amortization of other capital improvements).(24)

Employment and Economic Developments

In many large central cities, employment prospects are grim and deteriorating. Older cities in the Northeast and the Midwest are especially hard hit. While employment increased throughout the country between 1960 and 1975, growth rates in these two regions were substantially below those in the South and West. The overall decline in manufacturing employment in older, northern cities is striking: between 1960 and 1975, Northeastern cities lost 19.2 percent of their manufacturing jobs and Midwestern cities, 6.6 percent.(25) (See Table Twenty-Five.)

Most new jobs are heavily clustered in suburbs. This trend is especially evident in the Northeast and Midwest. Between 1960 and 1970, HUD figures indicate, employment increased in the Northeast thirty-five times faster in suburbs than in the cities. For the Midwest, the ratio was ten to one. In contrast, in the South and West, new jobs were evenly distributed between city and suburb. (See Table Twenty-Six.)

Obviously, this employment decline cannot be blamed on energy problems. However, in the last few years, energy problems have exacerbated regional employment problems. Obviously, increases in energy costs cannot help struggling city businesses anywhere. And the impacts of these increases will hurt some regions more than others: indeed, the South and West (net energy producers) are not likely to experience the energy-related hardships that the Northeast (a net energy "importer") will.(26)

These sobering generalizations notwithstanding, central cities could realize certain economic development advantages as energy becomes more costly. Gasoline prices, urban

TABLE TWENTY-FIVE

PERCENT CHANGE IN EMPLOYMENT BY REGION
(1960 - 1975)

<u>Region</u>	<u>Percent Change In Jobs (1960 - 1975)</u>	<u>In MFGR. Jobs Inside Central Cities (1960-1975) Percent Change</u>
Northeast	19.0	-19.2
Midwest	33.3	- 6.6
South	64.6	20.7
West	65.0	0.0

Source: Boynton (1979)

TABLE TWENTY-SIX

EMPLOYMENT GROWTH IN CITY vs. SUBURB
BY LOCATION (1960 - 1970)

<u>Region</u>	<u>Employment Growth Inside Central City (%)</u>	<u>Employment Growth Suburbs (%)</u>
Northeast	- 2.5	35.0
Midwest	7.0	65.0
South	23.3	43.2
West	28.0	38.4

Source: Boynton (1979).

mass transit systems, and the concentration of business may stay the flight of consumers to the suburbs. In addition, the city's residents and businesses constitute a substantial market for energy-conservation improvements, a market that could be served by new businesses and new jobs located in the city.

Overall, employment and economic development considerations are also urban energy planning considerations. First, since all businesses and industries are equally vulnerable to energy price increases or shortages, the city needs to know how much of its workforce is employed in each type of energy-intensive or labor-intensive industry and how price increases and supply cut-offs would affect the number of jobs in each.(27) Using this information, the city can identify those businesses that are most and least vulnerable to various energy problems, thus targeting energy-conservation and renewable energy programs toward the businesses and industries that spend (and stand to save) proportionately more on energy.

Second, the way a city encourages energy savings through zoning for denser development or mass transit improvements has broad influences on the local economy. Linking downtown shops to outlying areas through the mass transit system will not, for instance, have the same economic-development consequences as fostering new commercial centers will.(28) Thus, all energy policy options should be evaluated in terms of their impacts in local economic development goals.

Third, all cities have a strong incentive to adopt those energy strategies that create the most jobs for city residents. Accordingly, cities need to know how many and what kinds of local jobs the use of each conservation or renewable energy technology will create (or destroy). To find out, it needs information on the potential local sources of energy businesses and jobs, particularly for people who are unemployed or whose employment is jeopardized.(29)

Policies for protecting potentially vulnerable businesses and jobs should be shaped with two variables in mind--the type of business and the kinds of conservation and renewable energy measures it can use. If energy-conservation measures appear easy to implement and economically appealing, the city may need simply to show businesses which energy measures are cost-effective and to support their adoption of the most appropriate.

(For example, the city could underwrite a model energy-conservation audit on a typical business, disseminate the results to all similar businesses, and remove any unreasonable legal barriers to implementing the recommended conservation measures.)(30) If the energy-conservation measures recommended prove costly or if industry is financially strapped, the city may decide to finance large-scale improvements in energy efficiency.

Policies to develop energy-related jobs and businesses in the city must take account of two variables: potential markets for different conservation or renewable energy measures and the skill levels of available local workers. For example, creating jobs for installers of solar water heating will require substantial training efforts unless the workers have good construction skills already. Underskilled persons can more readily be employed to carry out simple conservation or passive solar retrofit techniques.

Where to Find Local Information

City energy officials should begin any search for information on the city's socio-economic characteristics by contacting other city offices--housing, community development, planning, economic development, human resources, and so on. In particular, records of welfare or fuel-assistance payments can be used to help target conservation programs to low-income persons. Some state employment offices predict the employment impacts of various large-scale or widespread energy developments. Information on unemployed skilled workers can be obtained from local state unemployment records, CETA prime sponsors, or local labor organizations.

Cities can turn to HUD's Annual Housing Survey for general information on tenure by city. HUD collects data on different cities' per capita income levels. Some information on local job markets or worker skills can be obtained from the Department of Labor's area or regional office. Alternatively, of course, city energy offices can work with other city departments to develop new information.

PART TWO INTRODUCTION

The overall purpose of this book is to give city officials technical information on energy conservation and on renewable energy technologies that can supply heat, electricity, and fuels to cities.

Although it spans a broad range of conservation and renewable energy technologies, the book does not pretend to be all-inclusive. Energy technologies are evolving too rapidly for that. The overriding purpose here is to encourage city officials to recognize how much renewable and conserved energy is available within and to cities and how various the energy-saving options have become. Indeed, the energy challenge of the eighties is to see conservation and renewable energy as sources of indigenous energy and as the foundations of a more self-reliant economy.

Most of the information presented here is drawn from the research of others, but only the most carefully, well-documented, and realistic studies have been used, and preference has always been given to performance data over theoretical studies. Where "hard" data are not available, economic analyses reflect consistent and reasonable assumptions about future energy prices, system costs, financing charges, and system performance.

Yet, to make wise energy choices, city officials need to know far more about a technology than whether its use is "technically feasible" in a narrow sense. Climate, land-use patterns, building stocks, energy systems, and socio-economic features must all be taken into account. And no matter how appealing a given technology sounds in the abstract, how useful it is depends on how easily it fits into the city's economy and social structures.

The first part of this book contained guidelines to help local energy officials assess their own "urban energy contexts." Parts Two and Three indicate how different energy technologies might "fit" within different city contexts or neighborhoods.

Among the wide range of energy-conservation and renewable energy technologies are some that are commercially available now and some that are still experimental. Some can be used on single buildings, others on a community scale, and still others in both. Then too, not all conservation and renewable technologies are equally competitive with all conventional energy sources. Some simple energy-conservation measures are, but some technologies can compete in the energy market only with electricity or fuel oil, and some will not be able to compete with any conventional energy source until their prices fall and the prices paid for conventional energy rise even farther. A final factor is neighborhood differences. Not all technically and economically feasible technologies fit every urban need. The key is making the optimal match.

Combined, all these factors mean that city officials must ask specific questions of five general types about different energy-saving options if their energy-management efforts are to succeed.

Technical Approaches

- How does a particular technology work? Is it commercially ready? Can its performance be predicted reliably? What technical problems can be anticipated? Can a city do anything to solve or reduce them?
- Are the current-model technologies likely to become obsolete? Are the second- or third-generation of existing technologies worth waiting for? How will the conservation and renewable energy technologies now available fit in with those under development?
- Is a city's climate more suited to the use of some technologies than others?

Economics

- How can the technology compete economically with the conventional energy sources that now do the same job? Is it more competitive with some conventional energy sources than with others?
- Is the technology's economic appeal expected to increase?

City Applications

- How can a particular technology be used in different parts of a city? Which technologies are most appropriate for which areas?
- Can a particular technology be used in existing buildings? Or in new buildings only? Which structural changes are needed to make buildings more compatible with particular energy-saving technologies?

Institutional Constraints

- What are the land-use impacts of particular technologies? How much urban-space will the widespread use of each require?

- How will different technologies fit with existing energy supply and distribution networks? Can public utilities' objectives be anticipated and answered?

Socio/Economic Considerations

- Can city residents afford a particular technology without financial assistance?
- What is the technology's potential for creating local jobs? For aiding local economic development?

Most of these issues or questions are fairly straightforward, but a word about economics is in order. Our discussions of economics begin with the perspective of local homeowners, building owners, or industries, since the appeal of energy technologies to private purchases is a key concern of city officials. Indeed, a technology's consumer appeal will determine whether the city's role will be limited to education and promotion or expand to include financing and other incentives.

Different types of consumers evaluate energy technology purchases differently. One criterion mentioned frequently is payback--the time it takes before the savings in conventional energy costs attributed to a conservation or renewable energy technology equal that technology's purchase price. But, in many cases payback can be much less important than other measures. A building owner may, in many instances, be more concerned about impacts in monthly or yearly cash-flows (the difference between added costs for energy-saving equipment and utility bill savings).

In this book, economic appraisals of indisputably cost-effective technologies are confined mainly to present costs and simple measures of cost effectiveness, while more expensive or less well-known technologies are examined more fully. Unfortunately, data on the costs and performance levels of many of the newer technologies are frustratingly sparse.

In developing energy programs (including incentives, regulations, or both), city officials will often have to determine if broader social welfare considerations override immediate economic appeal to the consumer. Accordingly, attention is also paid here to "social economics" and, thus, to differences between cities' and other actor's perspectives and interests. One such difference is time frame. To reflect the long time horizons cities have, estimates of dollars per million BTU of energy delivered over the lifetimes of various conservation and renewable energy technologies are presented.

Another important difference between public and private economic decisions is the treatment of energy prices. While private purchasers make their decisions based on average energy prices, these prices reflect neither the true monetary costs nor the non-monetary costs of producing additional energy supplies. Accordingly, the Energy Information Administration's projections of "marginal energy resource costs" are used in some of the "social economics" discussions. As for the non-monetary costs of continued reliance on conventional energy sources--the costs of reliance on imported oil or nuclear power, including impacts on the national balance of payments, environmental quality, inflation, worker health, unemployment, and national security--these are both vitally important and virtually impossible to quantify. Indeed, calculations based on marginal energy resource costs alone surely underestimate the true long-term economic appeal of conservation and renewable energy resources.

Chapter Eight

Supplying Domestic Hot Water

Domestic water heating accounts for a large portion of U.S. energy consumption. The residential sector uses about 2.3 quads (quadrillion BTU), or about 3 percent of the nation's total annual energy budget, to heat water.(1) Water heating in commercial buildings requires roughly 1.5 additional quads of energy annually. In much of the country, water heating soaks up more energy in the home than do lights and appliances or cooking or even space cooling. (See Table Twenty-Seven.)

Residential hot water use per dwelling unit has little to do with building type. A far greater influence is the number of people living in the home. A reliable rule of thumb is that each person uses 15 to 20 gallons of hot water daily. Under current system design conditions, a "typical" family of four thus uses between 17 and 25 MMBTU per year for heating water.

While the amount of hot water needed does not vary by housing type, the percentage of total energy consumption used for water heating does. Because multifamily buildings generally use less energy than single-family dwellings do for space heating, the larger buildings use relatively more energy for heating water. For example, in Baltimore an average single-family detached home uses about 10 percent of its energy to heat water, while rowhouses, townhouses, low-rise apartments, and high-rise apartments use 16, 13, 14.5, and 16 percent, respectively. (See Table Twenty-Eight.) Thus, cities with large numbers of multifamily buildings would find programs aimed at reducing the amount of energy devoted to water heating particularly worthwhile.

Generalizing about hot water use in commercial buildings is more difficult since building and business types in the commercial sector are so diverse. It is true, however, that commercial and institutional facilities use relatively small percentages of energy for heating water. In a study of commercial strips, warehouses, and central business districts in Baltimore and Denver, researchers found that, at most, three percent of the energy used in these areas was for heating water. In absolute terms, of course, small percentages can translate into large amounts. In the three commercial areas surveyed, annual hot water demands ranged between 300 and 16,000 MMBTU. (See Table Twenty-Nine.) In addition, laundries, restaurants, hotels, and some other businesses use fairly large percentages of their energy budgets on water heating. (See Table Thirty.)

In all buildings, the amount of energy needed for water heating depends not only on how much hot water is required but also on the differences between delivery and inlet temperatures, the energy source used, and the design and condition of the water-heating system.

As for temperature differences, the temperature of incoming city water usually falls between 50 degrees F and 60 degrees F.(2) A much more important and more controllable factor is the delivery temperature, which in most residential water-heating systems is about 140 degrees F--too high for the normal run of household applications. Reducing the design delivery temperature can, accordingly, be an important conservation strategy.

Most water-heating systems in the U.S. draw on natural gas or electricity. A diminishing number of oil-fired water heaters are also in use.(3) In all of these systems, incoming city water is heated upon contact with a heat exchanger inside the water tank. In gas systems, the heat exchanger is a flue heated by combustion; in electric waters, electric resistance coils immersed in hot water supply the heat. Hot water is then distributed through the plumbing system to points of use.

Since different energy sources contain different amounts of energy per unit, and because not all heating systems are equally efficient, different amounts of each energy source are needed to heat the same amount of water under the same design and climatic conditions. (See Table Thirty-One.) Thus, to provide the 25 million BTU a typical family uses for water heating, about 50 million BTU of fuel oil (357 gallons) would be required but only about 41 million BTU of natural gas (417 therms). As for electricity, it is very efficient to use but not to produce and distribute: about two thirds of the oil or coal used to produce electric power is lost in generation and transmission. Thus, supplying 25 MMBTU of electricity for water heating requires about 75 MMBTU of primary energy. If fuel oil were the primary generating fuel, about 535 gallons would be needed to provide 25 MMBTU of electrically-heated water to each family each year. (An electric heat pump, which extracts useful heat from the air, can usually offset about half of these losses.)

"Standby" losses (heat lost through the sides of the water storage tank) and losses through the pipes during distribution also account for some of the water heating energy consumption. Portland's energy study indicated that standby losses from tanks alone equalled more than 20 percent of all energy used for water heating.(4)

The amount of energy needed for water can be reduced in a variety of ways. Most are available and proven, and many are inexpensive. Several of these techniques and approaches can be combined. Most important, they are startlingly effective: relatively simple energy-saving techniques could reduce water-heating energy needs by at least one quarter and perhaps by one half. The more sophisticated energy-conservation technologies and renewable energy systems could make even greater cuts possible.(5)

TABLE TWENTY-SEVEN

RESIDENTIAL ENERGY CONSUMPTION BY END USE - SELECTED CITIES

<u>End Use</u>	<u>Percentage of Total Energy Use</u>						
	<u>Baltimore*</u>	<u>Dearborn</u>	<u>Dayton</u>	<u>Greenville</u>	<u>Boulder</u>	<u>Los Angeles</u>	<u>Seattle*</u>
Space heating	54.0%	62%	66.0%	72.0%	66.6%	45.2%	71.8%
Lights and power	19.3	15	9.3	13	12	17.7	14.7
Water heating	11.4	13	18.7	10.2	18.1	23.4	13.5
Space cooling	9.5	7	3	.8	1	2.8	N/A
Cooking and other	5.6	3	3.3	3.7	3.1	10.9	N/A

* Single-family dwellings only

Sources: Baltimore: Twiss (1980)
Dearborn: CCEMP Energy Audit - Wayne County (1980)
Dayton: CCEMP Energy Audit (1980)
Greenville: The Greenville Energy Program (1980)
Boulder: Community Energy Management Plan (1980)
Los Angeles: The Energy/LA Action Plan (1980)
Seattle: Energy Ltd. (1980)

TABLE TWENTY-EIGHT

PERCENT OF RESIDENTIAL ENERGY CONSUMPTION USED FOR
DOMESTIC HOT WATER IN DIFFERENT BUILDING TYPES
 (SELECTED CITIES)

<u>City</u>	<u>Single- Family Detached</u>	<u>Single- Family Attached</u>	<u>Multi- Family Low-Rise</u>	<u>Multi- Family High-Rise</u>
Baltimore	10.2%	16.0%	14.5%	18.9%
Dearborn	9.7	14	14.5	15.4
Dayton	17.8	19	25.7	15.5
Greenville	13.3	15.6	16.5	(no data)
Boulder	17.6	17.7	17.5	18.5
Seattle	13.6	(no data)	20.6	23.1

Sources: See Table Twenty Seven

TABLE TWENTY-NINE

MEASURED HOT WATER ENERGY USE AND POTENTIAL ENERGY COSTS
IN REPRESENTATIVE COMMERCIAL NEIGHBORHOODS

<u>Commercial Neighborhood</u>	<u>Hot Water Energy Demand MMBTU</u>	<u>Amount of Gas needed (Therms) *</u>	<u>Cost of Gas at 45¢ TH</u>	<u>At 70¢ TH</u>	<u>Amount of Electricity needed (KWH)</u>	<u>Cost of Elec. At 6¢/Kwh</u>	<u>At 9¢/kwh</u>
Commercial strip (Baltimore)	3,940	65,667	\$ 29,550	\$ 45,966	1,022,570	\$ 61,354	\$ 92,031
Central Business District (Denver)	16,000	266,667	120,000	186,667	4,688,000	186,667	421,920
Warehouse Area (Baltimore)	300	5,000	2,250	3900	87,900	5,274	7,911

* Furnace Efficiency at - 60

* Assuming 100% efficiency at building line

Source: Twiss (1980)

TABLE THIRTY

SAMPLE COMMERCIAL APPLICATIONS WITH LARGE HOT WATER LOADS

<u>Commercial Facility</u>	<u>Daily Hot Water Demands</u>	<u>Annual Hot Water Demands</u>	<u>Annual Energy Demands For Hot Water (MMBTU)*</u>
Hogate's Restaurant (Wash., DC)	7,000 Gallons at 150° F	2,555,000 Gallons	2,107 MMBTU
Aratex Laundry (Fresno, CA)	30,000 Gallons at 180° F	7,800,000 Gallons	8,365 MMBTU
Bartelsville Energy Tech Center (Office/Lab) (Bartelsville, UT)	1,700 Gallons at 120° F	442,000 Gallons	255 MMBTU

* Gallons per day x 8.25 lbs/gallon x (delivery temperature - 50° F) x 365 operating days (Hogate's) or 260 operating days (Aratex and Bartelsville).

Sources: Hogate's: v.s. Aquila, "Thermal Performance Evaluation of the Hogate's Restaurant Solar Energy Hot Water System." (1978)

Aratex: H.L. Armstrong, "Thermal Performance Evaluation of the Aratex Laundry Solar Energy Hot Water System." (1978)

Bartelsville: Harry A. Rockefeller and Jerry Tipton, "Thermal Performance of a Solar Heated Hot Water System." (1979)

TABLE THIRTY-ONE

BTU CONTENTS AND SYSTEM EFFICIENCIES
FOR CONVENTIONAL ENERGY SOURCES

<u>Energy Source</u>	<u>BTU per Energy Unit</u>	<u>Typical Burner Efficiency</u>
Natural Gas	100,000 BTU per Therm (100 ft ³ of Natural Gas)	50%-60% - Existing 65%-75% - New
Fuel Oil #2	142,000 BTU per gallon	50% or Below - Existing 55%-65% New
Electric Resistance Heat	3,413 BTU per Kwh	85%-100% On-Site 25%-33% Primary Fuel

SIMPLE CONSERVATION APPROACHES

Numerous simple approaches or practices can help reduce energy consumption for water heating. Most are either adjustments at the point of use to cut energy demand or efficiency improvements in the hot water delivery system.

Technical Approaches

Demand reductions can come from such simple usage changes as running dish- and clothes-washers only when they are full. They can also come from such simple technical "fixes" as reducing water-pressure, reducing the delivery temperature of water from 140 degrees F to 130 degrees or 120 degrees F, or installing flow restrictors in showerheads and faucets. (Together, the last three measures could reduce on-site residential energy consumption by nearly 50 percent.)(6)

Temperature reductions can also allow improvements to combustion efficiency. The gas or oil burner can be adjusted to operate less intensely for longer periods. Furnaces are more efficient when operating at "steady states" than when cycling on and off. (See Chapter Nine, Heating Buildings.) The need to maintain continuously burning pilots can be eliminated by replacing them with electric ignition devices, which spark the burner on when storage tank temperatures drop too low.

Besides these relatively simple approaches, more extensive improvements in combustion efficiency are now under study. One is the flue damper, which keeps heat from flowing out of the building once combustion has stopped. Flue dampers are being used in gas space heating units with increasing frequency though they may be less useful in gas water heaters since flue dampers must remain open long enough to allow all residual gases to be exhausted. (See Chapter Nine, Heating Buildings.) Then too, other more cost-effective combustion improvements may reduce some of the impacts of flue dampers. For example, operating the burner longer at lower temperatures improves steady-state efficiencies but also requires an open flue for longer periods.(7)

More experimental techniques for improving combustion include:

- Reducing fuel inputs to gas and oil systems;
- Replacing flues to provide more heat-exchanger surface, and
- Adjusting the amount of air used in the combustion process.

Water-heating system efficiencies could also be improved by reducing heat losses from tanks and piping. Most hot-water tanks and pipes are underinsulated, but blanket-type insulation can easily be cut to fit both. Pre-formed tank jackets and pipe coverings can also be purchased at hardware stores. Taking these measures to reduce heat losses saves energy both directly and indirectly. Since temperatures have been set high in the past to compensate for stand-by and distribution losses, lowering settings makes additional savings possible.

Economics

As indicated in Table Thirty-Two, many of these measures are quite inexpensive. Hot water insulation kits sell for around \$20. Flow restrictors for showers cost between \$5 and \$15. While materials and equipment for larger buildings obviously cost more, savings are commensurately larger. Insulating techniques will not become obsolete, and most insulation lasts as long as the water tank. A final advantage is that these approaches are necessary first steps toward adopting more extensive and effective energy conservation strategies.

Questions still exist about the technical and economic effectiveness of many combustion improvements, especially those to water heaters already in use. Flue replacements and, in some cases, electric ignition devices for gas furnaces are probably most economical when factory-incorporated into new water heaters.

City Applications

All of these techniques work in every urban setting and in every type of city building. In substandard housing, their use will immediately reduce energy bills because their effectiveness does not depend on the structural condition of the building. In multifamily buildings, where water-heating constitutes a larger percentage of energy use than in a single-family building, their use is especially appealing. Indeed, in both large multifamily or office buildings, system size and the difficulty of getting large numbers of tenants to change their water-usage habits make system improvements particularly important.

Institutional Constraints

TABLE THIRTY-TWO
ESTIMATES OF COSTS, ENERGY SAVINGS, AND
PAYBACK OF BASIC WATER-HEATING
ENERGY CONSERVATION MEASURES

<u>Measure</u>	<u>Estimated Costs</u>	<u>Estimated End-Use Energy Savings (mmBtu)</u>	<u>Estimated Simple Payback</u>
Temperature Reduction	None ^{2,3}	6-7 ^{2,3,4}	Immediate ³
Cold Water Washing in Laundry	None ³	4-8 ^{3,4}	Immediate ³
Low-Flow Shower Heads	\$5-\$15 ^{2,3}	8.2 ⁴	Less Than One Year ³
Water Tank Insulation	\$15-\$30 ^{1,3}	1.5-3.0 ^{1,2,3,4}	1-2 Years (Electric) 2-4 Years (Gas)
Spark Ignition Stack Damper	\$150 ¹	2 ^{1,2}	
Stack Heat Recovery	No data	10% Energy Savings ⁴	
Reduce Fuel Input Rate	No data	1 ²	
Reduce Excess Combustion Air	No data	3 ²	
Improve Stack Heat Transfer	No data	1 ²	
Increase Gas Furnace Efficiency (from 72% to 78%)	\$30 ¹		
Increase Gas Furnace Efficiency (from 72% to 82%)	\$55 ¹		

Sources: 1. A New Prosperity: The SERI Solar/Conservation Study (1981).
2. OTA, Residential Energy Conservation, Volume II (1979).
3. Mitre Corporation, Energy Technologies for New England (1980).
4. Joe Carter and Robert G. Flower, "The Micro Load," Solar Age, September, 1980.

Utility policies will be crucial in determining the level of financial savings these measures provide, particularly for electric water heaters. (See Part One, Chapter Six.) Combined utility load-management techniques and consumer education with the widespread adoption of these simple approaches could help flatten peak loads. Some utilities are, in fact, urging customers to consider changing their usage patterns and to insulate tanks and pipes.

Utilities are likely to respond negatively to techniques only if a large share of their clients have electric water-heating systems and if the utilities themselves have excess capacity. As noted earlier, many cities where electric water-heating systems are abundant are high-growth areas where utilities are straining to meet demands. Reducing electricity use through conservation can help such utilities meet the energy needs of new customers without investing heavily in expensive and environmentally threatening new power plants.

Socio-Economic Considerations

Since all of the immediately available approaches here are relatively low cost, all but the poorest of city residents can afford them. Moreover, payback is so rapid, that their appeal extends to renters who pay their own utility bills. Of course, such low-cost and easy-to-install measures are unlikely to be the source of many new jobs, though as components of more extensive energy-conservation rehabilitation or retrofitting projects (including the installation of solar water heaters) they could generate some employment.

CONSERVATION TECHNOLOGIES

Cost-effective in all buildings, the conservation adjustments discussed above can be implemented in every type of urban dwelling. After taking this solid first step, city officials should consider two groups of newer technologies: those designed to use non-renewable energy more efficiently and those designed to use renewable energy to heat water.

Technical Approaches

Hot Water Heat Pump

At least five major appliance firms now sell heat pumps that can be used solely for water heating, and other companies are likely to have marketable models soon.(8) The units operate much like conventional heat pumps, extracting heat from ambient air and then delivering it to the point of use--in this case, the domestic hot water tank. The heat pump itself operates on electricity, but it can provide two or three times the number of BTU supplied by conventional electric resistance heating. One manufacturer claims that the standard coefficient of performance (heat energy output divided by heat energy input) of his hot water heat pump exceeds 2.70 and promises substantial BTU energy savings over all competing fuel types.(9) (See Table Thirty-Three.)

Integrated Appliances

Another promising technological approach is represented by integrated appliances, which use excess heat produced in one operation to help raise the temperature of domestic water. For example, air conditioners extract heat from the inside air only to expel it from the building. Clothes dryers also vent heat to the outdoors, or at best, keep the immediate area hot. Refrigerators too cast off heat.

New integrated appliances can be built to do two jobs instead of one.(10) Alternatively, heat-recovery units (basically heat exchangers plus a piping system to move heat to the water tank) can be retrofitted onto existing appliances. Although many of these appliances or techniques are still being developed, some show promise of halving energy consumption for water heating.(11)

Heat Recovery from Grey Water

A related strategy is to recapture heat from used hot water ("grey water") from showers, dishwashers, and clothes washers before it is drained out of the building and to transfer that heat to the hot water tank.(12) In general, the approach is to install a holding tank to collect discharged grey water, a heat exchanger to remove heat, and a piping system that transfers that heat to the domestic water supply.

Downsized Water Heaters and "Tankless" Water Heaters

All of the above devices supply additional heat to a water-heating system already in use. An alternative option is to downsize the entire system by adding or substituting one or more smaller water heaters (of 10-15 gallon capacity as opposed to the standard 60-80 gallon capacity). Tank temperatures could be varied--lower for shower and tapwater, higher for dishwashers.

TABLE THIRTY-THREE

MANUFACTURER CALCULATIONS OF ENERGY SAVINGS
OF HOT WATER HEAT PUMP COMPARED TO OTHER SYSTEMS
(Single-Family Residences)

<u>System Type</u>	<u>Annual Purchased Energy Needed to Raise 64.3 Gallons of Water/Day 90°F (Btu)</u>	<u>Excess Over Hot Water Heat Pump (Btu)</u>
Hot Water Heat Pump (2.73 COP)	7,158,375	--
Electric- Resistance Water Heater	19,554,172	12,395,797
Fuel Oil #2- Fired Water Heater	34,802,460	27,644,085
Natural Gas-Fired Water Heater	29,500,000	22,341,625

Source: Fedders Corporation (1980)

A related approach would be to use "tankless" (or demand) water heaters--heat exchangers with small gas burners or electric elements that raise the temperature of incoming city water to meet specific needs. Some tankless systems can raise 2.5 gallons of water per minute from 70 degrees F to 100 degrees F and thus meet residential applications "on demand." Some of these units can be pre-set to raise temperatures by a given number of degrees. Others, more efficient, are thermostatically controlled to heat water to a given delivery temperature. (Non-thermostatically controlled units cost \$530 to \$550; thermostatically controlled units, \$50 more.)(13) Proponents of demand water heaters contend that gas-fired units can save 30 to 50 percent of the energy needed to maintain conventional gas water heaters to supply the same delivery temperatures. Compared to electric water heaters, these units save even more. For these reasons, demand water heaters could complement some of the solar water heaters discussed in the next section.

The above technologies merely suggest the range of those being developed to improve the efficiency of water-heating systems. Not all are equally technically advanced or commercially available. Hot-water heat pumps will soon be widely available, while the only integrated appliance currently marketed is a combined air conditioner/water heater.(14) Demand water heaters enjoy wide use in Japan and Europe, though they are available on a limited basis only in the U.S.(15) The future of integrated appliances is connected to that of more efficient appliances in general, although the impact of improved efficiency will differ from one integrated appliance to another. For example, an air conditioner able to extract hot air more efficiently will improve the cost-effectiveness of an integrated air conditioner/water heater. In contrast, a more efficient refrigerator gives off less heat and, thus, makes a poor candidate for part of an integrated appliance.

Economics

The economics of water heating conservation technologies are harder to calculate than those of simple conservation adjustments. Their effectiveness varies much more with climate, the nature of the existing water-heating system, and the types of building in which they are used. None of these technologies is inexpensive. (See Table Thirty-Four.) Therefore, climate, system, and building factors that affect their performance should be considered carefully before purchase.

For example, an integrated air conditioner/water heater works best in climates with high air conditioning loads. Accordingly, the Carrier Corporation calculates that its integrated Hot Shot(TM) unit can save up to 51 percent on hot water energy bills in Houston, but only 13 percent in Boston.(16) Likewise, since the hot water heat pump processes indoor ambient air, it will be most cost-effective where indoor air is naturally warm most of the year. Indeed, if hot water heat pumps process little purchased heat, they can pay for themselves in four or five years. But it will take much longer if large amounts of purchased space heat are used as the heat source.(17)

Obviously, each of these approaches will be more cost effective if it displaces expensive fuel. Currently, this means that, in most areas of the country, these devices will be more economical when they save electric resistance energy and less so when they reduce consumption of natural gas. (See Table Thirty-Five.) However, with natural gas price deregulation, energy-saving investments will become more attractive compared to all conventional fuel sources. For example, if an integrated air conditioner/water heater cut natural gas use for water heating by 51 percent in Houston, first year savings would be about \$45 at current gas prices. But if deregulated natural gas prices approximated crude oil prices (18) on a dollars per million BTU (\$/MMBTU) basis, first-year savings could more than double.

For the same reasons, replacing or supplementing natural gas water-heating systems with technologies that require electric resistance energy entails problems. Consider the example of hot-water heat pumps or electrically heated demand water heaters. Even with gas deregulation, electricity prices will generally be higher than most fossil-fuel prices since electricity production is inherently fuel inefficient. Energy-conserving appliances using electric resistance energy will thus probably continue to be unwise investments where natural gas is the alternative fuel unless only tiny amounts of electric resistance heat are used. The Office of Technology Assessment (OTA) found, for example, that the use of several small water heaters run on electric resistance energy can save about 10 percent of hot water energy bills if they replace a centralized electric resistance water heater. However, those savings disappear if the alternative water-heating system uses natural gas.(19) Chances are the same pattern would occur if gas water-heating units were downsized and supplemental water-heating units powered by electric resistance energy were used as needed to boost water temperatures. Likewise, replacing gas water heaters with hot water heat pumps that use electric resistance energy would probably save little energy or money. (See Table Thirty-Six.) So too, replacing electrical water heaters with fuel-efficient gas appliances can provide substantial savings, although natural gas price deregulation could change this. (See Table Thirty-Seven.) Overall, the technologies that recapture and use waste heat hold the most

TABLE THIRTY-FOUR

ESTIMATED INSTALLED COSTS OF ENERGY-SAVING
WATER HEATING TECHNOLOGIES (RESIDENTIAL)

<u>Technology</u>	<u>Estimated Installed Costs</u>
Hot Water Heat Pumps	\$600-\$700 ¹
Integrated A/C/Water Heaters	\$200-\$500 ²
Heat Recovery Units	\$100-\$200 ²
Demand Water Heaters (w/thermostat)	\$550-\$600 ³
(w/o thermostat)	\$530-\$550 ³

- Sources:
1. Evan Powell, "New Energy Saving Heat Pump Water Heaters," Popular Science; April, 1980.
 2. OTA, Residential Energy Conservation, vol. 1, (1979).
 3. Kit Mann, "Demand Water Heaters," Home Remedies, (1981).

TABLE THIRTY-FIVE

COSTS OF ELECTRICITY
AND NATURAL GAS IN SELECTED CITIES - JULY, 1981

<u>City</u>	<u>Electricity Costs (\$/kWh)</u>	<u>Gas Costs (¢/Therm)</u>	<u>Equivalent \$/mmBtu (Electricity)</u>	<u>Equivalent \$/mmBtu (Gas)</u>
Boston ¹	09.8	62.5	\$28.71	\$6.25
Washington, D.C. ²	06.5	46.3	\$19.04	\$4.63
Grand Junction, CO ³	05.6	34.4	\$16.41	\$3.44
Los Angeles	06.9 ⁴	29.7 ⁵	\$20.21	\$2.97

Sources: 1. Boston Energy Office
2. District of Columbia Public Service Commission
3. Colorado Public Utilities Commission
4. Los Angeles Department of Water and Power
5. Southern California Gas

TABLE THIRTY-SIX

FIRST-YEAR COST SAVINGS AND SIMPLE PAYBACKS OF
HOT WATER HEAT PUMPS VS. ELECTRIC-RESISTANCE AND
GAS-FIRED WATER HEATERS (RESIDENTIAL APPLICATION)

<u>System Type</u>	<u>First Year Energy Costs¹</u>	<u>First Year Energy Costs Compared with Costs of Hot Water Heat Pump</u>	<u>Simple Payback: Hot Water Heat Pump²</u>
Hot Water Heat Pump	\$125.88	--	--
Electric- Resistance Water Heater	\$343.86	+\$217.98	3 years
Gas-Fired Water Heater	\$132.75	+\$ 6.87	Not in System Life- time

¹Assuming electricity at 6¢/kwh and natural gas at 45¢/therm. Performance estimates from Table Seven.

²Assuming installed costs of \$650 and annual fuel escalation rates of 12 percent for electricity and 15 percent for natural gas.

TABLE THIRTY SEVEN

ADDITIONAL GAS COSTS VS. ELECTRICITY SAVINGS FOR GAS-FIRED DEMAND
WATER HEATERS REPLACING CONVENTIONAL ELECTRIC WATER HEATERS IN FOUR CITIES
(RESIDENTIAL)¹

<u>City</u>	<u>Additional Gas Costs (Month)</u>	<u>Electricity Savings (Month)</u>	<u>Net Savings (Month)</u>	<u>First Year Savings²</u>	<u>Simple Payback³</u>
Boston	\$2.50-\$5.00	\$29.40	\$26.90-\$24.40	\$337.80	Under 2 years
Washington, D.C.	\$1.72-\$3.44	\$19.50	\$17.78-\$16.06	\$203.04	Under 3 years
Grand Junction	\$1.38-\$2.76	\$16.80	\$15.42-\$14.04	\$176.76	Under 4 years
Los Angeles	\$1.19-\$2.38	\$20.70	\$19.51-\$18.32	\$226.98	Under 3 years

1. Performance estimates are Mann's (1980). First year fuel costs are \$0.45/Therm for gas and \$0.06/kWh for electricity.
2. Assuming average monthly savings are at mid-point of high and low possibilities.
3. Assuming installed costs of \$600 and yearly fuel escalation rates of 12% for electricity and 15% for natural gas.

promise for reducing natural gas consumption.

City Applications

Since the hot water heat pump draws indoor air, it must be located so that it uses only minimal amounts of purchased space heat as the heat source. Locating the heat pump in the living space presents no problem in warm climates where these units can help cut cooling energy needs by transferring warm air from the indoors to the hot water tank. But in colder climates, heat pumps should be installed in basements or utility areas to minimize the amount of heat extracted from the living space. For this reason, they may be hard to use in houses without basements or in individual apartments in all but very warm areas.

While most of the hot water heat pumps on the market today are sized for residential applications (80 gallons a day or less), at least one firm is marketing units large enough to process the 2,000 gallons of water or more a day used in multifamily or commercial buildings. (20)

While waste water recovery systems and integrated appliances can certainly be used in single-family residences, these technologies may ultimately prove best suited for use in large buildings that have high demands for air-conditioning and have large quantities of discharged waste water. Although the integrated appliances now available are sized for use in single-family homes, waste heat recovery systems now on the market can be used in multifamily buildings and in commercial facilities.

Buildings that discharge large amounts of grey water can take advantage of economies of scale and the high thermal efficiencies of large drainage tanks. For new buildings, installing a grey water heat recovery system simply requires locating the drainage tank properly and designing the heat-transfer system to take advantage of waste heat. In a retrofit, this may mean excavating open or interior space, probably in the basement. However, in many facilities, the tank area need be no larger than the buildings's conventional hot water tank. Then too, tanks installed under vacant land will not interfere with future above-ground construction.

Other waste heat recovery systems could use hot air vented from apartment house laundry rooms or extracted by office cooling systems. Both of these heat sources will be available most of the year in most climates. As it now stands, many offices use their cooling systems even in winter to offset heat gains from lighting, machines, and appliances.

To use waste-heat recovery systems, some buildings may have to have their heating and cooling systems altered. Engineers could integrate these systems within a larger energy-conserving design for new construction. In existing buildings, the efficiency of the whole building's energy system would have to be upgraded if these systems are to be used. Reducing lighting and using more energy-efficient appliances could cut cooling loads and thus reduce the amount of waste heat discharged by the cooling system. Alternatively, waste heat could be recovered for space heating, especially if hot water loads were small or met partly by solar heating.

Using downsized water heating systems or demand water heaters makes sense in both single-family residences and businesses. Already demand water heaters are being used in California in car washes.

Institutional Constraints

Since most of these approaches rely on new appliances, their widespread use should affect land use only minimally.

Electric utility concerns are likely to be similar to those discussed in conjunction with conservation adjustments. The problem could be greater if many larger buildings cut their demands for electric energy, but so is the potential for integrating use of these technologies with load-management approaches to help shave usage peaks.

Social and Economic Concerns

While these technologies are not outrageously expensive, they do cost more than the conservation adjustments discussed earlier. Consequently, the poor will need financial assistance to afford them. Then too, many current model water-heating technologies are suited primarily for use in single-family residences. Even when larger models are developed, whether they are adopted in large buildings will depend on landlords, not tenants.

These drawbacks aside, the widespread use of these technologies would increase business and job opportunities for appliance dealers, installers, and perhaps even local manufacturers. Most such appliances would be added on to hot-water delivery systems, replacing energy rather than other appliances. As for the installers' jobs generated, most would be relatively higher skilled than those created through the adoption of low-cost conservation adjustments.

SOLAR HOT WATER

Solar water heaters may seem novel, but their prototypes were used widely over fifty years ago in the United States. Many thousands of homes in California and Florida had solar water heaters until very low rates for electricity and natural gas prompted large-scale consumer shifts. Now, higher utility costs are beginning to make solar water heaters attractive again--and not just in hot, sunny regions.

In some ways, solar water heating represents a natural extension of many of the conservation adjustments and technologies discussed so far. True, some conservation technologies such as hot water heat pumps will compete with solar water-heating systems in some applications. But many others, demand water-heaters and waste heat recovery systems among them, can be highly compatible with solar energy use. Together, energy conservation technologies and solar water heating could reduce current water heating energy needs by up to 75 percent in some applications.(21)

Technical Approaches

As the solar water-heating industry becomes more competitive and diverse, the range of solar products continues to widen. Most solar heated water is now provided by thermal energy systems. In these systems, the sun either heats the water or heats a transfer fluid that does. (Solar electricity from windmills, hydropower, or solar cells can also be used to heat domestic water - see Chapter Twelve, Electricity.)

Typically, a solar water-heating system consists of a collector that absorbs solar heat, a transfer medium that carries the heat to a storage tank, and a distribution system that delivers solar heated water to points of use. The principal differences among the many system types available are in the kinds of collectors used, the transfer media employed and the methods used to move solar heat from collectors to storage to points of use. Most collectors are metal, but some are made of rubber, plastic, or other non-metallic materials. Some systems even use hot water tanks as solar collectors. For transfer media, systems may use city water, distilled water, antifreeze solutions, or oils or other synthetic compounds. To move heat, active systems use pumps or other mechanical means, while passive systems rely on the natural movement of heat supplemented occasionally by low-horsepower mechanical devices.

Active Systems: Flat Plate Collectors with Metal Surfaces

Most solar water heaters sold today are some type of active system using flat plate collectors with metal surfaces. The solar collectors are modular panels about twenty square feet each. The number of panels included varies with the building type, hot water needs, and climate. Usually, single-family residential systems employ two to four panels totalling 30 to 90 square feet. Collectors can be installed on rooftops, atop such structures as carports, or at ground level as long as they have adequate southern exposure. (See Chapter Four, Land Use and Energy, and City Applications, above.)

Collector panels consist of two major components: an absorber plate and a cover plate. Absorbers (which, in these systems, are thin and flat, thus "flat plate") are usually painted flat black so they can absorb heat efficiently, and the surfaces of some models are also treated with special coatings (selective surfaces) to increase absorptivity. Across the absorber surface are rows of metallic tubing (also painted) that provide flow channels for the transfer medium. In most solar water-heating systems, this transfer medium is a liquid. (Many of the solar collectors used for space heating employ air as a transfer medium and follow a somewhat different collector design. See Chapter Nine, Heating Buildings.)(22)

The collector surface is covered with one or more sheets of glazing material--usually glass, fiberglass, or plastic compounds--that allow sunlight to pass through but keep much of the absorbed heat from being lost to the air. More than one sheet of glazing is needed in colder climates since more heat will be lost from the collector surface as the difference between its temperature and the air temperature increases. To prevent additional heat loss, the collector is insulated on the back and the sides.

As sunlight strikes the collector surface, heat is absorbed by the transfer fluid, which begins flowing when the absorber surface's temperature reaches a pre-determined level and ceases flowing when temperatures fall below it.(23) How the piping system containing the transfer fluid is configured depends on which kind of transfer fluid is used. When ordinary city water is employed, the piping system continually circulates it between collectors and a conventional hot water tank, drawing cooler water from the bottom of the tank, heating it as it passes across the collector surface, and then returning it to the storage tank. At night or whenever it could freeze, the water is drained from the collectors either into a holding tank or out of the building. If a system uses distilled water or water containing a corrosion inhibitor, the piping will circulate it between the collectors and a separate storage tank, where heat transfer to

domestic water occurs as city water is pumped through a heat exchanger immersed in the tank. To prevent freezing, the transfer fluid will drain back into the storage tank when temperatures fall.

Since these systems must drain collectors at freezing temperatures, many used in northern climates employ an antifreeze solution (usually, a mixture of water and a glycol compound) as the transfer medium. When the system is not operating--at night or on cloudy days--the transfer fluid is simply halted. To keep the antifreeze solution out of the domestic hot water tank, these winterized systems employ "closed" loop piping: the antifreeze solution circulates only between the collector and a heat exchanger, which transfers collected heat to the domestic water. Whether inside or outside the storage tank, heat exchangers in systems that circulate a toxic antifreeze solution are required by most building codes to have double walls.(24)

Instead of an antifreeze solution, some systems use oil compounds as transfer fluids. Ostensibly, absorber tubing and piping will not corrode if oil is circulated through them, but oils absorb heat less efficiently than water solutions. At least some laboratory tests indicate that collector performance can fall by 10 to 15 percent when oils are used as heat-transfer liquids.(25)

In some systems, solar heated water can be stored in the building's normal domestic hot water tank. In these tanks, the gas burner or electric heating element will raise the temperature of the solar-heated water to delivery levels if it is not already hot enough.

Other solar water heating systems employ two domestic hot water tanks for storage. In the first, city water is heated when it comes into contact with the system's heat exchanger. This tank serves as a continuous source of water for a second tank, which pumps water to the end use on demand. If solar energy keeps the water hot enough for domestic use, no auxiliary energy is needed. If not, a heating element in the second tank will raise the water to delivery temperatures.

Active Systems: Non-Metallic Surfaces

Collectors are the most expensive components of the solar-water heating system, so most efforts to reduce system costs focus on reducing collector costs. One way to cut costs is to substitute rubber or plastic for the metal absorber used in conventional flat-plate systems.

In one type of the system, a light-weight synthetic rubber material, EPDM (ethylene-propylene-diene-monomer), is molded into a black mat containing small (1/5 inch diameter) water tubes to accommodate transfer fluid. For low-temperature applications in hot regions or for swimming pools and other summer seasonal uses, the collector mat alone may suffice. Otherwise, glazing and insulation are needed. Some manufacturers sell the collector in pre-glazed, pre-framed panels. But collectors are also available in rolls of various length, so that they can be sized, cut, glazed, and framed at the building site. (Rubber stripping for framing is included in the package.)(26)

The rubber system can use ordinary city water as a transfer medium in all climates. Freezing is not a problem because the transfer fluid is drained from the system during cold periods, and freezing does not damage molded rubber tubing anyway. However, if the collectors are not drained, the rubber tubing and the copper piping headers will have to be connected indoors to the building's plumbing system because the headers and piping cannot withstand freezing.

This system does not require heat exchangers and other components needed in systems that use antifreeze. As for its storage and distribution components, they are identical to those in flat-plate metallic systems.

Another low-cost collector currently being marketed is made of clear molded plastic and uses a black transfer fluid to absorb solar heat.(27) This collector is both simpler and cheaper than a metallic flat-plate collector. The absorber, fluid channels, cover glazing, and manifolds are all made of a single polymer materials, so they also weigh five to six times less than metallic collectors--about 2.4 pounds per square foot when filled.

In this system, the black liquid transfer fluid moves from the collectors through conventional metallic piping to a heat exchanger in a storage tank, where the heat is transferred to the household's water. This system also drains the fluid back to a holding tank when temperatures fall. Thus, the economic advantage of using lower-cost collectors is partially offset by the need for a holding tank and a heat exchanger.

Passive Systems: Thermosyphon

Thermosyphoning water heaters make use of natural heat movement to heat and store heated water. In such systems, solar storage tanks are elevated above the collectors, rather than placed in the basement. As the water in the collector warms, it flows naturally upward to the storage tank, where the warmest stored water also rises to the top. A pipe from the top level of storage carries water to the house either directly or (if the thermosyphon is used for preheating) through a main hot water tank. As warmer water flows from the collector to storage, colder water from the bottom of the storage tank flows to the collector for heating.

Thermosyphon systems come in two basic arrangements. The collector panel and the storage tank can be combined, with the storage tank positioned horizontally above the collector panel. Alternatively, the collector panel and storage tank can be separate units connected by pipe runs. The advantage of the first arrangement is that little heat is lost in moving heated water to storage. The advantage of the second is that lower-cost components can be used. Thermosyphon systems can be built on site using relatively cheap conventional building materials, and some new thermosyphon systems designs make use of lower-cost collectors (such as long, thin aluminum sheets painted flat black with copper tubing attached.)(28) In warm climates, the collector can be mounted outdoors on site-built frames; in colder areas, inside greenhouses or other glass-covered areas. In either configuration, storage tanks can be filled from a central storage tank inside the building or directly from the city water supply.

Since the storage tanks in thermosyphon systems can be located outside and since the transfer medium is ordinary water, heat loss and freezing are serious concerns. Consequently, such systems can probably be used only in relatively warm climates or warm seasons unless the storage tanks are in a greenhouse or some other conditioned space and the collector features a draining mechanism. (Some thermosyphon systems have an electric heating element in the collector(s) that protects against freezing.)

Passive Systems: Integral or Batch Water Heaters

Integral water heaters use the same component to collect and store solar heat, so no mechanism for transferring heat between collector and storage is needed. The simplest integral systems can be nothing more than black polyethylene bags or black plastic pipes that are manually filled in the morning, heated during the day, and then emptied as needed. (While these makeshift collectors work, they cool quickly in cloudy periods or after dark since they are not insulated or glazed.)

A more effective type of integral water heater is a so-called "breadbox" system, so named because of its oblong shape.(29) A breadbox system has three main components: a water tank, an insulated container that surrounds the tank, and cover glazing for reducing heat loss. Typically, a standard thirty- or forty-gallon hot water tank painted flat black or coated with selective surface is used as the collection/storage device for each breadbox unit.

To maximize energy collection, some systems direct larger amounts of sunlight onto the tank's surfaces via reflective devices. A curved surface of foil or plastic mirrors can be mounted inside the box or behind the tank. Alternatively, the tank itself can be mounted on a support frame atop reflector surfaces. The tank's absorptivity can also be improved by coating it with a selective surface paint or by glazing it. (If reflectors have been added to improve heat gain, using insulation covers at night or on cloudy days to prevent heat loss is especially important.)(29)

Breadbox systems can be integrated with conventional water-heating systems in several ways. In the sunniest locations, breadboxes could work alone in buildings with relatively small hot water needs. They could also serve as preheating tanks, drawing incoming city water directly, raising its temperature, and then piping it to conventional water tanks for "boosting" as necessary. As yet another alternative, a "stand alone" system employing an electric resistance coil as back-up could be used. However, because freestanding systems are entirely out of doors, losses of purchased electric heat from the hot water tank could offset solar savings. Overall, using breadboxes as pre-heating tanks is probably most efficient under most circumstances.

In a breadbox system that is not pressurized (through connection with a main hot water tank or incoming city water), the tank will need to be refilled when the hot water has been used up. In pressurized systems, which are more common, cold water is pulled into the tank as hot water is drawn so that some hot water gets mixed with cold. Such mixing can be minimized, however, by plumbing two or three tanks together, drawing hot water off from one and cold water into another.

Unlike most of the other systems discussed here, which can be either roof- or ground-mounted, most breadbox systems are too heavy and bulky to be roof-mounted on any but new houses. (30) Filled, breadbox systems weigh approximately forty pounds per square foot.

Breadbox systems have not been used much in colder climates since the storage tanks are kept outside and since the systems also seem to require fairly large amounts of direct sunshine to be effective. (One design firm states as rule of thumb that in any month with more than twenty cloudy days breadbox systems will lose heat.)(31) One group in Alaska is using an integral water-heating system that reportedly delivers water at 110 degrees F when the outdoor temperature range is between 32 degrees F and 40 degrees F, but few experts think these systems can be used except on a seasonal basis where freezing temperatures are common.

If performance advantages are the measure, no single system works best under all circumstances. Most operating data indicate that flat-plate metal collectors can deliver more BTU per square foot than any other collector type. But, in some cases, the difference is slight. (For example, a flatplate metal-collector system designed to

provide about 50 percent of a typical domestic hot water load in Washington, D.C. would need about 52 square feet of collector; a non-metallic collector using EPDM as the absorber needs only four square feet more. Moreover, flat-plate metallic collectors cost the most per square foot of the collectors discussed here, and many of the other systems compare favorably with them on a cost-per-delivered-BTU basis, though whether these low-cost systems can be used in colder climates remains an open question.

The most experience and best information has been accumulated for active flat-plate metallic systems, thermosyphons, and breadboxes. While non-metallic collectors are used widely for pool heating, they are seldom used to heat domestic water. The plastic polymer collectors do show promise, but they have yet to invade the marketplace full force.

Today, a well-made and properly installed active flat-plate system of conventional dimensions (30-90 square feet) can be expected to provide about half of the annual hot water needed by a family of four in a temperate or cold climate, assuming modest conservation measures are taken. In warmer, sunny areas, the same system will meet relatively more of the demand for hot water. Thermosyphon and breadbox systems can provide upward of 50 percent of a typical family's annual hot water needs in warm climates.(32) In colder climates, contributions from these systems may be quite high in the temperate and warm months.(33) But system shut-downs in freezing months are common--definitely an offsetting factor. For example, in Boston breadbox systems can be operated from about May until October.(34) Likewise, even though rubber collectors can withstand freezing, the system obviously does not work when it's frozen. (Plastic polymer collectors may represent superior cold-weather choices, though only experience will tell.)

The performance of all systems can be vastly improved if the simple conservation adjustments discussed earlier in this chapter are made. Reducing temperature settings and minimizing heat losses will improve the overall performance of any water-heating system, solar water heaters included. For example, both New England Electric and HUD demonstrations of solar water-heating systems found, the poor performance of many systems installed in the programs' early stages was due in part to the simple failure to insulate tanks and pipes. In New England Electric's program, the system's average contribution to family water-heating needs increased from 17 to 43 percent with conservation improvements and other relatively simple fix-ups.(35)

Performance levels will also rise as individual components are perfected and as manufacturers learn more about integrating collectors, storage, piping, and control into water-heating systems. (Many manufacturers already provide such packages for all of the systems described here.)

One concern yet to be resolved is how well the system wears over 10 to 20 years. For example, experiences in HUD's Residential Solar Demonstration Program indicated that some cast-iron piping and storage components in space-heating systems using liquid storage corroded after only two or three years.(36) Although this problem should be less critical in water-heating systems (because they use mostly copper piping and because city water contains relatively little oxygen, which corrodes metal), it does warrant continued attention. While non-metallic systems will not corrode, questions that only experience can resolve remain. One is how well such systems can withstand lengthy exposure to high temperatures and other environmental forces without degrading substantially. However, EPDM, the material used in rubber collectors, has a predicted life of over thirty years and can both withstand temperatures between -80 degrees F and 250 degrees F and resist ozone and weather deterioration. At least two collector companies warrant their EPDM components against environmental deterioration for fifteen years.

Economics

Single Family Applications

Solar domestic water-heating systems are economical today under certain conditions. Consumers whose water is heated by electric resistance heating or fuel oil will see their systems "pay off" much sooner than those who use gas-fired water heaters, at least until gas prices are deregulated.

As for the near future, it seems imperative that current lower-cost collectors be developed immediately. Under current terms for home-improvement financing, only these lower-cost systems come close to being economically attractive. All systems, however, are hurt by the high cost of money. Where solar water heaters are purchased with savings, they are economically attractive. For example, a lower-cost system purchased with savings and installed in Washington, D.C. pays for itself in three to four years when electric water heating is the alternative. But if the solar energy system is paid for with a standard home improvement loan, it is at best marginally economical in that application. But special financing packages can markedly improve the economics of both lower-cost and "standard cost" systems.

As Table Thirty-Eight indicates, the economics of solar water heater retrofits (the largest potential market in cities) varies from city to city. In four representative

TABLE THIRTY-EIGHT

ECONOMICS OF SOLAR DOMESTIC HOT WATER
SYSTEMS - SINGLE FAMILY RETROFIT APPLICATIONS USING
FLAT PLATE METAL COLLECTORS

<u>City</u>	<u>Collector Area</u>	<u>Auxiliary Energy</u>	<u>Years to + Cash Flow</u>	<u>Years to Recover Down Payment</u>	<u>Payback</u>
Boston	62 ft ²	Elec Resis	6	8	8
		Fuel Oil #2	6	11	11
		Natural Gas	6	12	12
Wash., DC	52 ft ²	Elec Resis	6	11	11
		Fuel Oil #2	6	11	11
		Natural Gas	6	15	15
Grand Junction	30 ft ²	Elec Resis	6	11	11
		Fuel Oil #2	6	11	11
		Natural Gas	6	17	17
Los Angeles	32 ft ²	Elec Resis	6	10	10
		Fuel Oil #2	N/A	N/A	N/A
		Natural Gas	6	19	19

Assumptions

1. Fuel prices: See Table 9, p. 33 .
2. Collector installed costs: Fixed at \$3,000.
3. Fuel Price escalation rates: 12% for electricity, 13% for fuel oil, 15% for natural gas.
4. Retrofit financed with 16%, 5-year home improvement loan.
5. Federal solar tax credit of 40% received in year 2.
6. No additional property tax owing to solar retrofit.

cities, no system achieves positive cash flow before the loan is paid off, and payback is shortest (eight years) in Boston homes with electric resistance heat. All other paybacks are ten years or longer.

To get an idea of system adjustments that could improve the economics of solar water heating consider three alterations on the base case described above. (See Table Thirty-Nine.) In one, assume a substantially reduced water-heating load with consequent reductions in solar energy system costs. In a second, the "standard" hot water demands assumed in the base case are met with currently available lower-cost (but somewhat poorer performing) solar collectors. In the final adjustment, the "mini-load" and the lower-cost collectors are combined.

The most significant results are the relatively more inviting paybacks for both the "low-cost" and "low cost plus mini-load" cases. However, even the use of lower-cost systems (with installed costs of \$20 per square foot) does not itself offset the high cost of money. Indeed, the cash flows under any of the proposed adjustments cannot be improved as long as interest rates remain high.

Some additional points from the comparisons also deserve notice. First, while adjusting for the "mini load" does not markedly improve the economics of the "base case," it does not make the option appear less economical. This suggests that extensive prior conservation alone does not make solar energy purchases less appealing, as long as the costs of active solar systems can be reduced in proportion to load reductions. (Remember here that active solar water-heating systems do have substantial fixed costs--costs that are incurred regardless of system size--ranging from \$1,000 to \$1,500.(37) Load reductions affect the economics of low-cost systems somewhat more adversely. Apparently, cutting the front-end costs of these systems does not completely compensate for the shrinkage of total energy savings due to the load reduction, perhaps because the tax credit is also lower.

A second point: as noted briefly already, lower-cost collectors do not require much more space than standard metallic panels do. Thus, using lower-cost collectors on small urban rooftops is not substantially more difficult.

Since interest rates have become so high, comparing alternative financing schemes is important. As Table Forty shows in a comparison of three financing packages, reducing financing charges can improve system economics markedly. The base case features a five-year 16 percent loan. The second resembles a program in Palo Alto that provides 20-year loans at six percent for conservation and renewable energy improvements in existing homes. The third uses a TVA program (20-year loans at 10.5 percent) as a model.

Not surprisingly, for the systems with electric resistance and fuel oil auxiliary, package two is the first to result in positive cash flow. But because interest accumulates over a much longer period under this option, payback is actually longer than in the base case for the systems with oil and gas back-up and remains unchanged for the system with electric resistance auxiliary. Nonetheless, since most consumers make purchases primarily on the basis of cash flow, package two probably holds the most appeal.

This relative appeal aside, because all standard flat-plate systems are expensive, even special financing programs may not be enough to offset the disadvantages of high initial costs. Package three reduces the number of years to positive cash flow only slightly in the electricity and fuel-oil cases. Thus, only lower-cost systems will enjoy wide appeal for single-family retrofits unless extremely low interest rates are available.

As shown in Table Forty-One, which summarizes economic analyses of combinations of low-cost systems plus special financing provisions, systems competing with electric resistance heat and fuel oil reach positive cash flow in the first year, regardless of how the system is financed. Even where natural gas is available, system buyers achieve positive cash flow in two years under the more generous of the two special financing packages.

Multifamily Applications

In general, owners of multifamily or commercial buildings will find solar water-heating systems very attractive if certain conditions hold true. The most important assumption is that the solar energy system will increase in value with the physical plant as a whole. As analyses summarized in Table Forty-two indicate, this factor is critical in determining the economic appeal of active solar water-heating systems for multifamily retrofits. With a five-year loan at 16 percent, no system achieves positive after-tax cash flow until after the fifth year. But if the solar energy system appreciates at 10 percent per year along with the rest of the building, the net present values of all systems in buildings with either electric resistance or fuel-oil auxiliary heating become positive in the first or second year. This happens because the net present value includes both the monetary value of fuel savings and that portion of proceeds from the property's sale attributable to the appreciated solar energy system. (For definitions of these terms, see box item.)

BOX ITEM NUMBER ONE

Net present value is defined as the sum of all fuel and tax savings minus all solar costs (including downpayment, financing charges, and operating and maintenance costs) over the 20-year life of the solar system, discounted at 15 percent. To this sum is added the discounted net, after-tax proceeds of sale of the solar energy system that would have resulted from disposition of the property that year. This indicator is affected by the key assumptions that the solar system increases in value along with the rest of the property at 10 percent annually, and that the system could be sold in any year for this appreciated value.

Internal rate of return treats the solar system as an investment and measures the after-tax, after-financing return on the investment. This indicator is affected by the assumed appreciation in value of the solar equipment.

After-tax cash flow is defined as the annual energy and tax savings provided by the solar system minus all annual solar costs (including downpayment, financing charges, taxes, insurance, and operating and maintenance costs). Both tax benefits-- such as the Federal solar tax credit and interest deductions on the solar loan--and tax losses such as sales tax on the system and increased property taxes due to the solar addition are included in the calculation. This indicator is not affected by the assumption that the solar system appreciates in value.

TABLE THIRTY-NINE

ECONOMICS OF SOLAR DOMESTIC HOT WATER
SYSTEMS - SINGLE FAMILY RETROFIT APPLICATIONS - VARIATIONS

Wash., DC	<u>Collector Area</u>	<u>Yrs to + Cash Flow</u>	<u>Yrs to Recover D.P.</u>	<u>Payback</u>
<u>Electricity</u>				
Base Case	52	6	11	11
Mini Load	29	6	11	11
Low Cost	56	6	6	6
Mini-Load & Low Cost	30	6	6	6
<u>Fuel Oil #2</u>				
Base Case	52	6	11	11
Mini Load	29	6	12	12
Low Cost	56	6	6	6
Mini Load & Low Cost	30	6	7	7
<u>Natural Gas</u>				
Base Case	52	6	15	15
Mini Load	29	6	16	16
Low Cost	56	6	10	10
Mini Load & Low Cost	30	6	11	11

Assumptions

1. Current fuel prices and fuel escalation rates, loan terms, and tax incentives identical to Table Thirty-Eight.
2. Mini-load reduces hot water demand by lowering delivery temperature from 140 degrees F to 120 degrees F and reducing consumption from 70 to 55 gallons per day.
3. Low cost system is \$20 per square foot of collector, installed.

TABLE FORTY

IMPACTS OF SPECIAL FINANCING ON ECONOMICS OF
SOLAR WATER HEATERS - SINGLE FAMILY RETROFITS (WASH., DC)

<u>Electricity</u>	<u>Years to + Cash Flow</u>	<u>Years to Recover Downpayment</u>	<u>Payback</u>
Package #1 ¹ (Base Case)	6	11	11
Package #2 ²	2	2	11
Package #3 ³	5	2	13
<u>Fuel Oil #2</u>			
Package #1	6	11	11
Package #2	4	2	12
Package #3	6	2	14
<u>Natural Gas</u>			
Package #1	6	15	15
Package #2	10	10	16
Package #3	11	16	18

1. Five-year home improvement loan at 16% interest.
2. Twenty-year loans at 6% interest.
3. Twenty-year loans at 10.5% interest.

TABLE FORTY-ONE

COMBINED EFFECTS OF SPECIAL
FINANCING PLUS USE OF LOW -
COST SYSTEM¹ ON ECONOMICS OF
SOLAR WATER HEATERS - SINGLE FAMILY RETROFIT (WASH DC)

	<u>Years to +</u> <u>Cash Flow</u>	<u>Years to</u> <u>Recover</u> <u>Down Payment</u>	<u>Payback</u>
<u>Electricity</u>			
<u>Package #1</u>			
(Base case) ²	6	6	6
Package #2 ³	1	2	5
Package #3 ⁴	1	2	6
<u>Fuel Oil #2</u>			
<u>Package #1</u>			
(Base case)	6	6	6
Package #2	1	2	6
Package #3	1	2	7
<u>Natural Gas</u>			
<u>Package #1</u>			
(Base case)	6	10	10
Package #2	2	2	10
Package #3	4	2	11

1. Low-cost system at \$20/ft², installed.
2. 5-year home improvement loan at 16% interest.
3. 20-year loan at 6%.
4. 20-year loan at 10.5%.

TABLE FORTY-TWO

ECONOMICS OF SOLAR DOMESTIC HOT WATER SYSTEMS - MULTIFAMILY
RETROFIT APPLICATIONS - FLAT PLATE METALLIC COLLECTORS

<u>City</u>	<u>Collector Area</u>	<u>Auxiliary Energy Type</u>	<u>Year in Which Net Present Value is Positive</u>	<u>IRR After 5 Years (%)</u>	<u>After Tax Cash Flow (5th Year)</u>
Boston	1500 ft ²	Elec Resis	1	31.8%	-2349
		Fuel Oil #2	2	21.9	-4501
		Natural Gas	3	18.6	-5263
Wash., DC	1300	Elec Resis	1	24.9%	-3384
		Fuel Oil #2	2	22.8	-3769
		Natural Gas	3	16.7	-5069
Grand Junction	750	Elec Resis	1	31.2%	-1344
		Fuel Oil #2	1	28.5	-1609
		Natural Gas	3	17.2	-3074
Los Angeles	800	Elec Resis	1	33.3%	-1170
		Fuel Oil #2	N/A	N/A	N/A
		Natural Gas	3	15.3	-3553

Assumptions:

1. System sized to deliver 50% of hot water needs to multifamily building of 32,000 square feet (100 residents).
2. Financed through five year loan at 16% interest.
3. Current energy prices and price escalation rates are those used in Tables Thirty-Eight through Forty.
4. System costs are \$4,000 plus \$25 per square foot of collector
5. Federal Business Energy Tax Credit of 15% is applied.

If the solar energy system does accrue value, internal rates of return are appealing--at least 20 percent for buildings with electric resistance or fuel-oil auxiliary in all locations and at least 30 percent for buildings with electric back-up everywhere except Washington. Because solar water-heating systems in multifamily buildings tend to be much larger and far less uniform than single-family installations, system costs will vary with location. Systems installed in sunny regions can deliver 50 percent of the building's domestic hot water with much less collector area than can systems in less sunny areas. Thus the Los Angeles system with electric auxiliary provides a slightly better internal rate of return (IRR) than the system in Boston: electricity costs more in Boston (9.8 cents/kwh vs. 6.9 cents/kwh in Los Angeles), but less collector area is needed in Los Angeles (800 square feet vs. 1,500 square feet in Boston).

As Table Forty-Three shows, assuming conventional financing adjustments cannot make fifth-year cash flows positive, but they can reduce negative cash flows significantly. In particular, reducing loads by making prior conservation improvements does make the overall economics of both the base case and the "low cost" scenario better. Reducing the hot water load for the base case lowers the IRR slightly, but by no more than 1.6 percent in any case. Only in buildings with electric auxiliary heat does reducing the load defer achievement of positive net percent value. But, both those slight drawbacks are offset by the improvement in fifth-year cash flow. Similarly, while using less expensive collectors does not make case flows positive in the fifth year for standard and mini loads, it does improve both IRRs and cash flows significantly. Even in the building with relatively low-cost (.465 cents/therm) natural-gas auxiliary water heating the solar system using low-cost collectors provides an IRR of over 20 percent and improves fifth-year cash flow by over \$3,000.

The much greater impacts of financing terms are dramatically illustrated in Table Forty-Four. Package one is the five-year, 16 percent base case. Package two incorporates provisions of a Palo Alto program that provides ten-year, eight percent loans for energy improvements to multifamily buildings. Package three is modelled on the provisions of HUD's 241 loans (ten years at seven percent). With either package two or package three, cash flow is dramatically better than in the base case, while package three provides about \$1,000 more in five-year cash flow benefits than package two.

The importance of financing provisions is underscored in Table Forty-Five, which describes the economics of a solar water-heating system installed in a new multifamily building. Assuming that the system used in the multifamily retrofit case is financed as part of a 30-year mortgage at 12.5 percent interest, all buildings but one (that in Los Angeles with natural gas auxiliary) achieve positive cash flows within five years. Internal rates of return exceed 50 percent for all buildings with electric-resistance back-up (except in Washington) and for the building with fuel-oil auxiliary in Grand Junction. Even the buildings with lower-cost natural-gas auxiliary heating show IRRs of roughly 30 percent in all cities except Los Angeles (where the IRR is 25.3 percent).

Analyzing this system using the same adjustments made in the single-family applications reveals that reducing the load in both the "base case" and "low cost" scenarios does not significantly reduce the economic appeal of either system. Using lower-cost collectors, in contrast, improves internal rates of return significantly in all cases. (See Table Forty-Six.)

Commercial Buildings

In general, it is much harder to predict the economics of solar water heaters for commercial facilities than for residential applications. Some rules of thumb do hold up, however. In smaller commercial buildings, savings roughly equal those for single- or multi-family buildings with comparable alternative fuels. In laundries, restaurants, hotels, motels, and other heavy users of water, savings on hot water bills can be substantial, which suggests that solar water heating can be economical when the costs of alternative fuels are high. For example, in DOE's Non-residential Solar Demonstration Program, such heavy users achieved savings of up to 65 percent. (See Table Forty-Seven through Forty-Nine.)

Public and Social Economics

While city officials must be aware of how economically appealing private users find solar water heating, they should also understand the differences between the purchasing criteria of private owners and those of the city government, both in its narrower role as potential user of solar heating equipment and in its broader role of custodian of the public good.

As they decide whether to purchase solar water-heating systems for city buildings, city officials will in some respects think like other building owners or managers. But in two important respects, they will differ. An important difference is that city officials will probably evaluate energy and other capital purchases over a longer time-frame than individual consumers will.

TABLE FORTY-THREE

ECONOMICS OF SOLAR DOMESTIC HOT WATER SYSTEMS -
MULTIFAMILY RETROFIT APPLICATIONS - VARIATIONS (WASH., D.C.)

	<u>Year in Which NPV is Positive</u>	<u>IRR (5 years) (%)</u>	<u>After Tax Cash Flow (After 5 Years)</u>
<u>Electricity</u>			
Base Case	1	24.9%	-3384
Mini Load	2	23.3%	-2315
Low Cost	1	29.6%	-1888
Mini Load + Low Cost	1	38.7%	- 842
<u>Fuel Oil #2</u>			
Base Case	2	22.8%	-3769
Mini Load	2	21.2%	-2551
Low Cost	1	26.6%	-2278
Mini Load/ Low Cost	1	34.3%	-1072
<u>Natural Gas</u>			
Base Case	3	16.7%	-5069
Mini Load	3	15.4%	-3348
Low Cost	3	18.3%	-3595
Mini Load/ Low Cost	2	22.9%	-1851

Assumptions:

1. Current fuel prices, fuel escalating rates, loan terms, and tax incentives identical to Table Forty-Two.
2. Mini-load reduces delivery temperature from 140 degrees F to 120 degrees F and cuts usage from 70 to 55 gallons per day.
3. Low-cost system is \$20/square foot of collector installed.

TABLE FORTY-FOUR

IMPACTS OF SPECIAL FINANCING ON ECONOMICS OF
SOLAR WATER HEATERS -- MULTIFAMILY RETROFITS

	<u>Year in Which NPV is Positive</u>	<u>IRR after 5 years (1%)</u>	<u>FMRR (%)</u>	<u>After Tax Cash Flow (5th Year)</u>
<u>Electricity</u>				
Package #1 ¹ (Base Case)	1	24.9%	25.6%	-3384
Package #2 ²	1	39.5%	31.7%	+ 714
Package #3 ³	1	39.9%	29.3%	+1731
<u>Fuel Oil #2</u>				
Package #1	2	22.8%	23.7%	-3769
Package #2	1	36.2%	30.1%	+ 329
Package #3	2	35.8%	23.6%	+1346
<u>Natural Gas</u>				
Package #1	3	16.7%	17.0%	-5069
Package #2	2	26.8%	24.8%	- 972
Package #3	3	24.5%	21.8%	+ 45

1. Five-year loan at 16%.
2. 10-year loan at 8%.
3. 30-year loan at 15.5%.

TABLE FORTY-FIVE

ECONOMICS OF SOLAR DOMESTIC HOT WATER SYSTEMS -- NEW
MULTIFAMILY APPLICATIONS -- FLAT-PLATE METALLIC COLLECTORS

<u>City</u>	<u>Collector Area</u>	<u>Auxiliary Energy Type</u>	<u>Year in Which NPV Is Positive</u>	<u>IRR After Five Years 1%</u>	<u>After-Tax-Cash- Flow (5th Year)</u>
Boston	1500 ft ²	Elec Resistance	1	56.9%	\$3,734
		Fuel Oil #2	1	38.0	1,582
		Natural Gas	2	31.6	821
Wash., D.C.	1300	Elec Resistance	1	43.8%	\$1,966
		Fuel Oil #2	1	39.7	1,581
		Natural Gas	2	28.1	281
Grand Junction	750	Elec Resistance	1	55.8%	\$1,991
		Fuel Oil #2	1	50.5	1,726
		Natural Gas	2	28.9	261
Los Angeles	800	Elec Resistance	1	59.8%	\$2,348
		Fuel Oil #2	N/A	N/A	N/A
		Natural Gas	2	25.3	-35

Assumptions:

1. All parameters identical to Table Forty-Two except financing terms (30-year loan at 12.5%).

TABLE FORTY-SIX

ECONOMICS OF SOLAR DOMESTIC HOT WATER SYSTEMS--
NEW MULTIFAMILY APPLICATION--VARIATIONS

Washington, D.C.

<u>Electricity</u>	<u>Collector Area</u>	<u>Year in Which NPV is Positive</u>	<u>IRR After 5 Years</u>	<u>After-Tax Cash Flow (5th Year)</u>
Base case	1300 ft. ²	1	43.8%	\$1,966
Mini load	750	1	40.6	1,019
Low cost	1400	1	81.2	1,456
Mini-load & low cost	750 ft.	1	77.8	1,357
<u>Fuel Oil #2</u>				
Base case	1300 ft. ²	1	39.7%	\$1,581
Mini load	750	1	36.6	783
Low cost	1400	1	71.4	1,214
Mini load & low cost	750	1	68.6	1,126
<u>Natural Gas</u>				
Base case	1300 ft. ²	2	28.1	\$ 281
Mini load	750	2	25.5	-13
Low cost	1400	2	45.4	396
Mini load & low cost	750	2	44.1	347

TABLE FORTY-SEVEN

ESTIMATED SYSTEM COSTS FOR SOLAR
WATER HEATERS IN EXISTING COMMERCIAL BUILDINGS

<u>Projected Name And Type</u>	<u>Estimated Total System Costs (1978 \$/FT² of Collector)</u>
Hogates (Restaurant)	\$60/ft ²
Aratex (Laundry)	\$40/ft ²
Iris Images (Film Laboratory)	\$40/ft ²

Source: Thomas King, et. al., "An Analysis of the Construction Costs of Ten Non-Residential Solar Energy Systems" (1978).

TABLE FORTY-EIGHT

COSTS AND ESTIMATED COST-EFFECTIVENESS
OF ACTIVE DOMESTIC HOT WATER SYSTEMS
INSTALLED IN HOTELS/MOTELS (1978)

<u>Project</u>	<u>ESTIMATED TOTAL SYSTEM COSTS (1978 \$/FT² Collector)</u>	<u>Estimated Cost Effectiveness</u>
Econo Travel (Woodbridge, VA)	\$21.03/ft ²	Payback less than 4 years
Econo Travel (Portsmouth, VA)	\$23.30/ft ²	"
LUCA (Duluth, MN)	\$21.14/ft ²	
Deer Creek Lodge (Deer Creek, OH)	\$47.07/ft ²	
Rock Resorts (Woodstock, VT)	\$52.23/ft ²	
Rock Resorts (St. John, VI)	\$34.13/ft ²	
Petruskey Motel (Petruskey, MI)	\$50.99/ft ²	

Source: R.G. Struss, et. al. "Evaluation of Economics of Hotel/Motel
Solar Hot Water Projects," (1978).

TABLE FORTY-NINE

ESTIMATED ECONOMICS OF SOLAR DOMESTIC
WATER-HEATING SYSTEM INSTALLED IN A
COMMERCIAL FACILITY (HOGATE'S
RESTAURANT) WITH ELECTRIC
VERSUS GAS AUXILIARY¹

	<u>Assuming Electric Auxiliary</u>	<u>Assuming Gas Auxiliary</u>
<u>Annual Energy Use</u> - No solar (MMBTU)	2367 ²	3512 ³
First Year Costs - ⁴ No Solar	\$45,068.68	\$16,330.80
First Year Costs - ⁴ 65% Solar	\$18,982.88	\$ 9,960.30
First Year Solar Savings	\$26,085.58	\$ 6,370.50
Fifth Year Savings	\$45,971.00	\$12,813.35

¹ Assuming DHW loads and system size reported in Table Thirty and system costs reported in Table Forty-Four.

² Water heater efficiency of .89 meets end use load of 2107 MMBTU.

³ Water heater efficiency of .6 meets end use load of 2107 MMBTU.

⁴ First-year fuel prices equal 6.5¢/KWH and 46.5¢/therm.

⁵ Fuel-price-escalation assumed to be 12% per year for electricity and 15% per year for natural gas.

In Table Fifty, the long-term cash flows associated with the purchase of a new multifamily building of the type that could be constructed in a city-financed housing program is examined. By the tenth year, cash flows for all systems in all cities are positive. The largest surpluses are in buildings using electric resistance or fuel-oil auxiliary heating. In nine of eleven cases, positive cash flows in the 15th year are \$10,000 or greater.

Even sketching the social benefits of solar water heating is difficult because of the wide range of factors involved--namely, long-range national security, environmental, and equity issues. Then too, many public benefits cannot be quantified. Nonetheless, some such assessment should complement conventional economic analyses of alternative energy systems.

One way to measure the public economic benefits of using alternative energy technologies is to compare the costs of these technologies with the marginal costs of producing new energy from conventional sources. (That is, the cost per kwh of electricity produced by new power plants or costs per therm of natural gas from newly drilled wells). Not a true measure of total social costs, higher marginal prices are nevertheless closer than lower average costs to the social costs of using depletable or dangerous fuels.

In Table Fifty-One, costs per million BTU of energy produced by solar water heaters are compared with estimates of current marginal costs per million BTU of electricity, imported oil, and deregulated natural gas. Even without the 40-percent Federal tax credit, solar costs can fall below the marginal costs of electricity delivered through existing lines. With the tax credit, even the highest solar costs are less than the marginal costs of delivered electricity, and the lowest solar costs are comparable to those of imported oil.

Solar energy's long-term competitiveness with conventional energy sources depends on how fast solar energy equipment costs increase relative to the marginal costs of conventional fuels. For example, if the costs of solar energy equipment increase only at the rate of inflation while the marginal costs of electricity, oil, and gas increase at higher rates, the marginal costs of conventional fuels will eventually exceed the costs of delivered solar energy--as Table Fifty-One shows they already do in some areas. (At 6.5 cents/kwh, one million BTU of electric heat costs \$19.05 in Washington and at .098 cents/kwh, \$28.71 in Boston!) Yet, solar energy collectors will not become clearly preferable to other sources of energy until they become cheaper, either through a reduction in materials cost, or the use of more efficient manufacturing techniques, or both. However, the Solar Energy Research Institute predicts (See Table Fifty-Two) that by the year 2000, costs per MMBTU of delivered solar heat will decrease markedly in all three cities compared in Table Fifty.

City Applications

Single-family residential and small commercial buildings in various climates can employ many of the solar water-heating technologies described here. However, most larger residential and commercial structures with solar water-heating systems currently use active flat-plate systems with metallic collectors, which have relatively high thermal outputs. As for the use of non-metallic collectors in large installations, their ultimate effectiveness cannot be evaluated without more experience.

Since few solar water-heating systems in single-family residences need more than one hundred square feet of collector area, most detached units and rowhouses will have enough roof or ground space for collectors. For example, analyses of rowhouse neighborhoods in Baltimore indicate that average dwelling units there had approximately 210 square feet of south-facing roof space, more than enough to accommodate solar collectors for a water-heating system.(38)

Like the conservation technologies described earlier, solar water-heating systems can be used effectively even where buildings shells are energy inefficient. However, solar water heating should be added when energy-efficiency improvements are made to the buildings's shell or later. The efficacy of this dual approach was borne out early in 1976. A burned-out tenement on East 11th Street in New York City was renovated with both energy-conservation measures and solar water heating. Heating costs were reduced by 50 percent by adding energy-conservation features, and needs for conventional water-heating were reduced by 70 to 80 percent with the use of an active solar water-heating system.(39)

In many city buildings, roof-mounted, flat-plate metallic collectors or thermosyphon or breadbox systems cannot be installed until the roof support structure is checked to make sure it can handle the added weight. While no roofs have collapsed under collector weight so far, the roofs of some older inner city buildings have had to be reinforced before collectors could be installed. For this reason, non-metallic rubber or molded plastic collectors are particularly appealing for use in older buildings.

TABLE FIFTY

LONG-TERM CASH FLOWS FOR A SOLAR WATER HEATING
SYSTEM-NEW MULTIFAMILY CONSTRUCTION¹ (\$ 1981)

City		Added Oper Net Income Yr-10 ²	Debt Service + MIP ³ Yr 10	Before-Tax Cash Flow Yr-10 ²	Added Net Oper Income YR-15	Debt Service + MIP YR-15	Cash Flow YR- 15
Boston	elec. resis.	\$16,864	\$3,801	\$13,063	\$29,942	\$3,801	\$26,141
	fuel oil #2	9,765	3,801	5,964	18,333	3,801	14,532
	natural gas	7,733	3,801	3,932	16,142	3,801	12,341
Washington, D.C.	elec. resis	\$10,202	\$3,343	\$ 6,859	\$18,203	\$3,343	\$14,860
	fuel oil #2	9,314	3,343	5,971	17,501	3,343	14,158
	natural gas	5,074	3,343	1,731	10,794	3,343	7,451
Grand Junction, (CO)	elec. resis	\$ 9,108	\$2,084	\$ 7,024	\$16,274	\$2,084	\$14,191
	fuel oil #2	8,613	2,084	6,530	16,210	2,084	14,126
	natural gas	3,645	2,084	1,561	7,920	2,084	5,836
Los Angeles	elec. resis	\$10,474	\$2,198	\$ 8,276	\$18,682	\$2,198	\$16,484
	fuel oil #2	n/a	n/a	n/a	n/a	n/a	n/a
	natural gas	2,578	2,198	379	5,773	2,198	3,575

1. System, financing terms, fuel costs, and fuel price escalation rates are those used in Table Forty-Five.
2. The sum of added rental income plus energy savings resulting from the solar installation in a given year.
3. MIP = Sum of added maintenance, real estate, insurance, and miscellaneous expenses due to the solar installation.

TABLE FIFTY-ONE

COSTS OF SOLAR DOMESTIC HOT WATER/SPACE
HEATING SYSTEMS VERSUS ESTIMATED MARGINAL
COSTS OF COMPETING FUELS (\$1980/MMBTU)

<u>Energy Source</u>	<u>1980 \$/MMBTU</u>	
<u>Regulated Gas</u>	<u>Raw Fuel</u>	<u>End Use</u> ¹
Existing Hook	\$2.10	\$ 3.50
New Hook	\$4.60	7.67
<u>Deregulated Gas</u>	\$6.80	11.33
<u>Oil</u> ("Social Cost")	\$10.90	21.80
<u>Electricity</u>		
Existing Lines	\$19.90	
New Lines	\$25.70	
<u>Active Solar Space Heating & DHW</u>		
Hartford	\$18.17-\$27.02	
Washington	\$17.46-\$25.13	
Los Angeles	\$12.63-\$21.24	
<u>Active Solar Space Heating & DHW</u>		
(With 40% Federal tax credit)		
Hartford	\$11.90-\$17.70	
Washington	\$11.40-\$16.40	
Los Angeles	\$ 8.30-\$13.90	

Source: A New Prosperity: The SERI Solar/Conservation Study
(1981)

1. End use costs include effects of 60% furnace efficiency in gas-fired systems and 50% furnace efficiency on fuel oil systems.

TABLE FIFTY-TWO

PROJECTED COSTS OF SOLAR HEAT IN 2000

(No Tax Credit)

(All 1980 \$)

<u>City</u>	<u>Cost of Delivered Solar Heat (2000)</u>	<u>Cost of Delivered Solar Heat (1980)</u>	<u>Difference</u>
Hartford	\$10.86-\$16.17	\$18.17-\$27.02	\$7.31-\$10.85
Wash., D.C.	\$10.50-\$15.10	\$17.46-\$25.13	\$6.96-\$10.03
Los Angeles	\$ 7.55-\$12.74	\$12.63-\$21.24	\$5.08-\$ 8.50

Source: A New Prosperity: The SERI Solar/Conservation Study
(1981)

Multifamily buildings are particularly well-suited for solar water-heating systems. Less collector area per dwelling unit is needed in large buildings than in single-family homes. Then too, larger storage tanks can operate more efficiently: their smaller surface-to-volume ratio means they lose less heat. These factors can combine to deliver as much or more hot water to multifamily units at less costs than in single-family applications. And most multifamily buildings are as high or higher than surrounding buildings so unwanted shading is not a problem. (See Institutional Constraints, below.)

Successful solar water-heating installations in multifamily buildings exist in cities from the East Coast to Hawaii. The solar energy system in Hei Wai Wong Apartments in Honolulu uses three collector arrays to supply hot water to the three wings of a 55-unit apartment complex. The system has supplied 98 percent of the building's hot water energy needs since installation in 1977.(40) Granite Place Apartments in Quincy, Massachusetts, uses a combination of flat-plate metallic collectors and relatively low-cost photovoltaic cells to heat 75 percent of the water its 270 dwelling units need.

The suitability of solar water heaters for commercial buildings depends primarily on those buildings' hot water requirements. Most businesses and institutions use 40 gallons or more a day--enough to make a solar water-heating system worthwhile. But whether solar water heating is effective in commercial installations also depends on when the hot water is used. If needs are greatest in late afternoon or evening, solar collection and storage are well suited to meet them. But if most of the demand occurs earlier, overnight storage--which could result in significant stand-by losses--is required.

A general ideal of usage patterns in commercial buildings emerges from the hot water demand profiles for twelve commercial and institutional building types DOE examined when developing the Building Energy Performance Standards. (See Table Fifty-Three.) Examining these demand profiles groups three kinds of buildings together. The first uses 50 percent of their daily hot water after two in the afternoon. The second uses between 30 and 50 percent then; the third, less than 30 percent. In general, building types in the first group are particularly well suited to using solar water-heating systems, those in the second group have an acceptable usage pattern, and those in the third group (depending on the amount of hot water they use) may find solar systems of questionable value. Since nine of the twelve building types fall into the first two categories and only three into the third, the obvious conclusion is that solar water heating and hot water usage patterns in commercial buildings are generally compatible.

Do note that this breakdown does not include restaurants, laundries, or other institutional facilities that use large amounts of hot water for domestic uses. In these applications, solar energy can be used with minimum standby losses if afternoon and evening demands are heavy.(42)

Facilities that use large amounts of hot water can also profitably combine solar energy systems with heat recovery from grey water. In the Aratex Laundry project in Fresno, for example, a waste heat recovery unit preheats incoming city water before pumping it to a storage tank where its temperature is boosted by solar heat. On demand, water from the storage tank is pumped through an auxiliary steam heater to points of use. Sequentially, both the waste heat recovery and solar energy systems pre-heat laundry-service water. Together, the two systems have lopped 48 percent off annual energy demand for water heating.(43)

Institutional Constraints

Land Use

Unlike the use of conservation techniques and technologies, the use of solar water-heating systems requires significant attention to land-use issues. As discussed in Chapter Four, solar collectors must more or less face south and they must be substantially free of shade. Guaranteeing both forms of solar access on a neighborhood-, area-, or city-wide basis may require adjusting land-use controls.

Proper orientation is the less serious concern, partly because orientation requirements themselves are being relaxed as experience confirms the idea that collector orientation can deviate substantially from true south without seriously diminishing system effectiveness. As recent research suggests, some collectors can face east or west with no more than a 20 percent decrease in system output.(44) In addition, many types of collectors can be oriented properly, at least in single-family systems, on buildings with almost any street orientation. For example, single-family residential solar water heaters using flat-plate metallic collectors never require more than 90 to 100 square feet of collector area. If the building is improperly oriented, metallic collectors can be mounted on support structures to compensate. Indeed, many water-heating packages include adjustable supports, as do rubber collectors. With thermosyphon systems, compensating for poor roof orientation may be harder since these systems are heavier.

With large multifamily and commercial installations, compensating for poor orientation is harder than it is with single-family residences. Yet, many of these facilities have flat roofs or open ground-level spaces that allow some flexibility in

TABLE FIFTY-THREE

PATTERNS OF DOMESTIC HOT WATER
USE IN COMMERCIAL BUILDING TYPES

Group One (over 50% of DHW use after 2:00 p.m.)

Clinics
Hospitals
Hotels/Motels
Nursing Homes

Group Two (30-50% of DHW use after 2:00 p.m.)

Gymnasiums
Offices
Secondary Schools
Shopping Centers/Stores
Warehouses

Group Three (Less than 30% of DHW use after 2:00 P.M.)

Auditoriums/Theaters
Community Centers
Elementary Schools

Source: U.S. Department of Energy, Standard Building Operating Conditions, Technical Support Document for Notice of Proposed Rulemaking on Energy Performance Standards for New Buildings, Nov., 1979.

orientating collector arrays.

As noted in Chapter Four, the collector's surface area should be shade-free between nine in the morning and three in the afternoon on December 21st. How much shading an individual system will tolerate, of course, varies. But daily and seasonal shading patterns, daily and seasonal hot water use patterns, and the size of the system's thermal output all matter.

As for sources of shading, low-density residential neighborhoods are more likely to have problems with trees. In high density or mixed use areas, tall buildings pose the greater problem.

Except where widespread constant shading occurs (for example, in low-rise housing immediately to the north of taller buildings), smaller water-heating systems can be manipulated to minimize shading problems. Support structures can be used to orient collector panels away from natural or built obstructions. Then too, if the solar building is as tall as surrounding buildings, shading problems for roof-mounted systems will be negligible.(45)

Given this much, two conclusions seem clear. Few land-use controls may be actually necessary to provide de facto solar access protection in many built-up city neighborhoods. On the other hand, to guarantee access in the future, cities may need to enact some of the zoning or land-use controls discussed in Chapter Four.

Protecting solar access for water-heating systems usually only requires safeguarding south-facing roofs. Often, no more than minimal changes in the zoning code are needed. For example, Los Angeles determined that for now solar access could be protected in many low-density areas simply by maintaining existing height limitations and by allowing more flexibility in the side-yard and set-back requirements that govern a building's location on a lot.(46)

Utilities

The same concerns raised about electric utility responses to conservation technologies apply to the use of solar water-heating systems, especially considering solar energy's economic competitiveness with electricity. How a utility will respond depends upon where the utility gets its fuel and whether it has excess capacity, as well as on the number of solar energy systems installed in the utility service area. Where the use of large numbers of solar water heaters reduces utility load factors without reducing peak demand, or where utilities operate significantly below capacity, solar users may see their unit costs of energy rise. (See Chapter Six.) However, until more experience has been accumulated, predicting exactly how problems will arise and exactly how they can be solved in different areas is mostly guesswork.

Some utilities have tried to cut peak demand and reduce the need for new power plants by encouraging their customers to use solar water-heating systems. The Tennessee Valley authority (TVA) has initiated a large-scale program to combine solar water heating with load management through the use of off-peak storage. In late afternoons and evenings TVA's customers use solar energy collected during the day. (At night, water in the system's storage tank is heated by off-peak electricity for use the next morning.) Generally, water heated by off-peak electricity can "carry" the home until adequate solar energy is available.(42) In another program, Los Angeles' municipal utility is offering no-interest loans for solar water heating systems that cost up to \$4,000 in one- to four-family buildings and up to \$10,000 in larger buildings.(48) Customers will have ten years to repay loans through utility bills. The utility intends to monitor the project to determine how effective the solar systems are (a 50-house test indicates that solar energy can meet about 60 percent of total hot water needs) and to study the impacts of widespread solar penetration on needs for additional utility generating capacity.

Socio-Economic Considerations

Even relatively low-cost solar water-heating systems represent major purchases for middle-income people. Given only conventional financing provisions, few poor families could afford even the least expensive solar water heaters. For example, a professionally installed lower-cost system for a single-family home in a warm climate costs at least \$400, even with Federal and state tax credits. (In fact, since up-front costs must be paid before tax credits can be taken and because few low-income people owe enough taxes to make the tax credits tempting, actual first costs are likely to be much higher.) In colder climates, costs may exceed \$2,000 (after tax credits) for professionally installed single-family systems. While costs-per-unit in multifamily buildings will be less, the total cost of systems will be high.

A second impediment to widespread solar use in many cities is the high proportion of rental housing in many urban areas. As explained in Chapter Seven, both tenants and landlords lack incentives to make large-scale energy investments in rental properties. Since solar water heaters are costly, private owners of rental buildings probably will not rush to install them on their properties without incentive or regulatory inducement, excellent performance records notwithstanding. (See Economics, above.)

Where cities do motivate residents to make solar energy investments in low-income and rental housing, as well as in more conventional conservation technologies, local economies will benefit from new job and business opportunities. According to the National Association of Solar Contractors, installing one solar water heater in an existing single-family home requires two person-weeks of labor. Thus, twenty-six retrofit installations would generate one job per person per year. Depending on the level of investment and on the nature of the local economy, either existing businesses will expand or new energy businesses will emerge. The manufacture of domestic water-heating systems can also be local. In particular, breadbox systems or other collectors can be assembled using locally available materials.

Jobs in both the manufacture and installation of solar water-heating systems can be targeted to unemployed persons. Most manufacturing jobs are likely to be for relatively low-skilled workers. In contrast, installation jobs will probably pay better and provide more opportunities for advancement. But because installation jobs are more complicated--requiring a combination of carpentry, plumbing, and electrical skills--more training and supervision is needed. Where neither can be provided, insulation and weatherization installation and greenhouse construction probably represent better job opportunities than solar water heater installation for unskilled workers.

Some cities and urban groups have adopted or implemented programs to provide both energy and employment benefits to poor people. For example, the Tennessee Valley Authority (TVA) and the South Memphis Community Development Corporation cooperated to train unemployed people to install one thousand solar energy systems on low-income people's homes.(49) Working under a grant from the Department of Energy's Solar Energy Utilization Economic Development and Employment (SUEDE) in Low-Income Communities Program, the Energy Task Force in New York City trained 15 workers with previously acquired construction skills from the city's Comprehensive Employment and Training Act (CETA) program to install domestic water-heating systems in several multifamily buildings.(50)

One of the most successful community-based jobs and energy programs in the country is operated by the San Bernardino West Side Community Development Corporation. Beginning with a small start-up grant from the Community Services Administration, this community group trained unemployed neighborhood people first to install energy conservation measures and then to put solar water heaters in single-family and multifamily homes. This highly successful program has placed many of its trainees in well-paying jobs in private industry, and it has expanded in cooperation with private industry into the production and installation of photovoltaic cells. Most important, it is currently developing an Energy Training Center--a complex of buildings heated by various renewable technologies and used to train neighborhood people to understand, build, and install solar energy systems.(51)

Chapter Nine Heating Buildings

BACKGROUND

About 20 percent of the nation's energy goes to heat buildings. In most climates, over half the energy consumed in residential buildings is for heating. (See Table Fifty-Four.) Even in relatively warm Greenville, North Carolina, 62 percent of the residential energy use goes for heating, and homes in Los Angeles use just under half of their total energy for space heat.

Recently, much has been written about the inherent energy efficiencies of multifamily buildings. (See Part One, Chapter Four, Land Use and Energy.)(1) Recent analyses have shown that most single-family detached homes use more space-heating energy per square foot of living space than do other housing types. Therefore, cities with large numbers of single-family detached homes probably have the greatest opportunities for cutting residential heating energy use. (See Table Two.)

Accurate as this generalization is, in older, central cities many multifamily buildings are not energy efficient either. As the information in Table Fifty-Five indicates, in Baltimore and Dayton space heating requires about the same percentage of total energy in single-family detached as in single-family attached buildings. In Baltimore, the percentage of energy used for space heating is actually greater in low-rise apartment buildings than in single-family homes. Space-heating energy use per square foot of living space is also comparable--41.8 MBTU/square foot/year in single-family detached homes and 40.3 MBTU/square foot/year in apartments.(2)

Caveats against over-estimating the energy efficiency of existing multifamily buildings also appear in a 1974 Project Independence study. Attached housing in the Northeast, the study says, consumed only slightly less energy per square foot than single-family detached homes in the same region, and attached units in the north-central region actually used more.

The lesson here is that virtually all city houses have ample opportunities for energy conservation.

As for space-heating energy consumption patterns in commercial buildings, they are harder to assess. Most such structures have heavier demands than homes for lighting and refrigeration and energy. But many use large amounts of space-heating energy too--just how much depends on the nature of the building and the business. One indication of the range is an analysis of commercial buildings in Boulder: some used as little as 14 percent of their energy for space heating, while others used over 80 percent. (See Table Fifty-Six.)

Even in similar buildings in similar climates, the actual energy used for heating will vary with the energy source employed. As noted in the previous chapter, different types of energy sources have different BTU contents, and different types of heating systems have different efficiencies. Beyond that, the principal energy sources for space heating vary by region. (See Part One, Chapter Six.) Oil is the primary heat source in much of the Northeast and in parts of the Midwest and Northwest; natural gas in the Mid-Atlantic, Southern, and Western regions and electricity in many parts of the West and South. (See Table Fifty-Seven.)

BTU contents and heating system efficiencies for different fuels used in space-heating are virtually identical to those discussed for domestic hot water applications. (See Part Two, Chapter Eight.) Accordingly, a house needing 50 million BTU of heat per year would consume about 83 million BTU of natural gas, 100 million BTU of fuel oil, and 150 million BTU of the primary fuel used to produce electricity. (See Tables Fifty-Eight and Fifty-Nine.)

ENERGY SAVING TECHNIQUES

No single approach to saving space-heating energy is "best" for all types of city buildings. Which works best varies with a particular building's size, age, use, occupancy profile, and condition.

Three complementary approaches to building energy conservation are discussed in this chapter: conservation improvements to the building shell, conservation improvements to the heating system, and the use of renewable energy technologies. While these approaches work in both new and existing buildings, retrofit applications are emphasized. Even in expanding cities, most of the housing stock that will exist in the year 2000 has already been built.(4)

Here, special consideration is given to differences among building types, particularly between single-family residential buildings (1-4 units), multifamily residential buildings (5 or more units), and commercial buildings.

ENERGY CONSERVATION IN BUILDING SHELLS

Technical Approaches and Issues

TABLE FIFTY-FOUR

SPACE HEATING LOADS AS PERCENTAGE OF TOTAL
LOADS--RESIDENTIAL SECTOR--SELECTED CITIES

<u>CITY</u>	<u>Percent of Total Energy Consumption Used for Space Heating in Residences</u>
Baltimore (SFD only)	48.4%
Dearborn	72
Dayton	65.8
Greenville NC	62
Boulder	66.6
Seattle (SFD only)	
Los Angeles	45.2
Portland (SFD only)	60

Sources:

Baltimore: Twiss (1980)

Dearborn: CCEMP Energy Audit

Dayton: CCEMP Energy Audit

Greenville: The Greenville Energy Program (1980)

Boulder: Community Energy Management Plan (1980)

Seattle: Energy Ltd., (1980)

Los Angeles: The Energy/LA Action Plan (1981)

Portland: Energy Conservation Choices for the City
of Portland, Oregon, 1977

TABLE FIFTY-FIVE

PERCENTAGE OF TOTAL LOAD FOR SPACE HEATING
IN DIFFERENT HOUSING TYPES (SELECTED CITIES)

<u>CITY</u>	<u>Housing Types</u> ¹			
	<u>SFD</u>	<u>SFA</u>	<u>MFLR</u>	<u>MFHR</u>
Baltimore	48.4%	47.5%	50.5%	41.7%
Dearborn	74.3	62.6	53.5	51.5
Dayton	66.9	65.8	56	50
Greenville	67.8	63.9	35.3	n/a
Boulder	70.9	56.7	49.2	46.8
Seattle				
Portland	60	n/a	47	n/a

1. Codes: SFD - Single-family Detached
SFA - Single-family Attached
MFLR - Multi-family low-rise
MFHR - Multi-family high-rise

2. Sources:

See Table Fifty-Four

TABLE FIFTY-SIX

PERCENTAGE OF TOTAL LOAD DEVOTED TO
SPACE HEATING--COMMERCIAL BUILDING TYPES (BOULDER)

<u>Commercial Building Type</u>	<u>% of Load devoted to space-heating</u>
Food Stores	29.8
Eating & Drinking	17.8
General Merchandise	40.4
Other Retail and Services	53.0
Wholesale	70.4
Office	62.7
Hotel/Motel	19.8
Auditoriums/Arenas	58.9
Movie Theatres	81.3
Hospitals	53.8
Terminals	64.4
Religious/Social	80.2
Cultural/Museums	60.0

Source:

City of Boulder, Community Energy Management Plan, (1980)

TABLE FIFTY-SEVEN

DOMINANT HEATING ENERGY SOURCE -- SELECTED CITIES

Principal Source(s) of Energy for Heating				Principal Source(s) of Energy for Heating			
City	Fuel Oil	Natural Gas	Electricity	City	Fuel Oil	Natural Gas	Electricity
Boston	X			Chicago		X	
Providence	X			Milwaukee		X	
New York City	X			Minneapolis		X	
Rochester		X		St. Louis		X	
Buffalo	X	X		Kansas City, MO		X	
Newark	X	X		Omaha		X	
Pittsburgh		X		Dallas		X	
Philadelphia		X		Austin		X	
Baltimore	X	X		Houston		X	
Washington, D.C.		X		San Antonio		X	
Norfolk		X		Oklahoma City		X	
Charlotte		X		Denver		X	
Atlanta		X		Salt Lake City		X	
Jacksonville			X	Albuquerque		X	
Miami			X	Phoenix		X	
Birmingham		X		Los Angeles		X	
New Orleans		X	X	San Diego		X	
Memphis			X	San Francisco		X	
Louisville		X		Oakland		X	
Cincinnati		X		Sacramento		X	
Cleveland		X		Portland	X		
Detroit		X		Seattle			X
Fort Wayne		X		Anchorage	X	X	
Indianapolis		X					

Source: Derived from Data collected by the Office of Technology Assessment.

TABLE FIFTY-EIGHT

ESTIMATED END-USE AND PRIMARY ENERGY CONSUMPTION
IN EXISTING RESIDENCES (BY REGION)

<u>Region</u>	<u>End Use Energy- Space Htg. (MMBTU/YR)</u>	<u>Principal Energy Sources</u>	<u>Primary Energy (MMBTU/yr)</u>
New England	113.63	Fuel Oil	227.26
Mid Atlantic	100.43	Natural Gas	167.38
East North Central	140.18	Natural Gas	233.63
West North Central	127.10	Natural Gas	211.83
South Atlantic	51.03	Electricity	170.10
East South Central	71.22	Natural Gas Electricity	118.70
West South Central	80.67	Natural Gas	134.45
Mountain	90.63	Natural Gas	151.05
Pacific	53.69	Electricity Fuel Oil	178.97 107.38

Source: Derived from data reported by General Accounting Office (1981).

TABLE FIFTY-NINE

ON-SITE AND PRIMARY ENERGY CONSUMPTION IN SINGLE -
FAMILY HOMES CONSTRUCTED IN 1965

(Selected Cities)

<u>City</u>	<u>Principal Heating Energy Source</u>	<u>End-Use Demand (MMBTU/YR)</u>	<u>Primary Energy (MMBTU/YR)</u>
Boston	fuel oil	152	304
Providence	fuel oil	152	304
New York	fuel oil	129	258
Rochester	natural gas	168	280
Buffalo	natural gas (55%) fuel oil (35%)	168	280-gas 336-oil
Baltimore	natural gas	124	206.7
Charlotte	natural gas	84	140
Norfolk	natural gas	98	163.3
Atlanta	natural gas	72	120
Memphis	electricity	65	197
Houston	natural gas	37	61.7
Dayton	natural gas	126	210
Chicago	natural gas	156	260
Los Angeles	natural gas	53	88.3
Seattle	electricity	96	N/A *

*Hydro power

Source: Arthur W. Johnson, Associates

The building shell affects how much hot or cold outside air gets inside the building and how much of the building's heating or cooling energy stays inside. Of the many structural characteristics that affect the building shell's thermal integrity, the three most important are overall tightness (affecting air infiltration and heat leakage), the amount and quality of insulation, and the window type and quality.

Each shell characteristic operates in conjunction with the others, and effective building retrofits must address all together. Implementing one does not make the others less important. To the contrary, the energy-saving effects of the combined measures reinforce each other. For example, with the addition of storm windows and attic, wall, and floor insulation to basic sealing and caulking a single-family home in the Northeast will consume up to 85 percent less energy for heating than a similar home without these features.(5)

Reducing Air Infiltration and Heat Leakage

The popular conception of energy-inefficient housing is underinsulated housing. While this charge is valid, inadequate insulation is not always the only or even the primary cause of energy waste. Air infiltration through cracks or gaps is a prime offender. Admitting in cold outside air and letting out warm indoor air, such gaps can be found at building joints between wall surfaces. They also appear between walls, foundations, and roofs, intersections of walls and window or door frames, and in spaces between framing and window glass or door panels.

Buildings of all types and conditions have infiltration problems. The effects of heat leakage are particularly severe for single-family detached homes, which tend to have relatively large surface-to-volume areas. However, rowhouses and townhouses can leak too.

An analysis of new townhouses in New Jersey found significant heat losses at joints, framing-to-wall intersections, and the space between the interior walls and fire walls.(6) While infiltration problems in multifamily and commercial buildings have received little study, it is obvious that multifamily buildings with many windows could be highly vulnerable. Then too, such large buildings lose heat through service or delivery areas, or through outside vents that have no dampers.(7)

Infiltration is worse in older buildings where walls, roofs or foundations are likely to be cracked or damaged. Even in new, well-insulated and well-sealed buildings, heat escapes through gaps between insulation batts and blankets, through such uninsulated "patches" in insulated areas as trap doors in uninsulated attics, or through cracks where pipes or electrical outlets penetrate walls or ceilings. One study by Princeton University estimated that "by-pass" leaks can reduce the energy savings expected to result from added ceiling insulation by 30 to 70 percent.(8)

In new houses, infiltration levels can be greatly reduced. Better sealing and framing practices and the addition of extra insulation account for the improvement. Greatly reducing air infiltration, however, raises concerns about the build-up of such indoor air pollutants as carbon dioxide, formaldehyde, and radon.(9) Indeed, if infiltration rates are brought to below 0.6 air changes per hour, stale air must be removed with an air-to-air heat exchanger or by some other means.(10) (In older housing, this is not a concern, even if buildings have been weatherized.)

Methods for reducing infiltration in existing buildings are also technically well-established. Indeed, leaks can be plugged in many different ways. (See Table Sixty.)

Reducing infiltration losses in multifamily and commercial buildings is relatively more complicated and expensive. Besides caulking, weatherstripping, and sealing, reducing infiltration in such buildings may require adding air-lock vestibules at main entrances or in service or delivery areas.

Although sealing leaks is relatively easy once the leaks are found, identifying them can be difficult. Cracked windows, large gaps between door frames and door panels, and many other leaks are harder to ignore than to identify. But trained personnel and even specialized diagnostic equipment are needed to find some heat leaks. In one test for leaks, a high-powered blower pulls air out of the house and an infrared scanner reveals the more obscure heat-loss paths. Trained home energy conservation specialists ("house doctors") can usually spot major heat leaks that the average consumer does not notice.

Insulation Improvements

Plugging leaks does not, of course, eliminate conductive losses of heat from walls and roofs. For this, adequate insulation is needed. Few buildings are insulated to cost-effective levels. Based on data from HUD and DOE, the Urban Institute estimates that about one quarter of the nation's one-to-four family houses have no attic insulation.(11) Yet, precisely assessing the insulation levels of buildings is difficult, as is estimating the effective levels of thermal protection in buildings that have some insulation.

Insulation effectiveness is usually measured by an R-value, which indicates how well a material resists conductive heat losses. The higher the R-value, the better insulated is the structure. Typically, new single-family homes now have R-19 insulation in the

TABLE SIXTY

SELECTED METHODS OF REDUCING HEAT
BY-PASS LEAKS IN BUILDINGS

- Weatherstripping doors and windows
- Installing foam baskets behind switchplates and electric outlets.
- Blocking gaps between interior and fire walls at foundation and attic levels
- Sealing gaps between foundation walls and sill plates
- Sealing spots where pipes or electrical outlets penetrate ceilings or walls.

Source: Dutt (1980)

ceilings and R-11 insulation in the walls.(12) In contrast, houses built between 1973 and 1976 commonly used R-13 in ceilings and R-11 in walls.

Effective insulation levels in older buildings are even harder to set. One variable is the building's age; another the uncertain effects of time on insulation quality. One rule of thumb the Lawrence Berkeley Laboratories (LBL) uses is that partially insulated single-family buildings built before late 1973 be assumed to have R-11 insulation in ceilings and R-7 insulation in walls.(13) By comparison today insulation to at least R-38 in ceilings and R-30 in walls can be cost-effective in very cold climates.

Upgrading insulation can significantly reduce a home's heating needs. Figures from the National Association of Home Builders (NAHB) Research Foundation indicate that in a cold climate increasing ceiling insulation from R-11 to R-38 could save nearly 15 million BTU of energy per year.(14) For the record, a small number of new "superinsulated" houses (which have insulation even in the eaves, window frames, and electrical boxes) can actually do without a central heating system.(15)

Insulation can be added to buildings in various ways. In residential and commercial buildings with attics, insulation batts or blankets can simply be placed over dropped ceilings. This strategy is effective not only in single family buildings, but in multifamily and commercial structures as well. An analysis of conservation options in Baltimore predicted that adding R-20 insulation to a previously uninsulated roof in a typical high-rise apartment building could reduce the heating load by 20 percent.(16)

Where cavities exist between interior and exterior walls, particle insulation can be blown in or foam insulation can be pumped in. (This approach generally suitable only for uninsulated wood-frame buildings, though, since masonry walls have few or no air cavities. Also, blown-in insulation is less effective where obstructions prevent the insulation from filling the cavity completely.) Blown-in insulation can also be used in attics. In contrast, foam insulation is a poor choice for attic use because high temperatures can cause foam to deteriorate. Urea-formaldehyde foam insulation should not be used. It has been banned by the U.S. Products Commission because of evidence that it causes eye and throat irritation.(17)

In rehabilitating masonry buildings or structures with no attics, insulation can be added by installing walls or ceilings inside existing ones and placing insulation in the newly formed cavities. While this new approach is expensive and reduces living space, it can save substantial amounts of energy. For example, a rehabilitation project in New York City cut its heating demand by an estimated 37 percent when it took conservation measures that included adding insulation behind new walls and new dropped ceilings.(18)

Another approach is to re-side the exterior, placing insulation outside the existing wall and adding a new layer of siding. This approach is probably economical only in a wood-frame building scheduled for re-siding.(19)

Improved Windows

Large amounts of heat can be lost through window surfaces by conduction, convection, and radiation. The U.S. Congressional Office of Technology Assessment (OTA) estimates that typical single-glazed windows have R-values ranging from 0.9 to 2.0--quite low considering that even poorly insulated walls have R-values to 7.0.(20)

In new buildings, heat losses through windows can be minimized by reducing window areas on the coldest sides of the building, by installing two or three layers of glass, or by using new heat-retentive window materials or designs. In existing buildings, the key to cutting losses is adding more glazing and thermal shutters or shades. A more ambitious approach is to retrofit the building with replacement glass that has improved thermal qualities.

The simplest retrofit is adding storm windows. According to the Urban Institute, about 40 percent of existing one-to-four family buildings lack them.(21) The proportion in multifamily buildings is probably even greater. However, while storm windows can cut heat losses, they are not always the most cost-effective window retrofit. For example, in some single-family homes in milder climates, adding insulating shades may be more economical.(22) In larger buildings, using reflective shades and making the heating system more efficient may be more economical choices.

With or without storm windows, the use of blinds, shutters, or shades can also reduce conduction (and infiltration losses by interposing another layer of material between heated air and the window's cooler surface in the winter and between cooler air and warm window surfaces in summer. Both engineering and economic analyses have indicated that shutters or blinds must be tight-fitting to be effective.(23) Where air gaps exist, heat can be let out (in winter) or in (in summer) by convection.

Window technology for use in older buildings and new construction is advancing rapidly.(24) Most improvements are in designs, glazing techniques, or shade and shutter materials. For example, glazing materials now being developed allow "high energy transmission," greater penetration of solar energy into the living space. Double layers of this glass can reduce conduction heat losses without sacrificing heat gain in the winter. Several designs for blinds have been developed that allow one side of the blind

to absorb heat in winter and another to resist it in summer. (One device actually allows heat trapped between two layers of glazing to be circulated for use in the building.) Some shading devices are so thermally efficient that they can be considered insulation, usable either on the inside or the outside of a building.

Since both outside air temperatures and climate control needs change daily and seasonally, effective window designs allow heat gain and retention when it is cold and prevent heat gain in hot weather. This means that they integrate heat collection, insulation, and shading functions. A typical integrated design might call for double glazing with highly transmissive glass, movable insulation, and either exterior overhangs or dual-function blinds. Glass with high transmissivity would improve heat collection in the winter, and double glazing would reduce conduction losses. Movable insulation would be used at night or on cloudy days to prevent conduction losses even further. Overhangs that provide shading could help prevent summer heat gain without keeping light from entering.

Economics

Which conservation improvements to building shells are most cost-effective depends upon the type and location of the building, as well as with the number of energy-efficiency features already installed. Although few conservation retrofits are cheap, a carefully chosen package of improvements can be quite cost-effective. (See Table Sixty-One.) In many cases, the simplest retrofits are the most immediately cost-effective. For example, the Urban Institute (UI) calculates that basic conservation techniques (caulking, weatherstripping, and adding clock thermostats) costing only about \$200 could save up to 25 percent of a home's annual heating energy.(25) Paybacks for even an extensive retrofit "package" (storm windows plus roof, wall and floor insulation) average 7.0 years nationally in owner-occupied housing. In colder regions with high utility costs paybacks can be much shorter, (4.0 years in the Northeast and 5.9 years in the Midwest), although in warmer areas they can take much longer (8.2 years in the south and 12.6 years in the West). Paybacks for adding ceiling insulation and storm windows are under three years everywhere but the west. (See Table Sixty-Two.)

As noted earlier, using payback as a criterion for cost-effectiveness assumes that retrofits are paid for with cash. If borrowed money is used, the more appropriate indicator is usually years-to-positive cash flow. Estimates of the time it takes to reach a positive cash flow are not as numerous as payback estimates. According to the Urban Institute, most single-family households installing stringent conservation packages (storm windows plus insulation on roof, walls, and floors) could achieve positive cash flow in a year or two if they claimed the full federal energy tax credit--perhaps sooner with available state tax credits.(26)

While these payback or cash-flow periods are economical for homeowners, they probably hold less appeal for occupants of single-family rental units. Even if tenants pay their own utility bills, they probably do not rent one place long enough to recoup conservation investments. They are also unlikely to borrow money to pay for improvements in homes they do not own. A final consideration is that single-family rental units may require more energy-conservation retrofit measures than owner-occupied homes,(27) so costs and paybacks are commensurately greater. (See Table Sixty-Three.)

Much less information is available on the cost-effectiveness of shell improvements in large multifamily and commercial buildings. It is more difficult to generalize about this class of buildings, and available energy-conservation studies tend to focus on adjustments to the commercial or apartment building's heating systems, as distinct from shell improvements. Still, a number of retrofitting guidebooks suggest that costs for reducing infiltration will be relatively low except where a vestibule or some other air-lock entryway must be added. The costs of improving glazing and insulation will depend on the size of the building, though the costs per square foot of materials will probably not be appreciably more or less than for the same material used in single-family homes. Installation costs may increase with the size of the building.

CONSERVATION IMPROVEMENTS IN HEATING SYSTEMS

While the building's shell affects the amount of heat needed, its heating system determines how much energy it takes to produce that heat. Improvements to both the building shell and the heating system are necessary for an effective energy-conservation retrofit.

Most heating systems used in single-family buildings are relatively simple. In an oil- or gas-fired unit, the fuel is burned in a combustion chamber to produce heat. That heat is passed over a heat exchanger that warms an air or water transfer fluid that is then circulated (by ducts in forced air systems and by radiators or baseboards in water distribution or hydronic systems) to the house. Space-heating furnaces are roughly as efficient as gas- or oil-fired water heaters--about 60 percent in older gas models, 50 percent in older oil furnaces, and up to 80 percent in the newer ones of either type.

TABLE SIXTY-ONE

ESTIMATED COSTS OF SELECTED SHELL-CONSERVATION MEASURES
(1980 \$)

<u>Measure</u>	<u>Area</u>	<u>Estimated Installed Costs</u>
Uninsulated ceiling retrofit to R-19	1350 ft. ²	\$ 470.00
- to R-27	1350 ft. ²	580.00
Uninsulated walls retrofit to R-11	1232 ft. ²	860.00
Single-pane storm windows	200 ft. ²	900.00
Double-pane storm windows	200 ft. 2	1,400.00
Infiltration reduction		240.00

Source: A New Prosperity (1981), p. 52

TABLE SIXTY-TWO

AVERAGE RETROFIT COSTS AND ESTIMATED
PAYBACKS FOR BASIC CONSERVATION
PACKAGES INSTALLED IN SINGLE-FAMILY
OWNER OCCUPIED HOMES (NATIONALLY AND BY REGION)
(1980 \$)

	<u>Retrofit⁴</u> <u>Costs</u>	<u>First Year⁴</u> <u>Savings</u>	<u>Estimated⁴</u> <u>Payback</u>
Package One ¹			
National	\$ 200.00	\$ 78.00	2.6
Northeast	200.00	157.00	1.3
North Central	200.00	82.00	2.4
Southern	200.00	70.00	2.9
West	200.00	29.00	6.9
Package Two ²			
National	\$ 390.00	\$119.00	3.3
Northeast	310.00	209.00	1.5
North Central	280.00	143.00	2.0
Southern	245.00	90.00	2.7
West	810.00	66.00	12.2
Package Three ³			
National	\$1,590.00	\$225.00	7.0
Northeast	1,420.00	353.00	4.0
North Central	1,385.00	235.00	5.9
Southern	1,710.00	209.00	8.2
West	1,845.00	146.00	12.6

1. Clock thermostat; caulking and weatherstripping; filling holes and air leaks; wrapping heating ducts and hot water pipes; insulating hot water heater.
2. Package one plus: attic insulation (R-19 in northeast and north central regions; R-11 in south and west); storm windows.
3. Package one plus: wall insulation (R-13); floor insulation (R-19) in northeast and north central; R-11 in south and west; attic insulation (R-30 in Northeast and North Central Regions; R-11 in South and West); storm windows.
4. Calculated taking account of items already in place.

Source: Urban Institute (1980), pp. 107,111, 116

TABLE SIXTY-THREE

AVERAGE RETROFIT COSTS AND ESTIMATED PAYBACKS FOR BASIC
CONSERVATION PACKAGES INSTALLED IN SINGLE-FAMILY RENTAL HOMES
(Nationally and By Region)
(1980 \$)

	<u>Retrofit⁴</u> <u>Costs</u>	<u>First Year</u> <u>Savings</u>	<u>Estimated</u> <u>payback (years)</u>
Package One ¹			
National	\$ 200.00	\$ 59.00	3.4
Northeast	200.00	132.00	1.5
North Central	200.00	69.00	2.9
Southern	200.00	53.00	3.8
West	200.00	22.00	9.1
Package Two ²			
National	525.00	113.00	4.6
Northeast	510.00	210.00	2.4
North Central	425.00	138.00	3.1
Southern	390.00	98.00	4.3
West	920.00	66.00	13.9
Package Three ³			
National	1,880.00	192.00	9.8
Northeast	1,720.00	331.00	5.2
North Central	1,640.00	225.00	7.3
Southern	1,980.00	174.00	11.4
West	2,025.00	121.00	16.7

1,2,3,4. - See Table Sixty

Source: Urban Institute, pp. 111, 113, 116

the efficiencies of complete systems often lower, depending on transport losses, the amount of power used to run blowers or pumps, and furnace location.

In a centralized electric heating system, an electric heating element is immersed in a boiler or located in a duct in the forced air system. In zoned electric resistance systems, electric elements are dispersed throughout the house in baseboards. Most of the heat these systems produce goes to the house so that electric resistance heating has a very high (95 percent or more) efficiency inside the building. But, as noted in Chapter Eight, when generation and transmission losses are counted the overall efficiency of electric heating falls below one third. For this reason, an increasing number of electrically heated buildings now have electric heat pumps that extract heat from the air and transfer it to the building. Essentially air conditioners working in reverse, heat pumps can usually provide about twice the heat contained in the electricity used to run them. Therefore, they can reclaim about one half of energy lost in generation and transmission.

In centralized heating systems in larger buildings, heat sources are larger, and control and distribution systems more complicated.(29) Sometimes, in fact, the heating and cooling systems work together. In most cases, the heat source is a fossil-fueled boiler that heats water or air or produces steam that is then circulated throughout the building. Control over operations is through a central thermostat (with individual radiators or manually operated air vents scattered throughout the building) or through thermostats in individual zones or rooms. When decentralized thermostats are used, the distribution system must provide a wide range of temperatures to meet varying demands. Some systems (Terminal-Rewheat systems, for example) raise the temperatures of centrally distributed forced-air by using individual heating units in each zone. Others (Dual Duct Systems and Multi-Zone Systems, among them) produce heated and cooled air flows at the central plant and then mix them to produce the desired temperature. Still others (including Induction Systems and Fan-Coil Units) mix centrally heated or cooled air with recirculated conditioned or fresh air at individual units in each room or zone.

Technical Approaches

Heating Systems can be made more efficient in surprisingly many ways. Strategies range from relatively minor adjustments to system replacement.

System Adjustments

Most of the many techniques available for improving the efficiencies of heating systems are available now, but these technologies are continually being improved. Of the technologies or approaches currently available, only the more common general strategies are discussed here.

Maintenance

A simple, but often overlooked, strategy is periodic maintenance. Furnaces or boilers should be cleaned and serviced periodically according to manufacturers' specifications. Periodic maintenance is particularly important in larger buildings, where boilers are large or more numerous. According to a Greater Washington (D.C.) Board of Trade estimate, simply removing built-up soot from a boiler's fireside could save up to 15 percent on annual heating costs.(30) - The National Electrical Contractors Association (NECA) and the National Electrical Manufacturers Association (NEMA) recommend fourteen maintenance steps in all kinds of boilers and from three to six additional steps in specific types of heating systems, all of which can enhance combustion efficiencies. (See Table Sixty-Four.) Among these steps are periodic servicing and cleaning, and regular monitoring through inspections. More particularly, keeping a daily log of pressure and temperature levels can indicate if tubes or nozzles need cleaning or if pressure adjustments are necessary, and checking smoke levels in stack gasses can indicate whether the burner is working efficiently.(31)

Upgrading Efficiencies

More complicated and effective technologies and approaches--most of them commercially available--increase overall system efficiency by improving the combustion, distribution, or control subsystems. The extent to which each is feasible in a given heating system depends on the system's overall condition and the operating environment.

Combustion

Furnace combustions can be improved in two ways--reducing fuel use but not heat output or increasing output without increasing fuel use. In many building heating systems, fuel can be saved by downsizing oil burners (by installing a smaller nozzle so the burner receives less fuel) or gas furnaces (by reducing the number of burner racks used). Down-sizing is feasible in most systems because heating units have traditionally been oversized. Most can produce more heat than is needed. Oversized systems burn more fuel more quickly than smaller units, so heat losses from combustion and distribution

TABLE SIXTY-FOUR

SUGGESTED MAINTENANCE PROCEDURES FOR FURNACES
AND BOILERS USED IN LARGER BUILDINGS

<u>Boiler/Furnace Type</u>	<u>Procedure</u>
general	Inspect for scale deposits on water side surfaces.
general	Inspect fireside of furnaces and tubes for soot deposits.
general	Check door gaskets for tight seal. Replace if necessary.
general	Keep daily pressure and temperature log to determine need for tube and nozzle cleaning, pressure, or linkage adjustments, etc. Keep log entries of firing rate realizing that stack temperatures, may vary 100° during load change.
general	Inspect stacks. If haze is present, a burner adjustment may be necessary.
general	Inspect linkages for tightness.
general	Observe fire when shut down. If it does not cut off immediately, check for faulty solenoid valve.
general	Clean and inspect nozzles and cup of oil-fired furnaces regularly.
general	Check stack temperature. If more than 150°F above steam or water temperature, clean tubes and adjust fuel burner.
general	Inspect boiler insulation, casing, refractory, and brickwork for hot spots. Seal as necessary.
general	Replace all obsolete or little-used pressure vessels.
<u>Boilers</u> <u>gas</u>	Clean mineral or corrosion build-up on gas burners.
fuel oil	Check and repair oil leaks at pump glands, valves, or relief valves.
fuel oil	Replace oil-line strainers when dirty.
fuel oil	Check oil heaters to see that manufacturers' recommended oil temperatures are being maintained.

TABLE SIXTY-FOUR (CONTINUED)

<u>Boiler/Furnace Type</u>	<u>Procedure</u>
<u>Boiler</u>	
coal-fired	Inspect stokers, grates, and controls for efficient operation. If ashes contain considerable unburned coal, adjustment probably necessary.
electric	Inspect electrical contacts and working parts to insure they're in good working order.
electric	Replace heater elements when dirty.
electric	Check and adjust controls as necessary.
central furnaces make-up air heaters and unit heaters	Clean all heat-exchanger surfaces. Check and adjust air-to-fuel ratio as necessary.
central furnaces make-up air heaters and unit heaters	Inspect burner couplings and linkages.
central furnaces, make-up air heaters and unit heaters	Inspect casing for air leaks. Seal as necessary.
central furnaces, make-up air heaters and unit heaters	Replace or repair faulty insulation.
Central furnaces, make-up air heaters and unit heaters.	Follow suggested guidelines for fan and motor maintenance.
Radiators, convectors, baseboard and finned tube units.	Inspect for obstructions in front of unit and remove whenever possible.
Radiators, convectors, baseboard and finned tube units.	Be sure air collected in high points of hydronic units is vented.
Radiators, convectors, baseboard and finned tube units.	Keep all transfer surfaces clean.
Electric heating	Keep heat transfer surfaces clean and unobstructed.
Electric heating	Keep air movement unobstructed.
Electric heating	Periodically inspect heating elements, controls, and fans to ensure proper functioning.
Electric heating	Check reflectors on infrared heaters for cleanliness and proper direction.
Electric heating	Determine whether electric heating equipment is operating at proper voltage.
Electric heating	Check controls for proper operation.

are commensurately greater. Also, because larger furnaces heat up quickly, they tend to operate for shorter periods and to lose fuel as the furnace or boiler starts and stops. Down-sizing can both lower heat losses by reducing the amount of heat generated at any one time and reduce fuel losses by increasing the time of operation (thus cutting "cycling" losses).(32)

Other efficiency improvements are in combustion techniques. In most new oil furnaces, a retention-head burner is used to enhance the flue-air mixture by recirculating the combustion air, thus allowing more complete combustion and increasing furnace efficiency by 20 to 30 percent. (Retention-head burners can also be retrofit.) Yet another approach is to reduce fuel use in gas furnaces by replacing the gas pilot light with an electronic ignition device like most oil burners already have.

Combustion efficiencies can also be improved by reducing the amounts of heat lost through the furnace walls, or, by convection, through the flue. Flues, metal plenums that lead from the furnace to the outside and allow combustion gasses to escape, must remain open as long as gasses remain to be expelled. But leaving flues open longer allows the furnace's residual heat to escape. Automatic flue dampers reduce heat losses by closing the flue once combustion gasses have been released. (A danger here is premature closure: dampers should always be left open after the furnace shuts off so all residual gasses are expelled.)

Since most furnaces use indoor heated air for combustion, some heated air will always be lost through the flue unless the furnace uses outside air in combustion. The sealed combustion furnace does just that. Connected to the outside via an intake duct, this furnace operates without indoor air. Since the outdoor air is colder, energy is spent raising it to combustion temperatures, but this drawback is minimal if outdoor air is circulated through a heat exchanger in the flue.

Just as correctly sizing a single boiler is essential in a small building, properly sizing and controlling a multiple-boiler system is necessary in larger buildings. Heating systems in larger buildings should use as few heat sources as possible--not several at partial capacity.

Using waste heat can also improve combustion efficiencies in large systems. For example, a heat exchanger known as a boiler stack economizer can recapture heat from the boiler stack and preheat water being fed into the combustion chamber. Other techniques now on the market can use different sources of waste heat in a boiler room to preheat either the oil or the combustion air.

Adjusting furnaces can improve residential heating efficiencies by as much as 25 percent, depending on the nature and condition of the system. A furnace-efficiency improvement program for low-income housing in Philadelphia records savings of over 20 percent from relatively simple repairs. (See Table Sixty-Five.)

Most estimates of potential fuel savings from furnace improvements are not cumulative. (How much each improvement saves is known. How much a combination of improvements saves is not.) For instance, while a downsized gas burner will lose fewer BTU in exhaust gasses, how this reduction affects the amount of energy and money saved by using automatic flue dampers has not been extensively analyzed.

Distribution

A distribution system is efficient when the building receives most of the heat the furnace generates. Most distribution inefficiencies stem from poor flow rates in the transfer medium and excessive heat losses from piping or ductwork. Sometimes, water or air flows are not what they should be because pumps or blowers do not work properly. In other cases, the distribution system is poorly designed--full of bends and turns. Most distribution heat losses occur because piping or ductwork is poorly insulated. According to one report, annual losses in a 100 feet of uninsulated pipe could waste as much as \$2400 (1980 dollars) worth of oil heat in a typical Washington, D.C., apartment house.(34)

Distribution systems can be improved mightily by checking and maintaining pumps and blowers periodically, by making small adjustments in the configuration of pipes or ducts, and by insulating piping and ductwork.

Besides taking these mechanical measures, managers of large buildings can make sure that the design water or air flow is not higher than necessary. It may well pay to convert a steady-flow system to one that--through the use of dampers or valves--reduces or increases the flow rate as heating needs change.

TABLE SIXTY-FIVE

ESTIMATES OF POTENTIAL ENERGY SAVINGS
FROM FURNACE-EFFICIENCY IMPROVEMENTS
(Residential Systems)

<u>Improvement</u>	<u>Estimated Energy Savings</u>
Furnace downsizing	10-20 MMBtu/yr ^{1,2}
Burner efficiency adjustments	5 MMBtu/yr ²
Convective stack dampers	20 MMBtu/yr ²
Variable-firing rate burner	30 MMBTU/yr ²
Hydronic reset	+ 10-15% seasonal efficiency ¹
Sealed combustion furnace	up to +5% seasonal efficiency ¹
Temperature reduction (to 65° - 68° F)	2%-4% fuel use/degree reduced ¹
Temperature setback (55°F 8 hr/day)	Up to 15% fuel use ¹

Sources:

1. MITRE, Energy Technologies for New England
2. OTA , Residential Energy Conservation

In two-way steam-distribution systems, efficiency can be improved by making sure that condensate return lines (pipes returning water that forms as steam temperatures and pressures drop) work properly. (In practical terms, this means checking for line blockages and pump malfunctions.) Since this water is already hot, converting it to steam requires less energy than converting city water at normal delivery temperatures. However, retrofitting one-way steam systems to allow condensate return may be prohibitively expensive except as part of complete building or heating-system rehabilitation.

Controls

Control adjustments are relatively straightforward in smaller buildings, but more complicated in larger ones. In most small buildings, a single central thermostat controls the heating system. Using a clock thermostat that automatically reduces the temperature setting at night and resets it as morning approaches can maintain comfort levels with less energy.

While larger buildings are likely to have more complicated controls, improvements to these controls are also likely to be commensurately more effective. Clock thermostats make sense in larger buildings--as do more expensive devices and techniques. One strategy is to reduce heating in empty offices or unoccupied areas of apartment buildings at night. Similarly, laundry rooms, rooms adjacent to boilers, and other areas where heat gains are unusually large need much less heat than other areas. In some cases, heat use can be balanced and overheating avoided if individual thermostats are installed in each dwelling unit or office, though such controls need to have automatic cut-offs at certain temperature levels or a centralized controller to prevent occupants from setting thermostats too high or forgetting to turn them down.

Control adjustments can be particularly effective in systems where heated and cooled air are mixed. Sometimes, lowering the delivery temperature of the heated air and raising that of the cooled air will mean that no mixing is necessary. Even when some is, efficiency improves as mixing decreases.

System Replacements and New Technologies

Nearly all the system adjustments just discussed could either be built into new heating systems or added on to those in operation. Primarily for economic reasons, many other technologies, though, are strictly for integration into new systems. Most of these technologies are development refinements of approaches used now, as the following discussion of representative approaches shows.

New Furnace Technologies

At least two new developments in furnace design may improve combustion efficiency markedly by 1990. One aims at varying the rate at which fuel is burned so as to match with heating loads of different sizes. This design allows steady-state operation at relatively low firing levels when heating needs are moderate but also permits greater fuel consumption in colder weather. A natural refinement of furnace downsizing, this system allows for close load tracking, in effect adjusting the furnace's "size" depending on the building's demand for heat.

For oil burners, one improved technology is a "fuel gun" for mixing oil and water droplets prior to combining oil and combustion air. Such pre-mixing reduces the amount of fuel needed by making all the oil droplets small enough to burn completely.

While these two approaches both aim at burning fuel more efficiently, others reduce the impact of heat losses. As noted, furnace heat losses usually occur through conduction (from the furnace's walls) or convection (through the flue). Some improved furnaces recapture and reuse heat that would otherwise be lost.

For example, a so-called thermally-purgable furnace now being developed uses circulating water to absorb heat stored in the furnace walls and transfers it to a holding tank. From there, the hot water would go to the heat distribution system or to the domestic hot water tank. In such a furnace, excess heat is absorbed by the circulating water. Because the system does not lose heat through conduction, it can be made of lighter and cheaper material than the steel or cast iron used now. Alternatively, liquid-to-liquid heat exchangers can be used to recapture heat contained in the flue gasses.

Akin to furnace downsizing is replacing a single central heating unit with smaller furnaces that could be brought into use incrementally as heating needs increase or dispersed to serve individual rooms or zones. This and the other technologies just mentioned probably will not be commercially available much before 1985,⁽³⁵⁾ and lack of operating experience makes it difficult to assess their future potential realistically. Thermally-purgable furnaces and some of the devices for recapturing heat from flue gasses seem most appropriate for hydronic distribution systems (although they could conceivably be used with forced hot air if a liquid-to-air exchanger were added to the system). As for variable firing, a reliable technique for lowering and raising the firing rate has

yet to be perfected. All designs for recapturing heat must pose solutions for corrosion caused by flue gasses and for scale build-up in heat exchange units. Modular furnace units will not be commercially ready for use in smaller buildings until near the end of the decade, although they can be used today in larger buildings requiring larger boilers.

In general, experience with multiple heating units in large buildings demonstrates that operations have to be controlled very carefully to avoid inefficiencies. Often, a slightly oversized furnace operating at full capacity is more thermally efficient and cost-effective than smaller units operating at partial capacities, especially if the multiple units require more complex controls.

Heat Pump Advances

In many parts of the country, air-to-air heat pumps are effective and economical alternatives to electric resistance heating. Heat pumps take heat from the outside air, raise its temperature, and transfer it to the house. (Heat pumps can also be used for cooling. Just as they can extract useful heat from the outside winter air, they can also remove heat from the inside summer air.) Most deliver about twice the amount of heat as the electricity they use contains. In technical language, this means that most heat pumps have seasonal coefficients of performance (COPs) of 2.0 for heating. For cooling, the seasonal COP is significantly lower than those of the newer central and room air conditioners available.(36) (See Chapter Ten.)

Although heat pumps have been commercially available for years, they have not been widely used. Questions about their reliability lingered and electric rates have until recently seemed low.(37) However, heat pumps are now beginning to appear in more new homes and commercial buildings. They are earning a positive reputation, they can be integrated with either hydronic or forced-air distribution systems on existing buildings, and they are now available in a variety of sizes.

Since air-to-air heat pumps draw heat from the ambient air, their usefulness varies somewhat with outdoor temperature, (efficiency falls with the outdoor temperatures.) For this reason, it often pays to increase the temperature of the heat source--by, for example, (where open land is available) ground-coupling heat pumps to take advantage of temperatures that tend to be warmer than ambient air in the winter months.(38) In industrial applications, heat pumps could use low-temperature waste heat as a heat source. It may in some cases be both efficient and economical to combine heat pumps with solar energy collectors. Whenever heat source temperatures are too low, heat pumps need to be backed up by another heat source, most commonly centralized electric resistance heating.

Most advances in heat pump technology are aimed at delivering more heat to the load or reducing the energy input or both. One approach is to make heat pump components more efficient. Heat pumps move heat to the indoors or outdoors through heat-transfer coils containing fluids that absorb or reject heat as temperatures and pressures change.(39) One way to improve the pump's efficiency is to make the heat-transfer mechanism more efficient either by increasing coil area or speeding up the rate at which heat is transferred to or from working fluids.(40) Where, for example, heat pumps are used for space heating only, coils and other components can be designed and sized for an optimal heating COP. (When heat pumps are used for both heating and cooling, however, design compromises are necessary.) A second general approach is to change the design fundamentally. For example, heat pumps that can operate on fossil fuels are now being developed. One gas-fired heat pump works on the principle of absorption rather than compression. In a conventional heat pump, the refrigerant rejects heat as pressure increases. In this new system, the refrigerant's latent heat is chemically absorbed by another fluid (the absorbent) so no compressor is needed. Natural gas could also be used to run heat engines that would in turn operate heat-pump compressors. In this system, less energy is needed to produce electric energy since high-level generation and transmission losses are minimal in "on-site" generation.

A different technique is to alter the design of the electric heat pump system. One alteration has replaced the fluorocarbon refrigerant fluid (used in vapor or Rankine thermodynamic circles) with air (Brayton Cycle). The advantage of this approach is that the heat transfer to and from the working fluid is not limited by the vaporization and boiling points of refrigerants.(41)

At least some versions of these advanced heat pump designs are or will soon be on the market. However, most analysts agree that improvements will be evolutionary, not revolutionary. The amount of heat energy delivered by a heat pump will continue to be limited somewhat by outside temperatures. Even as efficiencies improve, heat pumps will probably not be able to carry the entire heating load in extremely cold climates without some back-up. Then too, the improvements themselves may have technical or economic drawbacks. For example, using fossil fuels instead of electricity means that waste heat of use in the winter will need to be rejected in summer. These systems are also likely to be somewhat more complex and thus more vulnerable to operational problems than electrically powered ones. Finally, encouraging reliance on fossil-fuels instead of electricity may be unwise where electricity can be obtained from hydropower and other

renewable resources.

Heat Recovery Systems

Buildings that generate large amounts of waste heat make good candidates for using waste heat recovery systems. Such buildings include larger multifamily or commercial structures.

Most waste heat recovery systems use heat exchangers to transfer heat from an exhaust air stream or some other heat source to the forced air or hydronic heating system, usually before the air or water gets to the furnace or boiler. In effect, waste heat is used to preheat the distribution medium so less energy is needed to raise it to delivery temperatures.

Which type of system works best in a building depends on which type of heating system and heat source are used. Where a forced air heating system is used and supply and exhaust ducts are located close together, an air-to-air heat exchanger (which can transfer heat by direct contact) is the simplest option. A similar device, the rotary heat exchanger, uses a rotating drum or wheel installed between the two ducts to transfer both sensible heat and water vapor so the device can serve as both a preheater/precooler and a humidifier/dehumidifier.(42) While these systems are difficult to use if the exhaust air stream contains toxic or hazardous fumes, the problem can be minimized by including purge components in the drum or by adding special filters to the intake valve after the heat exchanger contribution.(43) Still, the hazards of exhaust air or the distance between exhaust and intake ducts may make using air-to-air or rotary heat exchangers impossible. In these instances, a preferable option is the so-called "run around" system, which circulates a working fluid between heat exhaust and intake air ducts. Like the other two systems, this one can enhance cooling in summer by transferring heat from intake to exhaust.

Heat can also be recovered from such liquid or vapor heat sources as grey water, hot condensate from steam distribution, or heated refrigerant gas. The basic process here is to circulate working fluid between two heat exchangers, connecting the water source and the heat distribution system.

Combined Heat and Power--On Site Cogeneration

Large-scale heat engines used in industrial facilities can "cogenerate" heat and power simultaneously. Smaller cogenerating units for use in smaller buildings are also beginning to appear commercially. Their use enables the building owner to obtain both heat and electricity from a single on-site system.

In the heating mode, these engines could work much as conventional boilers do, heating a liquid or air transfer medium that then circulates through the house. The critical difference is that part of the fuel input also runs an electric generator that provides on-site power.

Probably the first available residential-sized cogenerating unit is Fiat's Total Energy Module. TOTEM, the manufacturer claims, can cogenerate 15 KW of electric power and 133,000 BTU of heat at a 135 degrees F distribution temperature. The system's total fuel efficiency is 95 percent, compared with 60 to 75 percent for new gas furnaces and under 30 percent for most large power plants. The unit, packaged as a single module that can be installed easily in a basement, can be retrofitted to either forced-air or hydronic distribution systems. (Multiple units can be configured to provide heat and power to larger buildings.) It will be marketed in the United States starting in 1982.(44)

Another promising invention by Sunpower, Inc., uses a gas-fired Stirling engine both to drive a heat pump and to produce electricity. Essentially, this device simply improves upon the fossil-fueled heat pump by making on-site power production possible. The Sunpower Total Home Energy System should, according to the manufacturers, be available by 1984.(45)

(For more details on residential cogeneration units, see Part Three, Chapter Twelve, Electricity.)

Energy Management and Control (EMC) Systems

In many large buildings, different areas need different amounts of heat at different times and for different durations. Then too, many large facilities have their heating and cooling systems configured together. Accordingly, as noted earlier, some simple control adjustments can greatly improve building energy efficiency. However, the development of more elaborate control systems--some employing microprocessors and computers, is both new and exciting.

Different types of control systems are suitable for different types of buildings. The determining factors include building size and the nature of the heating, ventilating and air conditioning (HVAC) system. The simplest control systems can control the regular start-ups and shut downs of individual pieces of equipment according to pre-determined schedules. They can also help to optimize equipment operations based on climate conditions. More elaborate controls will manage several pieces of equipment or even several systems simultaneously. The most complete controls actually take over operations

of the buildings's or (in multi-building installations) the complex's energy system.

A computerized EMC system can control when particular building areas receive heat and how much heat they get. More sophisticated EMC systems use time- or environmentally activated controls in numerous locations throughout a building. For example, areas with south-facing windows may need less heat on a cold, clear day than on a cold, cloudy day but more heat on every cold day than does an area with no windows. Automated EMC systems can control heat distribution patterns based on these and other variables.

Sophisticated control systems can also monitor and adjust the operation of combustion and distribution subsystems. For example, an EMC system can oversee the operations of boilers, furnaces, or heat pumps in a central plant, indicating when, and often why, particular units need repairs.(46) Control systems can also manage the preheating (or pre-cooling) of intake air by a heat recovery technology and alter air or hydronic flow rates to track heating loads more closely.

The more elaborate HVAC control systems can even manage overall electricity demand so that buildings do not use expensive peak electricity unless absolutely necessary. To perform this "load shedding" function, the control system's computer traces current electricity consumption. When consumption surpasses a pre-set limit, the system shuts off unnecessary services or shifts consumption to uses that cannot be curtailed. (See Part Three, Chapter Twelve, Electricity.)

Economics of Heating System Improvements

The costs and cost-effectiveness of heating system improvements vary tremendously by applications. Because the systems installed in small and large buildings are of such different sizes and levels of complexity, it makes sense to discuss their economics separately.

Small Buildings

Some improvements in the combustion, distribution, and control subsystems are cost-effective for building owners no matter what kind of system is employed. As for which are most economical, that depends on the equipment's nature and condition and the building's location and size. The costs of various system adjustments vary widely, from less than \$25 (for furnace maintenance or simple oil-burner downsizing) to over \$500 (for adding variable firing rate burners).

The cost-effectiveness of furnace adjustments will also vary with the furnace type and the combinations of improvements made. (See Table Sixty-Six.)

Little has been written about the cost-effectiveness of combinations of heating-system improvements. But common sense can sometimes fill the void. Because nearly all furnaces are oversized and because furnace downsizing is relatively cheap, this improvement is virtually always cost-effective, and sometimes achieves payback in less than one year. For finding out whether more elaborate adjustments are needed, other criteria come into play. If, for example, a boiler or furnace is due for replacement (which most are after thirty years or so), installing an energy-efficient unit two or three years before necessary makes more sense than making a major improvement with a five-year payback.

The economic attractiveness of particular furnace or combustion improvements also depends on the heating load's size. In colder climates with longer heating seasons, more BTU are saved per year so paybacks are shorter. For example, a flame-retention burner that reduced fuel consumption about 16 percent would pay for itself in less than 18 months in a climate with a heavy heating load (for example, 90 MMBTU per year in Philadelphia) but not for nearly four years in a milder climate (for example, 30 MMBTU per year in Fresno.) Making shell improvements to reduce the overall heating load would also lengthen payback.

Improvements that require converting from one conventional fuel source to another should be evaluated carefully in view of the alternative--upgrading the efficiency of the existing system. The recent rash of conversions from oil burners to gas furnaces, for example, may not be cost-effective if natural gas prices are deregulated. By the same token, the economics of converting from electric resistance heat to an electric heat pump will depend on the costs of heat pump equipment, the extent of any alterations needed in the building's distribution system, and climate. Where it is very cold, seasonal coefficients or performance for heat pumps may fall below 2.0 and building shell improvements may be the better buy. However, converting from electric resistance heat to electric heat pumps may be a very good bargain in warmer climates. Thus, as part of its Energy Limited Plan, Seattle wants to encourage conversion from electric resistance heating to heat pumps.(47) TVA expects that a new heat-pump financing program will save between 4,000 and 7,000 Kwh (\$168 and \$294 (\$ 1981) per household) in some 60,000 homes by 1990.(48) Conversion from oil- or gas-fired units to electric heat pumps will probably be cost-effective only where fossil fuel prices are high and electricity relatively cheap.

TABLE SIXTY-SIX

ESTIMATES OF COSTS AND COST-EFFECTIVENESS OF SELECTED
HEATING SYSTEM IMPROVEMENTS-SMALL BUILDINGS

<u>Conservation Measure</u>	<u>Estimated Costs</u>	<u>Estimated Cost/Effectiveness</u>
Cleaning/Tuning	\$ 50	Less than one heating season ¹
Clock thermostat	\$ 60	1-2 heating seasons ¹
Downsizing	\$ 20 ^{1,2}	1-2 heating seasons ¹
Sealed combustion furnace	\$100-\$500 ^{1,2}	2-5 years ²
Electric convective stack dampers	\$200 ²	
Hydronic temperature reset	\$500 ¹	3-7 years ¹
Water-fuel emulsion gun	\$150-\$200 ²	
Condensing Flue - Gas		
Gas furnace oil	<u>New</u> \$1,100	<u>Retrofit</u> ² \$ 400
gas	800	300
Near-condensing oil	\$ 650	\$ 250
furnace gas	\$ 500	\$ 200
Variable firing-rate furnace	\$100-200 ² higher than conventional	
Thermally purgable furnace	\$400 (new) ²	

Sources:

1. MITRE, Energy Technologies for New England (1980)
2. OTA, Residential Energy Conservation (1979)

If retrofits can be timed to include shell conservation and furnace improvements, substantial energy savings and attractive paybacks or cash flows should be possible. If, for example, heavy insulation is added at the same time as solar features, oil- or gas-furnaces could be downsized significantly. Ostensibly, shell improvements could in some cases entirely eliminate the need for a central furnace, making it possible to obtain all of the heat from wood stoves, modular room-heating units, or water heaters large enough to supply heat space as well as water.(49)

In small buildings any distribution or control improvement short of completely reworking the distribution system is relatively inexpensive. For example, clock thermostats cost about \$60.00. Energy savings from these and similar improvements will result in swift paybacks.

Large Buildings

Improvements to large heating systems cost more than those to small systems, but resulting energy savings are commensurately greater too. Buying and installing an EMC system can cost upwards of \$200,000 for very large facilities. Nonetheless, the National Electrical Manufacturers Association (NEMA) and the National Electrical Contractors Association (NECA) claim that paybacks for such systems can be as short as two to three years.(50) A study by the Solar Energy Research Institute found that of twenty-five retrofits in larger commercial buildings, twenty achieved payback in less than four years and all did so within seven years.(51) For larger improvements, an engineering team should be called upon to make energy and economic analyses. Yet, such experts are not needed to assess the many system improvements that are almost immediately cost-effective in most large structures. For example, NECA and NEMA's guidebook for owners and managers of large buildings identifies one hundred and seventy eight separate heating-system conservation measures that can improve combustion, distribution, and control efficiencies at "minimal cost." (52) Some such steps involve improving regular operating practices and maintenance procedures; others, retrofitting boilers, furnaces, piping, duct work, or controls. The economics of higher-cost improvements, replacements, or additions, depends on three variables--the nature of the facility, the size of the heating and cooling loads, and the condition of the existing system. For example, installing a heat pump system may not be the best choice in a large building with high year-round cooling loads because cooling COPs for heat pumps are often less than those for central absorption or compression chillers. The same logic that applies to the choice between relatively major system alterations and system replacements in smaller buildings holds true here too. (See page xx-xx.) Decisions about high-cost system adjustments should be made only after the energy impacts and cost effectiveness of other building options have been weighed.

However, the building owner--and all heating-system improvements must be made by owners--may not be the best or only judge of the true economic worth of building energy retrofits. Some tenants pay their own utility bills directly, and most landlords who do pay for utilities can pass the costs on in the rent. Even if the landlord cannot recover all of his energy payments through rents, he can still deduct about half the total from his yearly taxes.(53) Then too, energy investments must compete with alternative investments, some with higher rates of return. All in all, few landlords will invest in energy conservation (or renewable energy) unless payback does not exceed three to five years or the annual internal rate of return after taxes equals at least 15 to 30 percent.(54) Thus, while many energy-saving techniques qualify as sound investments under this test, many other effective ones may not.

However, city officials may want to develop programs that encourage such improvements for a number of very good reasons. First, most large cities have many large buildings that consume considerable amounts of energy. Conservation retrofits could reduce energy consumption in typical commercial buildings from ten to 80 percent(55) - citywide, enough to enhance the city's energy stability considerably. Second, building owners are not always those most hurt by rising fuel prices. Poor people in larger residential buildings can ill afford direct or indirect increases in energy costs, and businesses occupying older, less energy-efficient buildings may be driven out of the city or into bankruptcy if fuel costs became unmanageable. Finally, many building owners do not have enough investment capital to take even cost-effective conservation measures.

For these reasons, city governments need to consider the "public side" of energy economics for larger buildings, however generally and subjectively. One simple way is to compare the costs per BTU of typical energy conservation measures with current or marginal costs of conventional fuel sources. In a small sample of larger buildings, the Solar Energy Research Institute found that of eight building retrofits, cost per million BTU saved were less than \$2.00 (1980) in six of them and no higher than \$6.00 in any.(56)

In contrast, average costs today for one million BTU of natural gas (at 46 cents/therm) are \$4.60. The equivalent of oil (at least \$1.26 per gallon) cost \$8.90, and electricity (at 6.5 cents per kilowatt hour) \$19.04.

CITY APPLICATIONS OF CONSERVATION MEASURES

Nearly all buildings need some improvements both to the building shell and to the heating system. According to surveys of existing one- to four-unit housing stock conducted in 1976 by HUD and DOE, about 50 percent of single-family homes and 70 percent of two- to four-family dwellings lack either storm windows or doors or attic insulation.(57) Presumably, even more have no wall insulation. Even though the reduced surface-to-volume area in larger buildings makes their shells relatively more efficient than smaller buildings, many of them do lack basic energy-saving features. (See Part One, Chapter Five, City Buildings.) The situation is much the same with heating-system improvements. Most existing smaller heating systems are oversized, and most larger ones are poorly managed.

City buildings do, nevertheless differ in terms of the relative effectiveness of building-shell versus heating system improvements and the kind of shell or system improvement that is most effective.

In most cases the choice of shell and heating, ventilating, and air-conditioning (HVAC) system improvements is not either/or, but rather a question of emphasis. For example, while most literature on energy conservation in larger buildings concentrates on upgrading the effectiveness of heating systems(58) the benefits of this move should not be pitted against those of basic shell improvements (caulking and sealing, better insulating the roof, and upgrading window efficiencies) which can also be substantial. Conversely, while heating-system improvements have proportionately more impact in larger buildings, upgrading makes sense in smaller structures too. OTA has, for example, pointed out that in some residential applications, improved furnace efficiencies could reduce heating energy consumption by 20 percent--the same effect as some major building shell conservation measures.(60)

Selecting the most appropriate shell-improvement technique requires knowledge not only of the types of energy-conservation measures already in place but also of the overall designs, materials, and conditions of different building types. Basic sealing and caulking measures can be easily applied everywhere, but adding roof insulation to buildings without accessible attics is quite difficult. Buildings with frame walls can have wall insulation blown-in, but masonry structures would require the "building out" approach--in effect, installing a new interior wall. Insulation - or window-improvements may be suitable for older buildings, but only on lower floors.

Similarly, which heating-system improvements prove feasible in different buildings depends not only on the condition of the existing system but also on its size and complexity. Thus, buildings with co-configured heating and cooling systems or with an assortment of area-specific heating demands could profit from installing even a relatively expensive energy-efficient control system.

Institutional Constraints

Materials and installation techniques used in building shell retrofits must meet normal building and fire code requirements, as must all the elements of heating-system improvements. Codes that require structural integrity or system safety are a help, rather than a hindrance, however since they at least minimally contribute to system quality and consumer protection.

How electric utilities react to large-scale shell upgrading efforts will depend partly on the utility's fuel and capacity situations, and partly on how many households make the changes, (See Part One, Chapter Six). In a computer simulation, OTA found that electric utilities would not be measurably affected by the widespread residential installation of insulation unless at least one third of the customers in the service area used electricity for space heating.(61)

Electric utilities probably will not react adversely to heating system improvements in oil- or gas-heated homes. Widespread conversions from electric resistance heating to electric heat pumps are a different matter, though electric utilities may support such conversions as part of load-management programs. For example, Seattle City Light is squarely behind Seattle's general conservation program, which includes some shifts from resistance heating to the use of heat pumps.

Socio-Economic Considerations

Since most low-income buildings are energy inefficient, great opportunities exist for reducing their energy consumption through fairly basic conservation retrofits. For example, fully retrofitting a five-story tenement in Lower Manhattan--including both shell conservation and heating-system improvements--will cut energy consumption by roughly one half.(62) A Philadelphia project to retrofit oil burners in low-income neighborhoods reaped savings of over 20 percent in some houses.(63) Insulating, caulking, and weatherstripping low-income housing in Fresno resulted in full savings of about 27 percent per dwelling unit.(64)

Still, the poor can afford few such improvements. The Urban Coalition of Minneapolis calculates that the average costs for a retrofit in its weatherization program was \$1,450, \$450 for materials and \$1,000 for labor.(65) A HUD study conducted by the Urban Institute indicates that basic shell retrofits (caulking, weatherstripping, clock thermostats, storm windows, and attic insulation) in single-family houses cost about one percent of the average annual income earned by families in the U.S. For families earning less than \$8,000 a year, however, the percentage of annual income needed to pay for these exact same improvements ranged from five percent in the East (where many houses already include some of these measures) to 14 percent in the West. (See Table Sixty-Seven.) Even the less expensive heating-system improvements can cost more than low-income persons can pay, and more extensive changes are out of the question economically unless financial assistance is available.

Moreover, in many low-income buildings, it is pointless to retrofit the shell unless the structure is rehabilitated--a considerable additional cost. Heating equipment, too, may have to be overhauled before efficiency improvements can be made. A building retrofit project in Philadelphia found that many oil burners in low-income houses had to have their flues rebuilt or replaced. A similar effort for low-income housing in Memphis found that heating-system repairs or replacements were essential in many homes before any further retrofits could proceed.(67)

Another factor is that many conservation measures appear substantially less attractive to those who rent homes or commercial space than for those who own either.

For these reasons, public action is needed to offset the barriers posed by income and tenure to energy conservation in urban buildings. (See Part One, Chapter Seven.) The case for municipal involvement appears all the stronger when some of the city-wide benefits that can result from such public action are taken into account.

The opportunities for massive energy savings in low-income or rental buildings have already been stressed. Besides their potential to reduce energy consumption markedly, widespread energy conservation retrofits also create a market that new or expanded energy-conservation businesses can serve, supplying jobs for unemployed or underemployed city residents in the process. By investing a minimum of \$200 per household in a city-wide conservation and heating-system improvement effort, cities could create an impressive number of jobs. Some studies suggest that up to jobs could be generated nationally by 1990.(68) Moreover, the job skills needed for installing shell and heating system conservation improvements are likely to be less complicated and to require less extensive training efforts than those needed for solar energy installation. For example, the Institute for Human Development in Philadelphia was able to train unemployed city residents to tune up and repair oil furnaces and to inspect and improve oil burners in some low income areas.

TABLE SIXTY-SEVEN

COSTS OF DIFFERENT RETROFIT PACKAGES
AS A PERCENTAGE OF INCOME FOR OWNER-OCCUPANTS--
SINGLE-FAMILY HOMES

(Nationally and Regionally)

	<u>National</u>	<u>Northeast</u>	<u>North Central</u>	<u>South</u>	<u>West</u>
<u>Package One</u>	1%	1%	1%	1%	1%
Annual income less than \$8,000		3%	3.5%	3%	3%
\$8,000-\$25,000		1%	1%	1%	1%
\$25,000 and over		0.5%	0.5%	0.5%	0.5%
<u>Package Two</u>	1%	1%	1%	1%	3%
Annual income less than \$8,000		5%	6%	5%	14%
\$8,000-\$25,000		1.5%	1.5%	1%	4%
\$25,000 and over		0.5%	0.5%	0.5%	2%
<u>Package Three</u>	6.5%	5.5%	6%	7.5%	7%
Annual income less than \$8,000		25%	26%	30%	32%
\$8,000-\$25,000		6.5%	7%	8.5%	9%
\$25,000 and over		3%	3%	3.5%	4%

1. See Table Sixty-Two for descriptions of measures included under each package.

Source: Urban Institute, (1980), p. 124.

SOLAR ENERGY AND ENERGY CONSERVATION

Solar heating might appear fascinating but unnecessarily sophisticated in view of the startling effectiveness of energy conservation techniques and approaches, the high first costs of some solar technologies, and the need for a back-up system in most solar homes. Yet, even after the vast savings possible through conventional energy conservation, solar heating constitutes an important addition--even an economical alternative in some cases--to some of the more extensive energy-conservation measures. Certainly, many buildings could be heated most cheaply if strict conservation measures were applied without adding solar energy techniques and devices. But combining the two is in many cases the ideal.

More specifically, six factors can make a conservation and solar match worthwhile. First, using renewable energy techniques allows a building to be a "safe" energy producer, meeting much of the "post-conservation" energy demand without causing pollution or depleting scarce resources.

Second, in some cases, a package of solar equipment or designs and moderate conservation measures may be more economical than extensive conservation measures alone. A computer simulation done by Los Alamos Scientific Laboratories (LASL) indicated that energy conservation retrofits (including multiple glazing and insulation) costing up to \$1,700 were preferable in the Midwest to an equal investment in passive solar heating, but that a mixed "conservation plus passive solar" strategy was best in most situations if larger investments were in the offing.(69)

Third, under certain utility rate structures solar systems may be better able to replace expensive peak electricity than strict conservation measures alone. For example, the Public Service Company of New Mexico monitored energy consumption in eleven solar homes, comparing results with consumption figures from well-insulated homes using electric resistance heat or electric heat pumps. The utility found that the passive homes consumed less energy than either of the other two during peak periods. If a time-of-day rate were developed, the utility predicted, an average passive home's seasonal heating costs would have been \$50 less than an average electric resistance home and \$90 less than for a home using an electric heat pump.(70)

Fourth, the line between energy conservation and solar energy techniques is sometimes thin. For example, many of the new window technologies described earlier can be used in passive solar energy systems. Heat pumps also combine conservation and renewable energy approaches since they use naturally heated ambient air as a heat source.(71)

Fifth, further developments in certain energy-conservation technologies may improve their economic appeal. If, for example, small furnace technologies are measurably improved, it may be possible to combine solar energy features, conservation measures, and a substantially smaller furnace into a total heating system that is cheaper than one using heavier conservation measures, no solar features, and a bigger furnace.

Finally, some buildings are so well suited for solar energy technologies that solar deserves special consideration. Buildings in sunny but cold climates, buildings that easily lend themselves to a passive solar retrofit (such as those with large areas of south-facing masonry walls), buildings that need heat primarily after peak solar energy collection periods, and buildings with such expensive back-up energy systems as electric resistance heat are all prime candidates.

So various are the possibilities of course, that no single assessment of the merits of combined solar energy and energy conservation approaches is possible. But the technical overview and evaluation criteria set forth here should provide urban officials with a solid basis for decision-making.

Technical Approaches

Despite the basic differences between active and passive solar heating systems, both types perform essentially the same functions. Both collect solar heat and either distribute it to the house immediately or store it for use as needed.

Passive systems distribute heat to a building by non-mechanical methods--heat conduction, convection, and radiation--while active systems use mechanical devices such as pumps and fans. Thus, most passive solar energy system "components" are parts of the buildings structure that have been modified but that continue to serve some structural purpose besides collecting or moving heat. In contrast, active solar system components are pieces of hardware or equipment--solar collectors, storage tanks, heat exchangers, and the like.

Passive Solar Heating

Thousands of U.S. buildings now use passive solar heating systems, and tens of thousands additional "sun tempered" buildings collect (though not store or distribute) heat through large expanses of south-facing glass.

The first such buildings were built by "solar pioneers" or, later on, by forward-looking architects and builders. Now, however, tracts of houses and clusters of offices with passive heating are appearing in all parts of the country. For example, the last Residential Solar Demonstration grants made by the U.S. Department of Housing and Urban Development (HUD) supported the construction of 91 house designs that tract developers could use,(72) and the U.S. Department of Energy (DOE) is supporting the construction or retrofit of passive heating systems in 30 typical commercial buildings of varying dimensions.(73) Billing itself as "America's First Solar-Assisted Business Center," a (privately funded) 45-acre light industrial/office park in Laguna Niguel, California, will make extensive use of energy-conserving designs and both passive and active solar heating.(74)

Types of Passive Systems

Direct Gain

Perhaps the simplest passive solar approach is to keep a living space warm by admitting solar energy directly through south-facing glass and storing some of the heat for use later in dark-colored mass walls or floors of tile, brick, or masonry. In most passive systems, heat is distributed to other parts of the building by means of carefully placed walls, doorways, and staircases that facilitate natural heat flow. Occasionally, a separate air plenum specifically designed to move collected solar heat from one end of the building to the other is added.

Two potential problems endemic to direct gain systems are heat loss at night or on cold, cloudy days through the glass surface and overheating of the living space, especially in the summer. Both problems can be avoided or minimized rather easily, however.

Heat losses can be cut by using more efficient glass. Passive buildings that employ conventional window glass will need double glazing (triple-glazing in cold climates). As noted, many innovative glazing materials that both allow increased transmissivity of solar energy into the buildings reduce conductive heat loss are now available. So is movable insulation, which most direct gain systems employ.(76)

Movable insulation (including thermal shutters) or reflective shades also prevent excessive heat gain, though at the cost of some sunlight and an obstructed view. Alternatively, overhangs specified in the building design can shade the glazing from excessive heat gain in the summer, yet allow full exposure to sunlight in winter. Vents in the glazing are another means of shunting out excess heat.

Indirect Gain

An indirect-gain system interposes an absorption and storage component between the glazing and the building's interior. Typically, this storage component is a mass (Trombe)(77) wall made of grouted cement blocks or some other type of masonry, or a water wall composed of single-or multiple containers of water. Usually, both the mass wall and the water containers are painted flat-black to help increase absorptivity. In new buildings, the storage wall can be inside the building shell with the glazing surface and framing serving as the building's exterior. In some designs, the building's exterior wall absorbs and stores energy--an appealing feature in retrofits, where glazing covers the existing brick or concrete exterior.(78)

Indirect gain systems run less risk of overheating than most direct gain designs. They are also somewhat more flexible in terms of heat distribution. If necessary, collected heat can be distributed immediately to the building through vents at the top and bottom of the wall. Air heated in the space between the wall and the glazing rises and exits through the vent to the living space. Circulation stops only when the temperature of the air between the wall and the glazing roughly equals that in the living space. When heat is not needed immediately, the vents can be closed.

Whether or not collected solar heat is used immediately, it can be distributed much as the heat collected in a direct gain system is. Additionally, plenums aided by small fans can also be used to connect the space between the glazing and the storage wall with areas farther from the glazing.

Indirect gain systems must also feature mechanisms for preventing heat loss at night (which occurs through what amounts to a reversal of the heat collection process) and overheating in the summer. Generally, the best means are those used to prevent these problems in direct gain systems--using insulation glass, installing movable shutters and shades, and using overhangs and vents.

The general effectiveness of indirect gain systems and the ease with which they can be installed are both being improved. Under development now are various modular wall units that combine glazing, absorption, and storage components in single packages. Most are sized so that they can be combined into fairly large (300-400 square feet) configurations or used in smaller designs.(79)

Some manufacturers are also developing mass wall units that make use of a phase-change storage medium--salt compounds or other materials that melt as they gain

heat and release heat as they recrystallize. Such materials tend to absorb much more heat per unit volume than water or masonry materials, so less space is needed for the storage component. These phase-change materials can be incorporated in packaged collector/storage wall systems in numerous ways. One design includes a pouch of phase-change storage within the cavity of a concrete block, while another features phase-change material in plastic rods.(80) Phase-change storage materials are also beginning to appear in conventional-looking building materials that can serve another function besides storing heat (for example, ceiling panels or floor tiles). This development makes phase-change storage useful in both direct gain or isolated gain systems.(81)

However, while indirect gain components can be prepackaged, they need not be. All can be assembled at the building site using conventional construction materials. Mass walls, for instance, can be built of conventional concrete blocks; and some water wall systems use drum barrels painted flat-black for storage.

Isolated Gain - Sunspaces

Both direct and indirect gain systems collect and store solar radiation in a portion of the heated space. In isolated gain systems, the difference is collected in an area that is not part of the building's mechanically conditioned space.

The most common type of isolated gain system is the sunspace--some form of greenhouse or, less commonly, an unheated atrium. A very different type of passive system that operates on isolated gain principles is the thermosyphoning air panel. (See next section.)

Sunspaces collect solar heat through south-facing glass, then store it in the floors or in the wall separating the sunspace from the living area. Stored heat can be distributed via radiation or convection from a vented mass wall into the house proper, via conduction through a storage mass floor extended from the sunspace under the adjacent conditioned area or via convection through air plenums.

A more elaborate version of this last approach is the so-called "double envelope" design. Essentially, this solar approach to new housing is based on the construction of two building shells, the outer one heavily insulated. The interstice is used to move heat collected by an integral greenhouse located on the building's south side. Air heated in the greenhouse rises to the top of the space where it enters a plenum extending upward through the roof, down the north wall, under the flooring and back to the greenhouse--bathing the interior walls with greenhouse-heated air.

As in all solar gain systems, the design of and materials used in a sunspace system must prevent nocturnal heat loss and summer overheating. Thus, in all but the mildest climates, sunspaces or greenhouses using window glass, acrylic, or fiberglass must be at least double-glazed. (The thermally efficient glass products available for direct and indirect gain systems can also be used in sunspaces.)

It is usually difficult to fit an attached greenhouse with an overhang suitable for preventing heat gain, but the greenhouse structure itself can be used to control heat penetration. Unfortunately, most attached greenhouses have sloping roofs, so they are vulnerable to large amounts of summer sun. Sometimes, a portion of the roof is permanently covered and insulated. In other designs, movable shutters or shades that can be partially drawn in the summer or fully closed at night or on cloudy days are used. Reflecting shutters and blinds can also be well utilized in the summer in sunspace systems, keeping excessive heat out, while allowing adequate light to enter. Largely made of glass and thermally isolated from the house, greenhouses may be more vulnerable than direct or indirect gain systems to overheating. Especially in hot, humid climates (where moisture builds up) vents in the glazing are needed.

Since so many sunspace designs use greenhouses, a relatively large industry now manufactures components for greenhouse construction--glazing materials, molded movable insulation, blinds and reflectors, and storage components--as well as packaged greenhouse kits.

Increased availability aside, however, even greenhouse retrofits using preassembled parts can seldom be justified economically on the basis of energy savings alone.(82) For one thing, much of the heat gained by the greenhouse will be used to heat the added space. Yet, the addition of attractive living space and the opportunities for cultivating plants and foods provide incentives too.(83) Where costs are a major factor, less expensive greenhouses can be assembled on-site using conventional, inexpensive building materials. For example, the Charlotte (North Carolina) Area Fund, Inc., used single-pane recycled windows for collectors and ordinary construction gravel and 65-gallon water drums (painted black) for storage in one of its greenhouse retrofit projects.(84)

Isolated Gain--Thermosyphoning Air Heaters

In some ways, this system represents a radical departure from other passive solar designs. Instead of using glazing in the building shell to collect solar energy, it employs modular flat-plate solar collectors mounted vertically on wall surfaces or at

angles sloping from the walls to the ground. As the collector panels heat air, it flows upward by natural convection and enters the living space through vents or ducts. At the same time, cooler air flows back to collectors through a vent that connects the bottom of the collector to the heated space.

The advantage of this kind of system is that it allows a much easier retrofit than most other passive designs. The collectors can also be configured in large arrays to heat bigger areas or in smaller arrays of one or two panels to heat single rooms.

The simplest version of this panel simply channels solar heat into a living area. More complicated storage- and distribution-techniques can also be used, depending on how the building's interior is designed and whether interior remodeling is acceptable. (Overheating and nighttime heat loss can be prevented by tight-fitting dampers in the inlet and outlet vents.)

Factory-built panels are available for use in these systems. Alternatively, panels can be site-assembled using fairly common (and fairly inexpensive) building materials. Vertical-wall collectors represent one of the most common urban retrofits in use. Indeed, the Urban Solar Energy Association (USEA) in Boston plans to sell a kit for assembling a thermosyphoning air panel for around \$400.(85)

Earth Sheltering

Strictly speaking, earth sheltering is not a passive solar heating system. Rather, it is a design and construction technique that works well in combination with passive solar design. Earth sheltering can also be used to enhance energy conservation in non-solar buildings.(86)

In Earth-sheltered design, earth serves as a barrier against wind and violent weather even as it moderates temperature fluctuations in the ambient air. Thus, infiltration heat losses are reduced, conduction heat losses through ceilings and/or walls are minimized, and the heat-storage capacity of the building is improved.

Various earth-sheltered designs are in use today. In some, relatively small mounds of earth are compacted against walls ("earth berming"), while in others walls and roofs are recessed several feet underground. Earth sheltering combines best with passive solar heating in buildings whose north walls are covered partially or wholly by earth, and one of the passive solar heating systems discussed above is used on the south side.

The chief technical concerns in earth-sheltered construction are ensuring adequate structural strength and preventing moisture accumulation and water penetration. Techniques for doing both are well-established, although they each require careful attention to construction details. The structural integrity of earth-sheltered housing can be guaranteed by employing materials that have greater mass than those used in normal building construction (that is, concrete and heavy timber instead of conventional masonry and lumber). Earth-sheltered housing can be waterproofed through careful use of vapor barriers and other sealing techniques.

Passive System Performance

Because many of the earliest passive solar buildings were built for private clients (often the architects themselves), performance data from systematic monitoring of passive solar homes has only recently begun. Then too, most solar applications--including many of the systems funded under HUD's Cycle Five Demonstration Grants--combine more than one system type.

These considerations make it particularly difficult to draw conclusions about or compare differences in performance among system types, let alone in different building types or climates. It is unarguable, however, that good passive solar heating systems can be strikingly effective, especially in new buildings. Indeed, performance monitoring of a few passive houses built with HUD grants in the late 1970s indicates that passive solar energy is meeting from 75 to 80 percent of the annual space-heating loads.(87) (See Table Sixty-Eight.) At least a general indication of system potential can also be inferred from predicted or computer-simulated performance figures, which are becoming more reliable as computer programs and other design tools are improved. (See Tables Sixty-Nine and Seventy.)

Assessing passive solar potential in existing buildings is harder. The interior and exterior design, the material characteristics of the building (unless a major rehabilitation is contemplated), and the building's pattern of heating demands must all be taken into account. For example, a mass wall retrofit of a Washington, D.C., commercial building (which uses more heat in the late afternoon and early evening than in the late evening) meets about 60 percent of the building's yearly heating needs,(88) partly because heating demands are lower at night when less solar energy is available. Other buildings less suitable structurally for large-scale retrofits and more in need of heat after dark will not be able to obtain such impressive results. The solar contribution in a renovated low-income apartment building in St. Johnsbury, Vermont, using fish-tank storage behind south-facing windows, prediction is only about 12 percent annually, though this approach is so cheap that the heat is a good buy.(89) Just how different the contributions from passive solar retrofits can be from one building to

TABLE SIXTY-EIGHT

MEASURED PERFORMANCE OF SOME PASSIVE SOLAR HOMES
(Single-Family - New)

<u>Installation Location and date completed</u>	<u>Percentage of Building Heating Energy Use Provided by Passive Solar</u>
Sommersworth, NH (1979)	66%
Ames, IA (1979)	32%
Prescott, AZ (1978)	81%
Royal Oak, MD (1976)	79%
Atascadero, CA (1976)	100%
Santa Fe, NM (1976)	96%
Bozeman, MT (1977)	85%
Yakima, WA (1977)	63%
East Pepperell, MA* (1979)	35%

* Super-insulated house with very low heating load.

Source: A New Prosperity (1981), p. 85

TABLE SIXTY-NINE

PREDICTED PERFORMANCE OF PASSIVE SOLAR DESIGNS FOR NEW TRACT HOUSES
(HUD Residential Solar Demonstrations)

<u>Location</u>	<u>House Type</u>	<u>House Size (net htd. area)</u>	<u>House Price</u>	<u>System Description</u>	<u>Heating Load</u>	<u>Predicted Solar Fraction</u>
Roswell, GA	rustic, contemporary, 2 story, earth-bermed	1823 sq ft	\$ 72,500	trombe wall, roofing air collector	44.2×10^6 Btu/yr	76%
Carrboro, NC	2 story, contemporary	1304 sq ft	70,000	greenhouse, vertical wall collector skylights	39.1×10^6 Btu/yr	41%
Huntsville, AL	2 story, contemporary	2000 sq ft	79,500	2 trombe walls, central atrium	56.2×10^6 Btu/yr	23%
Mat-su Borough, AK	2 story, earth-bermed	1466 sq ft	85,000	2 story greenhouse, trombe wall	57.9×10^6 Btu/yr	62%
Gaithersburg, MD	2 story contemporary	2737 sq ft	190,000	2 story atrium, skylights	91.2×10^6 Btu/yr	27%
Myersville, MD	2 level earth- sheltered	2036 sq ft	120,000	greenhouse, clerestory windows	46.1×10^6 Btu/yr	63%
Shelton, CT	2 story Cape Cod	1900 sq ft	85,000	2 story greenhouse, active air collectors	61.9×10^6 Btu/yr	49%
Putnam Valley, NY	ranch style, earth- bermed	1473 sq ft	60,000 + land	thermopane south wall, clerestory windows	42.0×10^6 Btu/yr	90%
New York City, NY	2 story contemporary	2550 sq ft	125,000	2 greenhouses with trombe wall backing; clerestory windows	146×10^6 Btu/yr	38%
East Wilton, ME	salt box, earth- bermed	1204 sq ft	55-60,000	trombe wall, triple glass	65.8×10^6 Btu/yr	71%
Turner, ME	2 story Cape Cod	1320 sq ft	85,000	2 greenhouses, skylights	68.7×10^6 Btu/yr	45%
Kent, OH	2 story contemporary	2158 sq ft	130,000	greenhouse, south aperatures	76.2×10^6 Btu/yr	46%
Ypsilanti, MI	2 story contemporary	2460 sq ft	123,000	2 story greehouse, backed by trombe wall	134×10^6 Btu/yr	51%
Walden, CO	3 bedroom contemporary	1660 sq ft	75,000	greenhouse	168.3×10^6 Btu/yr	36%
Truckee, CA	octagonal, earth- sheltered	1650 sq ft	140,000	greenhouse, floor-to- ceiling windows	63.2×10^6 Btu/yr	86%
Springfield, OR	contemporary ranch house	1719 sq ft	100,000	greenhouse, trombe wall, skylight	64.8×10^6 Btu/yr	60%
Pocotello, ID	2 story contemporary, earth bermed	2662 sq ft	92,000	greenhouse, trombe wall	106.6×10^6 Btu/yr	77%

TABLE SIXTY-NINE

PREDICTED PERFORMANCE OF PASSIVE SOLAR DESIGNS FOR NEW TRACT HOUSES
 (HUD Residential Solar Demonstrations)

<u>Location</u>	<u>House Type</u>	<u>House Size (net htd. area)</u>	<u>House Price</u>	<u>System Description</u>	<u>Heating Load</u>	<u>Predicted Solar Fraction</u>
Santa Fe, NM	contemporary adobe	1583 sq ft	\$ 85,000	double-glazed panels, active air system	90.0×10^6 Btu/yr	83%
Tucson, AR	3 bedroom rambler	2632 sq ft	167,000	sliding glass doors, skylights	71.4×10^6 Btu/yr	70%
Santa Rosa, CA	2 story, double envelope	1815 sq ft	169,000	greenhouse	30.1×10^6 Btu/yr	80%

Source: HUD Project Summaries (1980)

TABLE SEVENTY

PREDICTED PERFORMANCE OF PASSIVE DESIGNS FOR NEW COMMERCIAL BUILDINGS (DOE)

Location	Building Description	Heated Space S.F.	System Description	Heating Load MMBtu/yr	Solar Frac. %
Troy, NY	Single story contemporary visitor center.	4,316	Large sunspace with thermal storage in its walls and floor upper section serves as warm air plenum. Skylights on north side provide natural daylighting.	166.8	64
Syracuse, NY	Three story educational building.	47,000	Super insulated (roof R-80, walls R-30) and earth bermed where appropriate. Three different reflector aided daylighting systems providing some heat as well. Air-to-air heat exchanger ventilation.	88.0	51
Princeton, NJ	Single story contemporary office bldg.	64,000	Three sets of large atriums provide heat and daylighting. Atrium heat drawn to basement rock bed for storage. Unvented water wall serves as a thermal mass and absorber.	3084.8	72
Philadelphia, PA	Three story program center.	5,100	1170 sq ft trombe wall supplies heat to the main gathering space. 500 sq ft of glazing along south wall for direct gain.	200.0	50
Alexandria, VA	Single story auditorium/gymnasium	8,900	Two nonconvecting trombe walls tapered in thickness from 8" at bottom to 4" at top. Two linear clerestories admit light absorbed by walls and floor. Thermosiphon DHW tied to trombe wall.	127.0	52
Mt. Airy, NC	Single story contemporary public library	13,570	Shaded clerestories equipped with light shelves provide heat and daylighting. South glazing comprises 17% of gross floor area (1" insulating glass). Concrete roof, floors, and masonry walls provide storage.	83.0	50
Memphis, TN	Single story double shed type greenhouse Board and batter siding.	6,000	Design allows for clerestory effect. Vaulted skylights on sloped roof. South side lined with sliding glass doors. Back-up heat from a bin of decaying organic matter, heat ducted through plenum.	250.0	90

TABLE SEVENTY
(Continued)

Location	Cooled Space S.F.	Cooling Load MMBtu/yr.	Solar Frac. %	Lighting Load MMBtu/yr.	Solar Frac. %	DHW Load MMBtu/yr.	Solar Frac. %
Troy, NY	4,316	12.7	80	36.0	61	NA	NA
Syracuse, NY	47,000	39.0	NA	432.8	21	17.3	29
Princeton, NJ	64,000	2393.6	88	2272.0	76	742.4	50
Philadelphia, PA	-0-	-0-	NA	10	-	15.6	50
Alexandria, VA	8,900	87.1	100	68.6	65	87.9	26
Mt. Airy, NC	13,570	161.0	51	118.0	6	.002	55
Memphis, TN	6,000	250.0	60	-0-	99.9	-0-	NA

TABLE SEVENTY

(Continued)

Location	Building Description	Heated Space S.F.	System Description	Heating Load MMBtu/yr	Solar Frac. %
Bessener, AL	Single story contemporary public school	27,452	Rooftop clerestories provide heat and daylighting to each of 18 classrooms. Water-filled cement pipes beneath the clerestories absorb radiation and prevent glare.	326.5	45
Columbia, MD	One story church educational bldg.	5,493	Each of the building's 3 sections is equipped with a large clerestory with light shelf attached, and insulating shades. Insulated masonry walls serve as thermal mass.	62.1	45
Wells, MN	One story modified "v"-shaped bank bldg.	5,538	2240 sq ft of double glazing on south and southeast walls. Clerestories above the offices and lobby. More daylighting provided by lower windows along teller and bookkeeping wings. Gypsum ceilings, walls, concrete floors.	334.0	67
Grand Junction, CO	Two story airport terminal.	66,700	3380 sq ft of south clerestory contributes light and heat. South windows below admit radiation absorbed by mass floor. A vented trombe wall heats car rental area. South wall acts as hybrid collector.	1,239.0	24
Littleton, CO	Three story contemporary office bldg.	17,950	Glare free daylighting provided by a daylight space above a translucent ceiling. Considerable south glazing with insulating shades. When shades down, air channelled to ceiling plenum and convective loop.	301.1	40
Glenwood Springs, CO	Three story college multi-use facility.	26,948	Built into hillside. Large atrium acts as a collector from which all zones draw heat. Black DHW preheat tanks suspended in atrium. Clerestory windows and trombe walls in several zones. Greenhouse with water column storage in one zone.	578.4	56

TABLE SEVENTY
(Continued)

<u>Location</u>	<u>Cooled Space S.F.</u>	<u>Cooling Load MMBtu/yr.</u>	<u>Solar Frac. %</u>	<u>Lighting Load MMBtu/yr.</u>	<u>Solar Frac. %</u>	<u>DHW Load MBTU/yr.</u>	<u>Solar Frac. %</u>
Bessener, AL	27,452	240.3	17	235.9	25	7.6	NA
Columbia, MD.	5,493	14.5	11	21.4	11	NA	NA
Wells, MN	5,538	146.0	20	255.0	65	1.5	NA
Grand Junction, CO	66,700	688.0	100 with evap. cooling	1,084.0	50	52.0	-
Littleton, CO	17,950	164.4	50	235.0	NA	-	NA
Glenwood Springs, CO	31,037	49.3	81	478.0	44	101.1	40

TABLE SEVENTY
(Continued)

<u>Location</u>	<u>Building Description</u>	<u>Heated Space S.F.</u>	<u>System Description</u>	<u>Heating Load MMbtu/yr</u>	<u>Solar Frac. %</u>
Gunnison, CO	Two story airport terminal.	9,703	A distributing trombe wall (non-convecting) supplies heat to all terminal zones. Insulating shade prevents seepage. 160 sq ft clerestory storage in concrete slab floors, though primarily direct gain.	377.3	51
Missouri City, TX	Single story community center.	3,456	Structure built partially beneath the 70° F. earth. Clerestory windows provide some heat, but their primary function is daylighting, in combination with the north windows.	22.0	27
Irvine, CA	Single story elementary school.	40,000	Partial earth berming and large clerestory windows. (Many original passive features re-evaluated.)	275.0	18
Deadwood, OR	Single story contemporary community center with large octagonal mtg. rm.	2,635	Direct gain through south windows and clerestory. Skylid shades to be added to clerestory. Concrete filled masonry walls of meeting room act as thermal mass. Trombe wall with insulating curtain.	60.0	81
Albany, OR	Single story Mennonite health care facility.	35,000	A trombe wall with automatic insulating curtain provides heat. Static thermal storage walls in south rooms with insulating curtains. Clerestory supply light to corridors, storage in masonry walls.	249.6	45
Fairbanks, AK	Single Story 9-room school bldg., comprised of individual, modular rms.	each room: 600	Originally submitted as a portable classroom. South glazing, exterior night insulation, automatically adjusting daylighting system all to be included (R-15 shutters).	43.0	46

TABLE SEVENTY

(Continued)

Location	Cooled Space S.F.	Cooling Load MMBtu/yr.	Solar Frac. %	Lighting Load MMBtu/yr.	Solar Frac. %	DHW Load MMBtu/yr.	Solar Frac. %
Gunnison, CO	9,703	-	-	-	-	-	-
Missouri City, TX	3,456	34.0	44	20.0	60	80.0	80
Irvine, CA	40,000	1,070.0	18	650.0	50	-	-
Deadwood, OR	2,635	71.0	100	70.0	66	14.0	50
Albany, OR	35,000	-	-	274.0	-	275.0	52
Fairbanks, AK	200	-	-	11.1	-	NA	-

Source: U.S. DOE (1981)

another is indicated by projected savings from HUD grants for passive retrofits in multifamily buildings and DOE grants for passive additions in commercial structures. (See Tables Seventy-One and Seventy-Two.)

Generally, in both new buildings and retrofits, a passive system's effectiveness can be increased, or the costs of supplying a constant percentage of the heating load via passive solar can be decreased, if stricter energy conservation measures are taken. Yet, there is little experience on the direct effects of strict conservation measures on passive solar performance or costs, principally because most buildings with passive solar heating have had conservation measures installed at the same time. However, the importance attached to strict conservation measures in passive urban retrofits is apparent in the energy conservation measures chosen in residential retrofit designs funded by HUD and in commercial retrofit designs funded by DOE. (See Tables Seventy-Three and Seventy-Four; also see Economics, below.)

Although no serious performance or reliability concerns have emerged, limited experience has identified some design factors that substantially affect passive system performance. One potential problem is overheating, especially in direct gain and sunspace systems. For example, some overhangs positioned to provide shade at the summer solstice (June 21) are not at the right angles to work when the sun angles are lower, and some passive systems that do not have movable insulation often overheat during the day and then lose excessive amounts of heat at night.(90)

Another observed problem in passive systems has been the inadequacy of heat-distribution techniques in some designs. Sometimes this problem stems from poor interior structural layout or from attempts to move heat over long distances without the aid of fans. This criticism has been levelled particularly often at double envelope designs, some of which apparently do not move heat from the south to the north sides as efficiently as designs calling for ducts do and also heat the east and west sides of buildings inadequately. In any event, reservations about various passive distribution techniques can only be justified or refuted as experience accumulates.

Active Solar Heating

Active solar space-heating systems are neither as widely used nor as technically well developed as active solar water heaters or some types of passive solar space-heating systems. But thousands of active solar space-heating systems--many of them government-funded--are in use across all areas of the country.

Active solar space-heating systems can be viewed as larger and more complicated versions of active solar water heaters. (In fact, most heat water too.) In all, solar energy is collected by panels and moved by pumps or fans either directly to the building or, more often, to a storage container. From storage, solar heat is transferred to the building's heating system as needed. Auxiliary energy from a conventional furnace, an electric resistance unit, or a heat pump boosts distribution temperatures if the solar contribution alone cannot meet the buildings's heating needs.

Differences in active heating systems, all of which work this way, relate to the temperatures the collectors can reach, the transfer medium used, and the centralization or decentralization of the storage system.

Flat Plate Collectors

Metal Surfaces

Most active solar space-heating systems sold today use active flat-plate collectors with metallic surfaces. These collectors can deliver temperatures exceeding 180 degrees F to storage--more than adequate for space heating most buildings.

Two basic types of flat-plate systems are common. One uses a liquid solution for heat transfer; the other, air. Which collector, storage, transport and distribution components these systems use is determined by the type of transfer fluid used.

Liquid space-heating systems used the same collectors that active water-heating systems use. (See Chapter Eight.) In air systems, metal absorbers (usually sheet metal or aluminum) are crossed with ductwork that allows the transfer medium to flow across the collector surface. Different levels of glazing and different selective absorber coatings can be used in both air and liquid collectors. (See Chapter One.)

Both air and liquid flat-plate collectors can be purchased in modular, factory-built units assembled or built on site. The metal absorber plates, metallic or wooden framing and backing, glazing, and insulation that make up liquid collectors can be put together on-site. Most site-built air collectors are integrated with the roof structure: glazing is installed over wood plenums in which metal absorber plates are mounted.(92)

In liquid systems, pipes connect the collectors to a steel, concrete, or fiberglass storage tank. From storage, solar heat goes to the distribution system via other pipes that lead to a heat exchanger connected with ductwork in a forced air system, or to piping in an hydronic system.

TABLE SEVENTY-ONE

PREDICTED PERFORMANCE OF PASSIVE SOLAR RETROFITS IN MULTIFAMILY BUILDINGS
(HUD RESIDENTIAL SOLAR DEMONSTRATION PROGRAM)

LOCATION	# UNITS	SYSTEM DESCRIPTION	HEAT LOAD (Btu/yr)	PREDICTED SOLAR FRACTION (%)
Boston	12	Glazing retrofitted for direct gain & sunspace. Exterior brick retrofit as trombe wall.	234.6	28%
New York	8	Double glazed greenhouses with masonry storage walls.	299.5	46%
Boston	6	Glazing retrofit for direct & indirect (water storage) gain. Greenhouse additions on south walls.	152.5	45%
Providence	3	Trombe wall replaces conventional siding.	141.3	54%
Schenectady	3	Greenhouse addition on south wall of each floor.	91.5	26%
Boston	14	Atrium sunspace with clerestory south-facing windows. Bay windows retrofit with double glazing. Greenhouse additions.	170.4	72%
Bronx	10	Trombe Wall retrofit.	277.5	53%
Charlotte	4	Greenhouse retrofit with exterior walls used as storage.	89.11	34%
Kansas City	8	New glazing & interior sheet rock & plaster storage. Trombe Wall retrofit clerestory windows.	265	60%
Roanoke	15	Retrofit greenhouse with water storage. Trombe wall retrofit.	303.1	33%
Milwaukee	6	Two-story lean-to greenhouse. Thermo-siphoning air heaters.	364.0	34%
New Haven	7	Porches retrofit as greenhouses. Efficient glazing. Clerestory windows.	365.8	34%
New Haven	6	Trombe wall retrofit.	335.2	42%
St. Johnsbury (Vermont)	21	Fish tanks behind south-facing windows.	1520.0	11%
New York	5	Trombe wall retrofit. Window box collectors.	185.0	58%

Source: HUD Project Summaries (1980)

TABLE SEVENTY-TWO

PREDICTED PERFORMANCE OF PASSIVE DESIGNS FOR COMMERCIAL BUILDING RETROFITS

Location	Building Description	System Description	Heated Space S.F.	Heating Load MMBTU/yr	Solar Fraction %	Cooled Space S.F.	Cooling Load MMBTU/yr.	Solar Fraction %	Lighting Load MMBTU/ yr.	Solar Fraction %
Princeton, N.J.	2 story university architecture design studio.	Heat and glare-free day- lighting provided by a 2 story direct gain thermo- siphoning collector with 2 perforated, horizontal light shelves. Supplemented by 7 pairs of clerestories with insulating shutters. Window quilts on all windows.	13,700	1220.0	72	N/A	N/A	N/A	502.0	40
Philadel- phia, PA	4 story automobile rebuilding facility built in 1914.	A series of solar window furnaces retrofit to south wall provide both heat and daylight reflected 5878.0 by their light shelves. Fiberglass insulating panels replace old windows on northeast, northwest, and west walls. Improved ventilation.	57,000	5878.0	8	57,000	86.0	49	604.0	-
Essex, MD	Retrofit and new addition to two existing school-house type buildings. Now a senior citizens center.	A courtyard placed between the old and new sections allows daylight penetration. A clerestory window faces south on new addition. Greenhouse is added to south facade, with storage in internal mass walls and floor. Sliding doors next to vestibule.	13,500	603.0	23	5,000	193.0	38	193.0	68
Wassau, WI	2 story retail/ office building.	A sunspace is added to narrow south end of north-south elongated building, circulating warm air to both levels. Clerestories provide heat and light to upper level.	2,700	38.5	40	2,700	13.3	40	52.4	40
New Braun- fels, TX	Single story mental health center work- shop. Schoolhouse type building.	South-southwest orientation allows considerable solar gain from double-hung windows in winter, and ventilation in summer. Most of retrofit work in the form of conservation.	4,800	128.3	31	4,800	55.5	16	7.2	26

TABLE SEVENTY-THREE

PASSIVE SOLAR/ENERGY CONSERVATION COMBINATIONS IN MULTI-FAMILY RETROFITS
(HUD RESIDENTIAL SOLAR DEMONSTRATION PROGRAM)

<u>Location</u>	<u>Passive System Description</u>	<u>Energy Conservation Measures Employed</u>
Boston	Glazing retrofitted for direct gain and sunspace. Exterior brick retrofit as trombe wall.	Windows double-glazed and retrofit with insulated shutters, vestibule airlocks, low-flow plumbing fixtures, increased wall and ceiling insulation. Efficient appliances.
New York City	Double glazed greenhouses with masonry storage walls.	Aluminum siding backed by polystyrene on west wall. Aluminum storm doors and windows added. Exposed piping insulated, rock wool blown into roof. Caulking and weatherstripping.
Boston	Glazing retrofit for direct and indirect (water storage) gain. Greenhouse additions on south wall.	Air lock vestibules on both entrances, windows reconditioned and fit with insulating shades or shutters, flower beds raised for earth berm, increased insulation all around.
Providence	Trombe wall replaces conventional siding.	South windows double-glazed, 1st floor triple-glazed. Weatherstripping, storm windows and roll shades applied to upper story windows. Demand DHW heater and other efficient appliances installed, awnings added to S.E. and W. windows. Insulation increased.
Schenectady	Greenhouse addition on south wall of each floor.	Storm windows and doors, weatherstripping, hardboard siding retrofit to brick veneer in greenhouse, insulation increased.
Boston	Atrium sunspace with clerestory south-facing windows. Bay windows retrofit with double glazing. Greenhouse additions.	Double-glazing on south windows, triple on north. Vestibule retrofit to main entrance. Awnings positioned above clerestory array and greenhouses completely caulked and weatherstripped. Increased insulation.
Bronx	Trombe wall retrofit.	Windows double glazed, caulking and weatherstripping throughout, water conserving plumbing fixtures, lobbies and uninhabited spaces placed on north side. Increased insulation.
Charlotte	Greenhouse retrofit with exterior walls used as storage.	All windows fitted with storm windows and thermal shutters, completely caulked and weatherstripped. Airlock vestibules on all entrance ways. Evergreen windbreak on north. Increased insulation.

TABLE SEVENTY-THREE

(Continued)

<u>Location</u>	<u>Passive System Description</u>	<u>Energy Conservation Measures Employed</u>
Milwaukee	Two story lean-to greenhouse. Thermosiphoning air heaters.	Front door vestibule sealed, storm windows and doors added where needed. Complete weatherstripping and caulking. Roof vented and insulation increased.
New Haven	Porches retrofit as greenhouses. Efficient glazing. Clerestory windows.	Windows equipped with blinds and window quilts. Insulation significantly increased all around.
New Haven	Trombe wall retrofit.	New steelclad to be installed. Increased insulation.
St. Johnsbury VT	Fish tanks behind south-facing windows.	Thermal shades on 80% of windows. Dishwater wastewater incorporates heat exchanger for hot water preheat. Rock wool blown into attic. Pipes insulated.
New York	Trombe wall retrofit. Window box collectors.	South windows double glazed, caulking and weatherstripping to follow. Wall insulation increased.
Kansas City MO	New glazing and interior sheet rock and plaster storage. Trombe wall retrofit clerestory windows.	Evergreen windbreak, east wall grading raised 3 ft. All windows double glazed, some reduced in size. Insulating glass on north double-hung windows, complete caulking. Living areas repositioned to south, service areas toward center. Sheetrock added to plaster, insulation increased.
Roanoke	Retrofit greenhouse with water storage. Trombe wall retrofit.	Airlock vestibules insulating shades, complete caulking and weatherstripping. Roofline extended to shade trombe wall. Individual gas meters installed. Attic and foundation insulation increased.

Source: HUD Project Summaries (1980)

TABLE SEVENTY-FOUR

PASSIVE SOLAR/ENERGY CONSERVATION COMBINATIONS IN COMMERCIAL RETROFITS (DOE)

LOCATION (TITLE)	PASSIVE SYSTEM DESCRIPTION	ENERGY CONSERVATION MEASURES
Philadelphia, PA Auto Facility	South wall (previously 70% glass) retrofit to trombe wall. Reflector directs light to white ceiling. A destratifier and ceiling fans to be installed for cooling.	Building retrofit with increased envelope insulation, windows on northeast, northwest and west replaced by fiberglass insulating panels. Skyroof to enclose open area between paint shop and parts room, electronic door controls and damping devices to be installed, gas fired infrared heaters to replace boilers.
Essex, MD Senior Facility	Solar greenhouse on new addition, clerestory window facade running the width of the roof with fixed louvers for shading, exterior solar sunspace (courtyard) for daylighting.	Vestibule entrance, solar curtains for night-time insulation, bamboo shades, venting in clerestory and front entrance. Restrictions to structure changes since it is a woodframe built in 1900.
New Braunfels, TEXAS	Reflective white roof, passive water heater, attic ventilation added. (Pretty much a passive collector from the start; stone walls, orientation, etc.)	Ceiling insulation, roof shader, weatherized doors and windows, reflective film shading, ceiling fans, fluorescent lighting, desiduous trees planted, attic insulation.
Wausau, WI	Sunspace retrofit to south facade. Rooftop clerestories for heat and light on upper levels.	Destratification fans, sunspace insulation.
Princeton, NJ School of Architecture and Urban Planning	Two-story direct gain thermosiphon collector with two perforated horizontal light shelves. Seven pairs of small clerestories with insulating shutters.	Window quilts applied to all single glazed windows. Insulation blown into brick cavity walls.

Source: U.S. DOE (1981)

In cold climates, liquid solar space-heating systems need protection from freezing. where city water or distilled water is used as the transfer fluid, freezing is prevented by allowing the fluid in the collectors to drain back into the storage tank when outside temperatures fall. The other method of freeze-protection uses an antifreeze solution as the transfer medium, circulating it through a "closed" pressurized piping loop and transferring heat to storage via a heat exchanger.

In air systems, collected solar heat is moved through ductwork either to the house itself or to a rock storage bin. In site-built systems, the plenum in the roof structure performs the same function as the collector ductwork in factory-built models. From storage, another line of ducting transfers solar heat to the ductwork in the building's conventional distribution system.

In both liquid and air systems, solar heat is transferred to the domestic hot water tank by heat exchangers linked to the collectors or main storage tank.

Non-Metallic Collectors

If some of the lower-cost collectors used to heat swimming pools or water could be used for space heating, the cost of active solar heating could be substantially reduced. As noted in Chapter Eight, systems using rolled-out rubber collectors, plastic collectors with black transfer fluid, and other non-metallic collectors may cost less than \$20 per square foot, as compared with the \$40 to \$60 per square foot that conventional systems using active flat-plate collectors cost.

Low-cost systems operate just like those using flat-plate metal collectors. Most non-metallic active collectors use liquid rather than air as a transfer medium, so freeze protection is needed.

While some non-metallic collectors have reportedly been used in space-heating applications, practical experience is so far quite limited.

Solar-Assisted Heat Pumps

One anticipated problem with lower-cost collectors is that they may not deliver heat at temperatures high enough for space heating. One proposed solution is to combine lower-temperature, lower-cost collectors with heat pumps.

The solar-assisted heat pump offers some theoretical advantages over both stand-alone heat pumps and stand-alone active solar energy systems. The coefficients of performance of conventional stand-alone air source heat pumps decline as ambient temperatures fall. Active solar metal collectors are relatively expensive, and lower-cost solar collectors used alone may not do the job--hence, the appeal of a combination. If a heat pump is solar-assisted, it is not dependent solely on ambient air temperatures for heat sources. Likewise, the active solar energy system needs few, if any higher temperature collectors.(93). The lower-temperature collectors, unable by themselves to provide adequate space heat, could nonetheless serve as effective heat sources for the heat pump.

In this hybrid system, the solar collectors can be connected to the heat pump in one of two ways--making the heat pump either single-source or dual-source. In a single-source arrangement, sometimes called a series configuration, the heat pump uses only the solar-heated transfer medium as a heat source. In some single-source applications using higher temperature solar collectors, solar heat is used alone whenever it is adequate to heat the building. When it is not high-temperature enough, however, the building must rely wholly or partially on auxiliary energy (often supplied by electric resistance heat), and the heat pump cannot operate in a stand-alone mode.

In a dual-source arrangement, the heat pump can use solar energy, the ambient air, or a combination of the two as heat sources, depending on the amount of heat needed in the building. Thus, while series configurations are less complicated and possibly less expensive, dual-source systems are more flexible.

The efficiencies (amount of heat delivered divided by the amount of energy used to run the heat pump) of both single- and dual-source applications can be improved by reducing the amount of solar heat lost from storage. To this end, some experts have proposed using a ground-coupled storage system (instead of a conventional storage tank) to link the solar collectors and the heat pump. Since the temperature of the earth fluctuates less than that of the ambient air, heat stored in ground water or liquids circulated through underground piping tends to remain at more constant temperatures longer than heat stored in above-ground containers (even those located in conditioned space). For this reason, some stand-alone heat pumps are ground- rather than air-coupled. Systems that circulate solar-heated transfer fluid through ground-coupled storage--buried, sealed and pressurized water tanks, buried rock bins; or a network of pipes--can provide warmer heat than ground-coupled heat pumps alone.(94)

Although theoretically straightforward, the practical use of solar-assisted heat pumps is complicated because so many options are available.(95) The system designer or heating contractor must decide whether a solar-assisted heat pump is preferable to either a stand-alone heat pump or a stand-alone solar heating system. Other choices are between

heat pumps using an ambient air heat source and those that are ground-coupled, lower-temperature solar collectors and higher-temperature ones, and single source or dual-source pumps. Since heat pumps can also be used for cooling applications, the potential efficiencies of each combination in meeting heating and cooling needs also should be evaluated.

The technical factors governing particular choices among these systems are numerous. The amount of sunshine available, the average ambient temperatures during the heating season, and the size and patterns of buildings' heating and cooling loads--all must be taken into account. In cold but sunny regions, solar-assisted heat pumps and lower-cost collectors may be the optimal combination. Where there is less sunshine, stand-alone heat pumps (either air-coupled in warmer areas, or ground-coupled in colder areas) may work best. For buildings whose peak heating demands occur at night, solar-assisted heat pumps could be the best option since solar energy collected during the day can be stored for later use. Where heating loads are heaviest in the daytime (probably in a commercial building), a stand-alone heat pump could be the best choice providing ambient temperatures are warm enough to allow a fairly high coefficient of performance. In areas with high heating loads but low cooling needs, a stand-alone heat pump or a solar-assisted heat pump (depending on ambient temperatures) could be good choices. But as cooling loads approach or exceed heating loads, using stand-alone solar systems for heating with energy-efficient window air conditioners or natural cooling may be more appealing because heat pumps are less efficient in the cooling mode than efficient window or central air conditioners. (See Chapter Ten, Cooling Buildings.)

Trickle Down Collectors

Another active solar energy system design that costs less than conventional systems using flat-plate metal collectors is the so-called "trickle down" design, patented under the trade name of Solaris(R). This system has a corrugated sheet metal absorber plate mounted under glazing on the roof.(96) Water trickles down the corrugated channels, gaining heat as it flows downward. This heated transfer fluid is then piped to a steel storage tank surrounded by a rock bed. Heat is naturally transferred from the water tank to the rocks by conduction and is moved to the building through the home's conventional forced-air system.

High Temperature Collectors

The cost-effectiveness of solar space-heating systems can also be improved by upgrading collector performance. One option is using collectors capable of delivering higher temperatures to storage, thus giving the building a relatively higher solar contribution from a constant collector area or a constant level of solar contribution from a smaller collector area.

Numerous types of high-temperature active collectors are on the market today. Few are economical in space heating-only applications because the temperatures needed are not high enough to justify the added costs of the higher temperature collectors. These collectors are likely to be more cost effective in combined heating- and cooling (Chapter Ten), industrial process (Chapter Thirteen), or solar thermal-electric (Chapter Twelve) applications.

However, at least one higher-temperature collector model has been used in active solar heating systems in both homes and commercial buildings. Instead of using flat-plate collectors, this system circulates a liquid through specially coated metal tubes encapsulated within larger glass outer tubes. (The space between the inner and outer tubes is a vacuum, so the collectors are called evacuated tubes.) The tubes can absorb more energy per unit area than flat-plate metallic panels, and their absorptive capacity is boosted even further by reflecting surfaces placed behind them to concentrate more light on the tube's surface. Since the vacuum reduces heat losses, the collectors do not have to be insulated or glazed.

Phase-Change Storage

While most active space-heating systems use centralized storage tanks or rock boxes, smaller systems that can be decentralized throughout the building are being developed--a boon to retrofits since adding relatively large tanks or rock boxes to basements can be difficult and costly.

Research on decentralized thermal storage is proceeding rapidly, particularly as concerns low temperature phase-change storage. As noted earlier, phase-change storage technologies make use of chemical compounds that change form as they absorb and reradiate heat--melting as they gain heat and recrystallizing as they release it. Now available are phase-change compounds that begin melting at relatively low temperatures (say, 90 degrees F) and begin recrystallizing when the temperature of the melted solution drops only a few degrees below the initial melting point. This means that recrystallizing (and, thus, heat release) can begin as the storage melt loses heat naturally by conduction (the method of heat distribution used in passive phase-change systems) or as it is fan-cooled (in active systems).(97)

Active System Performance

Owing to the relatively small number of systems installed, monitoring results do not speak to the viability of the technology as a whole. Yet they at least broadly indicate certain trends. Most of the systems that have been surveyed use conventional flat plate metal collectors. There is no single, typical active solar heating system. System sizes vary with the size of the building, the building's regional location, the number of standard conservation features employed, and the extent to which passive solar design techniques are included in the building. Neither are there standard performance results.

Most commonly, solar system performance is measured in terms of system efficiency (the number of BTU of solar heat delivered to a building divided by the number of BTU of solar heat striking the collector surface) and solar fraction (the proportion of the heating load provided by solar energy). As a rule of thumb, a well designed and properly installed active heating system using flat-plate metal collectors should not have a system efficiency much below 20 to 30 percent or a solar fraction below 35 to 40 percent.

While the Federal Government, private engineering firms, and universities have monitored active heating systems, performance pattern has emerged in terms of system type, system size or regional locations. Indeed, the influences on system efficiencies and solar fractions are highly building-, system- and user-specific. They include collector efficiencies (which are theoretically predictable for different collector models), transport efficiencies, storage efficiencies, and distribution efficiencies--all of which vary with the quality of a system's design and installation. As for solar fractions, they too tend to vary with the number of standard conservation features employed and with the occupant's energy-use habits.

Monitoring has revealed that a number of materials, design, or installation problems keep many active space-heating systems installed over the last few years from performing as well as expected.(98) Some collector materials deteriorate under high heat, non-pressurized piping systems corrode in the presence of water with a high oxygen content, and heat losses from pipes, ducts, or storage tanks that were not properly insulated or sealed are sometimes excessive. However, all of these problems can be resolved as experience enables the active solar industry to improve its product design, quality control, and installation techniques.

Once these problems are corrected, active solar heating systems promise to be an effective solar technology, particularly in new buildings. Some government- and privately-funded projects with apparently well designed and properly installed systems have met over 50 percent of the user's annual heating needs with solar energy.(99) Prospects for retrofitting active space heating systems onto buildings will be enhanced as phase-change storage develops.

Much less experience has been accumulated on either low-or high-temperature solar collectors. Whether low-temperature models can generate temperatures adequate for space heating remains an open question. In addition, the durability of these systems under prolonged exposure to high temperatures and their ability to provide freeze protection have yet to be demonstrated. (See Chapter Eight.) With respect to high-temperature collectors, the issues are their cost-effectiveness in improving overall system efficiencies and their durability under prolonged exposure to high heat.

Most solar-assisted heat pumps use conventional flat-plate metal collectors rather than lower-temperature, lower-cost units. Experience clearly shows that special care is needed in combining solar and heat pump hardware and in controlling their separate and interacting operations. In some systems, solar storage has been oversized and thus cannot deliver high enough temperatures to the heat pump. Some engineers have also suggested that changes in heat pump designs will have to be modified for maximum effectiveness in solar-heat pump hybrids. Even lower-temperature solar collectors can sometimes deliver temperatures that can cause standard heat pumps to deteriorate.

Economics of Solar Heating

Active Systems

Active solar space-heating systems can be quite economically attractive from a private home- or building-owner's point of view under a number of conditions. Systems installed at construction time cost less than retrofits and can be more easily integrated with the building. Where solar insolation levels are high during the heating season (as they are in such cities as Denver and Albuquerque), these systems are all the more attractive. They also have added appeal where a high proportion of the combined water/space heating load is for water and where electric resistance heat or fuel oil is displaced. By the same token, where the weather is cloudy in winter or where (regulated) natural gas is the auxiliary fuel, active heating systems are less appealing to private purchasers. As Table Seventy-Five shows, a system designed to meet about half of a single-family home's space- and water-heating needs achieves positive cash-flow in four years or less when electric resistance heating is the auxiliary energy source and in six years or less with fuel-oil backup. Systems with natural gas backup are far less

TABLE SEVENTY-FIVE

ECONOMICS OF ACTIVE SOLAR SPACE HEATING SYSTEMS
NEW SINGLE FAMILY HOMES
FLAT PLATE METAL COLLECTORS
(1981 \$)

CITY	COLLECTOR AREA (sq ft)	AUXILIARY ENERGY	YRS TO + CASH FLOW	YRS TO RECOVER DOWNPAYMENT	PAYBACK
Boston	510	Elec. Resis. ¹	1	2	11
		Fuel Oil #2 ²	6	8	16
		Natural gas ³	8	12	17
Wash, D.C.	350	Elec. Resis.	4	2	14
		Fuel Oil #2	6	2	15
		Natural gas	10	15	19
Grand Junction, CO	215	Elec Resis	1	2	10
		Fuel Oil #2	2	2	10
		Natural gas	8	9	17
Los Angeles	80	Elec. Resis.	2	2	11
		Fuel Oil #2	N/A	N/A	N/A
		Natural gas	13	18	22

Assumptions

1. Financing: Costs of solar included in 30-year mortgage of 13 percent.
2. Costs of solar system: \$3,000 plus \$25/ft.²; System sized to meet 50 percent of load.
3. Fuel prices (first year):
 - Boston Electricity 9.8¢/KWH
Fuel Oil \$1.26/gal.
Natural Gas 62.5¢/therm
 - Washington Electricity 6.5¢/KWH
Fuel Oil \$1.26/gal
Natural Gas 46.3¢/therm
 - Grand Junction Electricity 5.6¢/KWH
Fuel oil \$1.12/gal.
Natural Gas 34.4¢/therm
 - Los Angeles Electricity 6.9¢/KWH
Natural Gas 29.7¢/therm
4. Electricity prices expected to increase at 12 percent per year, fuel oil prices at 13 percent, and gas prices at 15 percent.

economically appealing.

In computing cash flows, the annual principal, interest, and maintenance costs for the solar energy system are weighed against both annual utility bill savings and the tax savings. Besides the Federal tax credit which allows 40 percent of the installed system costs to be deducted for the purchase year, interest payments on the solar energy loan system are tax-deductible. In most cases, these tax savings allow a system to achieve positive cash flow sooner than it would if the solar costs were compared with utility bill savings alone. For example, the annual utility bill savings for the system installed in Boston do not exceed annual principal, interest, and maintenance costs until the fourth year. However, tax savings resulting from the Federal tax credit and added interest deductions help the system reach positive cash flow after the first year.

Tax provisions also shorten the time it takes to recover downpayments for all systems using electric resistance or fuel-oil backup, even for systems with relatively long paybacks (say, 16 years with fuel-oil backup in Boston). Since homebuyers often care more about these two factors than about payback, most systems where electric resistance or fuel-oil backup are the auxiliary fuels are at least marginally appealing on a strictly economic basis. Different circumstances make active solar heating economically attractive in different locations. In Boston, the economics are favorable principally because electric rates are high (.098 cents/Kwh). In Grand Junction, large heating-energy needs can be met by a relatively small system because Colorado receives large amounts of winter sunshine. The system installed in Los Angeles, in contrast, has to meet only a small heating load so it needs less collector area (80 square feet) than solar water heaters in Northeastern and Midwestern cities. Years-to-positive cash flow for systems with electric resistance backup are longest in Washington, which has relatively high heating loads and only moderate levels of solar insolation and moderately high electric rates (.065 cents/kwh).

In Table Seventy-Six, the economic consequences of various system alterations are summarized. In the "mini-load" case, the building heat loss factor has been cut to reflect strict energy-conservation measures. The "low-cost" case is predicated on the use of a system with lower-cost solar collectors, while the "low-cost plus mini-load" option involves using lower-cost collectors to meet a reduced load.

Just as for active solar water heaters, the most dramatic improvements in economic appeal occur when solar system costs are reduced. (See Chapter Eight. The economics of both the standard and reduced loads are improved significantly if lower-cost collectors are used, even where natural gas is the auxiliary heat source.

Reducing heating loads by taking prior conservation measures has relatively small negative impacts on solar economics in all cases. The largest change in system appeal occurs in the shift from base case to mini load with electric resistance backup: the achievement of positive cash flow is put off for two years by conservation improvements. (See Table Twenty-Four.) The economics of all of the low-cost cases remain virtually unchanged by load reduction, indicating that low-cost solar energy and energy-conservation packages have potentially great appeal. The only caveat is that solar system costs must be reduced roughly proportionally to heating-load reductions.

While solar systems in new homes may be marginally attractive, the economic barriers to active space-heating retrofits in single-family houses are significant--in part because conventional flat-plate collectors are expensive but also because interest on home-improvement loans is high. Table Seventy Seven summarizes economic analyses of four retrofits in Washington, D.C., made with a short-term (five years), high-interest (16 percent) home-improvement loan. (Compare Table Seventy-Six.)

In no case does the system achieve positive cash flow within the life of the loan. The only paybacks under ten years are reached with low-cost collectors where electricity and fuel-oil are backup heat sources. If standard flat-plate collectors are used, the situation is not markedly improved with more favorable financing.

Table Seventy-Eight summarizes the economics of a conventional active heating system installed in Washington, D.C., under three different financing packages: five-year, 16-percent loans; ten year, eight-percent loans; and 30-year, 15 1/2 percent loans. Even with lower interest rates, the longer terms usually mean longer paybacks, through improved cash flow. Since homeowners will probably use year-to-positive cash flow as their investment criterion in times of high inflation, special financing programs that extend loan terms make solar space-heating retrofits more economical.

The most promising situation occurs when low-cost (\$20/square foot installed) collectors can be bought on favorable financing terms. (See Table Seventy-Nine.) Under both special financing programs, systems with electricity and fuel-oil backup achieve positive cash flow before the loan is due for repayment. Paybacks are, again, extended under the longer term package, and load reductions affect the economics of these systems somewhat negatively. Still, prior conservation does not work against an otherwise economical solar retrofit.

Active space-heating installations in new multifamily buildings have considerable economic appeal if it is assumed that the solar equipment increases in value with the property. As Table Eighty indicates, all of the twelve systems analyzed reach positive

TABLE SEVENTY-SIX

ECONOMICS OF ACTIVE SOLAR SPACE-HEATING SYSTEMS -- NEW
SINGLE-FAMILY HOMES -- VARIATIONS
(Washington, D.C.) (1981 \$)

	<u>Collector Area (sq ft)</u>	<u>Years to + Cash Flow</u>	<u>Years to recover Down payment</u>	<u>Payback</u>
<u>Electricity</u>				
Base Case	350	4	2	14
Mini-load	270	6	2	15
Low Cost	380	1	2	10
Mini-load & low cost	290	1	2	10
<u>Fuel Oil #2</u>				
Base Case	350	6	2	15
Mini-load	270	7	2	16
Low cost	380	2	2	11
Mini-load & low cost	290	2	2	11
<u>Natural Gas</u>				
Base Case	350	10	15	19
Mini-load	270	11	16	20
Low Cost	380	7	2	15
Mini-load & low cost	290	8	2	16

Source: Residential Solar Viability Program (1981)

TABLE SEVENTY-SEVEN

ECONOMICS OF ACTIVE SOLAR SPACE HEATING
SYSTEMS - RETROFIT - SINGLE FAMILY HOMES -
VARIATIONS (WASHINGTON, DC) (1981 \$)

	<u>Coll Area</u> <u>(Sq. Ft.)</u>	<u>Years to +</u> <u>Cash Flow</u>	<u>Years to</u> <u>Recover</u> <u>Downpayment</u>	<u>Payback</u>
<u>Electricity</u>				
Base Case	350	6	10	10
Mini Load	270	6	11	11
Low Cost	380	6	7	7
Low Cost & Mini Load	290	6	8	8
<u>Fuel Oil #2</u>				
Base Case		6	11	11
Mini Load		6	12	12
Low Cost		6	8	8
Low Cost & Mini Load		6	9	9
<u>Natural Gas</u>				
Base Case		6	15	15
Mini Load		6	15	15
Low Cost		6	12	12
Low Cost & Mini Load		6	12	12

Source: Residential Solar Viability Program (1981)

TABLE SEVENTY-EIGHT

IMPACTS OF SPECIAL FINANCING ON ECONOMICS
OF ACTIVE SOLAR SPACE HEATING SYSTEMS -
S.F. - RETROFITS FLAT PLATE METALLIC
COLLECTORS (WASH., DC) (1981 \$)

	<u>Years to +</u> <u>Cash Flow</u>	<u>Years to</u> <u>Recover</u> <u>Downpayment</u>	<u>Payback</u>
<u>Electricity</u>			
Package One ¹ (Base Case)	6	10	10
Package Two ²	8	10	10
Package Three ³	6	2	15
<u>Fuel Oil #2</u>			
Package One (Base Case)	6	11	11
Package Two	9	11	11
Package Three	7	8	16
<u>Natural Gas</u>			
Package One (Base Case)	6	15	15
Package Two	11	14	14
Package Three	11	17	20

Code:

¹Package One: Five-year loan at 16% interest

²Package Two: Ten year loan at 8%

³Package Three: Thirty-year loan at 15½%

Source: Residential Solar Viability Program (1981)

TABLE SEVENTY-NINE

IMPACTS OF LOW COST SYSTEMS PLUS SPECIAL
FINANCING ON ECONOMICS OF ACTIVE SOLAR SPACE
HEATING SYSTEMS - SINGLE FAMILY-REFTOFIT - (WASH., DC) (1981 \$)

	<u>Years to +</u> <u>Cash Flow</u>		<u>Years to</u> <u>Recover</u> <u>Downpayment</u>		<u>Payback</u>	
	<u>Standard</u> <u>Load</u>	<u>Mini-</u> <u>Load</u>	<u>Standard</u> <u>Load</u>	<u>Mini-</u> <u>Load</u>	<u>Standard</u> <u>Load</u>	<u>Mini-</u> <u>Load</u>
<u>Electricity</u>						
Package One ¹ (Base Case)	6	6	7	8	7	8
Package Two ²	2	4	2	2	7	8
Package Three ³	2	2	2	2	11	11
<u>Fuel Oil #2</u>						
Package One (Base Case)	6	6	8	9	8	9
Package Two	5	5	2	2	8	9
Package Three	2	4	2	2	12	12
<u>Natural Gas</u>						
Package One (Base Case)	6	6	12	12	12	12
Package Two	10	11	12	12	12	12
Package Three	8	9	10	12	16	17

Codes:

¹Five-year loans at 16% interest

²Ten-year loan at 8% interest

³Thirty-year loan at 15½% interest

Source: Residential Solar Viability Program (1981)

TABLE EIGHTY

ECONOMICS OF ACTIVE SOLAR SPACE HEATING
SYSTEMS-- MULTIFAMILY BUILDINGS - NEW CONSTRUCTION
(WASH., DC) (1981 \$)

	<u>Coll. Area</u>	<u>System Price</u>	<u>Year Net Present Value Is Positive</u>	<u>IRR 5th Year (%)</u>	<u>After-Tax Cash Flow (5th Year) (\$)</u>
<u>Base Case</u>	7,500 ft ²	\$187,500			
Electricity			1	37.8	\$6,795
Fuel Oil #2			2	35.1	5,409
Natural Gas			2	27.3	732
<u>Mini Load</u>	5,300 ft ²	\$149,000			
Electricity			1	36.2	\$4,593
Fuel Oil #2			2	33.7	3,584
Natural Gas			2	26.5	177
<u>Low Cost</u>	8,000 ft ²	\$160,000			
Electricity			1	41.4	\$7,419
Fuel Oil #2			1	38.1	6,050
Natural Gas			2	28.7	1,429
<u>Mini/Load/ Low Cost</u>	6,200 ft ²	\$124,000			
Electricity			1	39.6	\$5,096
Fuel Oil #2			1	36.5	\$4,100
Natural Gas			2	27.8	734

TABLE EIGHTY

(Continued)

Source: Residential Solar Viability Program (1981)

- Notes:
- (1) The system's net present value is the sum of all fuel savings and tax savings minus all solar costs over the 20-year life of the system, all discounted at 15 percent. It also includes the (discounted) net after-tax proceeds of the sale of the solar energy system as part of the property in that year.
 - (2) Internal rate of return (IRR), which treats the solar energy system as an investment, equals the after-tax return on the investment.
 - (3) After-tax cash flow is defined as the annual utility bill savings attributable to the solar energy system minus annual principal and internal costs. It also includes tax benefits and tax losses (e.g., rates tax), but not solar energy equipment appreciation.

net present values by at least the second year. Even the lowest internal rate of return (in the "mini load" case with gas backup) is more than a respectable 26.5 percent. All systems with electricity or fuel-oil auxiliary have after-tax positive cash flows of at least thirty-five hundred dollars by the fifth year. (Note too that Washington has only moderate heating needs, moderate insolation levels, and moderate electric rates. In cities with colder climates and either better insolation or higher energy prices, the economic appeal should be commensurately better.)

It is more difficult to assess the economic feasibility of active space-heating in commercial structures, mostly because commercial buildings differ so greatly from each another. With no "typical" commercial buildings there can be no "typical" active solar heating installation to service it, so no general computer simulations have been run. Yet, it is reasonable to assume that the positive factors that contribute to active solar system feasibility in residential buildings apply for commercial structures as well. For example, DOE monitoring of nine commercial demonstration projects suggested that seven would have positive rates of return when competing against electricity.(100) In addition, some commercial buildings need less heat per square foot because they have larger surface-to-volume areas and enjoy relatively greater heat gains. However, sometimes these advantages may be offset by the need for a larger and more expensive collector support structure.

Solar-Assisted Heat Pumps

Few economic analyses cover all possible combinations of active solar collectors and heat pumps. Most research indicates that active solar heating and heat pumps can each save relatively large amounts of conventional energy,, not that systems combining both save appreciably more energy or money than either operating alone. In addition, improvements to collector efficiencies and heat pump COPs in solar-heat pump combinations are at least partially offset by the need to use more operating energy to run the heat pump longer. Ground-coupling has also been viewed as an alternative to solar assistance for stand-alone heat pumps. Ironically, while nearly all studies emphasize the need to analyze systems using lower-cost and lower-temperature collectors, few have done so.(101) Thus, the true economic worth of solar and heat pump combinations must remain questionable until projects combining lower-cost collectors and heat pumps prove otherwise.

Passive Systems

Broad analyses of the economics of passive heating systems are hard to obtain.(102) No passive system is typical, and many systems combine two or more passive technologies. Finally, because passive systems are integrated into the building structure, passive buildings tend to be much more individualized from a thermal energy use standpoint than conventional houses. Thus, instead of broad-based analyses, research has resulted in various simulations, and/or experiences, many of them confined to single hypothetical or existing buildings.

The impacts of a passive heating system's energy savings on a building owner's cash flow will be influenced by the initial cost of the system, the financing terms, the amount of conventional energy saved each year, and the price of conventional energy. Although increases in interest rates and conventional fuel prices are hard to predict over long periods, some general assessments of passive solar energy system performance and costs do provide some guidance.

As noted above, both simulations and experience suggest that passive solar heating systems can deliver substantial amounts of energy to a building. Many passive solar energy systems also cost far less than active solar energy systems designed to deliver the same amount of heat. The costs of passive solar heating systems vary much more with the costs of the building than do the costs of active solar hardware,(103) though they tend to fall between five percent and ten percent of the total construction costs.(104) (See Table Eighty-One.) For passive retrofits, system costs can be calculated on the basis of square footage of the materials used. Typical costs are \$15 per square foot for double glazing, \$5 per square foot for night-time insulations, \$12 to \$25 per square foot for mass storage. (See Table Eighty-Two.)

The variability of passive solar costs holds two advantages. First, in houses with lower construction costs (including most tract or "spec" houses), passive solar energy systems tend to be cheaper than most active solar energy systems that deliver roughly the same amount of energy. For instance, in a 1,500 square foot home costing between \$50,000 and \$60,000, a passive solar energy system should cost no more than \$4,000 or \$6,000. (See Table Twenty-Nine.) An active solar heating system in the same home could cost over twice that much. Second, combining a passive solar system with strict energy conservation measures can be very economical, since the passive system will require a smaller fixed investment than an active system.

These two factors, good performance and lower costs, make the cash-flow impacts of passive solar heating promising, if difficult to prove empirically. Table Eighty-Three summarizes rough calculations that indicate the potential ranges of cost savings for a

TABLE EIGHTY-ONE

CONSTRUCTION COST COMPARISON
OF NEW CONVENTIONAL, ENERGY-CONSERVING AND PASSIVE SOLAR HOMES
(1979 \$)

BUILDING CATEGORY	PASSIVE HOME	ENERGY CONS.	CONVENTIONAL
Block Stemwalls	\$ 1,935	\$ 1,935	\$ 577
16-in. Trombe Wall	818	-0-	-0-
Rigid Insulation	577	577	-0-
Exterior Framing	1,868	2,278	2,100
Exterior Sheathing	685	819	757
Interior Sheathing & Thincoat	2,104	2,317	2,317
Roof Insulation	909	909	587
Wall Insulation	496	872	582
Exterior Stucco	3,320	3,658	3,658
Interior Plaster	599	311	311
Venting Windows	1,194	1,870	1,692
Fixed Glass	2,029	-0-	-0-
	<u>\$16,734</u>	<u>\$15,546</u>	<u>\$12,581</u>
20% Labor Fringe	645	604	515
	<u>\$17,379</u>	<u>\$16,150</u>	<u>\$13,096</u>
15% Overhead & Profit	2,697	2,422	1,964
	<u>\$19,986</u>	<u>\$18,572</u>	<u>\$15,060</u>
Total House Costs	\$62,151	\$60,737	\$57,225
Cost per sq ft floor area:	\$45	\$44	\$42
% Cost Increase over conventional house	8.6%	6.1%	

Source: Taylor 1979, Reproduced in A New Prosperity

TABLE EIGHTY-TWO

ESTIMATED COSTS OF PASSIVE SOLAR RETROFIT TECHNIQUES (\$ 1977)

<u>Technique</u>	<u>Estimated Cost</u>
Movable Insulation	\$.50 - \$5.00 /sq ft
Trombe Wall	\$3.00 - 15.00 /sq ft
Glazing	\$5.00 - 25.00 /sq ft
Greenhouse	\$4.00 - 30.00 /sq ft
Thermosyphoning Air Heater	\$1.50 - 9.50 /sq ft
Awnings	\$3.50 - 6.50 /sq ft of shaded glazing
Porch/Overhang	\$4.00 - 15.00 /sq ft of shaded glazing
Windbreak	\$1.50 - 2.50 /sq ft of shaded glazing

Source: A New Prosperity (1981)

TABLE EIGHTY-THREE

ESTIMATED FIRST AND FIFTH-YEAR COST SAVINGS OF SELECTED PASSIVE SOLAR HOMES (1981 \$)*

Location	Yearly Heat load (mmBtu)	Solar %	Costs	Year 1 Savings (Electric Backup) ¹	Year 1 Savings (Gas Backup) ²	Year 5 Savings (Electric Backup) ³	Year 5 Savings (Gas Backup) ⁴
Sommersworth, NH	56.0	66%	\$1500	\$ 703.72	\$245.52	\$1,239.95	\$ 493.74
Ames, IA	44.4	32%	\$6000	\$ 270.52	\$ 94.38	476.65	\$ 189.78
Prescott, AZ	72.0	81%	\$3440	\$1,110.41	\$387.41	1,956.54	\$ 779.08
Royal Oak, MI	70.0	79%	\$2500	\$1,052.91	\$367.35	1,855.22	\$ 738.74
Atascadero, LA	32.0	100%	\$1815	\$ 609.28	\$212.57	1,073.55	\$ 427.47
Santa Fe, NM	69.0	96%	N/A	\$1,261.21	\$440.02	2,222.25	\$ 884.88
Bozeman, MT	80.0	85%	\$7920	\$1,294.72	\$451.71	2,281.29	\$ 908.39
Yakima, WA	32.0	63%	\$1000	\$ 383.85	\$133.92	676.34	\$ 269.31
East Pepperell, MA	17.0	35%	\$-0-	\$ 113.29	\$ 39.52	199.62	\$ 79.47

*Derived from Data Presented in A New Prosperity.¹Electric rates set at .065¢/kwh (\$19.04/mmBtu) - 100% furnace efficient.²Gas prices at .465/Therm - (\$4.65/mmBtu) - 70% furnace efficient.³Electric rates at Year 5 reflect yearly increases of 12% to \$33.55/mmBtu.⁴Gas prices at Year 5 reflect yearly increases of 15% to \$9.35/mmBtu.

number of passive systems whose performance has been monitored. (Gas and electric rates are here assumed to be uniform across the country and to increase at the same rate everywhere.

Even given these limitations, figures are encouraging, especially for electrically heated homes. In six of nine cases, first-year savings in homes with electric backup equal or exceed one third of the system's purchase price, which means that simple payback occurs in three years or less. While financing charges are not included, these systems appear relatively inexpensive, so additional interest payments may be largely offset by tax savings and increased utility bill savings as fuel prices escalate. Initial system costs could also be offset by lowered HVAC costs for smaller furnaces.

Combining Energy Conservation with Active and/or Passive Solar Heating

Even though passive or active solar energy systems promise to be economical in a number of circumstances, there are substantial questions about whether strict conservation measures might not be even more cost-effective. There have been a number of projects successfully combining solar and conservation approaches to reduce conventional energy use dramatically.(106) And numerous developing methodologies and guidelines exist to help designers choose the best energy-saving options.(107) But, since knowledge of the economics of different solar- and conservation-combinations is still preliminary, only a few general observations are possible.

First, most evidence suggests that the simpler conservation options are still the most cost-effective energy-saving strategies in new or retrofitted buildings. For example, a study of a Pittsburgh neighborhood indicated that basic conservation techniques would account for more than 75 percent of the total energy savings of a conservation/solar energy package applied to new or rehabilitated buildings.(108)

Second, much depends on climate. In climates with more winter sunshine than Pittsburgh gets, solar features could play a more prominent and immediate role. For example, a study done by Los Alamos Laboratories indicated that in a climate like Dodge City's (5,000 heating degree days, 65 percent winter sunshine), a "conservation only" strategy is preferable for retrofit investments of less than \$1,700, though more expensive energy improvements should combine conservation and solar measures.(109)

Third, energy-conservation and solar energy techniques can usually be combined most cheaply when a building is built or substantially rehabilitated, in part because the costs of adding each component are usually lower in new buildings. Similarly, it is always more economical to implement an energy conservation package than to add energy efficiency improvements one by one. At initial construction, it may sometimes cost less and save equal or greater amounts of energy to use a passive solar/energy conservation package than to employ stringent conservation measures alone. On the other hand, adding the same passive features to an existing house may cost much more (on a cost per BTU-saved basis) than say, adding insulation. Thus, while economic analyses of the step-by-step approach may be basically accurate for many retrofit situations, they may also mask the advantages of installing solar and conservation packages in new or rehabilitated buildings.

Fourth, whether a "total package" or "step-by-step" approach is used, one disadvantage of active solar energy systems is that much of their costs are fixed. In contrast, relatively few passive solar system costs are "fixed." Thus, the potential for reducing systems costs by taking stricter energy-conservation measures is proportionately greater with passive than active systems.

Finally, "solar plus conservation" packages are far more economical when compared with such expensive energy sources such as fuel oil or electric resistance heat than with, say, natural gas. For example, an economical analysis of conservation/solar options for new infill houses in Pittsburgh showed that with natural gas auxiliary only basic conservation options supplemented by a minimal direct-gain passive system achieve positive cash flow in the first year. If electric resistance heat is the alternative, however, several different passive solar energy systems could provide first-year cash savings.(110)

City Applications

The most basic factor governing the technical and economic feasibility of on-site renewable energy technologies is the availability of adequate south-facing roof, wall, or ground space that is unshaded from mid-morning to mid- or late-afternoon. With suitable collector space, orientation, and solar access, on-site solar heating is technically feasible in any building. Without any one of them, it is not.

Other factors are also important, if not strictly necessary, especially for choosing one type of solar heating system over another. These factors include the building's size and structural characteristics and the size and pattern of its heating load. The availability of solar access for active or passive solar energy collectors has been studied empirically in a number of city neighborhoods. Differing areas in Boston, Philadelphia, Baltimore, Minneapolis, Denver, and Los Angeles have all been

evaluated.(111) Results even in the densest areas have been encouraging. For example, a city-wide study of a small, but randomly selected number of buildings in Boston indicated that about one third of the two- and three-story buildings in the sample had adequate solar access on south-facing walls and from one half to three quarters on south-facing roofs. While taller buildings had less wall access, many had significant roof access. In Philadelphia, an assessment of three rowhouse neighborhoods indicated that in two, nearly 30 percent of the houses had unshaded front or back south-facing walls, while the other (the densest) had over 50 percent.(112)

Fewer studies have examined the actual structural space available for on-site solar collectors in buildings located in dense urban neighborhoods. Many experts hold that lack of adequate space could hinder the use of solar collectors there, even if solar access is good.(113)

Active Systems

The space needed for active collectors is influenced by collector efficiencies, the size of the heating load, and regional locations. For example, as summarized above, an active solar collector array capable of supplying 50 percent of the heating energy used by a 1,500 square foot house would need 510 square feet and 350 square feet of space in Boston and Washington, but only 215 square feet and 80 square feet in Grand Junction (Colorado) and Los Angeles.

The amount of space available on the roof of single-family detached homes varies by neighborhood and even by building. For example, houses in one single-family neighborhood in Denver have, on average, had only about 377 square feet of available roof space, adequate there but not in other cities with less winter sunshine. But a study of Roxbury, Massachusetts, suggested that single-family homes could accommodate up to 545 square feet of active collectors.(114) Then too, single-family attached homes are also more likely than others to have on-site ground space available. Thus, the average house in the Denver neighborhood could allocate over 720 square feet for active collectors if roof- and ground-spaces are considered in combination.

One consideration is that dwelling units in attached multifamily buildings may not need collector areas as large as those detached homes require. Average dwelling sizes may be smaller, and together with the use of common walls and floors, may cut heating needs. Then too, the flat roofs often found in rowhouses or low-rise apartment houses may accommodate a larger collector area than can the sloped roofs found on many single-family or semi-detached homes.

Even these advantages probably cannot compensate for the inadequacy of roof space on the top of mid- or high-rise buildings. And, although on-site ground-level space could be accessible to these buildings--other parking lots, for example--few high-rise urban apartments will have enough unshaded, south-facing ground to accommodate an array of collectors capable of heating the buildings. However, these features could make the difference for twins, rowhouses, or low-rise multifamily apartments. For example, some HUD demonstration projects using active heating in single-family attached or multifamily buildings have collector areas of less than 250 square feet per dwelling unit.(115)

These advantages reduce the difficulties of fitting on-site active solar collectors onto existing roofs in dense neighborhoods but the problems do remain. For one thing, older rowhouses may contain as much or more conditioned space as newer detached housing.

In the Philadelphia neighborhoods under study, typical two-story rowhouses without garages contained less than 1,000 square feet of conditioned space, while both two-story rowhouses with garages and three-story rowhouses enclosed conditioned areas of between 1,500 and 1,800 square feet.(116) A Baltimore study found that typical rowhouses built in 1912 contained over 2,000 square feet of heated space.(117) Second, even though they have common walls, older rowhouse or multifamily buildings that are not well insulated or weatherized may consume large amounts of space-heating energy.

The energy inefficiency of many city buildings can be gauged by comparing data on heat loads in existing buildings with projected heat loads of buildings similar to those assumed in the solar economics calculations above. When the effects of climate are taken into account, the "base case" load in the solar economics houses are less, sometimes substantially so, than those common in existing city buildings. (Table Eighty-Four) This conclusion is consistent with the findings of the Project Independence report cited earlier, which found no appreciable differences in energy consumption per square foot of living area between detached and attached single-family homes located in both the Northeast and Midwest regions. Thus, either energy-inefficient city buildings need more collector area than the "base case" houses to meet 50 percent of their space-heating needs or extensive energy-conservation measures are needed before even the "base case" levels of solar cost-effectiveness can be reached. As for conservation measures, certainly retrofits reduce heating loads, but the most extensive conservation steps are relatively expensive and may compete economically with active solar heating.

Other factors that could limit the use of on-site active systems in dense neighborhoods are the ability of older roof structures to support active solar collectors and the difficulty of retrofitting large storage tanks or rock boxes into individual

TABLE EIGHTY-FOUR

MONITORED HEAT LOADS IN EXISTING BUILDINGS COMPARED WITH
HEAT LOADS DERIVED FROM ASSUMPTIONS USED IN SOLAR
ECONOMICS CALCULATIONS

<u>House Type</u>	<u>Basic Features</u>	<u>Conditioned Space (sq ft)</u>	<u>Annual Heating Load (mmBtu)</u>	<u>Annual Heating Load (mBtu/sq ft)</u>
1. <u>BALTIMORE</u>				
<u>Solar base case</u>				
Single-family detached	8.42 heat loss factor x degree days x sq ft conditioned space	1500	59.7	39.8
<u>Existing houses</u>				
Single-family detached ¹	Two stories/ basement	1695	71.0	41.9
Single-family attached ¹	Two stories/ no basement	1300	63.2	48.6
Rowhouse ¹	Three stories/ basement	2255	44.2	19.6
OTA "1973" House ²	One story/ three bedrooms	1000	55.4	46.1
2. <u>PHILADELPHIA</u>				
<u>Solar base case</u>				
Single-family detached	8.42 heat loss factor x degree days x sq ft conditioned space	1500	60.8	40.5
<u>Existing houses</u>				
Rowhouse ³	Brick/two stories/ no basement	1210	88.9	73.5
Rowhouse ³	Brick/two stories/ basement/garage	1315	71.8	54.6
Rowhouse ³	Brick/three stories/ basement/garage	1906	88.3	46.3
Twin ³	Brick/two stories/ basement/garage	1436	94.9	66.1

Sources: 1. Twiss (1979), derived from Hittman (1975)
2. OTA Residential Energy Conservation (1979)
3. Philadelphia Solar Planning Project (1980)

basements. Experiences with active water-heating systems suggest that fears about the structural strength of urban rooftops are prudent but exaggerated, while concern about the difficulty of storage retrofits--justified as it is--stems more from common sense than from any detailed analysis of construction costs.

Improvements in active systems--including lighter collectors and smaller storage facilities--could solve these potential problems. As noted above, both of these improvement strategies are being pursued,(119) but systems combining lighter collectors and decentralized storage are not yet on the market.

The limitations surrounding the use of on-site active solar heating systems in dense residential neighborhoods are compelling reasons to consider active solar community-heating systems. (See Chapter Eleven.) In new residential or commercial buildings or in existing commercial buildings, the prospects for using active solar heating systems are much brighter. New buildings can be designed to ensure adequate roof space, structural strength and, in many cases, adequate orientation and solar access. Properly oriented roofs in new energy-efficient single-family attached homes or low-rise apartment buildings need be little or no bigger than roofs in conventional townhouses, rowhouses, or apartment buildings to accommodate solar energy collectors. Indeed, HUD has funded the installation of active solar heating systems in new townhouses and low-rise apartment buildings in such cities as Baltimore, New Haven, and Gainesville.(120)

Retrofits of active space-heating systems onto commercial buildings can be particularly attractive since many have more adequate roof space and open interior or exterior space for storage than homes and since heating-demand levels and patterns often favor the use of solar energy. For example, many warehouses have their thermostats set at relatively low temperatures so stored goods will not spoil and so active employees will be comfortable. In many office buildings or retail stores, internal heat gains from humans, machines, or office equipment can also make initial heating demands lower (per square foot) than in residences. Reducing heating needs even further through conservation can make a variety of commercial buildings well suited for solar energy. For example, the Concord Light Plant, a municipal garage and office areas in Concord, Massachusetts, need heat most in the early morning, just after employees arrive, and toward evening. Its active solar heating system provides much of the early morning heat because the collector array is oriented east of south to collect heat from the rising sun. Switching on the auxiliary electric heating system briefly, just before employees arrive (and off shortly afterward) is usually enough to provide adequate space heat for the morning. Collected solar heat is continuously used during the day, cutting down on storage losses.(121)

Passive Systems - Residences

If orientation and solar access are correct, most single- and multifamily buildings (including multiple-story structures) should be at least considered as potential passive solar retrofits. Retrofit strategies exist for molding passive solar to buildings with large amounts of south-facing glass as well as to those with none, to buildings of masonry exteriors, as well as to those with wood frames.

The space available for passive collectors may consist of the glass area only or the entire south-facing wall. Even where one of these areas is relatively small, passive solar can still be put to good use since costs of passive solar are variable. For example, in single-family houses, collector areas of no more than 100 square feet can be effective and economical.(122)

Although some passive techniques are appropriate for virtually every type of building exterior, one or two structural features are particularly well-suited for retrofits: relatively large areas of south-facing glass or masonry walls. To be sure, a large south-facing glass area is not by itself a passive solar energy system. On the contrary, large areas of single-paned glass are net heat losers in winter. Even double-glazing windows does little more than reduce conduction losses out of the building. A passive system, on the other hand, allows for efficient collection, at least some storage and distribution, and protection from overheating and nocturnal heat loss. For example, calculations comparing different passive retrofit options for a factory-cum-apartment building in New York City indicated that heating loads for apartments on the building's south side would be almost six times greater with direct-gain glazing than if a combination indirect-gain/sunspace system with mass wall storage was employed.(123)

Nonetheless, residential buildings with large south-facing window areas do have substantial passive solar potential. Where buildings do not have much glazing, it can be added. A simple strategy is to enclose an existing wooden or stone porch with glass, in effect turning a porch into a greenhouse.(124) More expensive alternatives are to "build out" a sunspace from the building's exterior surface or to replace part of a wall with glazing.(125)

Buildings with masonry surfaces have combined collectors and storage components potentially in place. By adding a layer of efficient glazing over the exterior masonry surface, a "trombe wall" retrofit can be completed. Given the number of single- and

multifamily (as well as commercial) buildings with masonry exteriors, the potential for this applications is massive in some cities.(126)

However, the availability of potential collector area is not the only condition necessary for a passive retrofit. Because the passive system must store and distribute collected heat, interior building materials and design are critical. In particular, wooden walls and floors do not store heat well, and the area closest to the collector will probably overheat if the design does not allow an easy air-flow. Thus, in many of the multifamily passive retrofit projects HUD funded in its Residential Solar Demonstration Program, substantial interior rehabilitation was needed. (Such comprehensive structural alterations probably would not be cost-effective under ordinary circumstances.) Unfortunately, even though the importance of interior design for effective passive retrofits cannot be overstated, few studies on the suitability of city building interiors have been conducted.

Passive Systems - Commercial Buildings

The appropriateness of particular types of commercial buildings for passive solar retrofits depends not only on how they are built but also on how they use energy. Smaller retail stores and offices or warehouses and factories with unshaded south-facing masonry walls may have the greatest retrofit potential. Retrofitting trombe walls onto these buildings is not much more complicated than residential retrofits, and many such buildings have energy use patterns well suited for passive heating retrofits. Since smaller buildings have larger surface-to-volume areas than bigger structures, they need relatively more heat than larger commercial buildings, but less heat per square foot than residences because of the benefits of relatively greater internal heat gains. Thus, a relatively small passive contribution could satisfy a relatively large portion of the heating--thus, total energy--demands.

The suitability of larger commercial buildings for passive retrofits is relatively harder to assess because so many factors need to be considered. Limitations in taller buildings may be the difficulty and expense involved in making structural additions or changes on upper stories.

Surface-to-volume ratios must also be taken into account. Even in large office buildings, they can vary substantially, depending on the design of the building frame. For example, a rectangular building can have a surface-to-volume ratio three to four times smaller than that of a U-shaped building.(127) In general, buildings with larger surface-to-volume ratios are likely to have relatively larger heating loads. Thus, passive heating retrofits may be able to save relatively larger amounts of energy--and be more cost-effective--there.

In large buildings with large glass areas, enhancing heat collection and retention on the south side and reducing heat loss on the north can cut heating loads dramatically. However, because many larger commercial buildings use much of their energy for lighting and cooling, steps taken to improve winter heat gain should not be allowed to add to cooling loads. Further, efforts to reduce winter heat loss should not be allowed to create a need for more artificial lighting, and thus to increase the cooling demand. Therefore, all glass areas will probably need double glazing or some other thermal efficiency enhancement, as well as night insulation. Most south-facing areas probably require some overhangs or movable blinds to prevent daytime overheating while allowing the continued and enhanced use of natural lighting ("daylighting"). (On northern sides, the need to prevent daytime heat loss should be balanced against need to ensure adequate daylighting.)(128)

In any large building with relatively heavy heating, lighting, and cooling needs, replacing some of a south-facing wall with glazing makes sense. This move could directly reduce heating and lighting needs and indirectly cut demands for cooling needs. But here the need for a well-designed passive system cannot be overemphasized. Using the wrong kind of glass or the wrong kind of structural controls could lead to both nocturnal heat loss (increasing heating demand) and daytime over-heating (increasing cooling demand).

New passive solar buildings can be easily accommodated in the urban environment since passive systems can be adapted to diverse building types, urban locations, and climates. One hundred double-envelope houses are under construction in Buffalo, and twelve earth-sheltered townhouses have been built in downtown Minneapolis next to an interstate highway. New commercial buildings using passive systems can boast nothing more than a single south-facing wall with glazing and mass storage (one installed in a light-industrial plant in West Hartford paid for itself in two years)(129) or features as innovative and sophisticated as the split envelope design that will provide lighting, heating and cooling to a new Tennessee Valley Authority building in Chattanooga.

Institutional Constraints

Land-use considerations will be more important for the use of solar space-heating systems than for the use of solar water heaters simply because greater solar access will be needed in space-heating applications.

The degree of solar access protection that can be reasonably accorded to solar heating systems will vary by neighborhood, depending on how much shade-free, south-facing area is already available, how much shading does or could pose a problem, and what future land development holds in store. For example, the Philadelphia Solar Planning Project found existing south-facing building fronts and rears of rowhouses to be relatively shade-free. In such neighborhoods, simply enforcing local height limitations with a formal recognition of the value of solar access might be enough to achieve reasonable protection. In a single-family, low-density area where vegetation is a major source of shading, a formal recognition of the value of solar access plus a shade-control ordinance could be effective. Where many taller buildings already have shaded walls, efforts to protect solar access in mid-rise neighborhoods should probably concentrate on protecting roof access for domestic water systems or centralized access for community systems. (See Chapter Four.)

Like the widespread use of conservation technologies, the widespread use of solar heating could prompt an adverse electric utility reaction only if a large number of homes in the city are electrically heated. Even then, solar heating equipment could be combined with utility load-management techniques to reduce peak demands for electricity. For example, the Public Service Company of New Mexico found that the passive solar homes it monitored demand far less energy during peak hours than conventional homes do, and that most of the demands of passive homes for backup energy occur in off-peak periods.(130)

Still, the widespread use of solar heating could greatly affect electric utilities. Therefore, cities wishing to encourage the use of solar heating where electric resistance is common may have to contend with adverse utility policies and reactions. (See Part One, Chapter Six, Energy Supply and Distribution.)

Socio-Economic Factors

Low-income city residents cannot afford most solar energy equipment without some form of financial assistance. Nor will solar heating be appealing to many owners of multifamily buildings, since they can either pass utility costs on to renters or deduct part of their energy costs from their Federal income tax. Cash-poor owners of older buildings (either multifamily or commercial) will not have the capital on hand to pay for energy-saving improvements with relatively high first costs, no matter how economical they are over the long run. In short, those who could benefit the most from solar heating are not those likely to make solar purchases--regardless of how economically attractive solar heating becomes for more well-off owners of single-family homes.

It is so, however, that solar heating technologies can measurably and palpably help low-income persons. Implemented by city governments or community groups, some (usually low-cost) solar installations in low-income areas have helped consumers cut utility bills and enjoy an improved quality of life. For example, the Office of Human Concerns (OHC)--a Community Action Agency in Rogers, Arkansas--has installed low-cost air heaters (typical thermosyphoning air panels supplemented by a blower) in dwellings occupied mainly by low-income elderly persons. The beneficiaries of this program have saved up to 25 percent on heating bills in previously weatherized homes.(131)

In Chicago, the Center for Neighborhood Technology (CNT) is helping to bring fresh vegetables and cheap heat to many city buildings by adding solar greenhouses to them. CNT's first and best known greenhouse project, a converted loft space at Operation Brotherhood, a senior citizen center located in a westside Chicago neighborhood--involves growing vegetables that are sold in OB's grocery store and heating adjacent space.(132)

Together, these potential benefits and real obstacles justify the development of financing options to help deliver solar heat to low-income and middle-income markets, such options can also help create jobs for low-income city residents. The Office of Human Concerns used Comprehensive Employment and Training Administration (CETA) workers both to build and to install solar air heaters. The Charlotte (North Carolina) Area Fund used CETA trainees to demonstrate the use of low-cost solar greenhouses in a few single-family homes.(133) CUANDO (Culturas Unidas Aspiran Nuestro Destino Original/Cultural Understanding and Neighborhood Development Organization), a group of young Blacks and Puerto Ricans that organizes community activities and projects cooperated with the Energy Task Force (ETF) to train fifteen unskilled teenagers to retrofit a Trombe wall onto the CUANDO City Center. The retrofit now stands as a symbol of the potential benefits of combining local energy and job-training initiatives.

Simple, low-cost passive solar energy collectors like the ones described here can provide good job-training opportunities. Trainees will acquire basic carpentry or construction skills of use in many occupations. At the same time, extended preparatory training and extensive on-site supervision is not needed.

Chapter Ten

Cooling Buildings

BACKGROUND

While demands for cooling energy do not begin to approach demands for heating energy in the U.S., reducing cooling loads and finding renewable sources of energy for cooling are vital for a number of reasons.

First, in a small but growing number of cities, cooling represents the largest building-energy drain. For example, the South Florida Regional Planning Council found that air conditioning constituted the highest building energy demand (45 percent, overall) for a tri-county area that includes Miami. According to OFA, a centrally air-conditioned single-family home in Houston demands about seven times the amount of cooling as heating energy. (See Table Eighty-Five.)

Of course, since not all homes are centrally air conditioned, actual cooling energy uses per house are commensurately less. Still, the South Florida Energy Audit predicted that fully 75 percent of all new construction would incorporate central air conditioning.(1) While DOE predicts that 90 percent of all new construction in the Southwest will be centrally cooled,(2) Even in the somewhat cooler climate of Greenville, North Carolina, newer multifamily low-rise buildings use almost 20 percent of their energy for air conditioning, as compared with seven percent for older single-family detached houses.(3)

Second, a number of factors combine to create higher cooling demands in cities than in surrounding suburbs. One factor is urban form. The same features that help to cut winter heating needs (dense housing patterns, taller buildings that function as wind breaks, etc.) often add to summer cooling loads. And lack of trees and other vegetation from many urban neighborhoods also makes people and buildings hotter. Moreover, in some large commercial buildings annual cooling needs exceed demands for heating. (Table Eighty-Six summarizes a comparison of heating and cooling needs in a prototypical glass office building for different cities in widely differing climates.) In addition, in many larger buildings, high cooling demands indirectly add to heating energy use. As noted in Chapter Nine, some space-conditioning systems (e.g., Terminal Re-Heat Systems) actually reheat chilled air before delivering it to certain building zones.

Likewise, insofar as cities contain relatively more poorly insulated buildings than surrounding suburbs do, urban demands for cooling per square foot of mechanically cooled space may well be greater. Also, since cities contain a greater proportion of lower-income residents than do suburbs, many of the window air-conditioning units in place in cities may be older and less efficient than the norm.

A final incentive for reducing the use of cooling energy is that most mechanical cooling is supplied by electricity--usually the most costly source of energy owing to increased costs due to generation losses. Thus, even though a typical row-house in Baltimore uses only about eight percent of its on-site energy for cooling, over 13 percent of the house's primary energy consumption (total fuel used including fuel for generating electricity) is for cooling. Indeed, cooling energy accounts for almost as much primary energy year-round as water heating. (See Table Eighty-Seven.)

ENERGY SAVING TECHNOLOGIES

Many of the space-heating technologies described in the last chapter can also be used in cooling. Improving the building shell and making cooling systems more efficient can help to reduce conventional energy use for cooling. On-site passive and active solar energy systems can supply coolness as well as heat. In addition, renewable sources of electrical energy (wind, hydropower, photovoltaics) can be used to power electrical cooling devices. (See Part Three, Chapter Twelve.)

TECHNICAL APPROACHES AND ISSUES

Shell Improvements

In smaller residential and commercial buildings with relatively high surface-to-volume ratios, building-shell improvements that can help save heating energy can help save cooling energy too. Reducing infiltration keeps hot air outside the building and mechanically cooled air inside. Better insulating most parts of the shell helps reduce conductive heat gains in summer. Using efficient window designs and materials can reduce the overheating in summer.

The effects these improvements have on cooling loads varies by climate. In general, their overall impacts will probably be proportionately less on cooling than on heating demands. According to the National Association of Home Builders Research Foundation (NAHBRF):

"First, even in very hot climates, where summer design temperatures are near 100 degrees F, the temperature difference between the outside and inside air is smaller than for most winter

TABLE EIGHTY-FIVE
RELATIVE SIZES OF RESIDENTIAL HEATING
AND COOLING DEMANDS
(Selected Cities)

<u>City</u>	<u>Percent of Space Conditioning Demand for Heating</u>	<u>Percent of Space Conditioning Demand for Cooling</u>
Baltimore	75.5%	24.5%
Chicago	85.3%	4.7%
Houston	12.8%	87.2%

Source: Office of Technology Assessment, Residential Energy Conservation, (1979)

TABLE EIGHTY-SIX

<u>City</u>	<u>Percent of Space Conditioning Demands Used for Heating</u>	<u>Percent of Space Conditioning Demands Used for Cooling</u>
Minneapolis	45%	55%
New York	31%	69%
St. Louis	29%	71%
Atlanta	21%	79%
Los Angeles	12%	88%

Source: S. Robert Hastings, "Passive Solar Design for Urban Commercial Environments," Presented at the 1979, National Passive Solar Conference.

TABLE EIGHTY-SEVEN
END USE VERSUS PRIMARY
ENERGY CONSUMPTION IN A
TYPICAL BALTIMORE ROW-HOUSE

<u>End Use Type</u>	<u>End Use Energy (%)</u>	<u>Primary Energy (%)</u>
Space Heating	47.5%	35.7%
Cooling	8.1%	13.3%
Water Heating	16.0%	14.8%
Lights/Power	17.9%	29.6%
Clothes/Cooking	10.5%	6.6%

Source: Twiss (1979) derived from Hittman (1975).

temperature differences. All other things being equal, the amount of energy used is directly related to the temperature difference. Second, the effect of double glazing for summer conditions is considerably less than for winter conditions. Third, the amount and effect of wind infiltration under summer design conditions is substantially less than for winter design conditions.(4)

Nonetheless, shell upgrading can significantly reduce heat gain. For instance, strict but technically simple shell retrofits could reduce total (external and internal) heat gains in a 1,500 square foot house in Baltimore by 38 percent (by 45 percent if external gains only are counted.)(5)

Most simple shell-conservation measures--adding attic insulation, double glazing, plugging leaks, etc.--require no special modifications to reduce cooling as well as heating loads. However, such relatively elaborate shell retrofits as the addition of large quantities of insulation or extensive south-facing window areas may. For example, OTA calculated that while adding floor insulation to prototypical single-family houses in Baltimore and Chicago cuts heating needs enough to make the net benefits worthwhile, cooling demand will increase slightly because the houses could not lose heat to the cooler ground in summer. But in Houston adding floor insulation does not increase mechanical cooling energy needs because floor heat losses are negligible in that hot, humid climate. (See Table Eighty-Eight.)

In buildings with high internal heat gains and (therefore) relatively low mechanical heat loads, the relative impacts of conservation measures on heating and cooling demands require even more analysis. Consider, for example, the results of Energy Ltd.'s analysis of a prototypical supermarket building in Seattle. Adding attic insulation to R-19 levels was predicted to reduce heating needs by over 70 percent but to increase cooling loads by over 30 percent. While the net benefit (assuming the building is both electrically heated and electrically cooled) was still positive, a better alternative would be to increase ventilation and recover waste heat: the second option costs the same and realized equally great heating-energy without increasing cooling loads. (See Table Eighty-Nine.) Clearly, tradeoffs between heating and cooling demand fluctuations have to be assessed in some detail for different types of commercial buildings.

Since moisture may accumulate in heavily insulated buildings, latent heat gain resulting from the additional humidity is another potential drawback to insulating as a way to cut down cooling loads. In practice, though, it is so difficult to add large amounts of insulation to all portions of the building shell that the problem is hypothetical. Even if moisture did build up, a relatively inexpensive air-to-air heat exchanger would solve the problem, as would better ventilation.

South-facing glazing too can add to cooling loads in summer. As the previous chapter makes clear, overheating from south-facing glazing can be prevented by properly sizing the glass area, using overhangs that block summer and early fall sunshine, and using reflective blinds or shades. In a few cases, adding south-facing glass areas should be discouraged altogether. To cut cooling demands, Florida's model building code encourages less glass on unshaded south-facing walls.(6)

In all-glass office buildings, the challenge is more complicated. Unwanted heat gain should be stopped but not at the sacrifice of daylighting, which complements artificial lighting, a high energy use in its own right and a chief source of internal heat gain. In such cases an integrated retrofit strategy may be necessary: reducing some glass areas on easily-accessible floors, installing reflective blinds and/or insulated shades, and eliminating unnecessary artificial lighting.

Reducing Internal Heat Gains

While much of the cooling demand in smaller buildings is climate-related, in larger ones cooling needs are dictated mainly by the heat generated inside the buildings. Many people working close together, machines constantly running, and high levels of artificial lighting all contribute to internal heat gains. Indeed, internal heat sources can account for percent of the cooling load in some commercial buildings.

The three main strategies for reducing internal heat are using more efficient appliances and machines, improving the design of building interiors, and--often most important--reducing lighting levels. Reduced lighting (achieved, for example, by using less bright bulbs or by removing some fixtures) cuts both direct energy use and space cooling demands dramatically.(8) For example, if buildings designed to use 5.0 watts of lighting per square foot of work space were improved to require only 1.5 watts per square foot (a level recommended by the California Energy Commission)(9) some 17.5 KW of cooling capacity could be saved in one 10,000 square foot office building.

Of course, the impacts of lighting improvements on cooling and heating demands must be assessed carefully. In colder climates, internal gains can lessen heating loads, so the impacts of different lighting efficiency strategies on different energy demands, the

TABLE EIGHTY-EIGHT

RELATIVE IMPACTS OF SHELL IMPROVEMENTS ON HEATING AND COOLING DEMANDS

<u>City</u>	<u>Conservation Level</u>	<u>Heating Load</u>	<u>Cooling Load</u>	<u>Total Load</u>	<u>Total Load Difference From Base Case</u>
Baltimore	Base Case	55.4 MMBTU	18.0 MMBTU	73.4 MMBTU	
	Moderate	43.7 MMBTU	15.8 MMBTU	59.5 MMBTU	13.9 MMBTU
	Heavy	9.9 MMBTU	20.4 MMBTU	30.3 MMBTU	43.1 MMBTU
Chicago	Base Case	81.1 MMBTU	14.0 MMBTU	95.1 MMBTU	
	Moderate	64.7 MMBTU	12.3 MMBTU	77.0 MMBTU	18.1 MMBTU
	Heavy	20.2 MMBTU	17.9 MMBTU	38.1 MMBTU	57.0 MMBTU
Houston	Base Case	8.4 MMBTU	56.9 MMBTU	65.3 MMBTU	
	Moderate	5.2 MMBTU	51.3 MMBTU	56.5 MMBTU	8.8 MMBTU
	Heavy	0.0 MMBTU	43.4 MMBTU	43.4 MMBTU	21.9 MMBTU

Source: OTA, Residential Energy Conservation (1979, p. 36)

TABLE EIGHTY-NINE

RELATIVE IMPACTS OF SELECTED SHELL
IMPROVEMENTS ON HEATING AND COOLING LOADS
(Prototype Supermarket in Seattle)

	Heating (MMBTU)	Cooling (MMBTU)	Total (MMBTU)
Base Case	992.1	509.9	1502.0
Attic Insulation	262.16	665.1	927.3
Wall Insulation R-13	727.0	546.1	1273.1

Source: Energy Ltd. (1980)

types of energy used to meet each of those demands, and the benefits of alternative approaches that combine selected lighting-efficiency improvements and shell-conservation measures must all be considered.

Table Ninety indicates some lighting conservation options open to building designers or owners. In each building category, delamping provides the most combined cooling and service-electricity energy savings. But in all cases, delamping also increases heating loads significantly. Where heating energy is provided by natural gas, the delamping strategy may be preferable. But where space heating is provided by electric resistance heat, delamping may be less cost effective.(10) It increases total energy demands in the mixed office/retail building. In both the small office and mixed office/retail building, a combination of more efficient light bulbs and basic shell-conservation techniques is more effective in reducing total energy demands. While this combination of retrofits will cost more than delamping, the additional savings in expensive electric energy can probably justify it. In fact it is possible that more extensive shell retrofits or solar heating could perhaps be economically combined with the use of more efficient light bulbs to reduce total energy demands even further. Only in the supermarket, which has very high cooling and service electricity loads, is delamping the superior option. The overriding point here is that the full impacts of lighting reduction strategies should be evaluated before any lighting retrofit is undertaken.

Conservation Improvements in Cooling Systems

Improving building shell and controlling internal heat gains can help to cut cooling energy demands. Improvements to air conditioners or central cooling systems can cut the amount of energy needed to meet that reduced demand.

Types of Systems

Most air conditioners in single-family homes use electricity. Window units operate on a vapor-compression cycle while central air conditioning systems use vapor-compression chillers or heat pumps in the cooling mode. At least one company also markets gas-fired absorption chillers for residential applications.(11) (According to OTA, 51 percent of all single-family houses in the U.S. in 1976 had either window units (30 percent) or central air conditioners (21 percent).)(12)

In larger buildings, most cooling systems chill water and then circulate it throughout the building. With a forced-air distribution system, the chilled water circulates through a liquid-to-air heat exchanger in the ductwork. The cooling modes of the more complicated systems that combine heating and cooling work on the same general principles as the complex heating system described in the previous chapter: the chiller simply replaces the furnace.

In the chiller, a working fluid (refrigerant) under low pressure absorbs the heat contained in the water returning from the conditioned space, cooling the water so that it can be recirculated. Heat is released by the refrigerant as it is pressurized by an electric compressor or as it comes into contact with an absorbent solution (such as lithium bromide). In the two types of commercial chillers available--electric compression chillers and gas-fired absorption units--(In these, the gas boiler provides heat that separates the refrigerant from the absorbent allowing the refrigeration absorption process to start again.) Heat can be discharged from the chiller by air-, water-, or evaporative-cooling. Some air-cooled systems (such as reciprocal electric compressors) employ a remote air cooling/condensation unit, while a cooling tower is needed in water-cooled systems.

Standard window units generally have measured capacities from 7,000 to 14,000 BTU, which means that they can remove that amount of heat from conditioned space in one hour. Larger central air conditioner capacities are generally given in tons, with one ton representing a capacity of 12,000 BTU per hour. Smaller single-family central air-conditioning units are in the 3-5 ton range. Moderate compression and absorption systems can vary from 10 to 25 tons; while larger buildings can use units of 100 tons or over. Single absorption units can reach over 1,500 tons of capacity, while the very largest compression units can reach 10,000 tons.(13) In larger buildings, cooling systems have two or more chillers.

System Efficiencies

The efficiency of an air-conditioning system or component is generally given in coefficients of performance (the BTU of heat removed divided by the BTU of energy used to operate them) or in energy efficiency ratios (EERs) (the BTU of heat removed divided by the watt-hours of operating energy). Currently, the Coefficients of Performance (COPs) of new room and central compression air conditioners fall between 1.6 and 3.1 (5.46-10.58 EER.)(14) COPs of larger electric vapor-compression chillers vary much more, depending upon the type and capacity of the compressor used, and whether the system is water- or air-cooled. As a range, COPs of compression chillers run from about 2.85 to 3.6 for reciprocating units, 4.1 to 4.9 for centrifugal units, and 3.3 to 4.5 for screwtype units.(15) COPs of absorption units are generally much lower, from 0.45 to 0.70

TABLE NINETY

ENERGY DEMAND IMPACTS OF LIGHTING EFFICIENCY STRATEGIES ON
HEATING, COOLING, AND ELECTRIC LOADS IN
PROTOTYPICAL COMMERCIAL BUILDINGS (SEATTLE) (In MMBTU)

SMALL OFFICE

	<u>Heating</u>	<u>Cooling</u>	<u>Elec.</u>	<u>Total</u>
Base Case	127.6	50.3	331.0	508.9
Delamping	180.1	37.1	252.1	469.3
Efficient Bulbs	127.6	50.3	292.2	470.1
Efficient Bulbs and Reduced Infiltration	100.1	49.8	292.2	442.1

MIXED OFFICE/RETAIL

	<u>Heating</u>	<u>Cooling</u>	<u>Elec.</u>	<u>Total</u>
Base Case	165.9	42.9	318.0	526.8
Delamping	290.2	32.1	253.1	575.4
Efficient Bulbs	165.9	42.9	276.4	485.2
Efficient Bulbs and Reduced Infiltration	134.9	42.3	276.4	453.6

SUPERMARKET

	<u>Heating</u>	<u>Cooling</u>	<u>Elec.</u>	<u>Total</u>
Base Case	992.1	509.9	4,138.6	5,640.6
Delamping	1,385.1	411.7	3,549.2	5,346.0
Efficient Bulbs	992.1	509.9	3,874.9	5,376.9
Efficient Bulbs and Reduced Infiltration	975.3	512.5	3,874.9	5,362.7

Source: Energy, Ltd.

for "single effect" and from about 1.0 to 1.15 for "double-effect" chillers.(16) (See next section.) However, primary-fuel COPs of compression and absorption units appear much more comparable if the penalties imposed by electric generation and transmission losses are taken into account. (For example, if two thirds of the primary fuel input to electricity production is lost, the primary fuel COP of an electric compression chiller with a nominal COP of 3.0 is approximately 1.0.)

Improving Chiller Efficiencies

Since both heat pumps and electric air conditioners operate on vapor-compression cycles, many of the techniques used for improving heat pump efficiencies also work to improve the performance of room or central air conditioners as well. (See Chapter Nine.) Indeed, COPs for electric air conditioning units have been improving for this reason.(17)

As noted earlier, at least one residential-sized gas-fueled absorption air conditioner is now on the market. Gas-fired heat pumps that operate on the absorption cycle in both heating and cooling modes are also being researched. Both devices could enable residential buildings to obtain energy sources that cost less than electricity.

Absorption chiller efficiencies are expected to improve as designs using the "double effect" absorption principle come into wider use. Because such units can accommodate higher temperatures, they can separate refrigerants and absorbents more completely, thus allowing for more effective heat transfer in the condensation, refrigeration, and absorption stages. Double effect absorption chillers can easily reach COPs of over 1.0, and thus compete with some of the larger electric compression units on a cost/BTU basis. Double-effect absorption chillers are available only in relatively large models (385 tons or over) and cost about 30 percent more than a single-effect unit of equal capacity.(18)

Both absorption and compression chiller COPs could also be improved with the use of on-site chilled water storage, which would allow the absorption unit to operate longer, at steady-state conditions, shaving electric demand peaks and cutting cycling losses. Another potential economy would be to use waste heat as thermal input to chiller combustion or compression processes.(19)

Newer Approaches

An innovative cooling system now operating in an experimental house in Knoxville uses a water source heat pump in winter to make ice that is then stored and used for cooling in summer. The heat pump of this system (called the Annual Cycle Energy System - ACES) operates in winter using a large (10,000 square foot) water tank in the basement as the heat source.(20) Its annual COP is 12.7. Variants of this kind of system are being studied carefully as community heating and cooling systems. (See Chapter Eleven.)

Advanced thermodynamic technologies could also be used in cooling systems. Perhaps closest to market readiness is an on-site heat engine fired by natural gas; it generates the electricity needed to run a vapor-compression chiller or heat pump that can be operated in the cooling mode. Prototype chillers operating on Rankine thermodynamic cycles can be manufactured by such firms as Carrier, General Electric and Honeywell on special order, though heat engines have been coupled with heat pumps or air conditioners only rarely.(21) (Higher temperature Rankine chillers have registered COPs of 0.8 and 0.9, comparable in primary fuel efficiency to electric chiller COPs of 2.4 or 2.7.

Such heat engines could generate electricity for sale under the provisions of PURPA 210, allowing their owners to defray systems costs.(22) It can also be economical to use the heat engine to run a heat pump that both heats and cools.

Improving System Efficiencies

Improvements to heating and cooling systems should be undertaken together, especially in large buildings. Most techniques for improving heating systems in large buildings can improve system cooling performance too. (See Chapter Nine.)

For example, heat-recovery systems can remove heat from buildings as well as help run absorption chillers.(23) Enthalpy heat exchange systems can cool and dehumidify incoming air in summer much as they can heat and humidify incoming cold air in winter.(24) Sophisticated control systems that monitor conditions in different building locations and climatic conditions can often reduce the amounts of artificial cooling needed. For example, a system known as an air-economizer cycle can substitute outside air for chilled air when outdoor air temperatures are cooler and drier than those indoors.(25) Control strategies governing the more efficient use of a building's total energy (for heating, cooling, and service electricity) usually reduce cooling energy needs the most because loads in many large buildings are cooling-dominated.

For perspective, Florida's Model Energy Efficiency Building Code, developed for an area where cooling loads certainly dominate, contains several provisions for reducing cooling energy use in large buildings. For instance, it encourages the use of automatic temperature resets to raise the temperature of cold air or lower the temperature of heated air to control interior temperatures with minimal energy expenditures.

(Increasing the temperature of existing chilled water can improve the COPs of compression chillers by 10 percent or more.) For buildings that need simultaneous heating and cooling, the code requires sequential temperature controls that raise or lower air temperatures to delivery levels instead of mixing air streams that are either too hot and too cold.(26)

A newer cooling approach is the development of dessicant systems that enhance the enthalpy systems described above. Dessicant cooling systems use some high surface-to-volume area solid such as silica gel, a molecular sieve, or zeolite to dry return air from conditioned space before the air is evaporatively cooled by a humidifier.

Unlike enthalpy systems dessicant systems have a drying agent so they work relatively better in humid climates. (The performance of the drying agents, however, is still being tested.)(27)

ECONOMICS OF CONSERVATION TECHNIQUES FOR COOLING

Building Shells

Few economic analyses of shell-conservation techniques distinguish between heating savings and cooling savings. Most, in fact, concentrate on heating energy savings because their magnitude is so much greater. Since most basic shell improvements cut both heating and cooling energy needs, it does make sense to count cooling savings simply as a dividend of economical retrofit strategies. (See Chapter Nine.)

To the extent that shell-conservation improvements do increase cooling energy demands, such impacts will have to be calculated case by case, bearing in mind that heating energy is often provided by oil or gas while cooling is usually supplied by more expensive electricity and that most cooling penalties pale beside heating savings.

Air Conditioning Equipment

The economics of replacing less efficient with more efficient window units or with small central air conditioning systems varies with many factors. If new air conditioning systems are to be purchased, the (sometimes) higher costs of more efficient systems are more than made up for in utility bill savings. (See Table Ninety-One) In most cases, however, replacing air conditioners that are still in good condition is not economically worthwhile.

The economics of the experimental ACES system have been calculated by researchers at Princeton University and Oak Ridge National Laboratories.(28) (See Table Ninety-Two) At baseline costs of six cents KWH for the electric resistance system, it is cheaper to install the ACES system than to purchase additional electricity for the resistance system. However, the air-to-air heat pump is the better investment still on a cents per KWH basis, though the pump saves far less energy than the ACES system.

The economics of fossil-fueled equipment that can replace electrical vapor-compression units vary greatly and may become even less predictable as efficiencies improve and natural gas price deregulation continues. For example, Allied Chemical Corporation and Phillips Engineering are developing a gas-fired absorption heat pump with a predicted COP of 1.2 for heating and 0.5 for cooling.(29) Since natural gas currently costs about one-third the price of electricity on a dollar per BTU basis, such a heat pump could deliver energy at costs equivalent to an electric heat pump with a heating COP of 3.6 and a cooling COP of 1.5. However, the relative advantages of gas-fired heat pumps may decline as gas prices are deregulated.

Costs for newer technologies are far less competitive. Rankine cycle engines alone cost between \$900 and \$1,600 (1978 \$ KW). Even if the costs of smaller (5-10 KW) Rankine units decline as predicted to \$200-\$300/KW (.20 cents - .30 cents/watt) with mass production,(30) the costs for compression cooling (the other "half" of the Rankine chiller) must still be added. (For comparison, entire absorption chiller systems could be purchased for 20 cents - 30 cents/watt in 1978.)(31)

The economics of such larger-scale building improvements as reconfiguring systems or making hardware substitutions depend heavily on the design and condition of existing buildings and systems. (See Chapter Nine.)

TABLE NINETY-ONE

INCREMENTAL COSTS OF IMPROVED PERFORMANCE IN NEW
CENTRAL OR ROOM AIR CONDITIONERS

<u>A.C. Type/ Capacity</u>	<u>Baseline EER</u>	<u>New Unit EER</u>	<u>Added Costs for Improved EER</u>	<u>Costs/Watt Improvement</u>	<u>Hours Operated (Yearly)</u>	<u>First Year Savings*</u>	<u>Lifetime Savings (10 Years)*</u>	<u>Simple Payback of Added Costs*</u>
Central (19,750 BTU/H)	7.5	8	\$ 33	20¢	800	\$ 8-60	\$ 151	3-4 years
Central (19,750 BTU/H)	7.5	13	\$446	40¢	800	\$57.90	\$1,016.10	5-6 years
Room (7,000 BTU/H)	6.5	7	\$ 15.40	20¢	700	\$ 3.50	\$ 61.50	3-4 years
Room (7,000 BTU/H)	6.5	11.6	\$190.00	40¢	700	\$21.60	\$ 378.50	6-7 years

*At electricity costs of 6.5¢/KWH in year one, with 12% price escalations in succeeding years.

Source: Derived from data collected by the Natural Resources Defense Council.

TABLE NINETY-TWO

COSTS AND ENERGY SAVINGS OF ACES SYSTEM AND COMPETITORS

<u>System</u>	<u>Capital Costs</u>	<u>Annual Energy Requirements (KWH)</u>	<u>Annual Electricity Savings</u>	<u>Costs/KWH Saved</u>
Electric Resistance and Central Air	\$1,068	13,700	--	N/A (baseline cost of .06¢/KWH)
Air-to-Air Heat Pump	\$1,552	11,100	2,600	\$0.023
ACES	\$4,069	6,800	--	--
VS. Air-to-Air Heat Pump	--	--	4,300	0.047
VS. Electric Resistance/ Central Air	--	--	6,900	0.038/KWH

Source: Ross and Williams, Our Energy: Regaining Control, p. 309

CITY APPLICATIONS

Nearly all city buildings can economically accommodate some improvements to both shells and cooling systems. While shell improvements (unlike internal load reduction and system improvements) are likely to be proportionally more effective in smaller buildings, they still tend to affect heating energy savings more than cooling energy savings. As a practical matter, city policies directed to saving cooling energy should thus probably concentrate on improving cooling systems. (See Chapter Nine.)

Opportunities for taking this approach are increasing. As noted earlier, over 75 percent of the new residential construction in warmer areas will most likely be mechanically cooled. Even in cooler areas, new townhouse units or multifamily low-rise buildings will probably incorporate more mechanical cooling, proportionately, than will single-family homes. This is true both for cities like Greenville (2,500 cooling degree days) and places like Boulder (500 CDDs), although the size of their respective cooling loads certainly differs.(32) Then too, growing or redeveloping downtown areas can expect increases in office building construction with consequent increases in total cooling loads.

Institutional Constraints

Unlike reductions in heating energy demands, reductions in cooling energy needs directly affect the public utility serving the city. Summer-peaking utilities will experience a seasonal production reprieve, and cooling load reductions and system efficiency improvements will also help shave daily peaks. Consequently, utility reactions will, most likely, be determined by the utility's overall fuel supply and capacity picture. (See Part One, Chapter Six.) Where utilities operate with little excess capacity, the conservation of cooling energy should dovetail well with utility efforts at peak-load management. But where excess capacity is ample or plant construction under way, conservation efforts may not be well received. In this case, city governments have a number of policy responses open to them. (See Part One, Chapter Six, Energy Supply and Distribution.)

Socio-Economic Considerations

Relatively few low-income persons live in buildings that are centrally cooled.(33) Most of those that do probably live in apartment buildings where landlords can make energy-conservation retrofits. Most mechanically cooled low-income housing probably has window units, often purchased second hand.(34) Consequently, a city government's options for reducing the impacts of cooling costs on low-income people are extremely limited. Weatherizing shells could help cut cooling demands somewhat, but few other cooling-conservation programs directly benefit poor people. Similarly, the most direct job benefits for structurally unemployed persons are likely to arise from weatherization programs, rather than from programs for improving cooling systems. (Large-scale city initiatives to make HVAC systems more efficient will most likely create jobs for relatively skilled workers.)

SOLAR COOLING

Technological Approaches

In general, solar cooling techniques and technologies are not as well-developed as those for heating. But numerous exciting passive solar designs can potentially replace some mechanical cooling energy in new and retrofitted buildings. Active solar collectors can be used to run absorption chillers or, in more experimental applications, to run heat engines in compression cooling systems.

Passive Systems

Reducing Heat Gain

As noted earlier, all passive solar systems must include some means of preventing heat gain. (See Chapter Two. In hot climates, designers must pay special attention to this--using overhangs, reflective blinds and shades, vents in collector glazing, strategically placed vegetation, and earth-berming. See Chapter Nine.)

Besides well established methods for preventing heat gain are numerous approaches designed to remove heat from buildings and to replace expensive-to-operate mechanical air conditioners.

Ventilation

Perhaps the simplest technique for removing heat is through ventilation. To maximize ventilations in new buildings, the structure should be designed to take advantage of prevailing wind patterns. In addition, solar heat can be collected, absorbed, and transferred in ways that enhance air convection in both new and existing buildings. For example, one multifamily retrofit project in Boston uses part of a trombe wall to trap heat on summer days. At night, vents from the glazing to the outside and from the building interior to the sun wall are opened, so hot air flows to the outside. Opening windows on the building's north side draws cooler night air through the entire structure. Average temperature swings between daytime and nighttime are 16 degrees F--adequate for natural ventilation. The building's designers expect room temperatures to stay within four degrees F or so of those window air conditioners would supply.(35)

Natural ventilation can also be facilitated by interior atriums that can be opened to the outside by roof temperatures. An enhancement of the "whole house" fan concept, the design facilitates the natural movement of air upward (the "chimney effect"). Another multifamily retrofit in Boston uses an atrium that adjoins the interior walls of apartments to create a natural air flow (sometimes assisted by a small fan) through the building. On very hot days, air from the atrium is circulated through the boiler room and passed over a cooling coil filled with well water. Rooftop windows are closed, so cool air flows into the apartments instead.(36)

Heat Dissipation

Another way to remove heat from buildings via passive solar design is to use components or materials to absorb hot interior air and then discharge it outdoors--the passive heating cycle in reverse. Hot interior air is collected and absorbed in storage materials and either discharged immediately or else stored. Whether discharge is immediate or delayed depends on the temperature difference between the storage materials and the heat sink. For example, ground-coupled mass-storage could discharge heat immediately because ground temperatures are generally lower than room and storage temperatures. However, designs that release heat to the outside air will usually need to delay heat dumping until nighttime, when outside temperatures fall.

"Ground coupling" can be accomplished in a number of ways. In slab-on-grade construction, the mass floor-slab can simply function as the storage-dissipation material. In buildings with basements, the mass storage in walls or floors will need to be thermally connected to the foundation. Not surprisingly, this technique works best where ground temperatures are reasonably lower than ambient temperatures. Thus the technique would probably work well in such cities as Baltimore and Chicago, but not in Houston.

A radically different way to use the ground as a heat sink is to employ so-called "cooling tubes." (This technique is a much more feasible retrofit technique than ground coupling by direct contact with storage mass, which can require difficult structural alterations.) One basic tube design draws outside air through a buried run of tubing made of aluminum or some other metal. As air moves through the tubes, it cools by losing heat to the ground. Air-flow through the tubes can be induced by natural ventilation or by a small attic fan. In either case, cooled air exiting the tubes replaces heated air since ground-coupling and ventilation techniques are used in tandem.(35)

Other tube designs could feature "closed" tubular loops, which could circulate return air from the building or a transfer fluid that could absorb heat from the building

and discharge it to the earth.

The most common method of "air-coupling" uses the roof's materials to store and dissipate ambient heat. Sometimes the roof's mass materials serve as storage. A more innovative approach is to use a "roof pond" or water-storage technique. In such air-coupled cooling systems, bags of water are placed atop a reinforced roof and covered with a movable shading device that prevents the water from absorbing too much outside heat. Heat from the building's interior flows naturally to the bags by convection and conduction. (In humid climates, a vapor barrier prevents moisture from penetrating the house.) At night, the movable shade is removed and the absorbed heat is reradiated to the outside air. In winter, the system works in reverse, discharging absorbed heat into the house at night.

Since the roof's heat-storage and -dissipating functions often occur when differences between inside ambient temperature, the outside ambient temperature, and the storage temperature are relatively small, heat absorption areas must be as large as possible. Accordingly, some designs increase the surface area by allowing water or air to circulate around the building shell, absorbing heat from walls as well as the interior roof surface.(38)

Naturally, the amount of water that can be stored on the roof above the living space is limited. The way around this problem is to plan the roof pond over, say, a garage or a carport. Cooler water can then thermosyphon to a standing water wall in the living area, where it absorbs heat and is then thermosyphoned back to the pond.(39)

In multistory buildings, using the roof to dissipate heat will not work since only the top floor would be cooled. Yet, some experimental designs can make air-coupled heat dissipation possible in large buildings. In one such design, a heat-dissipating sill would be installed above each floor. As hot air in the room rises, it is vented to sills where heat is lost to the air by radiation and evaporative cooling (from a built-in water pipe). As air in the sill cools, it convects to the bottom of the sill, and from there flows through ductwork under the floor to an air vent that opens to the room. This process continues until a sensor closes the sill vent.(40)

Another approach is to use innovative thermal mass construction to maximize heat absorption. For instance, precast hollowcore concrete can be used to absorb building heat during the day and to release it at night. The next day, thermal absorption begins again.(41)

Chilled Water from Passive Solar Design

Both absorption and compression chillers cool water that in turn cools a building through either a hydronic or forced-air distribution system. In some climates, passive heat transfer can be used to help make ice in winter then can be stored until summer, when it can be used to chill water.

One chiller design calls for the use of heat pipes that will allow natural heat transfer from a heavily insulated water bin under or near a building until the water freezes. In summer, the ice serves as a capacious heat sink to chill a transfer fluid that circulates through the building.(42)

A more ambitious "hybrid" approach, developed by the Princeton Energy Group, is to use snow-making equipment or atomizing spray nozzles to produce ice by exposing water to cold winter air. Stored in an insulated reservoir until summer, the ice can then help meet cooling loads: as it melts, it is circulated through pipes to a liquid-to-air heat exchanger that chills the air in a conventional forced-air distribution system. The ice supply perpetuates itself as returning water is sprayed over the remaining ice mass. Some prototypical ice-making cooling systems have predicted COPs (cooling energy stored divided by operational energy) of up to 23.1 and as high as 7.9 (about three times better than those of the most efficient conventional chillers) in field tests under unfavorable conditions.(43)

The first full-scale demonstration of an air-conditioning ice pond is in an energy-conserving office building in Princeton. A 19,200 square foot ice pond is predicted to supply the equivalent of 420,000 KWH worth of electrical cooling per year.(44)

Passive Cooling Performance

Most available information on passive system performance relates to heating. Even generalizations about heating are extremely tenuous, so generalizations about cooling are all the more so.

In general, techniques for reducing heat gain are effective if properly designed and built. True, overheating in summer is more than an occasional problem even in well designed passive buildings, as technical evaluations from the HUD Residential Solar Demonstration Program(45) and building surveys of passive solar home occupants done by the Memphremagog Group in Vermont attest.(46) Yet, most such problems can be easily remedied or controlled in a well designed system.(47)

Of the passive designs for removing heat, those relying on ventilation and direct dissipation by ground- or air-coupling seem most promising. Direct ground coupling or

air dissipation systems seem most appropriate for new buildings, while ventilation techniques also hold appeal for use in retrofits. For example, one multifamily retrofit in Charlotte, North Carolina, can do without mechanical cooling because it will rely on roof-mounted turbine ventilators that will draw cooler air from the crawl space through the whole building.(48)

One key to ventilating strategies is occupant participation. In the Boston retrofit described above, occupants must open north windows at the appropriate time. In another multifamily retrofit in Boston, occupant participation is so crucial that the community development corporation that started the project plans to write a manual and conduct workshops for the tenants and the live-in superintendent.(49)

The performance of all of these techniques in hot, humid climates is a subject of some disagreement even among experts. Both ground-coupling and air-coupling seem to hold less promise where diurnal temperature swings are slight, and ventilation is less effective if incoming air contains large amounts of latent heat. Yet, reducing infiltration to allow for less moisture build-up, using desiccant material to help dry incoming air, or using dehumidifiers (if they do not require large amounts of operating energy) are all solutions to the humidity problem. In cooperation with DOE, Trinity University in Texas is working on a high-efficiency, low-energy dehumidifier that would affect only condensation, leaving the removal of sensible heat to the passive solar cooling system.(50)

Active Systems

Active solar cooling systems can be used effectively in far-fewer settings than passive cooling systems. Confined mostly to larger buildings, active cooling may nonetheless work better than passive cooling in hot, humid climates.

Most active cooling systems use solar heat to help drive conventional cooling processes that remove both sensible and latent heat from conditioned areas. At least one more experimental collector is designed to produce chilled water directly in the collector itself.

The active solar cooling applications closest to commercial readiness are solar absorption chilling systems. In these systems high temperature collectors (either troughs or evacuated tubes) supply some or all of the thermal energy needed to raise the absorbent/refrigerant solution to working temperatures--200 degrees F to 300 degrees F.

At least two major HVAC equipment companies, ARKLA and Carrier, have made commitments to producing solar-powered absorption chillers.(51) Also, numerous absorption systems have already been installed,, a few in residential buildings and more in smaller or larger commercial facilities. Most have been paid for as part of a Federal demonstration program. In colder climates (such as Minneapolis and Keystone, S.D.) these systems also provide space heating.

Active high-temperature collectors can also provide some of the thermal energy needed to run heat engines that, in turn, generate electricity to run compression chillers. The heat collectors provided transform the pressurized working fluid into a vapor that can be used to produce mechanical power for electric generation. (See Part Three, Chapter Twelve, Electricity.) Some innovative Rankine chillers may be able to use lower temperature heat efficiently in this process.(52) As noted earlier, techniques for configuring Rankine-cycle engines with air conditioners or heat pumps remain in the demonstration stage. Obviously, integrating solar collectors with a Rankine-cycle cooling unit is a step beyond that. Nonetheless, solar-assisted Rankine cooling systems are in use in a few demonstration projects.)

A final approach to active solar cooling is to use active collectors to help dry desiccants in desiccant cooling systems. After the desiccants absorb moisture from return air, they must be dried before the cycle can begin again. Currently, a gas- or oil-furnace is used to dry desiccants, but solar heat could be used instead.

Since most desiccant systems for residential and commercial uses are still being pioneered, solar-assisted desiccant systems will not be commercially ready for some time.(53)

All the approaches discussed above combine active solar collectors with conventional absorption, compression, or desiccant-cooling equipment. A much more innovative design produces chilled water in the collector itself. The Zeropower(TM) system makes use of a fine-grained mineral called zeolite, which gives off refrigerant vapor when it is heated and absorbs it when cooled and can thus heat water in a collector during the day and cool it at night.(54) This unique system requires no additional chillers or cooling towers. Also, because it chills water directly, the system does not need to produce the high temperatures absorption chillers or heat engines need, which means that the collector area can be smaller (as much as 75 percent, the manufacturer claims).

Systems such as Zeropower(TM) do have drawbacks. They are still in the demonstration stage, they are very expensive, and they chill water only at night. Theoretically, though, none of these problems seems intractable.

Active Cooling Performance

Active cooling systems are not as developed or as reliable as active heating systems. Because all cooling applications require higher temperatures than solar heating, problems with heat loss from collectors, transport, and storage are more serious in cooling systems. Worries about collector materials' durability under high temperatures also abound.

In the case of Rankine cooling, the non-solar chiller system (engine plus compression chiller) needs further development. While absorption chilling is a developed technology, development is needed to bring down costs and help compensate for the relatively high cost of the solar energy system. For example, most commercially-sized absorption chillers discharge absorbed heat through flowing water in a "cooling tower." If chillers were air- or evaporatively-cooled, no tower would be needed so systems costs would be lower, perhaps low enough to make residential use feasible.(55) (Reportedly, Arkla is developing an evaporatively cooled, and Carrier, an air-cooled unit.) Another improvement would be the addition of a "cold storage tank" to solar cooling systems.

Active solar cooling applications have met with some success. A solar-assisted absorption chiller is successfully meeting the cooling energy needs of a thousand square foot college bookstore complex at the University of Minnesota. (Solar energy supplies an estimated 50 percent of the heat needed to run the 147-ton absorption unit.)(56) Certainly, the technology holds promise, especially where high levels of sunshine coincide with peak cooling demands. Yet, the technology will not be ready for widespread commercial use until certain technical and economic limitations can be overcome, and photovoltaic cells and other renewable energy technologies capable of driving the cooling process may eventually compete with it in the market. (See Part Three, Chapter Twelve, Electricity).

Economics of Solar Cooling

Relatively little information on the economics of solar cooling systems exist, in part because systems whose primary function is cooling are rare. In most passive designs, for example, cooling occurs through reductions in heat gain or the use of natural ventilation to enhance air flow. In practice, separating cooling-related costs and performance from the system's overall costs and performance can thus be difficult.

A few passive systems, however, have been monitored specifically for cooling performance. One new house in Starkville, Mississippi, (approximately 2,360 cooling degree days) uses special window designs, overhangs, and extra insulation to cut mechanical cooling energy needs by 30 to 50 percent. The solar features added three to five percent of the total costs of the home (or \$1,200) and stand to save between \$1,400 and \$2,100 over the ten-year life of the air conditioning system, with simple payback occurring in five to seven years.(57) (See Table Ninety-Three)

In Sacramento, two California Energy Commission employees retrofit a design for a thermal chimney onto a single-family home. At a materials cost of \$200, the system eliminates the need for any mechanical air conditioning. Meeting the same cooling needs with a central air conditioner (7.5 EER) would cost \$480 in capital costs and over \$100 in operational costs for the first year.

More strictly "solar cooling" systems are those using active collectors to run absorption chillers. In some applications, these systems provide both space cooling and space heating. However, in warmer areas some such systems are used primarily for cooling, so their costs and performance levels can, in theory, be isolated. (In practice most such installations have been funded with government support, so costs are very difficult to gauge.) Currently, small (three to five ton) absorption systems that provide both space cooling and heating cost an estimated \$30,000 to \$35,000 installed. While using larger systems brings the benefits of economies of scale, a typical 25-ton absorption unit still costs nearly \$100,000 installed.(58) Then too, the operational problems likely to be experienced with these types of systems make realistic predictions of performance levels difficult.

If any generalization is possible, it is that passive cooling features are likely to be much more economical than active cooling systems for the foreseeable future. Costs for more elaborate ice-making systems remain unknown, although some reasonable cost data will be available when the Princeton Project is evaluated.

City Applications

Passive cooling features can generally be included in any passive solar heating system, though the need for extensive structural adjustments will limit the feasibility of many passive cooling designs in retrofits. For example, a "roof pond" or even some of the innovative structural materials discussed above will probably be confined to new buildings. Therefore, most passive cooling retrofits will probably rely on techniques for reducing heat gain, although some can include fairly sophisticated mechanisms for removing heat. While ice ponds could be

TABLE NINETY-THREE

ESTIMATES OF ELECTRICITY AND \$ SAVINGS FOR
PASSIVELY COOLED HOME (STARKVILLE, MISS.)

	<u>Annual Energy</u> <u>Use (KWH)*</u>	<u>Incremental</u> <u>Cost</u>	<u>First Year</u> <u>Bill for Cooling *</u>	<u>Pay</u> <u>Back *</u>
<u>Base Case</u> (Central Air No Passive)	5,630 KWH	--	\$338	
<u>Solar One</u> (Central Air 30% Solar)	3,750	\$1,200	\$225	6- 7 yrs.
<u>Solar Two</u> (Central Air 50% Solar)	2,815	\$1,200	\$169	5-6 yrs.

Source: Derived from data presented in Community Renewable Energy Technologies, Bruce Green, 1981 (p. 91)

* Assuming a cooling load of 42.5 MMBtu/Year, met by a central air conditioning system with EER of 7.5. System operates 1,000 hours per year without solar, 666 hours with 30 percent solar, and 500 hours with 50 percent solar.

** At electricity costs of 6.5¢/KWH in year one, with 12 percent price escalation in succeeding year.

integrated with existing building cooling systems, land availability may limit the retrofit potential of this technology in many dense areas.

While active absorption or compression cooling systems can theoretically be used in single-family applications, for the near future, these systems will be used mainly in medium-to-large multifamily or commercial buildings.

As Table Ninety-Four indicates, collector areas for active cooling systems are likely to be quite large, partly because the systems are installed in larger buildings. However, even in smaller residential structures, more collector area will usually be necessary because of the higher temperatures needed. Thus, a three-ton residential, combined heating and absorption cooling system sized for Daytona Beach Florida needs an estimated 550 square feet of collectors.(59) Limits on space and solar access may restrict use of these active solar cooling technologies to relatively low-density areas or to community-scale systems. (See next chapter.)

Institutional Constraints

Passive cooling applications will likely raise the same land-use issues as passive solar heating systems do. (See Chapter Nine.) As for active cooling systems, they will likely raise more concerns than active heating systems because they require larger collector areas.

Public utility reactions to solar cooling will depend largely upon how much back-up power is needed and when. If solar cooling equipment or designs reduce the total need for electrical energy for cooling but not the demand for back-up cooling electricity at peak periods, utilities may levy additional demand charges on solar users. (See Part One, Chapter Six, Energy Supply and Distribution, Owners of passive systems may be slightly more vulnerable to this risk than owners of active systems, since active systems deliver the bulk of their output in the daytime or early evening, when peak electrical demands are highest. However, passive systems relying on such principles as nighttime ventilation may not be able to reduce peak-load consumption much.

In some situations, building owners or occupants may be willing to pay higher unit prices for infrequently used backup power. But this arrangement could work against the adoption of more expensive conservation or solar techniques that would reduce the need for off-peak electric cooling. A plausible solution in some cases is simply not to rely on electricity for backup. In some passive applications, no mechanical air conditioning may be needed. In active solar-absorption combinations, auxiliary energy can be obtained simply from the backup gas boiler. However, in many residences, the continued use of electricity for backup cooling will be necessary to ensure occupant comfort.

Potential conflicts with utilities could be considerably minimized if off-peak storage devices were included in solar cooling applications. For example, in active absorption systems, off-peak electricity could be used to charge the solar storage tank at night to keep storage temperatures hot enough to run absorption units during the day. The appeal of this approach would rest on the costs of off-peak electricity. Economy could also be improved by using a heat pump to heat the solar storage. Conversely, electric chillers could be run in off-peak hours to chill water that could be stored for use in tandem with solar cooling the next day. (This approach would, however, require the addition of a cold-storage tank and add to system complexity.) In passive systems, the backup cooling system could be operated at night, allowing the thermal mass to absorb the cool air and reradiate it the next day. Far from optimal, this approach may nevertheless be preferable--from the standpoints of energy savings and economics--to relying on peak electricity for backup cooling.

Ways for cities to deal with utilities that react adversely to solar energy use are mentioned in Part One, Chapter Six, Energy Supply and Distribution Patterns.

Socio-Economic Considerations

Passive solar cooling features can help to reduce electricity bills or (where mechanical cooling is not used) to help low-income persons stay comfortable and healthy. A HUD-funded passive retrofit in Charlotte, North Carolina, eliminated the need for mechanical cooling and thus helped low-income tenants realize substantial utility bill savings.(60) Even where the passive cooling output is not large, poor people, especially older ones, can benefit palpably by adding passive cooling additions to their homes. These considerations should prompt cities that support passive heating projects to pay attention to opportunities for passive cooling as well.

TABLE NINETY-FOUR
DETAILS OF SELECTED ACTIVE COOLING PROJECTS

<u>City</u>	<u>Bldg. Type</u>	<u>Bldg. Size</u>	<u>Coll Type</u>	<u>Coll Area</u>	<u>Chiller(s) # Type</u>	<u>Chiller Capacity</u>
Dallas, TX	Rec Center	16,000 ft ²	Flat Plate	3,650 ft ²	One-Absorption	100 Ton
Irvine, CA	School	41,109 ft ²	Evac Tubes	4,950 ft ²	Two-Absorption	100 Ton
Austin, TX	Office	800 ft ²	Conc. Coll.	1,380 ft ²	One-Absorption	100 Ton
Columbia, SC	Office	25,000 ft ²	Conc. Coll.	2,978 ft ²	One-Absorption	100 Ton
Padonia	School	45,000 ft ²	Para. Troughs	10,000 ft ²	One-Absorption	100 Ton
Topeka, KS	Bank	5,600	Evac Tubes	1,253 ft ²	Four-Absorption	100 Ton
Keystone, SD	Visitor Center	_____ ft ²	Flat Plate	2,000 ft ²	Three-Absorption	100 Ton
Charlestown WV	School	N/A	Flat Plate	11,000 ft ²	One-Absorption	
Montevallo, AL	Office	17,000 ft ²	Flat Plate	2,340 ft ²	One-Absorption	25 Ton
Lake Buena Vista, FL	Office	6,100 ft ²	Para. Trough	3,840 ft ²	One-Absorption	25 Ton

Source: U.S. Department of Energy National Solar Data Network

Chapter Eleven

Community Heating and Cooling Systems

BACKGROUND

Chapters eight through ten covered heating and cooling technologies that can be used in individual buildings. A very different, though complementary, approach to energy conservation involves community-sized heating and cooling systems. Known popularly as "district heating" systems, community energy systems can provide heating (or heating and cooling) alone, or they can supply both thermal energy and electricity. (See Part Three, Chapter Twelve.) One such "total energy" system not only supplies heat and power, but also provides for waste disposal and sewage treatment. Only heating and cooling systems are discussed here.

District Heating - What? and Why?

District heating systems produce heat centrally, then distribute it to individual buildings through a piping network. Sources of district heating include cogenerated heat from power plants, waste heat from industrial processes, heat produced expressly for district heating by heat-only boilers, heat from municipal solid waste-to-energy systems, small-scale cogeneration systems, renewable sources of district heat, or geothermal energy.

While all of these systems are "community scale," most serve large-scale central business districts. Yet, some smaller-scale heating systems are also in use, and some hospitals, campuses, and shopping centers are using community heating or combined heating-and-power plants.(1)

Community-scale heating systems are being examined with growing, though still cautious, optimism for several reasons. First, because urban heating and cooling demands in cities are highly concentrated, costs per delivered BTU could be relatively low. It may be more energy efficient and more economical to provide heat from a highly efficient centralized source than to rely on individual on-site heat-only systems. For example, a feasibility study done for St. Paul indicated that an efficient district-heating system could immediately deliver heat at less cost than fuel oil number two and could by 1989 beat the price of natural gas.

Second, district heating systems using cogeneration can provide a combined heat and power package that is more energy efficient overall than centralized power-only plants and on-site fossil-fueled heat-only systems. Oak Ridge National Laboratories calculates that a conventional power plant expels about 67 percent of its fuel input as waste heat. But the same plant retrofitted to cogenerate both heat and electricity would use 25 percent of its total fuel input for power-production and another 55 percent for heat-generation, dissipating only 20 percent of its primary fuel. (See Table Ninety-Five.)

Finally, district-heating plants can lessen dependence on oil and gas by substituting heat from coal-fired power generating plants or centralized boilers.

Problems With Existing Systems

For all their potential flexibility and economy, however, few district heating systems in the United States are currently operating successfully. Some of the newer and smaller-scale integrated energy systems installed in institutional or business complexes show promise of success. But most large-scale urban district heating projects are losing both money and customers. (See Table Ninety-Six.)

Most of these systems are old--built before World War II. Although initially economical, they lost out as oil and gas prices declined, as more sophisticated on-site heating systems were developed, as population density fell, and as power plants became larger and less likely to be built within city limits. While interest in upgrading, or expanding, and building systems has increased along with oil and gas prices, using conventional district heating in developed urban areas will require overcoming substantial difficulties.

Cities with existing systems have an inefficient and outmoded technology on their hands. These old systems all distribute district heat with steam. Most district heating systems in Northern Europe--where the technology is advanced and widely used--distribute heat through water. Such systems can move heat more efficiently and over longer distances, and water piping costs per foot of trench are lower, so systems are more cost-effective and can appeal to more customers.(2) Thus, most retrofits involve the eventual replacement of steam with hot water.

St. Paul's proposed retrofit and expansion of its district heating systems provides a good snapshot of the technical state of the art in this country.(3) The system will use cogenerated heat from a power plant to provide 250 degrees F water to buildings in the city's central business district. Using 250 degrees F hot water instead of steam distribution will allow the system to cogenerate heat at less cost because the lower distribution temperatures will mean less reduction in the plant's electrical generating capacity. Moreover, fitted steam pipes can be replaced by lower-cost prefabricated, polyurethane insulated pipes. Buildings with

TABLE NINETY-FIVE

RELATIVE FUEL-INPUT EFFICIENCIES OF
ELECTRIC-ONLY VS. COGENERATION POWER PLANTS

<u>Power Plant</u>	<u>Fuel Input for Electricity Production</u>	<u>% Fuel Input for Thermal Energy</u>	<u>% Fuel Input Expelled as Waste Heat</u>
Electric-only	33	0	67
Cogeneration	25	55	20

Source: Oak Ridge National Labs District Heating/Cogeneration Application
Studies for Minneapolis/St. Paul Area

TABLE NINETY-SIX

SOME FINANCIAL CHARACTERISTICS OF
SELECTED STEAM-BASED DISTRICT HEATING SYSTEMS

<u>City</u>	<u>Owner of District Heating System</u>	<u>Number of Customers</u>	<u>Return on Fixed Assets</u>
New York ^A	Consolidated Edison	2,285	7.4%
Philadelphia ^A	Philadelphia Electric	670	5.8%
Detroit ^A	Detroit Edison	843	-7.0%
Boston ^A	Boston Edison	465	10.3%
Baltimore ^A	Baltimore Gas & Electric	720	1.8%
Indianapolis ^A	Indianapolis Power & Light	703	4.5% ¹
Rochester ^B	Rochester Gas & Electric	271	N/A ²

Sources: (A) OTA (1981)
(B) Botsford (1981)

Notes: (1) Indianapolis is a successful, steadily growing system that is coal-based with about one-third the fuel costs of systems that use #6 oil.

(2) Return on investment represented % of RG & E's revenue dollar in 1980. Down from % in 1972.

steam-distribution systems will need to be retrofitted for hydronic operation, but costs can be reduced if the steam piping already in place is used and if heat loads are reduced through end-use conservation. Buildings using hot water or hot air distribution systems can be retrofitted somewhat more cheaply, simply by adding heat exchangers that connect the building's system with district heating piping.

Yet, even with cogenerated heat and hot water distribution, installing a new or retrofitted district heating system in an existing densely developed area can be both costly and complicated. The total price tag for St. Paul's system is estimated at \$77 million (1980), less than \$15 million of which is for heat sources. Piping costs of the St. Paul system range from \$95 to \$930 per foot of trench, and average \$200.(4) Costs could go even higher. For example, capital costs of \$2,000 per foot of pipe have been estimated for New York City, partly because substreets are already clogged with infrastructure.(5)

A final problem with conventional district heating concerns its impact on end-use conservation efforts. A district heating system financed and built without prior end-use conservation could damage both the attractiveness of post-district heating conservation initiatives and the long-term stability of the district heating system itself. With such a system, customers who make subsequent energy conservation improvements could end up paying higher unit costs, just as some electric utility customers who conserve must pay higher unit costs if they diminish the utility's load factor without contributing to shaved peaks. (See Part One, Chapter Six.)

But in the long run, district heating plants not optimized for end-use conservation will be overdesigned, under-utilized, and, consequently, uneconomic. For example, the levelized unit costs per delivered BTU of district heat can be 75 to 80 percent higher in areas with moderately energy-efficient buildings than in areas with structures that use considerably more energy.(6) OTA calculated that if 40 percent of a district heating system's customers took strict end-use conservation measures, total capital costs per delivered BTU would increase by about 40 percent.(7) This increase in costs would lead to even further consumer conservation and eventually price the district heating system out of the market.

Alternative Approaches

But, as the experiences of many European cities attest, district heating systems can be both energy-efficient and profitable.

Europe's many district heating successes can be attributed to three factors. One is the widespread municipal ownership of heating utilities in Europe. Publicly owned utility construction projects can obtain preferred financing and do not have to return profits to investors.(8) Another is the strict building energy conservation codes in place in many European countries. Such codes minimize potential conflicts between district heating system requirements and on-site energy conservation. Last and perhaps most important, European district heating technology is making great strides in efficiency and economy. Some systems use low-temperature district heat, which is cheaper to obtain and to distribute. For example, costs for large-diameter steel pipe-in-pipe hot water distribution systems in densely populated areas now run between \$700-\$1,000 per foot of trench. Using innovative distribution materials and designs could cut these costs to less than \$100 per foot. Smaller-scale cogeneration systems can make the production of heat and power on a block-or neighborhood-scale a real option. Techniques are being developed to store collected heat or cold over whole seasons, which improves both the potential for using renewable energy sources for district heat and the overall efficiencies of conventional heating and power-producing equipment.

Such advances may make lower-temperature district heating technically and economically feasible where conventional district heating would be out of the question. Yet, how these various technical innovations affect the economics of any particular system will vary with the heat sources available, the heat distribution systems in place in buildings to be served, and the ease of laying distribution pipes of varying sizes. Using low-temperature heat will decrease some distribution and buildings connection costs, but increase others. Where net distribution and connection costs are higher, they may in some cases be offset by cheaper heat. In others, using a slightly higher-temperature heat source may allow somewhat lower distribution and connection costs. And in some instances, extensive end-use conservation may make any district heating system uneconomical.

Some of the technical information that can help city officials make some of these choices follows. Evaluating proposed district heating systems requires analyzing their three principal components: end use systems, distribution systems, and heat sources, both separately and together. Most analyses of district heating systems consider heat sources first, then examine distribution and end use systems. But, the efficiency and economy of most systems (and especially lower-temperature systems) usually depend on making end use and distribution systems as cost effective as possible. Accordingly, end uses are considered first here.

THE EFFICIENT USE OF DISTRICT HEAT

Introduction

Although many Swedish district heating systems distribute hot water at 250 degrees F, properly built or retrofitted buildings can use much lower temperatures. In new buildings or in rehabilitated buildings that have their old heat-distribution systems replaced, hot water temperatures need be no higher than 100 degrees F - 120 degrees F in hydronic distribution systems or 90 degrees F in a hot air system. In existing buildings that retain their internal heating systems, distribution temperatures will have to be higher, 120 degrees F - 140 Degrees F in hydronic systems and 110 degrees F - 120 degrees in forced air systems. Actual minimum levels will depend on a number of building-specific factors. But, assuming strict end-use conservation and some retrofitting of internal distribution systems, virtually all buildings will be able to use lower temperatures than those conventional hot water district-heating systems provide. Equipping buildings to make efficient use of district heat requires three actions. First, end-use conservation is necessary to reduce heating loads. Second, internal heat distribution systems need to be adapted so they can use lower temperature heat to maximum advantage. Third, the interconnection between the building and its district heating system must be designed so that hot water is returned at the lowest temperature that is technically possible and economically practical.

End Use Conservation

As made clear in Chapters Eight through Ten, on-site conservation is the least costly energy option. Indeed, planning district heating systems in the context of strict end-use conservation is commonplace in Sweden and Denmark. The Swedish building code limits the consumption of space heating energy in new single-family buildings to about 15,000 KWH (51.2 MMBTU) per year.(9) Single-family houses served by the Lyckebo solar district heating project in Sweden will need only about 11,000 KWH (37.5 MMBTU) of space heating per year.(10)

Although conservation measures installed in existing buildings cannot cut space-heating demands to those of new energy-conserving structures, conservation can still reduce heating needs considerably.

Adapting Internal Distribution Systems

Technically and economically, it is quite easy to design new buildings to make effective use of low temperature hot water. Newer types of hot water radiators have surface areas and heat transfer capacities far above conventional baseboard hot water radiators, and cast-iron radiators from older buildings can be used very efficiently in low-temperature hot water district-heating systems.

The use of such energy-conservation measures has important implications for the retrofit of internal building distribution systems for low-temperature district heating. After conservation measures have been implemented, building "internals" sized to meet pre-conservation loads will be larger than needed to meet post conservation demands. In such oversized systems, lower temperatures can be used once conservation measures have been taken. In particular, hot water can be used in two-way steam systems and lower temperature hot water in hydronic or forced air systems.

If existing buildings use hydronic distribution, common in western Europe, conversion to low-temperature district heating is relatively simple technically. But in the U.S., the matter is not so simple. Many types of heat distribution systems are used--hydronic, forced hot air, one- and two-way steam, and electric resistance. (See Chapter Nine.) Of these, forced hot air and two-way steam are most easily retrofitted for hot-water district heating. Alterations to one-way steam and electric-resistance systems are more difficult and costly.

To retrofit a forced-hot-air system is to do nothing more than add a liquid-to-air heat exchanger to connect the district heating system's distribution pipes with the forced-air ductwork. However, the size of the heat exchanger needed will increase as district heating supply temperatures drop. (See next section.) The retrofit of two-way steam systems to hot water is not technically difficult or costly if existing piping and radiators are sound. Usually, the only additions needed are a hot water valve and a key air vent to allow air to bleed from the system, though steam vents must be eliminated in some cases.(11) Using hot water instead of steam in an existing system lowers maintenance costs and allows a more even flow of heat through the system.

Converting one-way steam heating systems to hot water poses much greater technical and economic problems. Radiators must be replaced, hot water return pipes installed, and both hot water valves and air vents added.

Relatively few city buildings use electric resistance heat. (See Part One, Chapter Six. But those that do can be retrofitted for hot water district heating only at great difficulty and prohibitive costs. The electric-resistance system must be replaced with one compatible with the hot water supplied by district heating. (In most cases, this means a hydronic system since it requires no heat exchanger and allows for direct connection. This extensive retrofit is justified only in those rare instances where the delivered costs of low-temperature district heat (including costs of end-use conservation) are very low as compared to electric resistance heating.

In Sweden, the groundwork is being laid for future district heating retrofits. There, all new buildings--regardless of their heat source (fossil fuels or electricity)--employ hydronic distribution.

Interconnecting Buildings and District Heat

Numerous techniques have been developed for interconnecting buildings and district heating systems. Which is best depends on the kind of internal distribution system in place and on the "match" between the quality (temperature and pressure) of heat in the building needs and the quantity of heat the district heating system supplies.

Conventional district heating systems in Sweden use heat exchangers for interconnections because of the great differences between the temperature and pressure of district heating hot water (250 degrees F) and the distribution temperatures and pressures required in the building (164 degrees F).⁽¹²⁾ Heat exchangers have also been necessary where land elevation varies wildly or high-rise buildings are plentiful (since both increase static pressure.)

Relatively efficient, heat exchange systems still lose heat as they transfer it from the district heating system to the building. Nor do they work well with low-temperature hot water: as hot water distribution temperatures decrease, heat exchange surface area (and costs) must go up. This is a particular problem when district heat from hot water distribution must be transferred to a hot air distribution system inside the building. According to one study, the required area for water-to-air heat exchangers increases 51 percent if the water temperature is reduced from 160 degrees F to 120 degrees F and 21 percent with a temperature drop to 140 degrees F. Compared with the base case, heat exchanger area is cut 17 percent if 180 degree F supply water is used and 27 percent with 200 degree F water.⁽¹³⁾ Although combining retrofit forced air systems with low temperature district heat entails some economic penalties, they can be diminished if heating loads are cut by conservation.

One alternative to heat exchangers is the direct connection of the district heating system to building distribution systems. Thermodynamic efficiency is greater, capital costs are less, and heat losses in the distribution system are less. The direct connection system also needs significantly less water over time than systems employing heat exchangers, so less electricity is needed for pumping power. Two other advantages are that corrosion is easier to control in water pipes in direct connection systems, and distribution pump speeds can fluctuate with demand. (Heat exchanger systems, in contrast, use fixed-speed pumps that lose efficiency if loads are partial.)

Compared with retrofits involving systems using high supply-and-return temperatures, indirect connection, and heat exchangers, a low-temperature distribution system retrofit interconnected directly can save 47 to 53 percent in capital costs for internal building distribution systems for district heating.⁽¹⁴⁾ However, direct connection can only be used with hydronic systems and in the district heating service areas where the water and pressure in the distribution system are relatively low.

One interconnection method currently under development would make low temperature hot water district heat and existing forced-air building distribution systems more compatible. A three-stage heat pump would boost temperatures of 120 degrees F hot water district heat to levels that can be used in hydronic, modified steam, or forced-air systems. Automatic controls would regulate the temperature of the water or air in the building's distribution system: all of the relatively little heat needed on mild days would be supplied from the district heating system's hot water via the heat exchanger, while on colder days the control system would turn the heat pump on little by little starting at a pre-set minimum temperature.

The efficiency of a district heating system combining the use of cogeneration, the production of low temperature hot water at a maximum of 120 degrees F, and multistage heat pumps at the point of end use can be very high. Depending on building efficiency and the internal building heat distribution system's ability to use low temperature hot water or hot air efficiently, individual building applications could achieve COPs of over 20. Of course, the overall district heating system COP would be much lower since many buildings require higher supply temperatures than 120 degrees F and, thus, use more operational energy to run heat pumps.⁽¹⁵⁾ (To achieve high temperatures, boilers in buildings might be employed to boost temperatures after heat pumps push the COP to the point of diminishing thermodynamic returns.)

BOX ITEM NUMBER TWO

INNOVATIVE METHOD FOR DIRECT CONNECTION

A recently invented method for interconnecting building distribution systems with hot water district heating combines the benefits of direct connection with the advantages of pressure separation achieved with heat exchangers. The device employs two positive displacement units (like those in rotary or piston motors) back-to-back. By controlling their speeds, the static and differential pressure within the consumer's system can be altered while still maintaining direct connection. When the devices are stopped, seals separate the home unit from the distribution network to prevent leakage and pressure transfer.

This novel unit can incorporate on the turbine a speed limiter that will automatically set the minimum water volume taken by the consumer. This limits peak demand and thereby reduces peak heat tariffs. It also acts as a safety device by limiting the rate at which water can flow from a leak. When the limiter detects differences in the amount of water flowing into and out of the building, alarms sound both in home and at the district heating utility.

Although this device is still being developed, it holds great promise--incorporating the economic and thermodynamic advantages of direct connection and most of the advantages of heat exchangers. Its use will be restricted to buildings with hydronic heating systems, a more serious limitation in this country than in Europe where those systems predominate.

Heat pumps can be used to solve some particularly difficult problems encountered in adapting low-temperature hot water district heating technology to American buildings. If older buildings with hydronic, forced hot air, or two-way steam systems are connected to hot water district heating systems without significant end-use conservation or heating system modifications, heat pumps are the only alternative to higher distribution temperatures. Studies of English buildings that retained their internal distribution systems after directly connecting to hot water district heating indicated that it would be prohibitively expensive to reduce supply temperatures below 158 degree F, even if energy priced tripled over their 1980 level.(16)

Solar District Heating-- End Use Implications

End-uses optimized for low temperature heat are hallmarks of most new Swedish solar district heating systems. Why is plain: solar collectors perform best at low collection temperatures; interseasonal heat stores hold heat most efficiently when lower temperature hot water is stored; and heat losses in distribution systems are minimal when end-users need only low temperature hot water.

Most buildings serviced by new Swedish solar district heating systems are designed to make use of hot water at very low temperatures. The first prototype Swedish solar district heating system at Studsvik supplies an office building that uses hot water at 86 degrees F via a water-to-air heat exchanger. The heat exchanger meets all the building's requirements, even though the differences between the distribution supply and return temperatures are only slightly greater than the temperatures required by the building. Within the building, warm air is distributed through hollow joist flooring with inlets to rooms along the external walls. About half the heat is supplied from convection through the floor, while the rest is supplied by ducts along the external wall.(18)

More recent Swedish solar district heating systems supply warmer water to end users. For example, the Lyckebo system will supply 135 degree F water and return 113 degree F water. The Lyckebo system does have a handicap. It requires heat exchangers that interface the building distribution systems and the district heating system: aerated water distributed in the district heating piping system must be separated from the metal pipe inside the building. (This would not be necessary with plastic piping.)

Domestic Hot Water From District Heat End-Use--Implications

Many district heating systems that employ direct connections or heat exchangers utilize instantaneous electric domestic hot water heaters. (See Chapter Eight.) With electric heaters, the system does not have to provide domestic hot water when space heating demands are negligible. Nor is there need for a separate distribution pipe for domestic hot water distribution.

Of the district heating systems that do provide domestic hot water service, many use an instantaneous water heater connected via a heat exchanger to the district heating system or to the building's space heat distribution system. This method is effective but it does require large quantities of water from the main distribution system to meet maximum demand.

Alternatively, domestic hot water heaters can be endowed with enough hot water storage capacity to level out the extreme peaks and valleys in domestic hot water demand curves.

Numerous types of storage water heaters can be employed in a low temperature hot water district heating system using direct connection for space heating. Domestic water heaters are not, however, directly connected to the district heating system since the corrosion inhibitors in district heating water are toxic. Domestic water heaters with storage have a heat exchanger through which district heating water passes, a thermostatic valve that controls the flow of the district heating water, and a return temperature limiter that ensures that the district heating water deposits as much heat as possible before being returned.(19)

Domestic water heating can also be provided via a heat exchanger interfacing with the space heat return pipe. The advantage here is that when demand for domestic hot water is high, return temperatures can be greatly reduced. Since peak demand for domestic hot water is so much higher than peak space heat demand, ample hot water storage allows a decrease in the peak demand and an increase in the base load demand for domestic hot water. In a system where domestic hot water requirements are met by return space heating water, storage also contributes to relatively even return temperatures. The drawback is that most such systems are shut down during the summer.

During summer, instantaneous demand gas-fired or electric resistance domestic water heaters can be used. Since domestic hot water demand declines appreciably in summer, energy consumption for seasonal off-peak domestic water heating is relatively small. Still, the ideal would be to meet this demand via the district heating distribution system, which is lying idle during summer if it is not also supplying space cooling.

District Cooling--End Use Implications

District cooling systems probably cannot compete economically with ultra-efficient on-site chillers unless building conversion costs are kept as low as possible. Most cost-reduction techniques are still developing.

As with district heating, direct connection of district cooling offers several economic and thermodynamic advantages. The system needs no heat exchanger, which is expensive and carries a thermodynamic penalty. Other factors influencing the choice of direct connection of district cooling to buildings are the high capital, operation, and maintenance costs of absorption or compressor chillers. If a building can use cold water directly, no capital need be expended on on-site air conditioning equipment.

Differences in heating and cooling distribution system capacity requirements can be minimized with the use of on-site storage. In a two-pipe system, cooling can use the same storage unit that holds domestic hot water during the winter, though additional storage capacity may have to be added since storage requirements for chilled water are likely to exceed domestic hot water storage capacities. On-site thermal storage would be particularly important if a full range of services was supplied from a four-pipe or pulsing distribution system. (See Distribution.)

DISTRICT HEATING DISTRIBUTION SYSTEMS

The most expensive component of any district heating system is the distribution network. In older steam systems and in higher temperature hot water systems, distribution costs can account for up to 75 percent of total system costs. The St. Paul feasibility study estimated capital costs for distribution at \$22.2 million for the first phase. (20) Distribution costs can be much higher or lower.

Reducing distribution costs is essential to the financial success of any district heating project. Currently, most analyses assume that high "heat densities" alone are the key. But, in addition, lowering district heating supply temperatures can, with proper system design, allow substantial reductions in distribution system materials and installation costs. Adopting innovative routing practices and installation techniques can significantly lower capital costs and the costs of heat to consumers.

TYPES OF DISTRIBUTION SYSTEMS

Steam Distribution Systems

Although the first district heating systems used steam, steam-based systems are inferior to contemporary alternatives. The distribution range of steam is usually three miles or less. (Thus, in the U.S., steam district heating systems have been confined to central business districts.) In cogeneration, steam is usually extracted from a high pressure turbine or from the cross-over point between a high- and low-pressure turbine, so the turbine does not generate all the electricity it could and steam heat thus costs commensurately more. Steam distribution systems also require elaborate, heavily insulated piping systems made of expensive materials (including stainless steel). Steam pipes require steam traps, inclined piping, manholes, and many expensive expansion joints to absorb the relatively high thermal stresses the low-pressure steam imposes.

Two other problems are corrosion and inefficiency. Steam ruins pipe insulation much faster than either moderate or low-temperature water systems do--a factor that contributes to heat losses (which range from 15 to 45 percent) and maintenance costs. It also corrodes both steel and stainless steel pipes. (Many steam district heating systems do not have condensate return pipes--which are the most prone to corrosion--but such systems waste potentially useful low temperature heat, water, and water conditioning chemicals.) Piping, boiler, and personnel codes are, accordingly, more stringent for high-temperature steam systems.(22) But even high standards do not prevent equipment failure or alleviate the problems of operating inefficiencies under part-load conditions.

Particularly inefficient are low-pressure steam systems that neither cogenerate nor return condensate. Cogeneration and condensate return can boost efficiencies (from lows of 30 percent) to 60 percent. But electrical efficiency is still low compared to cogeneration systems that produce hot water, especially at low temperatures.

While steam district heating is not out of the question for U.S. cities, it should be used only where steam is the only medium that can provide the required services--in some industrial process heating applications, or in light industrial and commercial applications where switching from steam to hot water distribution is prohibitively difficult and costly.(23)

Hot-Water Distribution Systems

Hot-water district heating technology has been developing steadily since World War II ended. During the last decade, important innovations in distribution systems were made and even more exciting changes are in the offing. Research has focused on making the most expensive component of district heating systems less costly, more efficient, and longer lived.

The pace of innovation in hot-water district heating increased considerably when fabricated pipe-in-pipe was developed in the late 1940s. Since the mid-1960s, pipe-in-pipes with plastic/polyurethane external waterproof jackets have been extensively marketed. Typically, in different district heating applications, a conventional hot water district heating system has one pipe for supplying hot water to buildings and another for returning water to the heat source, where it is re-heated and then recirculated.(24) In the two-pipe configuration, the system supplies domestic hot water inefficiently in summer because the pipes are sized to provide space heating in the winter. One way around this problem is to install hot water heaters in individual buildings and to shut down the district heating system when space heating demand falls off. But even this method is less than efficient, which is why three-pipe and four-pipe hot water distribution systems were developed.

In a three-pipe system, two pipes are supply pipes--one for space, the other for domestic water heating. The temperature in the space-heating pipe varies with space-heating needs. In the other pipe, water is at a constant temperature year-round.

The three-pipe configuration allows a relatively low volume of moderate temperature hot water to be supplied throughout the year in pipes sized to meet annual peak demand

for domestic hot water. As for the larger volumes needed for space heating, the system can meet them and then shut down when there is no demand. The drawbacks of three-pipe systems are that they waste hot water because they have no return pipe, and they have had performance problems when hot water demand falls.

The four-pipe system represents a further refinement. Here, two pipes each are used for space heating and domestic hot water supply and return. The two-, three-, and four-pipe configurations can each be combined in a single large prefabricated insulated pipe-in-pipe for higher pipe quality and lower installation costs. While multiple pipe systems have been too expensive to use on a large-scale, as fuel costs escalate, they might become more attractive, especially in multi-thermal (heating, cooling, refrigeration) district systems.

Low-Temperature Hot Water Systems

The costs of district heating distribution systems can also be cut by reducing hot water supply temperatures. For example, although many Swedish hot water district heating systems supply water at maximum temperatures of 250 degrees F, end-use conservation in conjunction with adjustments in internal building heat distribution systems can reduce required supply temperatures to 120 degrees F in new, or extensively rehabilitated buildings and to 140 degrees F (for hydronic systems and even lower for hot air systems) in existing buildings.

Most new Swedish solar district heating systems also supply hot water at low temperatures to optimize solar collector efficiency. The prototype Swedish solar district heating system at Studsvik supplies 86 degrees F hot water to an office block equipped with a water-to-air heat exchanger and a forced hot air heating system able to use very low temperature heat.

Most recent Swedish solar district heating systems distribute heat at higher temperatures. For example, the Lyckebo system will supply 500 buildings with water at 131 degrees F. One Swedish district heating system being developed in Lund will have distribution temperatures of 140 degrees F, so solar heat sources can be employed.

Conventional Swedish district heating systems operate with a maximum supply temperature of 248 degrees F and a minimum return temperature of 112 degrees F. In contrast, some Danish district heating systems have much lower supply temperatures so as to obtain higher levels of electricity output in cogeneration. In these systems, the district heating system and individual building (hydronic) heat distribution systems are directly connected to eliminate the thermodynamic and economic penalties associated with the use of heat exchangers. In the Odense (Denmark) district heating system, the maximum hot water supply temperature is 203 degrees F and the average return temperature is 105.8 degrees F. The heat from this low-temperature system costs about one third as much as space heat from on-site oil-fired, heat-only boilers. It also enables the system to be extended to areas of very low heat density which have been considered economically impossible to service with most conventional hot water district heating systems.

Impacts of Increased End-Use Conservation on Distribution Systems

Increasing end-use efficiency will not reduce distribution system costs without corresponding changes in piping materials and designs. If the designs of distribution systems remain unchanged, increased end-use efficiency will increase the delivered unit costs of district heat. According to one study, levelized unit energy costs for district heating were 75 to 80 percent higher where buildings had moderate conservation measures installed than in a neighborhood where buildings were less efficient. Heat costs were proportionately higher in a neighborhood with very efficient buildings.(25)

Delivered unit costs are higher in energy-conserving areas primarily because capital costs do not fall proportionately when energy demand decreases. Since, for example, piping costs decrease more slowly than delivered energy levels, the only way to profit fully from increased end-use conservation is to use more innovative and less costly distribution systems. Many of these less costly alternatives go hand-in-hand with supply temperature reductions. For example, greatly reduced supply temperatures must be compensated for by some increases in pipe diameter in order to provide constant end-use temperatures. But since pipe surface areas change more slowly than temperature levels, a great decrease in supply temperature may mean only a small increase in pipe size. One study found that decreasing supply temperatures by 20 percent (from 200 degrees F to 160 degrees F) required only an eleven percent increase in pipe diameter, (26) and with lower temperatures less expensive pipe with less expensive insulation can be used.

Innovative Distribution Techniques

New Piping Technologies

Of the numerous recent advances in distribution piping technologies and techniques, most involve the substitution of nonmetallic for carbon steel pipe. Fiberglass, reinforced plastics (FRP), cross-linked polyethylene, polybutylene, and concrete pipes have all been used as replacements. FRP pipes are now being seriously evaluated for use in district heating systems in Europe. While FRP carrier pipes cost more than the equivalent in carbon steel, the installed costs are ten to fifty percent lower due to other factors:

- Savings in labor for handling and assembling the light-weight FRP piping;
- Reduction in the insulation thickness required;
- Reduction in the number of expansion devices needed;
- Elimination of the need for a ground water drainage system; and
- Some reduction in trenching cost. (28)

Polybutylene pipes are flexible, lightweight (up to 90 percent lighter than steel), and resistant to organic solvents, salts, acids and alkalines even at elevated temperatures. But since polybutylene is partially soluble in aromatic and chlorinated hydrocarbon solvents above 140 degrees F, polybutylene pipe is recommended for use only in some secondary low temperature district heating systems, pending further testing in order to ensure reliable performance. (29)

A number of pipes made of stressed concrete, polymer concrete, and asbestos cement have also been developed. The first two, relatively large, are used mainly in long distance heat-transmission systems. They are particularly effective in transmitting fluids, such as geothermal brine, that would erode steel pipes. They can also withstand relatively high pressures and temperatures, though concrete is particularly sensitive to temperature shock. While both types of piping cost less and perform better than the carbon steel alternative, further testing is necessary before they can be widely used.

The asbestos cement pipe also resists corrosion and chemical attack, but it is very brittle and subject to rupture from severe temperature shock. Its cost is only about three-quarters that of the carbon steel alternative, but it too requires additional testing before it can be employed on a large scale. (31)

Along with the FRP pipe, perhaps the most promising recent innovation in district heating piping technology has been the cross-linked polyethylene pipe used for years to distribute heat inside buildings. This piping has recently also been used underground in district heating networks, particularly in Sweden. (31)

Cross-linked polyethylene pipes hold out many advantages--high corrosion resistance and high piping strength among them. Less pumping power and no expansion devices are needed when these lightweight pipes are used. As for major disadvantages, operating temperatures cannot surpass 200 degrees F, the pipes deteriorate when exposed to direct sunlight, and oxygen diffusion in the pipe could corrode the fittings.

Although encouraging results have been achieved and cost reductions of up to 50 percent over conventional steel conduits may be expected, cross-linked polyethylene piping cannot be widely utilized in district heating networks until further development and tests take place. (32)

Low-Cost Adaptations of Existing Technology

Instead of waiting until new low-cost, high-performance distribution systems are developed, some more conventional technologies could be adapted to use low-temperature district heat. A unique approach to district heating developed by Timmerman involves a low-cost method of retrofitting power plant retrofits so they can become "cogenerators" and thus provide 120 degrees F hot water at a very low fuel cost. (See Heat Sources Sources.) At temperatures and costs this low, Timmerman contends hot water can be economically distributed to end users via uninsulated concrete sewer pipe.

Sewer pipe, costing 25 percent of what insulated steel pipe-in-pipe costs, would be laid in sand trenches below the frost line. More sand--a fairly good, low-cost insulator--would cover the pipe. The system would carry water at temperatures no higher than 120 degrees F, so heat losses would be minimal.

As noted, using less expensive piping systems can offset the costs of the slightly larger pipes lower-temperature distribution systems need. But lower-temperature hot water also requires a higher flow rate than a higher temperature system does. Without some system modifications, the pumping power requirements of very low temperature systems might increase electricity use to unacceptability. However, larger pipes would allow higher flow rates per unit of pumping energy expended since there is less surface resistance to water flows than in smaller piping systems.

Reducing Heat Losses

Combining lower-temperature distribution with improved piping designs reduces heat losses. As Geller has observed, annual heat loss declines approximately 16 percent when the supply water temperature is reduced from 160 degrees F to 140 degrees F, approximately 30 percent if to 120 degrees F. Heat loss increases about 11 percent if 160 degrees F water is raised to 180 degrees F and about 24 percent if to 200 degrees F.(33)

Reducing heat loss both saves fuel dollars and improves the viability of district heating in lower-density areas. Although the annual distribution system losses amount to no more than about five percent in a conventional hot water district heating system serving high-density areas, distribution heat losses increase as densities decrease and as buildings become more efficient.

Reducing heat losses in these situations might require adopting an alternative piping system. As Geller calculated, if two feeder pipe trenches were extended under sidewalks on the edges of a central area, the feeder-to-house connection distance could be reduced from 80 to 30 feet. Besides saving capital, this technique could also reduce distribution system heat losses to five percent in thermally typical buildings and to 10.5 percent in moderately conserving buildings.(34)

Another way to reduce heat loss is to super-insulate pipes. The key to knowing how much to insulate is knowing the value of the heat being transported. High-cost heat will require more insulation than low-cost heat, and supply pipes distributing higher temperature heat to end-users require more insulation than return pipes.

Maximizing Differences Between Supply and Return Temperatures

Increasing the temperature differences between supply and return pipes also optimizes system efficiency. With lower temperature return water, pumping energy needs are reduced and heat losses are cut. Dropping return water temperatures can also make it possible to use much less expensive piping materials than those needed to transport higher temperature return water and (when the difference between the temperature of the water and the temperatures of the ground surrounding the pipe is small) much less insulation.

Since overall system efficiency is also aided by lower supply temperatures, achieving the maximum temperature differences between supply and return water hinges on minimizing return water temperature--basically, a matter of end-use efficiency. (See The Efficient Use of District Heat.)

Another way to lower return temperatures would be to use the return water to meet low-level heating needs. For example, a heat pump connected to secondary distribution circuits has been proposed to supply heat to greenhouses in a district heating system in Denmark.(35) Other useful applications for low temperature return water include aquaculture, crop-drying, or the drying of biomass or municipal solid waste fuels.

Planning District Heating Distribution

Thermal Load Density

In planning a district heating system, determining the feasibility of serving different areas is one of the first steps. The key need is to find out whether heat demands are sufficient to pay back investments in the system.

An area's thermal load density is determined by the thermal load per unit of building floor space, the number of stories these buildings have, and the number of such buildings in the area to be served. When heat demands in all potential district heating service areas are mapped, these areas are then classified according to their heat density--the maximum connected heat demand the district heating system can meet. Even residential areas that do not have particularly high thermal demands per unit of floor space can have high thermal load densities if buildings are multi-storied and close together. In contrast, some industrial districts have high thermal load densities, even though the buildings are often single-story and far apart. In cities, the central business district is usually where heat density is highest.

Engineers express such heat density in terms of MW/square km or MBTU/h/acre. This shorthand is used in heat maps to indicate the gross quantity of heat demand for a given area, but energy quality or the temperature of the heat required is not measured in this way. Therefore, heat mapping should also include assessments of the minimum temperature required by each building after all economic investments in increased efficiency have been assumed.

Although taking existing heat demand as given is common practice in Sweden and Denmark, conservation practices in Scandinavia are more stringent and codified than in the U.S.(36) In this country, therefore, given the ample room for end-use efficiency, considerations must be more explicit in the planning and design of district heating systems. Existing loads should be mapped for a number of variables--the amount of heat needed, the types of energy systems currently in place, and the temperature levels of existing demands. At the same time, prospective district heating service areas are mapped for current levels of end-use efficiency; additional maps should indicate the impact of various energy conservation measures on both the quantity and quality of heat demand, and conservation measures should be ranked (least costly first) and the combined affects of several measures should be gauged. Such analyses will help planners determine optimal levels of investment in end-use efficiency; the most cost-effective quantity and temperature for supply and return water, the right size pipes, the most appropriate piping materials, the best transmission and distribution system routes, the required capacity of heat sources, the best location for the heat sources, and the temperature of the hot water output from the heat sources.

Although an analysis of gross heat density indicates that only areas with the highest heat requirements can make economic use of district heating, different assumptions and analytical techniques yield different conclusions. As Table Ninety-Seven indicates, downtown highrise and multi-story commercial and residential areas are prime candidates--at least until the wider use of conservation measures brings down commercial building heat loads dramatically.

Even so, the costs of installing district heating distribution systems are high. A veritable tangle of pipes and wires rests beneath an urban street. Lines for gas, water, sanitary and storm sewers, telephones, electricity, subways, abandoned utilities, and so on pose very difficult challenges for routing and installing district heating pipes. Equipment could be relocated, but only at great cost, and excavation can take place when traffic is light--the very times workers must be paid premium wages. Indeed, some studies demonstrate that piping costs double when interferences are included.(37)

Distribution System Design Alternatives

Although such extreme difficulties are less typical of areas outside central business districts, excavation should always be avoided if possible. One less disruptive alternative to excavation in larger urban district heating systems is tunneling. Tunnels are dug underneath the city in bedrock and shafts are driven vertically to connect urban blocks or groups of blocks. Pipes are then run through the basements of attached buildings to supply buildings with space- and water-heating.

Another alternative is to locate distribution pipes under the sidewalks rather than in the middle of the street. (Work time can thus be cut anywhere from 33 to 42 percent.) It also saves money to route district heating pipes through basements. For example, the Baltimore Gas and Electric Company has placed four inch welded steel pipe through basements for only \$30-\$35 per foot of pipe installed.(38) The company encountered no legal problems, even though occasional leaks or breaks have damaged individual building basements.(39) But, hot water pipes are less given to rupture and leakage, and potential damage and safety problems could also be minimized by using lower temperature, lower pressure hot water pipes.

The routing of pipes through basements is particularly appealing when flexible plastic pipes are used. Although cross-linked polyethylene pipes cost about half of normal steel pipe in-pipes, their installation cost is no lower if substantial labor is required for street excavation and utility routing and rerouting. Much of this labor cost could be reduced if pipes could be routed through basements.

A district heating design strategy that routes pipes through the basements of attached buildings could take several forms. One might be the development of block-, multiblock-, or neighborhood-scale district heating systems served by small cogeneration units. If small-scale systems are properly designed, fuel cells using coal-based fuels, solar heating systems, coal-fired fluidized bed boilers or advanced, externally-fired coal-burning engines could be incorporated later.

Alternatively, block-, multiblock-, or neighborhood-scale district heating systems with basement pipe routing might be designed to interconnect with a large district heating system later. Supplying a group of "small time" heat consumers with a single connection in effect makes the group a large user of heat. Grouping connections in this way has an overriding advantage: it can reduce distribution system costs enough to offset the higher costs of district heating in areas with low heat density or difficult distribution system installation conditions.

TABLE NINETY-SEVEN

<u>Heat Density</u> (MW/km ²)	<u>Area</u>	<u>Category</u>
MMBTU/h/acre		
70 (MW/km ²) over 0.97 (MBTU/h/acre)	Downtown, high rises	Very Favorable
70 - 50 0.97-0.70	Downtown - multi- storied buildings	Favorable
80 - 20 0.70-0.28	City core-commercial buildings & multi- family apartment buildings	Possible
Less than: 12 0.17	One-family houses	Not Possible *

Source: Wahlman (1978)

District Heating in Areas of Low-Heat Density

If distribution-system capital and installation costs are reduced, distribution systems can tolerate greatly decreased heat densities while remaining economically attractive. Using low-temperature distribution techniques at lower capital costs has, for example, made extending the district heating system in Odense (Denmark) to detached suburban neighborhoods economical.

Even areas that are not densely developed may be feasible for some form of district heating if the population is concentrated along major traffic arteries and utility corridors.(40) A bonus of using district heating in such pockets of heat-density is that substreets are less likely to be cluttered and commerce less disruptible. A drawback, on the other hand, is that in low-density areas, each delivery unit may have to be connected to the district heating system. (In high density areas, a single connection may be enough to link hundreds of apartment dwellers to the system.) Nonetheless, lower distribution costs could at least partially offset this added expense. And the use of more innovative connection techniques could reduce costs significantly.

"Greenfield" Sites

Another potentially excellent site for a district heating and cooling system is the so-called "greenfield" site--any site for which new, large-scale residential, commercial or industrial development or thoroughgoing redevelopment is planned. At such sites, district heating mains can be installed at the same time as other services, so installation costs are appreciably less. In addition, both new and rehabilitated buildings can be designed to use energy efficiently and to tap into the district heating system from the outset. Further if energy cascading techniques can be employed in industrial developments, investments in efficiency and heat supply systems are optimal and affordable.

Greenfield sites are also attractive as sites for solar district heating- and cooling-systems. Besides the advantages already noted, the relatively large land areas required by solar collectors and by heat- and cold-storage facilities are easier to acquire in developing than in developed areas.

Facilitating High Rates of Interconnection

One factor crucial to the financial success of a district heating system is interconnecting a high proportion of consumers to the system. In Sweden, law requires consumers to interconnect with the system, though district heating costs notably less than any alternative (usually, heat-only, oil-fired boilers) anyway. The utility purchases the on-site boilers, the consumer pays only the connection costs, and grants and loans are available for on-site equipment and necessary modifications to internal building distribution systems.

In Denmark, the approach is strictly economic--the Danes have pursued a strategy of cutting both the capital and fuel costs of district heating to offer thermal services at costs below the competition. In Odense, the district heating utility actually has a backlog of neighborhoods lobbying for interconnection.

Where interconnection rates are low, the-utility will have to charge connected parties relatively more to cover the under-utilized system's high fixed costs. In the worst case, declines in inter-connection as a result of rising heat prices could cause a district heating system to fail financially.

U.S. district heating system planners have sought ways to ensure high rates of interconnection. Long-term "take-or-pay" contractual relationships between the district heating utility and consumers could ensure sufficiently high rates, though consumers will probably be reluctant to enter into take-or-pay contracts if no appreciable investments have been undertaken in increased building efficiency; if the price for delivered thermal services is not lower than the prices of conventional forms of energy; and if project cost overruns appear likely.(41)

Rather than compelling consumption, district heating planners should encourage the application of technical innovations that could significantly reduce district heating capital and fuel costs since a competitive price is the only sure guarantee of high rates of interconnection.

One factor that both encourages high initial rates of interconnection and jeopardizes those rates over the long-term is inefficiency at points of end use. Ignoring end-use efficiency will intensify heat density and perhaps even lower initial consumer costs. But, unless long-term take-or-pay contractual agreements are in effect, consumers may later invest in more efficient on-site conservation devices and disconnect or reduce demand. If, in turn, district heating rates of return decline, utilities could raise rates and bring about additional disconnections or cutbacks in demand--essentially, a "no win" situation. The way around this problem is to determine the optimal level of investment in building conservation and to provide consumers with access to affordable financing for these measures--in effect, considering building conservation, modifying internal building distribution systems, interconnecting to the district heating system, and the district heating system itself as components of a single energy strategy. The

capital, interest, and fuel costs of this alternative must compare favorably with those of other supply-and-demand alternatives if rates of interconnection to a district heating system are to stay high over time.

In Danish and Swedish municipal utilities, this integrative approach has been institutionalized. Publicly owned local energy corporations take responsibility for planning, financing, and implementing virtually all energy supply and demand strategies. Despite a considerable deal of public scrutiny and the availability of other options for consumers, district heating has emerged as one of the most widely applied energy supply technologies.

Increasing District Heating Load Factors

A district heating system's load factor is the ratio of the amount of energy demanded annually to the system's peak capacity. Most cities in cold climates have longer heating seasons and higher load factors than cities located in moderate or warm areas. (See Table Ninety-Eight.) In a northern city with a high load factor, a system will deliver more heat for a given fixed cost than a system located in the South, and the sale of heat will generate more revenue in the high-load city.(42)

Obviously, the ideal city from a district-heating perspective has long cold winters and cool summers. But nearly all northerly U.S. cities, in contrast, have space cooling requirements, and most sothern U.S. cities spend more energy on cooling than on heating. Thus, nearly every urban electric utility in the U.S. experiences a summer electrical demand peak because of air conditioning.

Also worth noting is that in most northern urban areas, heating and cooling loads with end-use conservation are higher together than pre-conservation heating loads alone. Thus, providing cooling services can both increase the distribution system's post-conservation load factor and introduce more efficient ways of cooling buildings.

One method of supplying district cooling is to supply hot water to on-site absorption chillers. However, this would require a relatively high temperature distribution system since most conventional (single-effect, Lithium-bromide) absorption chillers operate at heat source temperatures above 185 degrees F.

Another alternative would be to produce chilled water at a central location and distribute it to buildings for direct use. However, unless the differences between supply and return temperatures were relatively even for heating and cooling distribution temperatures, the pipes would have to be oversized for the heating season to provide enough peak cooling.

If on-site chillers become extremely efficient, conventional district cooling may not be able to compete with them on its own. Therefore, to be a viable option district cooling systems may have to make use of inexpensive cooling sources and/or provide additional services such as refrigeration.

For example, renewable supplies of cold water for district cooling can be obtained by producing ice from a snow machine using ambient winter air as a source of cold or deep lake or sea water located reasonably nearby cooling loads. (See Renewable Sources of District Heat.) However, the temperatures of these waters must not be as cold as is required or optimal for direct end use. In such areas, additional refrigeration equipment at additional costs might be needed to lower temperatures to the required levels. In a "full service" approach, district systems could employ a four-pipe (two for supply, two for return) system to iron out peak supply and return temperature differences and (in the case of space heating and cooling) to equalize demand levels. Cold and hot water would seasonally alternate in the same supply and return pipes, while smaller supply and return pipes would distribute hot and cold water in alternate seasons for domestic hot water and refrigeration. In summer, space cooling and refrigeration could be supplied from the larger pipe and hot water from the smaller one. In winter, space and water heating could be provided by the larger pipe and refrigeration by the smaller. (This system would also require distributed thermal storage at the point of use.) Another possibility would be using a two-pipe system that would alternate the supply of district heating in winter with district cooling in summer. Domestic hot water could then be efficiently supplied in the summer from on-site equipment such as solar collectors.

In any attempt to deliver additional service, however, one overriding fact needs attention: the fewer thermal services that are supplied, the lower the distribution system capacity factor. If one of the primary reasons for providing additional thermal services is to increase the distribution system's capacity factor to maximize investments, the capital costs of adding each service will have to be carefully analyzed.

Through "pulsing," it may some day be possible to achieve a high capacity factor without incurring capital costs greater than those associated with a conventional district heating system. "Pulsing" distribution systems are used extensively in the oil products industry to transmit different grades of petroleum products. One grade is sent through a pipe for a certain period of time, followed by another grade. Only slight mixing occurs at the boundary between products. In the distribution of different temperature thermal services, hot water and chilled water would alternate in the supply

TABLE NINETY-EIGHT

Climatic Determinants of Heating Loads for Selected Cities

Region City	Annual Heating Degree Days (HDD) ^a	Heating Design Day (97.5%) (°F) ^b	Design Day HDD ^c	"Load Factor" ^d	
Northeast					
Boston [*]	5621	9°	56	.28	42°20'
New York	4828	15°	50	.27	40°45'
Philadelphia [*]	4865	14°	51	.26	40°00'
Averages	5105	13°	52	.27	41°02'
North Central					
Chicago [*]	6497	-4°	69	.26	41°55'
Cleveland [*]	6154	5°	60	.28	41°30'
Detroit [*]	6228	6°	59	.29	42°20'
Milwaukee [*]	7444	-4°	69	.30	43°00'
Minn.-St. Paul	8159	-12°	77	.29	45°00'
St. Louis [*]	4750	6°	59	.22	38°30'
Averages	6539	-0.5°	65.5	.27	42°02'
West					
Denver	6016	1°	64	.26	39°45'
Los Angeles	1819	40°	25	.20	34°05'
Phoenix	1552	31°	34	.14	33°30'
Seattle	5185	26°	39	.36	47°35'
Averages	3643	24.5°	40.5	.24	38°44'
South					
Baltimore [*]	4729	13°	52	.25	39°20'
Dallas	2382	22°	43	.15	32°50'
Houston	1434	33°	32	.12	29°45'
Memphis	3227	18°	47	.19	35°05'
Miami	206	47°	18	.03	25°55'
Washington [*]	4211	14°	51	.23	38°50'
Averages	2698	24.5°	40.5	.16	33°37'

a. Ref. 5 b. Ref. 6 c. 65° - design day temperature

d. Annual HDD + (Design Day HDD x 365 days)

pipe.

To minimize losses of heat or cold in the pipes, Howard Geller has suggested that return water be recirculated before a transition either to cool pipes down or to recover the heat stored in the pipes. While of limited application in pipe-in-pipe or other highly insulated systems, the principle of pulsing holds considerable promise in pipes with low heat capacity.(43)

SOURCES OF DISTRICT HEAT

Given the relatively high cost of distribution systems and building conversion in conventional district heating systems, it is important that heat-sources be kept as low in cost as possible. This can be done in various ways including: using existing surces of waste heat, using new heat sources that are low in capital costs, and using new heat sources that will use low-cost fuels.

Of course, the type of heat source used will affect not only heat source-related costs, but also the capital and operating costs of the entire system. Using low-temperature heat sources can be particularly helpful to both heat source and system economics.

For one thing, lower temperature heat sources are often lower in capital costs than higher temperature options. Lower temperature heat can often be supplied by waste heat from power plants or industries. Even when newly constructed heat sources are used, lower temperature options are often less expensive. For example, higher-temperature solar collectors are more costly than lower temperture techniques. Second, the use of lower temperatures can facilitate many of the distribution system economies discussed in the previous section. Finally, where cogeneration is used to provide heat, providing lower temperature heat can make it possible to produce relatively more electricity.

Cogeneration

Both in this country and in Europe, one of the most common sources of district heat is cogeneration--the production of both heat and power in a single energy-conversion system. Cogenerating both power and heat is significantly more efficient and economical than producing each separately.

Cogeneration systems can be topping cycles or bottoming cycles. In the more commonly employed topping cycle, electricity is generated first and heat in the exhaust stream is made available at various pressures and temperatures. In a bottoming cycle, thermal energy is produced for process uses, and relatively high temperature and pressure waste heat is then recovered and used to generate elelctricity.(44)

The most commonly employed topping cycle technology used to supply district heat is the steam turbine. Steam turbines use fossil or other fuels to produce steam in a boiler. The high pressure steam then drives a turbine producing mechanical energy to drive an electric generator. The exhaust from the turbine can provide low-temperature and low-pressure heat as either steam or hot water to industrial processes or to district heating networks.

Although steam turbines have lower electricity-to-thermal ratios than other heat engines such as the combined-cycle gas turbine or diesel, they can utilize a wide variety of fuels. (See Table Ninety-Nine.) Since most gas turbines and diesels now available run on natural gas or refined oils, steam turbines are thus likely to continue to be extensively used in cogeneration.

Types of Turbines

Backpressure steam turbines expand steam through all stages of the turbine, exhausting steam at the temperatures and pressures required by an industrial process or district heating system. The amount of heat produced in a back-pressure turbine is inversely related to the amount of electricity generated. Therefore, to obtain exhaust temperatures useful for district heating, some power output is sacrificed. Still, the combined thermal/electrical efficiency of the backpressure turbine can be very high, especially if the heat outputs are closely matched to industrial or district heating loads. Their electrical and thermal output cannot fluctuate with varying loads, so these devices are usually used in cogeneration to meet the base heat load requirements of either an industry or a district heating system. In such a set-up, electricity production cannot be increased as heating loads drop, but both heat supply and electrical capacity can be increased significantly if sufficient thermal storage is provided (about five hours in a large urban district heating system in Northern Europe.)(45)

The inflexibility of these units during periods of low heating or cooling requirements (spring and fall) do limit their potential as base-load electrical generators. Indeed, backpressure turbines are most appropriate for use in industrial environments where heat and electric demands are fairly constant both daily and seasonally. However, since backpressure steam turbines supply both electricity and heat efficiently and economically when operated at full loads, modifying rather than rejecting the technology might be worthwhile where demand profiles are not completely out of phase with electrical demand profiles.

TABLE NINETY-NINE

FUELS USED IN COGENERATION SYSTEMS

<u>System</u>	<u>Fuel Type</u>
Gas Turbine	#2 light distillate oil or natural gas
Diesel Engine	Oil or gas
Steam Turbine	All types of fuel (oil, gas, coal, wood, wastes)

Source: Eric Bazques, "Brief Overview of Cogeneration." Sept. 1980.

The second type of turbine commonly used in cogeneration is the extraction-condensing turbine (also called the condensing or intermediate take-off, turbine). In this turbine, steam is bled off during the intermediate stages of the turbine cycle and is then either passed through heat exchangers to produce hot water or depressurized to supply consumer demands. Compared with a backpressure set, this type of turbine is easier to control and more flexible. If extra power is required for electricity generation during hours or seasons when heat requirements are minimal, an extraction-condensing unit can be precisely regulated to produce little or no heat while generating electricity at either partial or full capacity. If thermal storage is adequate, the heat supply can be reduced and electrical capacity increased while still meeting the requirements of the district heating network. (Without thermal storage, electricity-production from an extraction condensing unit is also dependent on the heat load, but only while heat is actually required.) An extraction-condensing plant with thermal storage can meet up to 85 percent of a district heating system's peak heating load and also generate electricity year round.

Although a new extraction-condensing cogeneration plant is significantly more expensive than a plant with the equivalent backpressure capacity, its much higher diurnal and seasonal electricity capacity factors compensate. In retrofits, however, condensing turbines for cogeneration are less flexible and economical since it is difficult to vary the steam-extraction and retrofitting permanently derates electrical capacity to some extent.)

Efficiencies of Cogenerating Steam Turbines

Efficiency, in terms of cogeneration/district heating systems is a relative concept. The efficiency of a single operation can be examined only as one component of an overall system with a number of interacting operations. Thus, it means little to say that a cogeneration unit has an "efficiency" of 85 percent. The key factors are the relative sizes of power and heat outputs.

In a cogenerating steam turbine, the cost of thermal energy is directly related to the cost of electrical energy: both utilize the same fuel for production, and both are outputs of a single process. Since electrical output decreases in inverse proportion to the temperature of the heat needed, the cost of thermal energy includes the cost of "sacrificed" electricity.(46)

As for overall efficiency of a steam turbine, it does not change appreciably as long as low-temperature hot water (under 212 degrees F) is being produced. But the amount of heat obtained for each unit of electricity lost varies considerably with the water's output temperature. (See Table One Hundred.) Obviously, as hot water temperature increases, progressively less heat is obtained for every unit of electricity sacrificed. So, if the goal is to increase electrical-generation efficiencies and reduce heat energy costs, district heating output temperatures should be kept as low as possible.

Retrofitting Urban Electric Generation Capacity for Cogeneration

Since many American cities with a potential for district heating have older, small-to-medium sized straight-condensing turbines located relatively near high urban heating loads, these units have attracted attention as sources of district heat. Few such units are among the most important in an electric utility's capacity, so using them in cogeneration need not entail critical losses of electrical output.(47)

The appeal of retrofits stems partly from an analysis of utility capacity. Many utilities in the northeastern and north central states have or face the prospect of having excess capacity while electricity growth rates remain relatively constant. In these regions, building new cogenerating facilities makes little sense. (See Part One, Chapter Six.) Then too, conversion typically costs only 35 to 40 percent of new construction.

The most common conversion is that of a turbine from a straight condensing unit to a backpressure unit. When several low-pressure turbine stages are removed, the exhaust pressure increases enough to heat the district heating water. (The retrofitted backpressure turbine operates much as the original turbine does except that the desired exhaust pressure is determined by heating rather than by electrical load.) This involves the loss of some electric-generating capacity during periods of low heat demand, but its simplicity and low cost make it appealing nevertheless.

Converting Turbines to Low-Temperature Cogenerators(48)

Another method of converting steam turbines to cogenerators appears both simple and inexpensive, although the method has been tested only in a small-scale, waste-heat recovery application. It involves regulating the power plant's flow of cooling water to produce a supply of low-temperature (104 degrees F to 120 degrees F) water for district heating. Technically that means installing a shutoff valve in the water discharge system so the entire flow can be diverted through a central valve and forwarding pump. A forwarding pump control is used to vary water flow so that changes in the electrical load

TABLE ONE HUNDRED
TRADEOFFS IN HEAT VS. ELECTRICITY PRODUCTION
FOR DIFFERENT HOT WATER DISTRIBUTION TEMPERATURES

<u>Hot Water Temperatures</u>	<u>Number of Units of Heat Obtained for Every Unit of Electricity Sacrificed¹</u>
216°F	6.12
183°F	7.79
151°F	11.67
120°F	27.80*

1. Units of both heat and electricity express in Btu.

Source: Robert O. Timmerman (1980)

on the plant (which changes the heat output) will not change the outlet temperature of the cooling water. The cost of converting a conventional steam turbine to this type of low-temperature cogeneration has been estimated at about \$25 per KW. However, using this system for district heating would require at least some low-temperature distribution and end-use modifications discussed earlier.

The Prospects for Coal-Fired Generation

Since steam turbine cogeneration units can burn alternative fuels and oil is no longer a bargain, steam turbines must be converted to cogenerators that run on fuels. In fact, only then are they an economical source of base-load district heat.

Converting oil-fired power stations to coal can be difficult. Many urban power stations that used to burn coal converted to use oil to comply with environmental regulations. Switching back would require extensive modification of air pollution control equipment. Even for new coal-fired plants on open sites, capital costs of pollution-control equipment can be high, and trouble-free operation is by no means assured. In any event, alternative fuels and technologies probably cost less and involve fewer technical difficulties than converting to coal use does.

One alternative fuel that an oil-fired power station may be relatively easily adapted to use is coal-oil slurry--a mixture of about 40 percent pulverized coal and about 50 percent heavy fuel oil. Many oil-fired boilers can burn it without extensive boiler retrofits, especially if such boilers were initially designed to burn coal. (Here, care must be taken to make sure sulphur emissions do not increase.)

Technical and economic considerations permitting, the use of slurry-burning boilers could enable small- to medium-sized urban cogenerating power stations to supply district heat at affordable prices. If the oil in the slurry mix later becomes unacceptably expensive, another retrofit may be in order--that to fluidized bed boilers.

In fluidized beds, finely ground particles of inert matter (such as residual ash from coal combustion, sand, graded limestone or dolomite) absorb sulphur dioxide during combustion on a base surface pervious to air. Air at high pressure and velocity is then blown upward through the particle bed so that the particles remain suspended, behaving much like violently boiling liquid. Fuel is injected into this turbulent inert matter, which is preheated by gas. Combustion is rapid and efficient, and heat transfer (through tubes immersed in the bed) is much more efficient than that in conventional boilers. And because fluidized beds are so efficient, they can also be compact and thus relatively easy to integrate with steam turbine cogeneration capacity.(49) Also important, sulphur dioxide emissions can be reduced by 80 to 90 percent if fluidized beds replace coal-fired boilers.

So far, coal-burning fluidized bed units are currently operating only at Georgetown University in Washington, D.C., and in Enköping, Sweden (where a 25 MW-plant supplies the district heating requirements of 16,000 dwellings). But small-to-medium scale units should be commercially available within the next few years, and pressurized fluidized beds (which may be able to burn mixes of gaseous and liquid fuels, coal, wood, peat, and waste materials in the same reactor) may be available within a decade.

Small-to-Medium Scale Cogeneration Technologies

Cogeneration technologies using oil or natural gas will become ever less attractive as fuel prices increase. But their use may be economical over the short-term. Relatively small-sized units--which are highly efficient--could supply both heat and power to commercial, institutional, or larger residential complexes. As Table One-Hundred-One indicates, combined cycle gas/steam turbines and diesel engines operating in a cogeneration mode are especially economical.

Although only natural gas or highly refined petroleum fuels can be used in gas turbines, some technologies can use less expensive alternative energy sources. In use for 80 years, gassifiers can be combined with gas turbines or dual fuel engines to use solid fuels such as coal, wood, peat, agricultural waste, and urban waste. While gassification entails some loss of efficiency, most losses can be recovered if the low-temperature heat is used in a district heating system or to dry the solid fuel prior to gasification.

Except for small units, gassifiers are difficult to buy in the United States. But small-scale gassifiers are being developed for diesel power plants so that these plants can use gassified peat, wood, agricultural waste, and coal.

These diesels can be highly efficient cogenerators, obtaining efficiency levels over 80 percent if used to supply a low-temperature district heating system. Diesels are also exceptionally efficient in electricity production, frequently achieving over 40 percent electric generation efficiency prior to any waste heat recovery. The capital cost of diesels is also relatively low--about \$500 to \$800 per KW(e).

Oil-fired diesels operating in a cogeneration mode have supplied hot water for district heating in Western Europe for decades. Typically, large, slow-speed marine diesels that use heavy fuel oil have been employed. In the United States, however, medium- and high-speed units are more readily available.

TABLE ONE HUNDRED ONE

CHARACTERISTICS OF SMALL TO MEDIUM SIZED COGENERATION PLANTS

<u>Turbine</u>	<u>Output Range (nue)</u>	<u>Peak Electrical Efficiency (%)</u>	<u>Peak Overall Efficiency (%)</u>	<u>Power-to- Heat Ratio at 80°C (176 F)</u>	<u>Power-to- Heat Ratio at 160°C (288 F)</u>	<u>Port-Load Efficiency</u>
Backpressure	1 - 125		83 - 92	0.4 - 0.6	0.27 - 0.40	Good
Uncontrolled Extraction	5 - 300	33 - 40	up to 89	0.4 - 0.6	0.27 - 0.40	Good
Controlled Extraction	60 - 700	28 - 41	up to 85	0.4 - 0.6	0.27 - 0.40	Good
Open-Cycle Gas Turbines	1 - 100	22 - 32	65 - 83	0.4 - 0.7	0.4 - 0.7	Poor
Combined Cycle Gas-Steam	6 - 300	33 - 45	65 - 83	0.6 - 1.1	0.6 - 1.1	Good
Diesel or Gas Engines	0.1 - 30	38 - 40	60 - 80	Diesel Oil 0.9 - 1.1 Gas 0.6 - 0.8	Diesel Oil 0.9 - 1.1 Gas 0.6 - 0.8	Very Good

Source: Robinson, Peter J., "Transmission and Distribution Networks and The Consumer - The Potential for Development" in W.R.H. Orchard and A.F.C. Sherratt, Combined Heat and Power: Whole City Heating - Planning Tomorrow's Energy Economy, Halsted Press, Division of John Wiley and Sons, N.Y., 1980, p.188.

Recently, the larger marine diesels have attracted attention because they can burn ash-free and pulverized coal mixed with oil. (They may also be able to burn solvent refined coal (a liquid) if it ever becomes available.

Overall, diesels are very reliable engines--particularly those of the large, heavy slow-speed, marine variety--and easy both to buy and maintain. Nitrogen oxide (NOx) emissions resulting from fuel combustion do continue to pose problems, however. In district heating, salvation may consist in the fact that while NOx levels would rise greatly near the cogeneration site, total air pollution levels in the area served by the diesel cogeneration district heating system would fall if individual, heat-only boilers were replaced by this system.

Thermal Storage in Cogeneration/District Heating Systems

Using heat-only boilers to meet peak heating loads over the long term is inefficient and expensive in most applications. An increasingly plausible alternative to using heat-only peaking boilers is using thermal storage to increase the baseload unit's contribution to peak heating requirements and its electricity capacity rating. Storage could also increase the proportion of heat supplied by the base-load cogeneration unit, thus decreasing the requirements for peak-load boilers.

If hot water storage is to contribute significantly to the peak-load contribution from heat-only boilers, storage facilities must be located near heat loads. One option is using large water storage tanks at atmospheric pressure that would be charged by the base-load cogeneration unit when demand is low. When demands peak, some of the hot water could be supplied to the system.

Thermal storage is especially important with district heating systems that operate at low temperatures. To utilize low-temperature hot water effectively, buildings and their heat-distribution systems need to be made more efficient. As a result, the heating system's baseload requirements will fall and its peak heat demands rise accordingly. Hot water storage at the cogeneration site and near high heat loads will mitigate the need to rely on peaking boilers to meet peak demands.

Another option for meeting peak daily heating demands mostly through base load capacity would be to combine various scales of thermal storage with variable speed pumping capacity. Instead of merely increasing hot water temperatures in response to peak demand, water flow velocities could be controlled to deliver hot water at relatively constant temperatures and appreciably greater flow rates. Heat pumps could also be an economical source of peak heat supply.

Given the alternatives, oil-fired, heat-only boilers should be used only where they have already been installed in buildings slated for district heating hook-up. There, they could meet system peak-load requirements for individual buildings while the system is developing. But if larger-scale boilers are needed to provide transitional hot water supplies during system development, small fluidized bed boilers capable of using coal or urban waste could make a more economical and efficient choice, if they become available.

District Heating Using Industrial Waste-Heat

Residential and commercial areas near industrial facilities could use the excess heat from industrial processes as a source of district heat. Industrial cogeneration and industrial process heating can be "cascaded" so that energy of progressively lower quality is matched with industrial processes requiring progressively lower temperatures.

This strategy can be extended beyond the boundaries of the industrial plant to the community, with the low-temperature district heating system at the bottom of the energy cascade. While the efficiency and economy of this system depend a great deal on the capability of the distribution systems to utilize lower-temperature hot water effectively, industrial waste heat is at least potentially a very inexpensive source of district heat.

The contribution of low temperature industrial waste heat to a district heating system can be optimized in various ways. Since light industrial, commercial, and residential users' temperature demands may vary considerably both diurnally and seasonally, thermal storage facilities can maximize the contribution of industrial surplus heat. Another option is using heat pumps to boost low-temperature heat to levels adequate for space- and domestic water heating. Here, the closer the temperature of the surplus heat source and the temperature required by the district heating system, the better system efficiency and economy will be. (50)

Using low-temperature industrial surplus heat for district heating also increases the cost-effectiveness of more intensive and costly industrial energy-conservation measures. The possibility of earning substantial profits from selling low-temperature surplus heat to a district heating system should prompt industry to make investments in process energy conservation, either by reorganizing or replacing industrial processes and energy end-use equipment or by making more modest adjustments. (Investments in the energy-conservation measures an industry needs to recover large amounts of surplus heat for a district heating system could be financed cooperatively by the industry, the municipality, and/or the district heating utility.)

Implementing extensive industrial conservation measures before providing waste heat for district heating is also essential to assuring long-term availability of a heat source. Reducing either the quality or the quantity of available waste heat once the system is in place could seriously imperil the technical and economic viability of the district heating system. Unless industrial processes employ cost-effective levels of conservation at the outset, energy price increases could stimulate conservation investments that might reduce the level of waste heat supplied to the district heating system. Thus, industrial energy conservation and cogeneration dovetails with commercial and residential district heating. (See Part Three, Chapter Thirteen, Industrial Process Heat.)

To help use excess heat to meet heating needs, cities could also encourage energy-intensive industries to locate close to other industrial producers or consumers of waste heat (including district heating systems.) (51) Cogeneration capacity can then be pooled, and energy of varying quality can be cascaded among different industries and processes. Already in Denmark, energy-intensive industries have been encouraged and subsidized to locate near communities with district heating systems that can effectively utilize of industrial surplus heat. (52)

The availability of lower cost energy could be a powerful advantage for communities that want to attract new plants or encourage local industries to remain in the community or to expand production. Thus, cogeneration/district heating development strategies can also be employed to stabilize and expand a community's industrial and commercial base.

Municipal Solid Waste Systems as a Source of District Heat

Introduction

With landfill areas becoming scarcer and environmental controls more costly to meet, some cities have built plants to recover resources--and marketable energy--from municipal solid wastes. While nearly all existing or planned municipal solid waste-to-energy systems in the U.S. produce either steam or fuel for sale to utilities or industries, a few supply urban areas with district heat.

Some "resource recovery" systems have as their first order of business the reclamation of metals or glass; others energy production, and still others, both. Most energy resource-recovery plants coming on line recover at least some metal and glass at the plant because these materials are becoming more expensive and valuable. But none is really combined with a good source-separation program that would both maximize recyclables and improve the homogeneity of the waste stream.

Recycling should be made part of every resource-recovery plan and plant. If it is not, either future recycling efforts will be stifled or resource-recovery plants could be oversized and uncompetitive if recycling diminishes the waste stream. Indeed, successful "source separation" programs can make "garbage to energy" projects uneconomical. (53) Here, though, the assumption is that fully adequate provisions for prior recycling will leave room for a viable waste-to-energy facility.

Of the 57 municipal solid-waste-to-energy facilities operating or under construction in 1981, only seven were connected to district heating or cooling systems. (See Table One-Hundred-Two.) In part, this is because in most cities the waste stream cannot meet a large base heating load. (OTA notes that only twenty-three cities produce over 1,000 tons of refuse per day, and that even 1,000 tons of daily refuse would generate only about 700,000 MMBTU of heat in a heating season.) (54) Then too, many cities prefer to sell the products of resource-recovery facilities to selected local industries that can help to maintain the tax base and provide jobs--a strategy that the U.S. Conference of Mayors sees as essential in any resource-recovery/economic development program (55)

These limitations aside, energy from municipal solid waste facilities could meet a portion of a large city's need for base-load heat and supplement the contributions of cogeneration or industrial waste heat systems. They could also be used to help supply base heating loads for clusters of industries or businesses whose access to cheaper or more secure heat sources would help stabilize the local economy. Currently, over 250 plants in Europe are supplying district heat from incinerated urban wastes. (56) In this country, a resource-recovery plant processing 140,000 tons of refuse a year provides about 25 percent of the total heating and cooling needs of twenty-eight commercial buildings in downtown Nashville. (57)

Types of Energy Resource-Recovery Systems

Energy resource-recovery systems can produce different forms of energy from municipal solid waste via different technologies. (See Table One-Hundred-Three.) Waterwall combustion systems use furnaces jacketed with water filled-tubes. Heat is recovered as either low- or high-temperature steam, depending on whether electricity is to be generated. Recent variations on waterwall combustion removes glass and metals before combustion so shredded waste can be more easily handled and system reliability is improved. Shredded waste from which most inorganics have been removed can be either burned on site or used elsewhere under the label of RDF (refuse-derived fuel). RDF may

TABLE ONE HUNDRED TWO

RESOURCE RECOVERY ACTIVITIES			PRODUCTS						
			Steam	Ferrous Metals	Non-Ferrous Metals	Glass	Refuse Derived Fuel	Electricity	Hot Water
LOCATION		STATUS							
Batesville	Arkansas	Operational	x						
Blytheville		temp. closed	x						
North Little Rock		Operational	x						
Osceola		Operational	x						
Bridgeport	Connecticut	temp. closed		x			x		
Windham		under construction (U C)	x						
Wilmington	Delaware	U C		x	x	x	x		
Dade County	Florida	U C	x	x	x				
Jacksonville		Operational	x						
Lakeland		UC	x	x					
*Orange County (Walt Disney)		U C							x
Pinellas County		U C		x	x			x	
Honolulu	Hawaii	planning		x				x	
Burley	Idaho	U C	x						
Chicago (NW)	Illinois	Operational	x	x			x		
Chicago (SW)		temp. closed		x					
Ames	Iowa	Operational		x	x		x		
New Orleans	Louisiana	Operational		x	x	x			
Auburn	Maine	Operational	x						
*Baltimore	Maryland	temp. closed	x						
Baltimore County		Operational		x		x	x		
TOTAL (Page)		Operational/ Temp. closed	8	6	2	2	4	0	0
		U C or planned	4	5	3	1	1	2	1
		TOTAL (Page)	12	11	5	3	5	2	1

TABLE ONE HUNDRED TWO
(Continued)

RESOURCE RECOVERY ACTIVITIES			PRODUCTS						
LOCATION		STATUS	Steam	Ferrous Metals	Non-Ferrous Metals	Glass	Refuse Derived Fuels	Electricity	Hot Water
Braintree	Massachusetts	Operational	x						
East Bridgewater		temp. closed		x			x		
Haverill & Lawrence		U C	x					x	
North Andover		planned	x					x	
Pittsfield		operational	x						
Saugus		operational	x	x					
*Detroit	Michigan	planned	x	x					
Genesee Township		temp. closed	x						
Collegeville	Minnesota	U C	x						
Duluth		operational	x	x			x		
Redwing		U C	x						
Ft. Leonard Wood	Missouri	U C	x						
Livingston	Montana	U C	x						
Durham	New Hampshire	operational	x						
Groveton		operational	x						
Portsmouth		U C	x						
*Albany	New York	operational	x	x	x		x		
Glen Cove		U C	x						
Hempstead		temp. closed		x	x	x		x	
Morroee Country		operational		x	x	x	x		
Niagara Falls (Hooker Chemical)		operational	x	x					
TOTALS (Page)		operational/ temp. closed	9	7	3	2	4	1	0
		U C or planned	9	1	0	0	0	2	0
		Total (Page)	18	8	3	2	4	3	0

TABLE ONE HUNDRED TWO

(Continued)

RESOURCE RECOVERY ACTIVITIES			PRODUCTS						
LOCATION		STATUS	Steam	Ferrous Metals	Non-Ferrous Metals	Glass	Refuse Derived Fuel	Electricity	Hot Water
New York City	New York	temp. closed	x						
Oceanside		operational	x						
Westchester County		U C	x	x				x	
*Akron	Ohio	temp. closed	x	x					
Columbus		U C						x	
Lane County	Oregon	temp. closed		x			x		
*Harrisburg	Pennsylvania	operational	x	x					
Warwick	Rhode Island	planned	x						
Crossville	Tennessee	operational	x						
Dyersburg		operational	x						
Gallatin		U C	x						
Lewisburg		operational	x						
*Nashville		operational	x						
Gatesville	Texas	operational	x						
Palestine		operational	x						
Hampton	Virginia	operational	x						
Newport News	Military	operational	x						
Norfolk	Military	operational	x						
Portsmouth	Military	operational	x						
Portsmouth		planned		x	x		x		
Salem		operational	x						
TOTAL (Page)		operational/ temp. closed	15	3	0	0	1	0	0
		U C / planned	3	2	1	0	1	3	0
		Total (page)	18	5	1	0	2	3	0

TABLE ONE HUNDRED TWO
(Continued)

RESOURCE RECOVERY ACTIVITIES

			PRODUCTS						
LOCATION		STATUS	Steam	Ferrous Metals	Non-Ferrous Metals	Glass	Refuse Derived Fuel	Electricity	Hot Water
Tacoma	Washington	operational		x			x		
Madison	Wisconsin	operational		x			x		
Milwaukee		temp. closed		x			x		
Waukesha		operational	x						
TOTAL (Page)			1	3	0	0	3	0	0
TOTAL (All Pages)		operational/ temp. closed	33	19	5	4	12	1	0
		U C /planned	16	8	4	1	2	7	1
		TOTAL	49	27	9	5	14	8	1
		Rank Order	1	2	4	6	3	5	7

* District Heating

Source: National Center
for Resource
Recovery

Note: Might be sold for
generating electricity

Note: Might be sold for use
in generating electricity

Note: Only listed are those
where electricity is product of plant

TABLE ONE HUNDRED THREE

ENERGY PRODUCTS FROM VARIOUS RESOURCE RECOVERY PROCESSES

<u>Product</u>	<u>Technology (Process)</u>
<u>Steam or Electricity</u> generated "on-site" for sale	Waterwall cumbustion system (bulk burning) Waterwall combustion system (processed waste) Pyrolysis to low Btu gas, which is burned in afterburner Bio-conversion to a gas, which is burned in an afterburner
<u>Production of a solid fuel</u> for use "off-site" as a supplement to coal or oil	Solid Refuse Derived Fuel (RDF) system
<u>Production of a gas or liquid</u> <u>fuel</u> for use "off-site" as a supplement to oil or gas	Pyrolysis to a medium Btu gas Pyrolysis to a liquid Bio-coverision to medium Btu gas

Source: EPA, Resource Recovery Plant Implementation, Volume D.,
Technologies.

also be in the form of compacted pellets or briquettes that are easy to transport.

Widely used combustion and RDF production technologies nevertheless have had substantial technical problems. The pipes and boilers of incineration systems have corroded in presence of hot flue gases produced in combustion, a problem that could be reduced if plastics were removed from the waste before incineration. Refuse derived fuel can be difficult to store and handle. Recyclable materials can foul production or combustion equipment. And the relatively low energy content of RDF limits economies in transportation and combustion.

Still in the developmental stages are pyrolysis and bioconversion. Pyrolysis exposes organic matter to heat in the absence of oxygen. The process yields either liquid or gaseous fuels, depending on the specific process used. Bioconversion involves extracting gaseous fuel from MSW through a process similar to that now commonly used to produce sludge in many sewage plants.

Pyrolysis is a potentially attractive technology because the liquid or gaseous fuels produced can be easily stored, transported, or used on-site to generate electricity or steam. Its drawbacks are high costs, complicated technology, and operating problems.(58)

As for bioconversion, the recovery of methane from landfills is considered developmental, though from an economic rather than a technical standpoint. More needs to be known about the reliability of methane supply from landfills over time. The production of gas through anaerobic digestion of MSW is also still experimental. One problem hindering its use is that contaminants and erratic waste flow composition make it difficult to maintain the environment the bacteria involved in the process need.(59) (See Part Three, Chapter Fourteen.)

Technical Concerns and System Efficiency

One of the most significant technical problems surrounding an MSW processing plant is oversizing or undersizing the plant relative to the size of the waste stream so that the plant is either overloaded or operating at less than full capacity. To avoid this problem, cities must compare a resource-recovery facility with all plausible alternatives--continued landfilling, incineration, and vigorous source-separation and recycling--during the design stage to make sure the plant is needed and effective.(60)

Another design problem is redundancy of equipment, which oversizes a plant but is needed as protection against breakdowns. Clearly, some redundancy is needed, especially with very large-scale plants. It could be kept to a minimum, however, if some other design and operational problems were corrected.

The reliability and durability of many major system components also remains questionable. Because many waste-to-energy plants use relatively new technologies or new combinations of existing technologies, equipment mismatches or control problems cause short-to-extensive shutdowns. In 1981, a survey of plants indicated that eleven of forty-five operational facilities were "temporarily closed."(61)

Nationally, technical problems affect system efficiency. Typically, the heat value of unprocessed MSW ranges from 3,500 BTU/lb to 6,500/lb (averaging about 4,600 BTU/lb). Overall, the efficiency of a waste-to-energy system is the percentage of this value ultimately converted to useful energy (generally, steam). For the broad range of energy recovery processes listed in Table One-Hundred-Four, from 14 to 63 percent of the energy contained in combustible refuse can be recovered. The overall efficiency of most systems actually falls between 40 and 60 percent.

Where metals and glass are recovered for re-use, efficiency is subtly being increased, since recycling materials usually requires less energy than smelting or fabricating virgin materials does. (See Table One-Hundred-Five.)

Economics

While resource-recovery plants require major capital investments, the range of capital costs per input ton per day of capacity is considerable. (See Table One-Hundred-Six.)

Assessing the economics of a waste-to-energy-system requires considering both how much money is saved on the purchase of conventional fuels and how much money is saved on alternative means of waste disposal. If, for example, landfilling costs are quite high, an energy-recovery plant may represent only a relatively small increase in a city's disposal expenditures, though some resource-recovery projects will need relatively large landfill areas for combustion-residues.(62)

Many factors influence the costs of steam or electricity produced by a resource recovery facility--the reliability of markets for metal and glass, the size of tipping fees for unloading refuse,(63) and the cost increases for plant operation relative to increases in oil and gas prices. Another economic variable is the possibility of offering lower rates to customers with long-term contracts to enhance the market's stability. For example, Ohio's 1,000-ton-per-day facility charges from \$1.87 to \$4.37 per thousand pounds of steam depending in part on the reliability and duration of the customer's demand.(64)

TABLE ONE HUNDRED FOUR

COMPARISON OF ENERGY RECOVERY EFFICIENCIES
FOR VARIOUS SOLID WASTE ENERGY RECOVERY PROCESSES

Process	Net Fuel Produced	Total Amount Available as Steam
	(Expressed as percent of heat value of incoming solid waste)	
Water Wall Combustion	—	59
Fluff RDF	70	49
Dust RDF	80	63
Wet RDF	76	48
Purox Gasifier	64	58
Monsanto Gasifier	78	42
Torrax Gasifier	84	58
Oxy Pyrolysis	28	23
Biological Gasification *		
With use of residue	29	42
Without use of residue	18	14
Brayton Cycle/combined cycle		19 plus
Waste Fired Gas Turbine		12 directly as electricity
*Includes energy recovered from sewage sludge.		

TABLE ONE HUNDRED FIVE

1985 ENERGY SAVINGS--
RECYCLING VS. USE OF VIRGIN MATERIAL

	<u>Recovered materials</u>		
	<u>Ferrous metals</u>	<u>Aluminum</u>	<u>Total</u>
Tons recoverable annually for recycling (millions)	9.5	0.6	10.1
Energy required to manufacture a ton of new product using virgin material (kWhs per ton) (note a)	4,270	51,379	55,649
Energy required to manufacture a ton of new product using recycled material (kWhs per ton)	1,666	2,000	3,666
Energy saving per ton as the result of recycling (kWhs per ton)	2,604	49,379	51,983
Annual energy savings (million kWhs)	24,738	29,627	54,365
Annual energy savings (billion Btus) (note b)	84,431	101,117	185,548
Equivalent barrels of oil (thousands) (note c)	14,557	17,434	31,991
Estimated value (\$, millions) (note d)	\$211.7	\$253.5	\$465.2

a/KWh = Kilowatt-hour.

b/Based on standard conversion of 3,413 Btus per kWh.

c/Based on 5.8 million Btus per barrel of crude oil.

d/Based on \$14.54 price per barrel of imported crude reported in "Monthly Energy Review," U.S. Department of Energy, Energy Information Administration, (NTISUB/D/127-010) Oct. 1978.

Source: GAO

TABLE ONE HUNDRED SIX

Sept 1981 NCRR

CAPITAL COSTS PER INPUT DAILY TON - MSW PLANTS

<u>STEAM SYSTEMS</u>			
Location	Capacity (tons per day)	Capital Costs (Millions)	Capital Costs/ Capacity (\$/TPD)
Batesville, Arkansas	50	1.2	24000.
North Little Rock, Arkansas	100	1.45	14500.
Osceola, Arkansas	50	1.1	22000.
Windham, Connecticut ⁺	108	4.125	38195.
Dade County, Florida ⁺ *	3000	165.	55000.
Jacksonville Nas, Florida	40	2.8	70000.
Burley, Idaho ⁺	50	1.5	30000.
Chicago, Illinois	1600	23.	14375.
Auburn, Maine	200	3.97	19850.
Baltimore, Maryland	600	30.1	50167.
Braintree, Massachusetts	250	2.8	11200.
Saugus, Massachusetts [*]	1200	50.	41667.
Genesee Township, Michigan	100	2.	20000.
Collegeville, Minnesota ⁺ ³	70	2.5	35714.
Ft. Leonard Wood, Missouri	75	3.3	44000.
Durham, New Hampshire	108	3.3	30556.
Glen Cove, New York ⁺ *	225	34.	66176.
Hempstead, New York ¹	2000	130.	65000.
Niagara Falls, New York ²	2200	90 ⁺	40909. ⁺
Oceanside, New York	750	9	12000.
Harrisburg, Pennsylvania	720	8.3	11528.

(+) soon to be operational

(*) Steam for producing electricity

1. Electricity from burning MSW and RDF.

2. Cogeneration by Hooker Chemical

3. St. Johns University

TABLE ONE HUNDRED SIX
(Continued)

Sept 1981 NCRR

CAPITAL COSTS PER INPUT DAILY TON - MSW PLANTS

STEAM SYSTEMS (Cont.) Location	Capacity (tons per day)	Capital Costs (Millions)	Capital Costs/ Capacity (\$/TPD)
Crossville, Tennessee	60	1.1	18500.
Dyersburg, Tennessee ⁴	100	2.	20000.
Gallatin, Tennessee ⁺	200	8.1	40500.
Lewisburg, Tennessee	60	1.75	29167.
Nashville, Tennessee	530	24.5	46226.
Gatesville, Texas ⁵	7	.2	28571.
Palestine, Texas ⁵	28	.3	10714.
Hampton, Virginia (NASA)	200	10.3	51500.
Ft. Eutis, Newport News, VA	40	1.4	35000.
Norfolk (VA) Naval Station	360	2.2 (1967)	6111.
Norfolk Naval Ship (Portsmouth)	160	4.5	28125.
Salem, Virginia	100	1.9	19000.

(+) soon to be operational

(*) steam for producing electricity

4. Colonial Rubber Works

5. Texas Department of Corrections (Prison Facility)

TABLE ONE HUNDRED SIX
(Continued)

Sept 1981 NCRR

CAPITAL COSTS PER INPUT DAILY TON - MSW PLANTS

<u>RDF SYSTEMS</u>			
Location	Capacity (tons per day)	Capital Costs (Millions)	Capital Costs/ Capacity (\$/TPD)
Bridgeport, Connecticut	1800	53.	29500.
Ames, Iowa	200	6.3	31500.
Baltimore County, Maryland	1200	8.4	7000.
East Bridgewater, MA	550	10 - 12	20000.
Duluth, Minnesota ⁺	740	19.	25676.
Albany, New York	750 (TP Shift)	26.6	
Monroe County, New York	2000	62.2	31100.
Tacoma, Washington	500	2.5	5000.
Madison, Wisconsin	400	2.5	6250.

(+) soon to be operational

Source: National Center for Resource Recovery (1981)

A final economic consideration is that new municipal energy recovery projects can be economically competitive today only if they receive "special" financing. Sometimes, this translates into public ownership, especially in cities that own their public utilities. Sometimes it means developing some creative public-private arrangements. In Saugus, Massachusetts, a privately-owned resource-recovery system was designated as real property to be taxed at full value, so the city was willing to help finance the project through tax-exempt revenue bonds. Now, the facility pays the town \$1.4 million in taxes each year.(65)

Institutional Concerns

Even relatively small resource-recovery facilities require fairly large tracts of land. Small plants processing from 200 to 500 tons input per day require three to five acres of land just for plant operations and larger plants (1,000 tons or more input per day) can require as many as ten acres. In some cases, additional acreage for use as a buffer zone may be needed. Truck routes are another land-use concern.

Against the need for land, resource-recovery plants' beneficial impacts on land use should be weighed. Where landfilling sites are becoming scarce, MSW processing could reduce the net flow of material into existing landfills. Resource-recovery plants can be well integrated with centralized industrial operations with ready markets for recovered energy and materials. Indeed, the development of "urban resource recovery parks" might be stimulated using materials and energy from MSW.(66)

Lack of utility cooperation in resource-recovery projects can be a major institutional stumbling block. Utilities have little economic incentive to participate in resource-recovery projects since even large facilities will be unable to produce more than a small fraction of the steam a utility needs.(67) If a district heating system (or a high concentration of industrial operations able to utilize steam or RDF from a MSW processing plant) can provide an attractive primary market for energy from resource-recovery plants, utilities' unwillingness to cooperate may not be a serious problem. Then too, if the MSW-derived energy has to be distributed through a utility grid, its availability is not likely to stimulate new (or sustain existing) industrial and commercial development.

From an environmental perspective, resource-recovery is usually preferable to landfilling and simple incineration. Re-using materials and otherwise wasting energy means that less land is altered by landfilling or mining. On the other hand, resource recovery is a more centralized process than "source separation," which imbues participating individuals with an environmental ethic. Safe in the knowledge that materials will ultimately be "recovered" at the MSW processing plant, consumers may use and dispose of them wastefully.

The production and use of energy from garbage also entails environmental problems. Burning plastics and hazardous wastes can create unacceptable emission levels of toxics and organic hydrocarbons.(68) Supplementing coal with RDF in boilers can actually increase stack emissions and corrosion can also reduce the operating efficiency of pollution-control equipment.

Smaller Scale Sources of District Heat

Most district heating applications have been used in central business districts or large cities. But with the rise of fuel costs and with the maturation of small-scale cogeneration technologies with potentially high efficiencies, neighborhood-, or block-scale district heating systems are becoming increasingly realistic.

Using Alternatively Fueled Small Engines Appropriate in Residential and Commercial Applications

The U.S. Department of Energy has recently supported research on the potential of relatively small cogenerating engines.(69) (See Tables One-Hundred-Seven and One-Hundred-Eight.) All the engines studied have combined heat and power efficiencies of 60 percent or greater, and the generation costs (cents/KWH) associated with such engines are becoming competitive with those in central generating plants. Although the advanced closed-cycle Brayton and Stirling engines cost more than currently available technologies, their potential efficiencies and lower fuel (coal) costs will make these developing technologies increasingly competitive.

Assuming that these coal-fueled technologies utilize fluidized bed combustion units, most give off fewer emission levels than centralized electric generating stations and on-site fossil-fueled boilers. Compared to an all-coal-using utility, all total energy technologies except diesels and steam turbines showed a significant reduction in overall emissions.

Other potential advantages of relatively small district heating systems include their potential for distributing lower temperature heat and, thus, making use of relatively inexpensive pipe. Routing such pipes through the basements of buildings served by block or multi-block scale systems further reduces capital costs. Overall, using

TABLE ONE HUNDRED SEVEN

FUELS, EFFICIENCIES AND CAPITAL COSTS OF
VARIOUS COGENERATION ENGINE TYPES

PRIME-MOVER	FUEL	EFFICIENCY (%)			CAPITAL COST ¹ (\$/KW)	
		Elect	Recoverable Heat	Reject Heat	1000KW	3000KW
Diesel	Oil	36	42	22	375	336
Gas Turbine (Simple)	Oil	25	45	30	519	372
Gas Turbine (Regen.)	Oil	38	22	40	735	513
Adiabatic TC Diesel	Oil	47	36	17	397	354
Stirling	Oil	34-46	41-54	12-13	420-487	373-429
Stirling	Coal	34-46	41-54	12-13	537-604	479-535
Open Cycle Brayton	Coal	34	36**	30	814	713
Closed Cycle Brayton	Coal	34	41**	25	574	443

Notes: 1. 1977 Prices

* Includes Generator Efficiency of 95%.

** At 150°F exit temperature from heat recovery exchanger.

*** At lower temperatures (120°F) greater percentages of recoverable heat are possible.

TABLE ONE HUNDRED EIGHT

COAL-FIRED ENGINES SHOW REDUCED GENERATION
COST DUE TO LOW FUEL PRICE

Prime Mover	Generation Cost ^A (¢/kwh)		
	Fuel		
	Distillate 5.44 \$/MBTU	Residual 3.65 \$/MBTU	Coal 1.85 \$/MBTU
Diesel	7.13	5.77	---
Adiabatic Diesel	6.13	5.10	---
Gas Turbine (Regenerative)	9.09	7.81	---
Stirling	7.69-8.10	5.30-6.67	4.59-5.47
Closed Cycle Brayton	7.92	6.53	5.28
Open Cycle Brayton	9.40	7.96	6.75

^A1980 prices; 1000 KW prime movers

Source: Marciniak, T.J., Ibid.

smaller distribution networks greatly diminishes overall distribution system thermal losses and facilitates the direct connection of hydronic distribution systems in buildings to district heating systems. (See District Heating Distribution Systems and The Efficient Use of District Heat.) In addition, smaller systems can be built in far less time and with far fewer institutional, planning, financial, and logistical problems than larger systems.

While the precise circumstances under which these small-scale systems are most applicable and economical awaits research, one study of Pittsburgh found that the use of gas-fired cogeneration units at the block scale is more cost-effective than using either larger gas-fired cogenerators at the ten-block scale or fluidized bed coal-fired cogeneration units at the 50-block scale. In Pittsburgh, the higher capital costs of large-scale distribution systems make the small-scale option appear more cost-effective.(70)

Renewable Energy Sources of District Heat

Community-scale solar energy systems have several potential advantages over on-site solar energy applications. One is economy of scale. Less collector and storage areas per dwelling unit are needed in larger systems, and economical and efficient storage is possible only in large-scale systems. Since storage tanks have smaller surface-to-volume areas as volume increases, larger volume storage tanks can store more heat (a function of volume) at reduced unit costs (a function of surface area). A second advantage is that using a community-scale system eliminates the needs for properly oriented and unshaded space for collectors on each building and for installing individual storage tanks in retrofits. Finally, community energy systems will likely receive better maintenance.

Renewable-energy based community systems can also be attractive long-term alternatives to conventional district heating. A "solar district heating" system entails no pollution control problems, it can provide lower temperature heat than conventional systems can so materials and installation costs for the distribution are commensurately less, and their use is more compatible with extensive end-use conservation measures.

For all their theoretical advantages, however, serious practical concerns surround the use of solar district heat. First, economies of scale may not be great enough to offset the high purchase price of active collectors. Until cheaper collection strategies are developed, solar district heating systems cannot compete economically with either conventional district heating or on-site conservation alternatives, though modified solar ponds may be able to since they collect more solar energy at lower unit costs. Second, numerous technical questions need answers. Will some of the materials and installation problems experienced with on-site active solar systems reoccur in community-scale applications. (See Chapter Nine, pp. xx-xx, above.) Do community-scale systems that distribute heat over relatively long distances lose too much heat or use too much operating energy to be economic? Finally, it may not be easy to secure adequate, affordable space for solar collectors amid competing demands for urban land. Then too, protecting solar access for a relatively large community system may limit surrounding development.

Since none of these questions can be resolved without operating experience and since most "real-world" demonstrations of this technology are in Sweden, the following discussion relies heavily on Swedish experiences.

Active Solar District Heating

Several district heating systems using active solar collectors are being operated in Sweden. The largest is designed to meet about 90 percent of the space-heating and water-heating requirements in a 56-house project now under construction, though a 500-house project now under construction will obtain all of its heating needs from solar energy.(71) A project still in the design stage may provide 750 new housing units with all of their annual heating needs. (See Table One-Hundred-Nine.)

Theoretically, these systems work the same way on-site active solar heating systems do. Solar energy is collected via active solar panels, transported to storage, and then distributed to points of use. However, the collector, storage, and distribution components of community-scale systems do have special design requirements.

With only limited experience to draw on, engineers cannot yet identify a typical, let alone an optimal, active solar district heating system. While all systems will doubtless use water (rather than air) as the transfer and storage medium, other materials and design details vary from project to project. Some will use decentralized collectors with centralized storage, while others will use centralized collectors and decentralized storage, and still others will use centralized collectors and storage.

In one Swedish project, all the collectors have been dispersed onto the roofs of attached buildings. But this "landless" approach is feasible only in a new community or in a neighborhood whose buildings happen to have excellent solar access. Elsewhere, collector locations will have to be centralized--a definite drawback in some existing

TABLE ONE HUNDRED NINE

SUMMARY OF SWEDISH SOLAR DISTRICT HEATING PROJECTS

<u>Project</u>	<u>Collector Type & Area</u>	<u>Storage Type</u>	<u>Annual Heating Load</u>	<u>Predicted Solar Fraction</u>
Studsvik	Concentrating	Inter- Seasonal	22.5 MWH (Th)	100%
Boras	Flat Plate (1620 ft ²)	Short Term (with heat pump)	116 MWH (Th)	70%
Lambohov	Flat Plate (28,080 ft ²) (dispersed)	Inter- Seasonal (with heat pump)	1070 MWH (Th)	92%
Ingelstad	Parabolic Concentratqrs (14,256 ft ²)	Inter- Seasonal	940 MWH (Th)	50%
Lyckebo	Flat Plate (216,000 ft ²) (21,600 ft ² - dispersed) (194,400 ft ² - central)	Inter- Seasonal	5500 MWH (Th)	100%

urban areas. The amount of land area needed, however, can be minimized by reducing heating loads through end-use conservation, by using long-term storage (see below), or by using more centralized auxiliary systems such as heat pumps.

Whether flat-plate metal collectors or concentrating collectors constitute the optimal choice in district heating systems depends mostly on the design delivery temperature of the system. Where design delivery temperatures are less than, say, 130 degrees F, it makes sense to use lower-temperature flat-plate panels.

In colder climates, to avoid dissipating heat from storage water to the outside in winter(72) and to take advantage of the 30-fold increase in sunlight in summer, interseasonal storage is a necessity. Less crucial in this country, interseasonal storage would allow northern cities to get by with substantially less solar collector area than would otherwise be needed. For example, a space heating system in Seattle without long-term storage would require almost nine times the collector area as one with storage. (See Table One-Hundred-Ten and One-Hundred-Eleven.) Even in Sweden, however, interseasonal heat storage is possible only on a very large scale since large tanks lose heat relatively slower than small tanks do and since insulating them costs proportionately less.

In Sweden, various long-term storage designs have been employed. In one project, a prototype demonstration of the interseasonal storage concept, storage consists of a pit in the earth in the shape of a truncated cone. The upper edge consists of concrete blocks added above grade level, and the pit's interior is sealed with a plastic liner and then insulated. Research conducted in both Sweden and the U.S. indicates that this design--which includes no separate tank or costly structural support--is probably the most cost-effective. But it is feasible only where the existing geological structure is highly stable. The project is also unique in design: the concentrating solar collectors "float" on a buoyant cover atop the filled storage container so heat losses in collector-to-storage transport are eliminated and collectors can track the sun at optimal orientations throughout the day and year. The system needs only 100 watts of electricity per year since friction between the floating lid and the water's surface is low.

In other projects, storage tanks have been constructed above ground or partially buried. Most such tanks are made of concrete (which does not corrode) and heavily insulated, typically with one-half to one meter of mineral wool.

An interseasonal storage system's effectiveness is also a function of the internal tank configuration. Because hot water rises to the top of a tank and cold water sinks to the bottom, the supply and return piping must enable the coldest water to circulate to collectors (so that they absorb the most heat) and the warmest water to the heating load.

In on-site solar storage systems, thus, storage water circulated to the house should come from the top of the tank. However, in large storage tanks temperature layers vary so a more sophisticated control system (such as multiple piping) is needed to avoid supplying more heat than necessary.

Against the backdrop economies of scale large storage tanks enjoy, extra materials and labor costs must be viewed. One way of keeping storage to a minimum is to obtain as high a heat storage capacity as possible by using solar collectors that provide hot water at the highest temperature collectors can tolerate without performance losses. However, higher-temperature concentrating collectors cost significantly more than flat-plate models. Both storage and distribution components also become more expensive as a system's "design temperatures" increase.

An alternative to this approach is to use lower-temperature collectors and to boost storage temperatures with heat pumps. For example, the Lambokov project in Sweden uses storage temperatures as low as 50 degrees F, raised to 113 degrees F by a heat pump.(73)

The Swedish systems developed so far should perform well. (See Table One-Hundred-Nine.) But their capital costs are very high. For example, the Lyckebo project costs about twice as much to build as a conventional district heating project in Sweden--an estimated \$93.00 per million BTU, if amortized at .15 per year.(74) Reducing costs can be a matter of using lower-cost or higher-efficiency collectors or (primarily in new developments) of optimizing the entire solar district heating system for low-temperature collection, storage, distribution, and end-use.

Solar Ponds

Solar district heating systems using solar ponds as heat sources can be far less expensive than those using active collectors, partly because ponds combine collection and storage functions. A solar pond could supply district heat by circulating a transfer fluid between the pond and end-uses via pipes and heat exchangers. Solar ponds capable of reaching temperatures sufficient for electricity generation will probably be located in more southerly regions. (See Part Three, Chapter Twelve.) But, solar ponds capable of providing heat energy can operate in colder climates as well.

Numerous types of solar ponds exist. The salt-gradient pond utilizes high concentrations of salt near the bottom and a black plastic liner to collect solar radiation and store heat in the lower regions of the pond. This increased density prevents the continuous convection of the warmed water from the bottom of the pond to the

TABLE ONE HUNDRED TEN

PERCENTS SUNSHINE AND SUNSHINE INTENSITIES
FOR SUMMER AND WINTER SEASONS (SELECTED CITIES)

<u>City</u>	<u>% Sunshine Summer</u>	<u>% Sunshine Winter</u>	<u>Solar Radiation - Summer¹ (BTU/ft²)</u>	<u>Solar Radiation- Winter² (BTU/ft²)</u>
Boston	63.3	54.6	1470.5	738.9
Providence	59.0	54.5	1456.7	767.7
New York	63.0	53.5	1437.8	759.9
Rochester	62.0	40.8	1444.1	641.9
Buffalo	61.8	37.5	1437.7	630.9
Newark	n/a	n/a	1505.2	825.4
Pittsburgh	55.5	39.0	1444.5	693.4
Philadelphia	60.2	53.5	1507.3	830.3
Baltimore	60.3	53.2	1557.1	872.8
Washington	61.5	52.3	1566.3	850.5
Norfolk	64.7	60.0	1650.0	1000.5
Charlotte	68.8	61.5	1648.6	1040.1
Atlanta	65.5	55.8	1651.7	1038.9
Jacksonville	60.7	62.3	1667.2	1209.2
Miami	70.7	64.5	1617.3	1161.9
Birmingham	58.5	53.3	1662.6	1027.1
New Orleans	60.8	56.5	1680.0	1148.9
Memphis	72.3	55.5	1733.5	998.3
Louisville	57.7	47.2	1590.7	840.7
Cincinnati	64.0	45.7	1536.0	781.0
Cleveland	60.7	36.8	1506.9	674.2
Detroit	61.8	42.0	1520.4	719.7
Fort Wayne	68.5	46.8	1515.5	730.2
Indianapolis	66.0	46.8	1551.2	779.0
Chicago	65.2	45.8	1630.3	799.9
Milwaukee	62.8	45.8	1607.4	775.0
Minneapolis	63.0	49.7	1572.7	767.8
St. Louis	65.2	51.3	1731.5	921.8
Kansas City	70.3	60.7	1743.6	936.6
Omaha	68.0	53.5	1730.5	910.4
Dallas	73.0	50.7	1826.8	1114.6
Austin	68.2	52.8	1813.6	1139.2

TABLE ONE HUNDRED TEN (Cont)

<u>City</u>	<u>% Sunshine Summer</u>	<u>% Sunshine Winter</u>	<u>Solar Radiation - Summer¹ (BTU/ft²)</u>	<u>Solar Radiation - Winter² (BTU/ft²)</u>
Houston	62.8	51.8	1656.0	1046.7
San Antonio	67.5	53.7	1836.6	1161.3
Oklahoma City	71.8	60.7	1821.3	1101.8
Denver	71.3	69.3	1971.6	1165.4
Salt Lake City	79.3	57.2	2150.6	1055.7
Albuquerque	79.0	74.0	2252.4	1402.7
Phoenix	89.0	81.7	2297.8	1441.1
Los Angeles	74.7	71.5	1877.4	1260.4
San Diego	64.7	71.0	1899.9	1296.1
San Francisco	69.7	67.5	2013.1	1092.6
Oakland	n/a	n/a	1974.9	1095.5
Sacramento	91.5	60.8	2232.8	1053.1
Portland	57.5	34.7	1514.5	619.0
Seattle	56.8	35.0	1530.7	574.7
Anchorage	44.5	43.8	n/a	n/a

Codes: 1. May - October
 2. November - April

Source: NOAA

TABLE ONE HUNDRED ELEVEN
COMPARISONS OF SPACE HEATING SYSTEM COLLECTOR AREAS
WITH AND WITHOUT LONG TERM ENERGY STORAGE

<u>Indicator</u>	<u>Location</u>									
	San Diego CA	Denver CO	New York NY	Yuma AZ	Chicago IL	Sacramento CA	Cleveland OH	Seattle WA	Sault St. Marie MI	Spokane WA
1) Annual deg.(C) heating days	836	3339	2693	561	3400	578	3415	2880	5102	3793
2) December deg.(C) heating days	142	558	507	153	629	330	592	422	772	619
3) Annual horizontal insolation (GJ/m ²)*	6.62	6.50	4.55	7.96	5.03	5.81	4.52	4.36	4.32	5.07
4) Dec. insolation on a surface tilted at lat. +15° (GJ/m ²)*	.511	.410	.32	.60	.24	.284	.15	.12	.108	.098
5) (1)/(3)	141	513	592	70.4	675	232	755	660	1181	748
6) (2)/(4)	277	1360	1584	255	2620	1162	3947	3517	7148	6316
7) Ratio of collector area without long term storage to area with long term storage ((6)/(5))	1.96	2.65	2.68	3.60	3.88	5.00	5.22	5.32	6.05	8.44

*1 GJ = 1 billion joules

Source: Theodore B. Taylor, "Long Term Storage of Heat and Cold" (1981)

cooler layers near the top, so heat is transferred to the surface primarily by conduction, which is slow enough to enable the lower regions of the pond to maintain a high stable temperature (212 degrees F has been measured in operating ponds.)

Salt gradient ponds have three layers. In the top layer, vertical convection takes place due to the effects of wind and evaporation. This layer serves no useful purpose and is kept as thin as possible. In the next layer, which is non-convecting, salt concentrations increase with depth. The bottom layer is a convection layer that provides most of the thermal storage capacity and facilitates heat extraction.

Boundaries between layers can be controlled in many ways. The so-called "membrane pond" contains a horizontal partition to separate the lower convecting zone from the middle nonconvecting zone. Some variations also feature a second partition, this one slightly below the surface of the pond to minimize the depth of the surface-convecting layer.

Solar ponds require large land areas and ensured solar access. Consequently, solar ponds are not likely sources of district heat for neighborhoods in larger cities. But in smaller communities, the story is different. For example, in a Hampshire College study, a modified salt-gradient was selected for a proposed district heating system in Northampton, Massachusetts, even though almost two percent of the city's land would be needed for the project.(75)

While solar ponds of this type can collect and store thermal energy at very low temperatures, their exposure to sunlight is restricted in winter, and they can lose large amounts of heat to the cold air if left thermally unprotected. Potentially, the large amounts of salt needed create environmental problems too.

Some solar ponds have been modified in view of these problems. In such modified ponds, a layer of fresh water under an insulating layer supports a shallow black-bottom pool that functions like a flat-plate collector. As water in the pool heats, it could be circulated to the pond and be replaced by cooler water that would, in turn, be heated. This pond would work better than the salt-gradient pond in colder months because both the floating lid and the plastic liner would guard against heat losses. While most of the work on this design has been theoretical, it has been encouraging.(76)

Modified solar ponds could probably provide district heat at far less cost than active solar collectors. But salt-gradient ponds are not cheap. The proposed Northampton pond, for example, would cost an estimated \$100 million--excluding land and distribution costs for some 445 acres of ponds.(77)

Natural and Waste-Water Sources

Bodies of surface, ground, or waste water could also supply district heat. Technically, they would work much the same as solar ponds. A transfer fluid (usually water) could be circulated through a lake or underground aquifer absorbing heat that would then be distributed to individual buildings. In most instances, the temperatures of natural water resources will have to be boosted via a heat pump because the temperatures available from these sources alone would be too low for direct use in space-heating or water-heating applications.

Diesel-driven heat pumps combined with natural or waste-water heat sources have been designed to supply the base-heating load to some small Danish towns. By one calculation, a fossil-fueled heat pump could boost the temperatures of a sea-water heat source enough to supply district heat to 2,000 homes using about half the fossil fuel a heat-only boiler system would require. In another design, heat from sewage water combined with recaptured waste heat from the diesel-powered heat pump, supplies about 35 percent of a small town's heat energy demand. A study of the Stockholm suburb of Lidingo concluded that a sewage water heat source with heat pumps could supply about 60 percent of the heat needed for the town's district heating system.(78)

Since more than 60 percent of the land area (and 75 percent of the population) in the continental U.S. is reasonably close to aquifers, these underground stores of water could be also be used as sources of district heat. Indeed, a University of Alabama research team has proposed a community heating and cooling system combining an aquifer heat source with temperature-boosting heat pumps in each building in the system. Instead of absorbing heat from ground water with a separate transfer fluid via a heat exchanger, ground water itself would be used to distribute heat.(79)

Although interest in using aquifers in heating/cooling applications abounds, it should be tempered with concern for the environmental effects of these systems. Until questions about thermal pollution are resolved, caution is advised.

Ice Ponds for District Cooling

The ice pond concept being demonstrated in Princeton could be used to provide community-scale, as well as on-site, cooling. (See Chapter Ten.) Probably the most promising immediate candidates for community-scale ice pond systems are relatively small clusters of residential or commercial buildings adjacent to land areas large enough to accommodate a reservoir. Obviously, multiple reservoirs could also be interspersed among clusters of buildings. In the future, very large ice ponds could be developed to serve

large scale developments. At any size, ice ponds are probably most feasible in new developments or in existing ones near adequate open lands.

Biomass

Most of the known biomass-burning plants in the U.S. produce electricity or cogenerate electricity and process steam. However, these plants could also provide district heat if they were suitably retrofitted. (See Cogeneration.) For a discussion of biomass resources in the production of electricity and industrial process steam, see Part Three, Chapters Twelve and Thirteen.

Geothermal

Few cities are located in areas rich with high-temperature geothermal resources. Those that are, however, could make use of geothermal energy for district heat, at least on a neighborhood scale. (See Table One Hundred-Twelve.) Boise, Idaho is currently rehabilitating its old (1890s) district heating system to use local hydrothermal resources. When completed, the system could serve up to five hundred homes and forty commercial buildings, as well as state office facilities--replacing 1,750 billion BTUs of fossil fuels (natural gas) a year.(80) The city of Klamath Falls, Oregon, will use hydrothermal resources in a hot-water district heating system that will eventually heat its entire 54-block central business district.(81) The Klamath Falls system will circulate hot water from two geothermal wells through concrete-encased steel tunnels to heat exchangers that will transfer heat at 200 degrees F to a secondary piping loop serving the connected buildings. The system will expand in three phases, and the city has received a grant from HUD to expand the system to provide heat to one hundred-twenty homes.

Of course, geothermal resources are ultimately exhaustible. Accordingly, geothermal-based district heating systems could circulate the hot water back to the wells after it is passed through the heat exchangers and thus recharge the store. How effective this strategy is only experience will tell.

As a final note, cities should realize that they may lie near lower-temperature (under 100 degrees F) geothermal reserves of considerable use in district heating. But such reserves have not yet been measured.

Conclusion: Making Use of District Heat

Cities thinking about district heating must carefully weigh the technical and economic factors discussed here. They must also consider the costs of money, the availability of experienced professionals to run the system, and the number of customers willing to hook up to the system. A full-fledged framework for decision-making is too complicated to construct here, but some of the conditions that will favor or impede district heating development in a given area are outlined below.(82)

Climate and Resources

- Cities in colder climates will be able to use a district heating system more of the year and, thus, recapture development costs sooner. In warmer climates, costs cannot be recouped as fast unless other thermal services (such as district cooling) are provided. However, mechanisms for delivering non-heating services are not yet fully developed, and some district cooling approaches may work against lower-temperature system design.

- Cities close to natural heat/cooling sources (such as geothermal stores or surface water) may be able to put them to use economically. However, comprehensive energy and economic analyses will be needed to confirm their thermal capacity, their compatibility with existing building heating demands, their duration (for finite resources such as geothermal), and the environmental consequences of using them. Finding cheap heat sources may offset high distribution- or building-conversion costs, while reducing costs of distribution and conversion subsystems will entail making some of the tradeoffs discussed above.

Land Use

- Cities need large areas of areally or lineally dense neighborhoods to make use of district heat.

- Cities with large amounts of so-called "greenfield" sites should seriously consider district heating, especially if low-cost heat sources are nearby.

- Land uses should be mapped so it is apparent where sources of waste heat abut areas of high demand or where areas with progressively lower temperature demand levels make energy cascading possible.

Buildings

- Thermally inefficient buildings can usually be retrofit for less than the cost of installing district heat. Even after building retrofits, district heating may be

TABLE ONE HUNDRED TWELVE

WESTERN CITIES OF 100,000⁺ POPULATION
CLOSE TO PROVEN HYDROTHERMAL RESOURCES OVER 150°F

<u>Population Level</u>	<u>Cities</u>
Over 200,000	Albuquerque Long Beach Los Angeles
Circa 100,000	Boise Concord, California Fremont, California Huntington Beach, California Las Vegas Mesa, Arizona Riverside, California Salt Lake City San Bernadino Tacoma

Sources: Allen & Shreve (1980)
SAI (1980)
Struhsacker & Blackett (1981)

suitable in some cases, but systems need to be planned carefully to deliver lower-temperatures economically.

- Buildings with hydronic, forced hot-air or two-way steam distribution systems make much better candidates for hook-up than those using one-way steam or electric resistance heat. Fortunately, relatively few urban buildings are electrically heated.

Energy Supply/Distribution Networks

- Cities with existing district heating systems should consider whether retrofit or expansion is desirable. In many cases, the existing district heating system will need substantial upgrading simply to keep its customers, much less attract new ones. Areas served by existing systems will include large numbers of buildings with compatible distribution systems.

- Buildings using fuel oil and electric boilers (hydronic, air, or steam distribution) will probably find district heat more economically attractive than those using natural gas, at least until natural gas prices are deregulated.

- Cities should also examine existing energy use patterns to identify potential sources of energy supply. Power plant or industrial waste heat could be tapped, as well as cogeneration units in businesses or large residential complexes.

Socio-Economic Considerations

- Some form of public support may be necessary to keep financing costs down. Indeed, the office of Technology Assessment has concluded that under private financing arrangements, conventional district heating is economically risky and marginal in the best of cases.(83)

- Subsidizing a district heating project is a substantial undertaking for cities acting alone. Usually, the sale of revenue bonds is unwise unless a large number of customers is committed to hooking up to the system.(84)

- Customer availability may be limited, especially when existing sources of heat (such as natural gas) cost less. Building conversion costs tend to be high, and will be beyond the pale for owners in marginal financial shape without subsidy.

- District heating projects have often been praised as sources of jobs. But, how many of those jobs would be locally based depends largely on the nature of the local labor pool. Extensive on-site conservation programs may provide more and longer-term jobs for the local populations, though this comparison needs to be elaborated to be sure.

Part Three

Electricity, Fuels, and Industrial Process Heat

Chapter Twelve

Electricity

BACKGROUND

Electricity is a versatile energy source that can heat, cool, light, and run appliances. But on a cost per BTU basis, it is also the most expensive of our conventional energy supplies. Indeed, in twenty-six of twenty-seven representative cities, electricity costs more per BTU than either fuel oil or natural gas. (See Table One-Hundred-Thirteen.) Inherently inefficient to produce, electricity from thermal power plants is likely to remain the most expensive fuel source too.

Fortunately, numerous technologies can be used to improve electrical efficiency on-site, thus offsetting some of the inefficiencies of centralized power stations. For example, an electric heat pump with a coefficient of performance of 2.0 is as fuel efficient with regard to primary energy as a gas furnace. (It can, in other words, deliver about the same number of BTU for an equal BTU input.) The efficiencies of lighting and other appliances are improving. And numerous technologies for producing power on-site are available--advanced cogeneration, fuel cells, and such renewable resource technologies as wind-energy conversion systems and photovoltaics).

City governments need to take an increasing interest in how electricity can be produced or used more efficiently and economically. For one thing, payments for electricity help deplete municipal budgets. (A recent International City Managers Association study indicated that electricity for street lighting was second only to gasoline among most cities' energy purchases.)(1) For another, electricity costs can affect a city's economic development prospects. In many areas, the commercial and industrial sectors consume proportionately more electricity than residences. (See Table One-Hundred-Fourteen.) Cities with large numbers of office buildings or large industrial areas may find that improving electrical efficiency will help to stabilize local consumer prices and job opportunities. In growing areas, improved electrical efficiency can help to shape utility peaks, thus stabilizing electricity prices and helping attract new businesses.

A third factor is that cities must now cushion the impacts of rising electricity costs on ordinary citizens. Although relatively few older cities in the Northeast and Midwest make much use of electric heating, in many cities in the West and South substantial growth in electric heating in new construction is projected. For example, Portland predicts that of 8,000 new single family homes and 32,000 new apartments built between 1975 and 1995, 6,000 (75 percent) and 30,000 (94 percent), respectively, would use electric heat.

Electricity usage for residential cooling is also likely to grow. Although the amount of energy used for cooling is still small in most cities, (See Table One-Hundred-Fifteen) it is increasing as window air-conditioning units or central air conditioning systems are added to more and more new construction. (See Part Two, Chapter Three, Cooling Buildings. Since many cities are served by public utilities with summer peaks, electricity for cooling usually costs more per kilowatt hour than electric heat. (See Part One, Chapter Six, Energy Supply and Distribution Systems.)

Even in cities that expect to see relatively little new residential construction, lighting and appliances consume already relatively large amounts of electricity in homes.

In both Dayton and Boulder, for example, residential lighting and appliance operations account for more than twice the electricity use than residential space- and water-heating do. Philadelphia's non-heating residential electric use is over 70 times that of its electric consumption for home heating. (See Table One-Hundred-Fifteen.)

Finally, cities that own their electric utilities have considerable incentive to reduce on-site electrical consumption and to develop cheaper ways to produce electricity.

Municipal utilities such as Jacksonville's need to decrease their dependence on imported oil, while those like Seattle's need to consider how they can meet increasing demands without building or buying into new generating facilities. End-use electrical conservation or smaller scale electrical production initiatives are particularly needed for municipal utilities that only distribute power generated elsewhere.

City governments can take action. As electricity users, they can purchase more energy efficient products. (Oakland cut its annual street lighting bill by over \$1 million by replacing its less efficient light bulbs.)(3) They can also stimulate the efficient use of electricity in new buildings by developing and enforcing building- and lighting-efficiency standards, by providing incentives or information to developers, and making new subdivision ordinances and zoning provisions reflect energy conservation. Efficiency standards for older buildings could also be employed, though with greater difficulty. As for appliance efficiency, information programs probably represent cities' most promising approach.

Cities can also take steps to encourage the use of on-site renewable energy technologies that produce electricity. Cities in areas with high electric rates and abundant sunshine or wind resources could launch incentive programs to encourage the use of photovoltaic or small wind energy conversion systems.

Opportunities for affecting how electricity is centrally generated and supplied are fewer, but cities that own their public utilities can significantly influence electricity

TABLE ONE HUNDRED THIRTEEN

CURRENT ENERGY COSTS BY FUEL TYPE
(SELECTED CITIES)

<u>City</u>	<u>Natural Gas</u>		<u>Fuel Oil</u>		<u>Electricity</u>	
	<u>¢/Therm</u>	<u>\$/MMBtu</u>	<u>\$/Gallon</u>	<u>\$/MMBtu</u>	<u>¢/Kwh</u>	<u>\$/MMBtu</u>
Boston	.61	6.1	1.278	9.128	.083	24.444
New York City	.74	7.4	1.28	9.143	.127	37.077
Buffalo	.51	5.1	1.291	9.222	.067	19.631
Newark	.74	7.4	1.28	9.143	.127	37.077
Pittsburgh	.41	4.1	n/a	n/a	.063	18.318
Philadelphia	.60	6.0	1.235	8.822	.077	22.631
Baltimore	.53	5.3	1.235	8.822	.068	19.906
Washington, D.C./VA	.57	5.7	1.277	9.122	.068	19.866
Atlanta	.48	4.8	n/a	n/a	.051	14.886
Miami	.55	5.5	n/a	n/a	.075	22.095
Cincinnati/KY	.43	4.3	1.226	8.757	.054	15.758
Cleveland	.41	4.1	n/a	n/a	.082	24.150
Detroit	.50	5.0	1.267	9.050	.068	19.830
Chicago/N.W. IN	.46	4.6	1.236	8.829	.082	24.168
Milwaukee	.55	5.5	1.187	8.479	.055	16.109
Minneapolis/St. Paul	.47	4.7	1.181	8.436	.059	17.294
St. Louis	.49	4.9	1.187	8.479	.056	16.365
Kansas City, MO	.38	3.8	n/a	n/a	.069	20.173
Dallas/Fort Worth	.46	4.6	n/a	n/a	.065	19.043
Houston	.47	4.7	n/a	n/a	.064	18.805
Denver	.45	4.5	n/a	n/a	.065	19.149
Los Angeles	.37	4.1	n/a	n/a	.071	20.760
San Diego	.41	4.1	n/a	n/a	.098	28.584
San Francisco/Oakland	.39	3.9	n/a	n/a	.053	19.433
Portland, OR	.59	5.9	1.170	8.357	.042	12.399
Seattle	.68	6.8	1.269	9.064	.024	6.986
Anchorage	.25	2.5	1.232	8.800	.054	15.723

Source: Bureau of Labor Statistics (1981).

TABLE ONE HUNDRED FOURTEEN

ELECTRICITY'S SHARE OF TOTAL CONSUMPTION - TOTAL USE AND BY SECTOR (SELECTED CITIES)

<u>City</u>	<u>Total Energy Use</u>	<u>% of Total Electricity (BBtu)</u>	<u>Electricity Used in Residential Sector</u>	<u>% of Total Res Use</u>	<u>Elec Used in Commercial Sector</u>	<u>% Total Comm Use</u>	<u>Elec. Used In Industry</u>	<u>% Total Ind. Use</u>
Boulder	12952.0	17.9%	1080.0	21.2%	546.33	35.6	263.25	23.0%
Bridgeport	56820.0	11.8	2271.5	10.6	1875.2	25	2504.5	20.9
Dayton	32863.66	23.0	1876.0	15.4	1680.1	37.9	4014.8	24.7
Dearborn	26582.0	15	989.9	15.5	423.3	40.4	2495.4	20.0
Greenville	4971.45	28.3	558.81	35.0	357.6	56.2	331.2	40.7
Knoxville	79156.3	17.1	7645.0	63.8	3133.4	38.2	2261.9	28.7
Los Angeles	361000.0	15.8	16300.0	18.5	23700.0	42.9	13200.0	29.5
Miami	83613.69	92.5	41324.6	90	30119.73	92.8	4716.77	90
Philadelphia	237000.0	15	10310	11	17272.0	34	20700.9	17
Portland (1971)	204866.66	22.0	16873.0	39.2	9079.0	41.6	22199	28.4
Seattle								

Source: Portland: Energy Conservation Choices for the City of Portland Oregon (1977)

Other Cities: CCEMP Energy Audits (1979)

TABLE ONE HUNDRED FIFTEEN

RESIDENTIAL ELECTRICITY USE
(Selected Cities)

City	Electric Energy For Space Heating		Electric Energy For Water Heating		Cooling		Lighting or Other Electric	
	BBTU	% of Total Res Heating	BBTU	% of Total DHW Heating	BBTU	% of Res Use	BBTU	% Res Use
Boulder	260.0	7.6 %	60.0	6.8%	54.0	1.0 %	614.0	12.0%
Bridgeport	513.65	1.1						
Dayton	560.67	7.0	196.31	8.6	363.2	3.0	1127.5	9.3
Dearborn	19.75	.43	22.0	3.4	55.28	.87	838.87	13.2
Greenville	59.12	6.0	118.35	58.6	116.01	7.3	240.51	15.0
Knoxville	4616.56	59.8	1487.55	87.4	365.0	3.0	1714.0	14.3
Los Angeles					2500.0	.7	5000.0	1.4
Miami	3390.0	56.3	9960.0	80.0	32470.0	45.3	15900	22.2
Philadelphia	140.0	.23		10470 BBTU	36.1% of Non-Heating			
Portland (1971)	4704.03	15.4	4378.78	72.7	-	-	1720.9	4.0

Sources: See Table One Hundred Fourteen

supply decisions. Seattle's municipal utility backed out of plans to support the construction of new thermal power plants and chose instead to implement a broad variety of energy conservation programs.(4) Still, few large cities own their electric utilities,(5) and investor-owned utilities (IOUs) can be regulated only under limited circumstances. In Kansas and Ohio, for instance, municipalities can regulate only IOUs whose service areas are wholly within city limits.(6)

Clearly, most cities will exercise power over utility supply decisions as advocates and petitioners before the state Public Utility Commissions--not as utility owners. Cities can scrutinize utility plans for expanding conventional power production and recommend and support PUC consideration of alternative electrical conservation production programs or technologies.(7) They can also forestall or block utility discrimination against residents who become small power producers under the provisions of Section 210 of the Public Utilities Regulatory and Policy Act (PURPA), which allows owners of small cogeneration or renewable energy electrical systems to sell power to public utilities. (Box One) Most significantly, cities themselves could become power producers by, for example, developing existing hydropower sites or by constructing city-owned wind power systems or cogeneration facilities.

Some recent "supply side" developments may also prompt utilities to welcome city participation in or leadership of electrical conservation programs. Most public utilities are compelled to manage baseload consumption better. Many oil-dependent utilities serving older cities must find substitute fuels or reduce demand. In high-growth areas, utilities are straining to meet increasing demands even as the political and economic costs of new thermal power plants skyrocket.

Most utility conservation programs now in effect either encourage builders (or owners) to cut electricity use in new or existing buildings or they help local governments undertake larger-scale load-reduction efforts. Both Pacific Gas and Electric (PG&E) and the Tennessee Valley Authority (TVA) have programs to encourage builders to use more efficient electrical heating systems and appliances in new homes. For existing houses, Southern California Edison, the New England Electric System, and TVA are experimenting with load-management devices that will increase reliance on off-peak electricity via storage or limit the use of peak electricity. The New England Electric System is experimenting with heat storage in ceramic brick units and Southern California Edison is marketing a Demand Subscription Service that allows a customer to pre-select a maximum level of demand. In a pilot program covering 150 homes, the New England Electric System is also trying out a two-way automatic communication system to regulate peak demands.(8)

Larger-scale conservation programs include PG&E's pilot project to involve city governments in conservation efforts. The utility proposed to make incentive payments to three pilot communities for each one percent of load reduction. All three cut by over 10 percent in 1980. PG&E also helps large users of electricity, mostly businesses and industries, design and implement in-house conservation programs. (See Table One-Hundred-Sixteen.)

A few investor-owned utilities have also shown some interest in developing renewable technologies capable of supplying electricity to the grid. A Southern California Edison study shows that (on a life-cycle basis) wind, solar thermal-electric, hydroelectric, and geothermal systems using 1981 technology are cost-competitive with combustion turbines. Wind and hydropower can compete with coal in utility applications, and both solar thermal-electric and photovoltaic systems are expected to compete economically with combustion turbines and coal by 1981. (See Table One-Hundred-Seventeen) Note that if nuclear plants become more expensive and renewable technologies less expensive (as predicted), renewable-based technologies could become even more appealing.)

Partially as a result of its analysis, Southern California Edison plans to include about 2,000 MW of "renewable" electrical supply--a third of the capacity increases projected for the next decade.(9) The utility recently began operating a 35-MW unit on line and to obtain about 100 MW of power from smaller hydro facilities. SCE is also helping build the first grid-connected solar thermal-electric facility at Barstow.

Also in California, Pacific Gas and Electric, (PG&E), owner of the Geyser Geothermal Plant is reportedly planning to retire about 1,000 MW in the next decade and is considering using renewable energy sources to replace at least part of it. A large (151 MW), new PG&E hydroelectric plant is scheduled for completion by 1983, along with a 50 MW biomass-fueled power-plant by 1982. The utility also plans to install 2.5 MW of wind power capacity as a pilot program. Besides evaluating investments in its own renewable energy installations, the company also plans to purchase power from cogenerators or small producers using renewable energy.

On the other side of the country, the New England Electric System is developing more modest plans to include hydroelectric, wood, and wind power systems within its generating mix.(10) It plans to get 60 MW of capacity from hydro, wood, and wind power by 1996. In addition, it is contracting to purchase power from the developer of a small hydro project in Lawrence, Massachusetts, and it intends to study the feasibility of other hydro and wood-fired plants. Cooperating with Wind Power, Inc., the company is also installing from

BOX ITEM NUMBER ONE

LEGAL DEVELOPMENTS CLOUDING THE FUTURE OF PURPA

The status of the Public Utility Regulatory Policies Act of 1978 (PURPA) is currently unclear owing to two lower court rulings. In Mississippi Power and Light and the State of Mississippi vs. the Federal Energy Regulatory Commission (FERC) et al., a case now before the Supreme Court, the U.S. District Court for the Southern District of Mississippi ruled that Titles I and III and Section 210 of PURPA violated the Tenth Amendment by Federally pre-empting state powers. Section 210 of PURPA requires utilities to interconnect with and buy power from cogenerators and small power producers.

In January of 1982, the U.S. Circuit Court of Appeals for the District of Columbia Circuit held (in American Electric Power Service Corporation et al. vs. FERC) that FERC did not adequately justify its requirement that utilities purchase power from cogenerators and small power producers at "full avoided costs." This court also rejected FERC's decision to allow cogenerators and small power producers to interconnect with utilities without meeting requirements of the Federal Power Act. FERC has asked for a rehearing.

The resolution of these two cases holds the utmost importance for the future implementation of PURPA. In this chapter, the assumption is that PURPA can be implemented roughly as Congress intended and as FERC originally ruled, but city energy officials must pay heed to these court decisions and their implications for utility relations to small power producers.

TABLE ONE HUNDRED SIXTEEN

SELECTED UTILITY ON-SITE CONSERVATION INITIATIVES

<u>Utility</u>	<u>Programs</u>
Pacific Gas & Electric	● Rate incentives for energy-efficient new construction ● Zero-interest loans for weatherization of existing homes in service area. ● Incentive payments to communities for demand control (demonstration)
Southern California Edison	● Street light conversion assistance ● Field tests of heat pump water heaters ● Load management devices installed in demonstration homes.
New England Electric System	● Distribution of high-efficiency light bulbs ● Distribution of guide to energy labelling ● Demonstrational field tests of interactive load management devices ● Demonstration of off-peak heat storage in ceramic tiles ● Partial grant for attic insulation in electrically heated homes.
Arkansas Power & Light	● Encouraging load management of air conditioning
Tennessee Valley Authority	● Rate incentives for energy-efficient new construction ● Load management of water heaters and air conditioners via demand controls ● Low-interest loans for heat pumps.

Source: William Snyder. "Report on Survey of Utility Investments in Conservation and Renewable Energy Resources," (1981)

TABLE ONE HUNDRED SEVENTEEN

SUMMARY OF SOUTHERN CALIFORNIA EDISON STUDY OF CURRENT AND
FUTURE COSTS OF RENEWABLE SOURCES OF ELECTRICITY

Approximate Estimated Life Cycle Costs (1980 cents per Kwh)

	<u>1981 Technology</u>	<u>1990 Technology</u>	<u>Fuel Costs</u>	<u>O & M Costs</u>
Nuclear	8.0	8.0	1.5	1.25
Coal	13.5	13.5	4.5	2.0
Combustion Turbines	15.5	15.5	12.5	.5
Wind	14.0	12.0-10.0	-0-	.5
Solar Photovoltaic	160.0	31.5-14.5	-0-	.5
Solar Thermal	26.0	20.0-16.0	-0-	1.0
Geothermal	20.0	20.0	8	1.5
Fuel Cells	35.5	26.0-15.5	11.5	1.25
Hydro	15.0	15.0	-0-	N.A.

Source: Southern California Edison, "Energy Issues...and Answers,"
Congressional Briefing, July, 1981.

20 to 60 small wind machines in southern New Hampshire that will eventually generate up to 13 million kilowatt hours annually.

In the South, Arkansas Power and Light is actively developing advanced cogeneration technologies.(11) Surveying its service area, the utility has identified 23 potential industrial customers, for whom it is developing a wide range of financing options, including third-party arrangements and the creation of a non-regulated subsidiary. The company's basic approach is to perform a preliminary economic and engineering feasibility study on its own, investing \$5-\$10,000 for each study in the effort. If results are positive, the company will encourage the potential cogenerator to finance jointly the final engineering study.

Also, the company expects potential power production from combined cycle advanced cogeneration to be 1,700 MW--or almost 43 percent of the utility's 1980 summer peak load--and to be cost effective by 1985.(12)

This chapter provides city officials with some of the technical information on how to conserve electricity (particularly in lighting and appliances) and to develop new sources of production (cogeneration and renewable resource use). Ways to conserve or substitute for electrical energy used for heating and cooling have already been discussed in Part Two.

ON-SITE CONSERVATION OPTIONS

Technical Approaches

Most studies have found that electricity is the most elastic (price sensitive) of energy demands.(13) Electricity consumption can be reduced easily by using fewer appliances, using appliances less often, or turning off appliances and lights not in use. Consumers can also cut their electrical bills by trying to use peak-load power. (See Part One, Chapter Six, Energy Supply and Distribution.)

By conducting information programs, cities can encourage consumers to achieve these savings. But consumer-oriented information programs need to be supplemented by equipment and system-related changes--the subject of this discussion.

Energy Efficient Appliances

From an energy-efficiency standpoint, appliances can be compared either in terms of how much energy each needs to supply its rated output or in terms of the average amount of electricity (kilowatt hours) each will use per year under normal operating conditions.

Like air conditioning systems, a new generation of light fixtures and appliances is becoming more efficient. (See Part Two, Chapter Three, Cooling Buildings.) For example, new high-efficiency, long-lived fluorescent bulbs for indoor use and high-pressure sodium outdoor lamps can deliver many times the light output (lumens) per electrical (watt) input of incandescent lamps. (See Table One-Hundred-Eighteen.) Similarly, the most efficient frost-free refrigerators available in 1980 used about 400 kilowatt hours per year less than models sold in 1972.(14) (See Table One-Hundred-Nineteen.)

Making any single appliance more efficient may produce relatively small savings. But household energy consumption can be greatly affected by cumulative appliance efficiency gains. In the mid-1970s, an average household used some 9,000 kilowatt hours annually, assuming no electric heating or cooling. Substituting new, top-of-the-line, appliances could reduce that figure by one-third or more.

In larger commercial or institutional buildings where electrical use is often close to half of total energy consumption, efficiency-related savings can be greater still. In many buildings, simply using more efficient lamps--in particular, replacing large numbers of lower wattage lamps with fewer high wattage and higher efficiency lamps of the same type--can save up to 25 percent of lighting electricity usage.(15) Seattle calculated that using more efficient lamps, relamping, could cut service electricity use by up to 15 percent in four prototypical commercial buildings.

Industrial electricity conservation also starts with the use of more efficient appliances. For example, the Solar Energy Research Institute calculated that improving motor efficiency could boost industrial electrical efficiency (electricity use per unit product output) by five percent.(17) A team studying industrial electrical use in the United Kingdom reached even more optimistic conclusions, suggesting that fully half of the electricity used in industry could be saved by downsizing motors, improving maintenance, using better controls, and the like.(18)

Planning and Managing Electrical Systems Better

The other side of increasing the efficiency of lighting and appliances is planning and managing building electrical systems better. If more electricity is provided than is needed, even energy-conscious building occupants can do little to conserve once the system is installed.

A "classic" example of electrical overdesign is the typical lighting system found in many larger residential or commercial buildings. Seldom is this system integrated with

TABLE ONE HUNDRED EIGHTEEN

COMPARATIVE EFFICIENCIES/APPLICATIONS OF LAMPS

<u>Lamp Type</u>	<u>Available Wattages</u>	<u>Efficiencies (lumens/Watt)</u>	<u>Typical Applications</u>
Incandescent	6 - 1500	15 - 25	Residential, commercial spotlighting
Flourescent	4 - 219	55 - 92	Residential, commercial, industrial interiors
Mercury-Vapor	40 - 3000	20 - 63	Outdoors
Metal Halide	150 - 1500	80 -100	Commercial interiors, exteriors
High pressure sodium	100 - 1000	100 -130	Outdoors, street- lighting

Source: Milton Meckler, Energy Conservation in Builders and Industrial Plants (1981)

TABLE ONE HUNDRED NINETEEN

PROJECTED IMPROVEMENTS IN APPLIANCE EFFICIENCIES

<u>Appliance</u>	<u>Electricity Consumption 1980 Stock (kWh/yr)</u>	<u>Electricity Consumption 1980 New (kWh/yr)</u>	<u>Electricity Consumption 1985 - 2000 New (kWh/yr)</u>
Freezer	1285	1285	1000-500 (19)
Refrigerator	1700	1700	750-500 (1900-2000)
Electric Ranges	970	900	600-100 (1991-2000)
Televisions	350	250	100 (2000)
Dishwashers	250	250	150 (1990)
Room Air Conditioners	1440	1170	936-720 (1990-2000)

Source: A New Prosperity (1981)

daylighting techniques. Seldom are illuminations levels as low as needs would allow. (The Portland study noted that the "Illuminating Engineering Society (IES) lighting standards have tripled since the 1950s" but "researchers say they could be cut in half without impairing visual acuity.") (19) Seldom are lighting systems geared to provide more light for task areas, relatively less for remaining areas.

Lighting system overdesign can be combatted. In new buildings, artificial lighting demand can be cut by making prudent use of daylighting techniques. (A study of one energy-conserving Federal office building in Manchester, N.H., indicated that "daylit" areas were the best lit in the building.) (20) The daylit areas could either be used for work needing more light or artificial lighting levels in those areas could be reduced. Either way, the result would be light as less cost.

Since the extensive use of daylighting also affects heating and cooling loads, daylighting features need to be evaluated in terms of their impacts on total building energy use. (See Part Two, Chapters Nine and Ten.) For example, using many north-facing windows for daylighting purposes could add to heating loads in a cold climate. In most cases, though, a balance can be struck between these mutually offsetting factors. While design options are much more limited in existing buildings, internal office operations can in many cases be rearranged to make better use of available daylighting. (21)

Homes, offices, and commercial buildings can be delamped without loss of utility or comfort. Seattle's Energy Ltd. study indicated that delamping could in some cases double the electrical energy savings obtained by switching to more efficient light bulbs. (See Table One-Hundred-Twenty). The Portland study suggested that reducing lighting levels in non-work areas could cut wattage use per square foot by one third in large office buildings. (22) The California Energy Commission sets 1.5 watts/square feet as the illumination level in its Lighting Standards for New Buildings--less than one third of the norm in comparable buildings. (23)

The simplest way to delamp is to remove or disconnect fixtures. (The risk here is uneven light distribution.) An alternative is to replace higher wattage bulbs or tubes with lower wattage bulbs or tubes that cut light output along with energy output. Still another is adopting such new devices as dummy tubes (which replace one lamp in a two-lamp fluorescent fixture) and light-polarizing acrylic panels (which improve the quality and distribution of reduced lighting levels). (24)

All of these delamping strategies, of course, need to be evaluated in terms of their impacts on total building energy (lighting, heating, and cooling) demand. (See Part Two, Chapter Three, Cooling Buildings.)

Electrical System Management

Even a well-designed electrical system using efficient lighting fixtures and appliances can achieve its potential savings only if it is managed and controlled properly. In smaller residences, businesses, or industries, simple, accessible controls and occupant education can help ensure better energy management. For example, switches installed in small areas of office buildings can allow an employee to turn the lights out when they are not needed. Electrical machines that shut off automatically can also save energy. Some industrial machines can be designed so that they will not run unless a worker is present. (25)

Larger buildings or complexes can make profitable use of more centralized control systems, some of which involve computers. Many of the heating system control strategies discussed in Part Two, Chapter Nine, can be used to improve electrical system efficiencies. Area-wide lighting levels can, for instance, be controlled automatically either by timers or by light-sensitive cells (photocells). More sophisticated electrical control systems can monitor a building's overall electrical consumption to protect owners or occupants from high electricity costs or power outages. Computer-operated load-shedding programs can even predict when peak demands are imminent and reduce or shift consumption to shave peaks and save money. (26)

Economics

Replacing a relatively new appliance with a more energy-efficient model may not make sense until the appliance begins to wear out. Yet, if the appliance is inefficient and local electricity costs high, replacement of even late-model appliances may be economically justified. For example, replacing an inefficient refrigerator (205 yearly Kwh consumption) with a more efficient model (90 yearly Kwh) costing \$600 is an investment that will pay for itself in six years where electricity rates are over ten cents per kilowatt hour. (27) When the refrigerator is due to be replaced any way, additional costs (if any) for energy efficiency are nearly always worth it.

Larger equipment purchases or systems cost more, but save more. Oakland's new street lighting system will pay back its capital costs (\$4 million) in less than three years. An apartment building owner in Santa Monica, California, saves at least \$700 annually in lighting costs as a result of a \$1,500-investment in more efficient lamps and better design. (28)

City Applications

TABLE ONE HUNDRED TWENTY

LIGHTING ENERGY SAVINGS FROM DELAMPING VS. THE USE OF MORE EFFICIENT
BULBS IN PROTOTYPICAL COMMERCIAL BUILDINGS

<u>Building Type</u>	<u>Service Electrical Consumption (Base Case) (MMBtu)</u>	<u>Energy Saved by More Efficient Bulbs (MMBtu/Yr)</u>	<u>Energy Saved by Delamping (MMBtu/Yr)</u>
Small office	331.0	38.8	78.9
Mixed Office/Retail	318.0	41.6	64.9
Warehouse	62.29	9.01	12.6
Supermarket	4138.6	263.7	589.4

Source: City of Seattle, Energy Ltd. (1980)

Basic electrical energy-conservation measures are possible in virtually every type of city building. In most smaller buildings, the wisest first step is replacing less-efficient appliances with more efficient ones. In larger buildings, the most savings will accrue from improved system designs and controls. In some cases, system design improvements will be possible only when rewiring is planned anyway. In all, the difficulty and costs of each proposed alteration must be carefully weighed against the outcome.

Institutional Constraints

Electricity conservation directly affects a public utility's financial situation. A utility straining to meet capacity or to reduce oil consumption may welcome local government's efforts to reduce electricity consumption. But those with excess capacity or relatively stable primary fuel sources may fear that conservation efforts will cut revenues without shaving peaks. Where utilities are uncooperative, the city government has numerous strategies at its disposal. (See Part One, Chapter Six.) Where utilities are actively pursuing conservation strategies, city officials should try to ensure that those strategies meet the city's needs and fit in with the city's plans. Where local utilities are as yet uninvolved, the city should encourage constructive action, perhaps by pointing to some of the more notable utility conservation programs already in place.

Nonetheless, some utility analysts have pointed out that Federal and state subsidies, tax policies, and regulatory practices encourage utilities to build power plants at the expense of on-site conservation and smaller-scale supply technologies.(29) For example, utilities can receive tax benefits for large-scale construction programs, but not for conservation programs. Subsidies for conventional power plants are, by one count, twelve times those available for conservation.(30) Some regulatory provisions also penalize utilities in rate-setting if sales fall below a certain level. Finally, relatively few PUCs help utilities to consider alternative conservation and small-scale supply options. Cities can address these larger-scale problems by lobbying their state and Federal representatives to make constructive changes.

Socio-Economic Considerations

Appliance, lighting, and other electrical users are usually the first energy purchases lower-income persons eliminate. But what electricity they do purchase is usually used inefficiently because their appliances are so old,(31) and many residential electrical uses and costs are beyond the individual consumer's direct control. For example, even in apartment buildings with individual metering, electricity costs for such communal uses as hall lighting and elevators will be apportioned among tenants.

How best to reduce the electric bills of low-income tenants depends on the nature of the housing stock. Where most low-income people own their homes, or where much of the rental stock is in single-family houses, a city government could develop programs to help replace inefficient appliances. Alone or in a public-private partnership, it could purchase newer appliances in bulk and sell them at cost or at subsidized below-cost rates to low-income persons. In a city with large numbers of multifamily buildings, electrical conservation programs could be targetted at landlords and emphasize better system design or controls. For example, the city could offer (or encourage the local utility to offer) a basic, low-cost audit of multifamily buildings that would include an electrical-system audit. At a minimum, it could simply supply building owners with information on cost-effective electrical conservation strategies.

ON-SITE POWER PRODUCTION

Opportunities for individual home or building owners to produce their own electricity are expanding as technical advances make on-site power production feasible on a smaller scale, as the cost of electricity purchased from the grid makes small electrical facilities more economical, and as new Federal and state laws encourage the development of small power facilities by requiring regulated electric utilities to purchase power from them.(32)

To the extent that individuals seize these opportunities, electrical power production, distribution, and sales will change--in some cases radically. For that reason on-site electrical production might strike cities a limited option for most urban areas where customers are already served by existing utility grids. On the other hand, technical and economic advances in small power-production conjure up for many visions of complete independence from the utility grid and cheaper electricity. Neither of these accurately represents the potentials and limitations of small power production.

This section provides a general overview of small power production technologies--on-site cogeneration and renewable sources of electricity--and a preliminary assessment of their potential contribution in cities.

ON-SITE COGENERATION

Many industries, businesses, and apartment complexes already produce their own power by using on-site heat engines to run electric generators. They can then recapture the excess heat energy and use it to heat space or water. Now, with the development of smaller cogeneration units, combined power and heat production may be possible in some individual homes too.

Technical Approaches/Issues

As Chapters Nine and Eleven of Part Two make clear, commercial and industrial cogeneration units can make use of topping or bottoming cogeneration cycles and a number of different fuel sources. In the topping cycle, a steam turbine or a fuel-fired heat engine runs an electric generator and the waste heat is used for water for space heating. The bottoming cycle uses waste heat from an industrial process to run a turbine or heat engine that, in turn, operates a generator. Oil, gas, coal, wood, or municipal wastes can be used as fuel sources for either cycle assuming the proper turbine is used. Smaller topping-cycle cogeneration units using gas turbines, diesels, or advanced heat engines can deliver heat and electricity to single businesses and residences or clusters of each.

Economics

The economic appeal of on-site cogeneration technologies is based on two related assumptions. First, as it was early in the century, it may now be cheaper to use lower-quality heat energy to generate electricity on-site than to purchase large quantities of electric energy from the grid. Second, it is cheaper still if on-site process heat can be used to generate power (bottoming cycle) or if the excess heat from power-production can be put to productive use (topping cycle) especially if excess power can be sold to the utility at favorable rates.

Assessing the economics of a typical cogeneration system is difficult because few typical systems exist. Cycles, output levels, and power-to-heat ratios vary. In addition, sometimes end-use conservation options are economically preferable to cogeneration. Typical (unfinanced) capital costs for different cogeneration systems are summarized in Table One-Hundred-Twenty-One. Then too, the economics of a particular cogeneration system will depend not only on financing terms but also on such technical factors as the differences between the price of the cogeneration fuel source and the price of electricity, the power-to-heat ratio of the cogeneration facility, and the nature of other energy conservation measures employed at the site. For example, a cogeneration system that uses natural gas to replace high-priced electricity will pay off sooner than one in which higher priced oil offsets lower cost electricity. Where both heating fuel and electricity prices are high, topping cycle cogeneration can make economic sense if the applications's power-to-heat ratio is high. Bottoming-cycle applications can pay off even where electrical costs are low if waste heat is available in quantity. Finally, a favorable utility sell-back rate may make cogeneration systems profitable investments no matter how much competing fuels cost. The Arizona State Corporation Commission recently ordered public utilities to buy back on-site produced power at time-differentiated rates higher than the utilities' average rates. A cogeneration facility could, therefore, obtain a greater price for each kilowatt hour generated by selling all power to the utility rather than by using some of it and selling the rest.

Like all energy-conservation purchases, cogeneration systems should not be evaluated apart from both complementary and competitive conservation strategies. For example, since with many cogeneration technologies, electrical output decreases as heat output increases, reducing process heat demands in a topping-cycle application can make it possible to generate increased amounts of electricity with the same fuel input. But either reducing temperature levels or the amount of waste heat produced may be more economical than opting for bottoming-cycle cogeneration. Which combination of end-use conservation measures and cogeneration techniques is best will vary.

As noted, few studies of the economics of generic cogeneration systems exists. However, case studies summarized in Table One-Hundred-Twenty-Five do reveal the kinds of situations in which cogeneration systems are economically viable. For example, two of the plants (paper/pulp and textile) use relatively low-cost coal as a cogeneration fuel. Although the chemical plant uses oil for the majority (61 percent) of its cogeneration input fuel, that oil is replacing very high-priced electricity. The importance of system design features is illustrated by the food processing and oil refining cases. The food processing plant uses oil and gas as cogeneration fuel sources to meet all its relatively small electrical demand. Finally, the oil-refining plant uses oil to cogenerate but achieves an acceptable rate of return because the cogeneration unit has a high utilization factor (93 percent).

City Applications

TABLE ONE HUNDRED TWENTY-ONE

TYPICAL CAPITAL COSTS FOR VARIOUS COGENERATION TECHNOLOGIES

<u>Technology</u>	<u>Capital Costs (\$/kW)</u>
Gas turbine (topping cycle-5mw)	\$ 500 ¹
Diesel engine (topping cycle-5mw)	\$ 550 ¹
Steam turbine (oil fired) (topping cycle - 5 mw)	\$ 875 ¹
Steam-turbine coal-fired (topping cycle - 5mw)	\$1250 ¹
Steam turbines coal-fired (topping cycle - 27.5 mw)	\$ 319 ²
Oil and gas-fired turbines (topping cycle-16.6 mw)	\$ 322 ²
Gas and oil-fired turbines (topping-cycle - 13mw)	\$ 445 ²
Coal-fired steam turbines (topping cycle - 29 mw)	\$ 486 ²
Oil-fired steam turbines (topping cycle - 12mw)	\$ 416 ²
Steam and organic bottoming cycles up to 0.5 mw	\$ 400 - \$ 700 ³
0.5 to 10.0 mw	\$ 700 - \$1000

- Sources:
1. Eric Bazques, "Brief Overview of Cogeneration: Technological and Economic factors," September 25, 1980.
 2. H. M. Bushby "Industrial Cogeneration: Five Case Studies - Synthesis And Observations." (Draft) (1981)
 3. Resource Planning Associates, (1979)

TABLE ONE HUNDRED TWENTY-TWO

SUMMARY OF ECONOMIC ANALYSIS OF FIVE COGENERATION CASE STUDIES

Industry Type	Fuel Sources	Electrical demand (peak capacity)	Process Steam demand (lbs/hr)	Cogeneration Capital Costs (\$/kW) (1980 \$)	Fuel Used In Cogeneration Equipment	Capacity Factor	% Elec demand from Cogeneration	After Tax IRR (%)
Paper/pulp	● Black liquor (coal by-product) ● Electricity	26,000 kW	60,000	\$319	coal	51%	65%	39.4%
Chemical	● Residual oil ● Natural Gas ● Electricity	14,200 kW	48,000	\$322	oil and gas	48%	51%	38.0
Food processing	● Residual oil ● Natural Gas ● Electricity	11,000 - 13,000 kW	35,000	\$445	gas and oil	58%	98%	33.9
Textile	● Coal ● Electricity	35,000 kW	70,000	\$486	coal	57%	55%	29.3
Oil refining	● Electricity ● Natural Gas ● Fuel oil ● Fuel byproducts	27,000 kW	33,000	\$416	oil	93%	54%	29.0

Source: Bushby (1981)

Any large user of heat and power is a good candidate for an on-site cogeneration system. Along with industry, commercial facilities with high thermal loads (such as laundries, hotels, schools, or hospitals) should have their cogeneration potential investigated. So should larger residential complexes located where prices for both heat and power are high. (See Table One Hundred Twenty-Three.)

Assuming high prices for competing fuels and/or good sell back rates, a number of more specific factors will help determine whether a facility is particularly suitable for cogeneration. One key is consistently high year-round demand for both thermal energy and electricity. High year-round heating and electrical demands are most common in industrial settings, but larger residential, commercial, or institutional buildings or complexes also generally have high demands for electricity throughout the year for lighting and equipment-operation. In such facilities, heat could be used in summer to provide domestic hot water or, perhaps, to run an absorption cooling system.

A high year-round electrical demand may not be necessary to economic success if a favorable sell-back rate were available when the facility's own electric demand was low. For example, a college served by a summer-peaking utility would probably find it profitable to cogenerate electricity in the summer even if most of the buildings were closed. The only costs would be those for equipment for waste heat disposal and the loss of useful thermal energy in summer.

Also important--primarily in equipment choice--is how heating and electrical demands relate to one another over the year. Since most cogeneration units that can "track" fluctuating heating and electrical demands are more expensive than those delivering a constant thermal/electric output, a facility whose proportional demands for heat and electricity are relatively constant may find cogeneration more economically attractive than one that requires much more heat than electricity in one season, much less in another.

Finally, environmental considerations may prevent some urban facilities from installing new cogeneration equipment if the systems would violate air quality standards. (See Institutional Constraints, below.) Especially controversial from an environmental perspective are new cogenerating facilities using diesel fuel, oil, coal or waste for fuel. Factors helping or hindering the use of on-site cogenerators are summarized in Table One-Hundred-Twenty-Four.

Institutional Constraints

Two major types of institutional concerns surround the use of on-site cogeneration facilities. The first is regulating development and operation of such facilities. The second is relating cogenerating facilities to the problems and needs of public utilities. While the Public Utility Regulatory Policies Act (PURPA) of 1978 addresses both concerns, it does not remove all institutional barriers and it leaves numerous implementation decisions with state public utility commissions.

Even before the passage of PURPA, facilities that used all of their cogenerated electricity on-site were not subject to Federal or state regulation as public utilities. But, as point sources of emissions, they were subject to air-quality regulation.

As noted, the impacts of state and Federal clean air standards on cogeneration facilities are both complex and site specific. Owners of new cogeneration facilities must show they have complied with clean air requirements. When they violate these standards, they must either offset emissions from other sources⁽³⁵⁾ or clean up existing sources so that no net increase in emissions results.⁽³⁶⁾ Finally, even if no significant pollution control investments prove necessary, most cogeneration facilities have to go through a long licensing process. As one study reports:

"New York State, for example, requires a construction permit and operating certificate for any owner of a emissions source with a net input greater than one million BTUs per hour if residual oil, coal, and other solid fuels are used. The state may require the applicant to conduct testing, data analysis, and preparation of a report at his own expense...If a cogeneration plant is planned for a small industry or building, the time and cost uncertainties of site-specific review may constitute a de facto prohibition in themselves."⁽³⁷⁾

Public utilities' reactions to cogeneration facilities are also critical to cogeneration's economic success or failure since most potential cogenerating facilities are large electricity users. As noted, a utility's reaction will be determined largely by how much capacity it has and needs and by which fuel sources it uses. Utilities with growing demand will probably support or encourage the development of cogeneration facilities to offset the need for new power plants. For example, Pacific Gas and

TABLE ONE HUNDRED TWENTY-THREE

SELECTED COMMERCIAL/RESIDENTIAL COGENERATION FACILITIES IN NEW YORK CITY

<u>Facility</u>	<u>Description</u>	<u>Total Capacity (kW)</u>	<u>Peak Demand (kW)</u>	<u>Excess Capacity (kW)</u>	<u>Fuel Types</u>	<u>Grid Connected</u>
Rosedale Village	• 5800 Units • Shopping Center	18,000	9,800	8,200	• oil • natural gas	No
Starrett City	• 5000 units and stores	18,000	11,200	6,800	• oil • natural gas	No
Warbasse Houses	• 2585 units	12,500	4,200	8,300	• oil • natural gas	No
Kings Plaza	• Shopping center	11,000	7,500	3,500	• oil • natural gas	No
Big Six Towers	• 1000 units and stores	4,000	2,400	1,600	• oil • natural gas	No

Source: Richard Stone, "Large Residential/Commercial Applications for Cogeneration," (1980)

TABLE ONE HUNDRED TWENTY-FOUR

FACTORS AFFECTING THE ECONOMICS OF COGENERATION

HELPFUL

- High purchased electric rates
- Available low-cost cogeneration fuel
- High year round demands for heat and power
- Stable power/heat demand ratio
- Favorable sell-back rate and no penalty for interconnection
- No violation of new source review requirements under Clean Air Act

HARMFUL

- Low purchased electric rates
- Available cogeneration fuels are high in cost
- Heat and power demands seasonal
- Power/heat demand ratio fluctuates
- Low sell-back rates and/or back-up connection rate penalty
- New source review violation-offsets needed or cleanup of existing sources.

Electric recently invited 12,000 potential industrial suppliers of cogenerated electricity to submit proposals to deliver firm amounts of electricity to the company's grid. It also plans to purchase electricity from a plant fueled by nut shells.(38) Arkansas Power and Light is marketing advanced combined-cycle cogeneration technologies to large industrial users on a cost-sharing basis.(39)

At the other end of the spectrum, utilities that use expensive primary fuels or have excess capacity may react adversely. Consolidated Edison in New York, for example, has continually attempted to discourage large customers from using on-site cogeneration, arguing that other rate-payers would be harmed if the utility's load factor were reduced.(40)

Utilities affect the economics of cogeneration systems through the rates they charge for backup power and by their willingness to purchase excess power from cogeneration systems. PURPA 210 both prevents local utilities from charging cogenerators or other small power-producers "discriminatory" rates (rates different from those charged to other customers in the same class) and requires utilities to buy back excess power at avoided energy and/or avoided capacity costs.(41) However, some utilities argue that a customer's reliance on cogeneration puts him in a different class from non-cogenerating customers. Moreover, utilities may often be able to keep the avoided costs (as determined by state PUCs) relatively low. Even if PURPA and related regulations stand, backup and sell-back rates have yet to be set in most states.(42) (See Box One, pp. xx-xx.) Cities who wish to encourage the use of cogeneration facilities within their boundaries would thus do well to follow the state PUCs implementation of PURPA or similar state legislation.

Socio-Economic Considerations

Cogeneration facilities serving low-income areas could reduce heating and electricity costs for poor people. For example, larger buildings housing lower-income tenants could use on-site cogeneration units fired by fossil fuels or even urban wastes.(43) Lower-income neighborhoods could be served by a community heating system using cogenerated or industrial waste heat. However, the capital costs of such systems would have to be heavily subsidized, and no systems should be purchased until the economics and the technical feasibility relative to that of alternative heating and electrical conservation strategies have been determined. (See Part Two.)

ELECTRICITY FROM ON-SITE RENEWABLE ENERGY TECHNOLOGIES

Electricity can be produced in various ways. In most power plants, the generating system consists of an immovable unit (the stator) that contains large numbers of coils that set up a magnetic field through which a moving unit (the rotor) passes. Moving the rotor within the stator converts mechanical energy into electricity. The mechanical energy is produced via steam turbines or heat engines. (In a steam turbine, the steam produced in a boiler is used to rotate the turbines's moving parts; in a heat engine, the combustion of input fuel causes movement.)

Electricity can also be produced by initiating physical or chemical reactions in certain solids, liquids, or gasses that are good conductors of electrical charges. For example, fuel cells can produce electricity through a controlled chemical reaction between hydrogen and oxygen. Solid state "semi-conductors" can produce electricity when heat or light is applied to conductive solids. A process called magneto-hydro dynamics (MHD) induces a current when very high temperature exhaust gasses from coal combustion are passed through a magnetic field.

Renewable energy technologies capable of producing electricity are of two main types. In the first, a renewable energy source is used instead of fossil fuel to move the rotor in a conventional generating arrangement. Such renewable resources as wind and water can move the rotor or renewable energy can supply steam or heat to turbines or heat engines that do the job. In either case, conventional electric generators (stators and rotors) are used to produce power. The second broad type of renewable electric technologies, photovoltaics, has no turbine/engine-generator configuration. Instead, it converts sunlight directly into electrical energy when light strikes solid state solar cells.

Renewable electric technologies are available in different sizes or scales. The final section of this chapter discusses larger-scale applications usable in a centralized grid. This section covers those technologies that could be used on-site in individual buildings--small wind energy conversion systems, solar thermal-electric applications, and photovoltaics.

SMALL WIND ENERGY CONVERSION SYSTEMS TECHNICAL APPROACHES/ISSUES

Wind System Description

The kinetic energy contained in winds can be extracted directly as mechanical energy or converted to electricity. For hundreds of years, slow-turning, multi-blade windmills that generated high torque (force) at relatively low wind speeds has been used to pump water, process grain, or cut lumber. More recent uses of wind energy including heating water through friction, though the most common current application is electricity generation.

The size of a wind energy conversion system is indicated by its "rated output," the number of kilowatts (KW) it can generate at a given wind speed. Small wind systems are usually defined as those with rated outputs of less than 100 KW, though a number of wind systems with rated outputs of two KW or less are available. Since one family's electrical demand equals five to seven KW or less, some wind systems could serve whole neighborhoods or communities.

Wind-electric systems use turbines or rotors mounted on a tower to extract kinetic energy from the wind. The mechanical movement of the rotors is transferred to a gearbox that enhances rotational speed enough to run a generator (to produce direct current-DC-electricity) or an alternator (to produce alternating current-AC). If direct current is supplied but alternating current is needed (as it is for most household appliances), the system must also include a synchronous inverter to convert DC to AC and make the wind system's electricity complement that of utility-generated power. If the system is not connected to a utility grid, batteries or some other means of storing electricity for use in calm periods is needed.

The various turbine and rotor designs available can be divided into two general categories. Horizontal axis systems use turbines resembling airplane propellers. These systems come in upwind and downwind varieties, depending on the position of the turbine blades relative to the mounting tower. Vertical axis systems have blades configured to resemble an egg-beater. Unlike a horizontal axis system, these systems can use winds from any direction without reorienting the blades. They also cost less per unit of output, and they are simpler, lighter weight, and easier to maintain.(45) Vertical axis turbines have yet to match the efficiencies of horizontal wind machines, however, and the rotors on most vertical axis systems require some external energy source to begin turning at low wind speeds.(46)

Both performance and safety dictate that wind systems be carefully matched with sites. Wind generators cannot produce power until wind speeds exceed seven to ten miles per hour. The minimum wind speed at which the system will work varies with the design, as does the "rated" wind speed or the velocity at which maximum power output (in KW) is

achieved. Similarly, the set speed beyond which systems shut down to prevent blade or generator damage varies with the design.

As noted in Part One, Chapter Three, both the average wind speed and the wind speed distribution at a given site help determine a wind system's energy output. The amount of energy contained in a "given wind" is proportional to the cube of its speed. (Thus, doubling wind speed increases the energy available in the wind by a factor of eight.)

Wind speed distribution is also critically important to system efficiency. Take the given average annual wind speed: daily averages may fall within a relatively narrow range or fluctuate from weak to very powerful winds. The amount of energy available in each case is quite different, and so is the ideal technology. If the average annual wind speed is composed of steady, moderate winds a system with a low-rated output, a low minimum speed, and little storage is desirable. But, if winds are highly variable, the minimum speed is less important but a comparatively high rated output and relatively greater storage are needed. (Alternatively, a backup system could be used when reduced wind activity is low.)

Fortunately, few sites experience such extremes in wind speed distribution. In most sites, the variability of winds is similar to the so-called Rayleigh distribution.(47) (Also see Part One, Chapter Three, The Natural Context, and Appendix I.)

System Efficiencies

The efficiency of a typical wind energy conversion system can be measured in terms of the amount of energy it extracts from a given wind as compared to the amount available. Most experts agree that wind systems have a maximum theoretical efficiency of 59.3 percent. Actual efficiencies, however, will always be lower. Friction in hub bearings and other factors keep high-speed horizontal axis systems from extracting more than about 40 percent of the wind's energy at the rotor. From that point on, there are additional losses at each set of gears and bearings and at the generator and control device. More losses occur at rotor-to-shaft, shaft-to-gearbox, and gearbox-to-generator connections and converting from DC to AC involves losses. Thus, current system efficiencies of 20 percent to 25 percent are the norm,(48) a percentage that could rise if systems featured equipment designed especially for wind energy conversion as few now do. (49)

Improvements unrelated to conversion efficiency could also improve the cost-effectiveness of wind energy conversion systems. For example, most mounting towers now in use are made of steel lattice material, which is expensive, heavy, and stiff. When more flexible, cost-effective cylindrical steel towers are available--soon, by all accounts--wind energy conversion systems will appear more economically attractive.

Improved methods of storage should also enhance the cost-effectiveness of both large and small scale systems though on-site storage is unlikely in cities. For example, larger systems could make use of pumped water or compressed air to store wind-generated electricity in off-peak hours and release it during demand peaks. In smaller systems, flywheels using strong, lightweight materials could be used.(50)

Significant breakthroughs are also likely in weight-reduction. In early models of larger systems, for example, most blades were made of steel. Experimentation now under way with both wood and fiberglass blades could help reduce noise, weight, TV interference problems, and costs. (See Table One-Hundred Twenty-Five.)

Potential Technical Problems

Few of the growing number of small wind systems being sold and installed have been operating long. Thus, technical concerns about durability and reliability over time are largely conjectural. Still, minimizing the number of times a given system must start-up and shut-down obviously requires attention since turning a system on and off is a major source of stress over a system's projected thirty-year life. System durability can also be enhanced if the system is sited far from sources of turbulence--natural or built obstructions. (Such stress problems are significantly more troublesome with larger systems since turbulence-induced stress grows as blade diameter increases.) Finally, systems must be grounded to protect them and the people around them from lightning damage.

Economics

On all on-site renewable electricity technologies, small wind energy conversion systems (SWECS) are probably the most economical now. Economy does tend to be greater with larger systems rated over 40 KW, but smaller systems can now or soon compete with the electricity grid on a life-cycle (25-30 years) cost basis where wind resources are abundant.

The costs of electricity from small wind energy conversion systems fall into two general categories: initial or capital costs for equipment, installation and financing, and operational costs for maintenance.

Since most SWECS now in use have a rated output of less than 15 KW, capital costs for the smaller machines are reasonably known. (See Tables One-Hundred Twenty-Six and

TABLE ONE HUNDRED TWENTY-FIVE

IMPROVEMENT STRATEGIES FOR NEXT GENERATION OF
PROTYPICAL SMALL AND ENERGY CONVERSION SYSTEMS

<u>System/Capacity</u>	<u>Improvement Strategy</u>
<u>North Wind</u> - 2kW	Reduced materials costs Improved performance
<u>Enertech</u> - 2kW	Reduced materials costs Improved performance
<u>UTRC</u> - 8kW	Reduced materials costs Weight reduction Improved performance
<u>Windworks</u> - 8.5kW	Reduced materials costs Design simplification
<u>Grunman</u> - 11kW	Reduced materials costs Weight reduction Improved performance
<u>Kaman</u> - 40kW	Reduced materials costs Weight reduction
<u>McDonnell</u> - 40kW	Reduced materials costs Weight reduction

Source: Rocky Flats Wind Systems Program, Small Wind Systems
Technology Assessment (1980)

One-Hundred-Twenty-Seven.) As always, however, financing charges will affect the level of "paid out" capital costs substantially. Both the U.S. Department of Energy and wind systems manufacturers are working to reduce the capital costs of turbines by some 25 percent and the costs of towers by 10 to 15 percent.(51) Installation costs are also expected to fall significantly as production volume increases. Yet, these are predictions that will have to be verified by experience, and declining Federal support for solar energy research and development could delay cost breakthroughs for all solar technologies.

Until experience proves otherwise, maintenance costs for small wind systems are assumed to be relatively low. For example, the systems listed in Table One Hundred Twenty-Seven are assumed to have annual maintenance costs ranging from 0.6 percent to 3.0 percent of capital costs.

Besides capital, financing, and operational costs, the economics of SWECS is also determined by electric output, current and future electricity prices in the service area, and the sell-back rate available from the local utility. Of course, the best circumstances are abundant wind resources, high competing electricity prices, and favorable sell back rates.

Few analyses of the life-cycle (or long-term) economics of small wind systems have been conducted. (See Table One Hundred Twenty-Eight.) While it is impossible to draw any general conclusions from those available they do highlight the influence of certain factors on the economic feasibility of small wind systems. The Minnesota results, for example, indicate that even without guaranteed sell-back and a Federal renewable energy tax credit, in areas with good wind resources, wind systems can deliver electricity at a cost that is closely competitive with conventional electricity prices over the systems' twenty-five year useful life. With tax credits, current electricity prices can be matched, pending the availability of favorable financing.

The Boston/Dodge City comparison illustrates how different factors can be positive influences on wind system economics in different areas. In Dodge City, where wind resources are abundant and electricity costs (including sell-back) relatively low, a typical wind system could deliver electricity at competitive costs over the system's useful life. In Boston, wind resources are more limited but electric rates are higher so a wind system can produce electricity at a competitive life-cycle cost there too.

Of course, all life-cycle cost analyses are limited because few purchasers make decisions on life-cycle cost bases. To get a clearer idea of the potential economic appeal of small wind systems, cash flow and payback analyses of actual or prototypical installations are needed. The positive results from the analyses summarized here suggest that such efforts would be worthwhile. They also indicate that decision makers who use life cycle costs as economic criteria should look seriously into small wind system applications when possible.

City Applications

Small wind systems with less than five KW capacity can probably be put to best use in relatively sparsely populated single-family areas. Larger systems (up to 100 KW) could also be used to provide service electricity to larger buildings in relatively open areas or to clusters of single-family residences in newer developments.

These systems will be hard to use in dense inner city areas for several reasons. Row houses on small lots with slanted roofs do not have enough space on which to mount the towers. In row houses with flat roofs, towers could be mounted on rooftops only if structural modifications were made since towers usually require highly reinforced bases and anchor points for guy lines.(52) Even with adequate roof space and strength, wind systems need assured access to turbulence-free winds--a difficult proposition in most inner city neighborhoods. Then too, every roof-mounted wind system installed in a single-family neighborhood creates turbulence for other wind systems.

Small wind systems hold somewhat more promise in relatively low-story apartment or office buildings, though roof strength and wind access must still be counted problems. For example, had the East 11th Street project in New York not been lucky enough to be able to use an old chimney foundation to support its wind tower, steel beams would have had to be run through the existing building structure.

Electrical demand stands as another important factor would-be wind-users must consider. For example, many lighting systems can be operated on either AC or DC current, so a SWECS could provide DC directly (or through a storage system) to lights when needed. A simple switching device could allow changeover to utility-supplied AC when wind speeds or storage capacity was inadequate.

Institutional Constraints

Wind systems mounted on-site must meet code and zoning requirements. Codes may call for the reinforcement of any rooftops that will support wind towers, or zoning provisions may forbid the use of wind towers over a certain height. Of course, where wind systems

TABLE ONE HUNDRED TWENTY SIX

SMALL WECS COSTS (4-15 KW)
(Grid - Connected)

<u>Component</u>	<u>Current Cost (\$/kW)</u>
Turbine, generator & gearbox ¹	\$1500/kW - \$1000/kW
Tower	1200 - 3000
Controls ²	2500
Installation ³	3000 - 4000
Site Assessment ⁴	500
Total Installed Cost	\$13,700 - 25,000 (less land)

¹These components usually run about 20% of costs

²Includes switches, speed sensors, etc. If the system is as small as about 4 KW not many controls are needed. Control cost without a synchronous inverter will range from \$1000 - 1500. If a SI is needed (as for tying into the utility grid) add from \$1000 to \$2000 to that base amount. The figure given is a good average estimate.

³Usually runs from 1/4 to 1/3 of total installed cost. Includes \$2000 for site preparation (pouring footings, reinforcing roof, etc.); \$400 for crane rental (1 day); and \$1000 for labor (3 men, 2 days). Jay Carter, Inc has reportedly brought down the cost of their 25 KW system to \$15,000 mostly because of new installation procedures.

⁴For a 6 month to 1 year survey. Cost will vary, depending on who reads the anemometer and how often readings are taken.

Sources: Natural Power, Inc.; Rocky Flats (1980)

TABLE ONE HUNDRED TWENTY SEVEN

CAPITAL COSTS OF SELECTED WIND MACHINES

<u>Manufacturer</u>	<u>Rated Output (kWp at mph)</u>	<u>Cost of Machine</u>
Aero Power	1.5 @ 22 mph	\$ 3,000
		3,200
Aerowatt S.A. (Fr.)	1.125 @ 16	19,689
Altos Corp.	2.5 @ n/a	4,340
	1.5 @ n/a	
American Wind	25 @ 25	2,975
Astrel	10 @ 23	7,900
Bertola Station	4 @ 18	5,000
Dakota Wind	4 @ 27	7,500
	4 @ 27	7,200
Dunlight Electric	2 @ 25	4,800
Enertech Corp	1.5 @ 21	3,475
Hinton Res.	3 @ 28	1,995
Independent Energy	4 @ 23	5,395
	4 @ 23	5,995
	2 @ 23	3,995
Kedeo, Inc.	5 @ 27	4,975
	3 @ 26	4,495
	2 @ 22	4,195
Millville	10 @ 25	6,600
North Wind	2 @ 20	7,200
Pinson Energy	5 @ 30	9,600
Power Group	4 @ 24	4,990
Product Development	4 @ 20	7,995
Tumac Industries	7.5 @ 28	\$13,000
Whirlwind Power	4 @ 22	3,900
	2 @ 25	1,995

Source: "Wind Products Supplement," Solar Age, February, 1980.

TABLE ONE HUNDRED TWENTY-EIGHT

ECONOMICS OF SELECTED WIND SYSTEMS

<u>Location</u>	<u>Rated Output</u>	<u>Annual Output (kWh)</u>	<u>Installed Capital Costs</u>	<u>System Life</u>	<u>Levelized Costs w/o Tax Credit (¢/kWh)</u>	<u>Levelized Costs With Tax Credit (¢/kWh)</u>
Minnesota ¹	2 kW at 14 Mph	4,805	\$ 6,110	25	11.0	7.0
	4 kW at 14 Mph	8,995	9,800	25	9.0	6.0
	10 kW at 14 Mph	22,502	19,500	25	8.0	6.0
	40 kW at 14 Mph	94,346	60,000	25	5.0	4.0
Boston ²	10 kW at 25 Mph	13,200	16,714	30		6.0
Dodge City ²	10 kW at 25 Mph	24,700	16,494	30		3.0

Sources: 1. Minnesota Energy Agency (1981)

2. SERI, Cost of Energy From Some Renewable And Conventional Technologies (1981)

are economical and technically safe, cities may exempt them from certain height or aesthetic zoning provisions, just as many have exempted solar collectors.

Land-use requirements for small wind towers may be minimal. However, assuring adequate, turbulence-free wind access may require land-use controls far in excess of those needed to protect access to sunlight for solar heating systems.

Utility responses to small wind systems will be determined by the utility's financial health and by the state's method of implementing PURPA. Since states have substantial leeway to implement PURPA, cities interested in safeguarding the interests of urban SWECs owners should carefully follow PURPA implementation procedures in their states.

Utilities may request special backup rates and lower sell-back rates for small wind facilities on grounds that a wind system's peak output occurs during non-peak periods or that the wind system is unreliable. Then too, wind resources are generally greatest on winter evenings, so wind systems' outputs could reduce the load factors of summer-peaking utilities without cutting peak loads. Almost any utility would oppose them under such circumstances and would be justified in proposing lower sell-back rates to wind system owners than, say, to owners of photovoltaic systems whose peak output would occur in summer. As for higher back-up rates, utilities could not expect to get them without first proving that owners of wind systems constitute a different class of customers than similar residential or commercial customers without windmills.

The question of reliability is another matter. Some studies indicate that in areas with good wind resources, wind machines can be at least as reliable as some thermal power plants.⁽⁵³⁾ Large numbers of wind machines may in the aggregate be more reliable since a decline in wind speeds in one micro-climate can easily be offset by an increase in wind speed somewhere else closeby. Accordingly, PURPA requires utilities to take account of the numbers of cogeneration or renewable electric facilities operating in a given area in establishing sell-back rates.⁽⁵⁴⁾

Socio-Economic Considerations

As noted, small wind systems in areas with good wind resources or high electric rates promise to deliver electricity at a competitive or reduced life cycle (25-30 years) cost. Their use could, therefore, help reduce the long-term electrical costs of the poor. However, the first costs of these systems would have to be subsidized. "Sweat equity" arrangements, such as that used in New York's East 11th Street project could reduce labor costs but not system costs. Finally, other electrical conservation or renewable electrical production technologies may be much more technically or economically suitable for use in urban buildings housing low-income persons. For example, a city-owned, community SWEC (under 100 KW) could provide electricity at life-cycle costs lower than those of individual on-site systems if PURPA sell-back revenues were taken into account. Encouraging or assisting landlords to upgrade their lighting systems and tenants to use more efficient appliances could also help lower poor people's electric bills.

SOLAR THERMAL ELECTRIC SYSTEMS

Technical Approaches

Solar thermal-electric systems use high-temperature active solar collectors to provide heat to turbine boilers or heat engines connected to electric generators. All such systems are large, and most require several thousand feet of collector area. While many designs call for the use of these systems in utility-owned facilities to produce electricity for the grid, others are envisaged for use "on-site" in industrial facilities to supply both heat and power.

Theoretically, solar thermal electric systems operate much the same as active solar heating systems. However, collection, storage, and transport temperatures are much higher, and collected heat goes to a thermal (space or process heating) end-use only after being expended from a heat engine or boiler.

Typical solar thermal-electric systems collect solar energy at high temperatures in a receiver, then transport it either to storage or to an energy conversion system, where electricity is generated.⁽⁵⁵⁾ (See Table One-Hundred Twenty-Nine.)

Receiver systems can be of two basic types. A distributed receiver arrangement concentrates sunlight in many solar collectors. A central receiver system reflects sunlight onto a single location by means of a field of distributed mirrors called heliostats.

For all the different designs used or suggested for distributed receiver systems, the goal is to collect high-temperature heat at the lowest cost. The parabolic trough collector, often referred to as a line-focussing model, has a transfer fluid that flows through a tube mounted above and across the trough's surface so that light striking the

TABLE ONE HUNDRED TWENTY-NINE

POTENTIAL COMBINATIONS OF COLLECTORS AND CONVERSION SYSTEMS

FOR 0.1 - 10 MW (e) SOLAR THERMAL ELECTRIC SYSTEMS

<u>Concentrator</u>	<u>Conversion</u>	<u>Transport</u>	<u>Storage</u>
1. Point Focus, Central Receiver	Central Rankine	Salt	Salt
2. Point Focus, Central Receiver	Central Brayton	Electrical	Electrical
3. Point Focus, * Central Receiver	Central Stirling	Electrical	Electrical
4. Line Focus, ** Central Receiver	Central Rankine	Salt	Salt
5. Point Focus, Distributed Receiver	Central Rankine	Salt	Salt
6. Point Focus, * Distributed Receiver	Distributed Rankine	Electrical	Electrical
7. Point Focus, Distributed Receiver	Distributed Brayton	Electrical	Electrical
8. Point Focus, Distributed Receiver	Distributed Stirling	Electrical	Electrical
9. Fixed Mirror Distributed Focus	Central Rankine	Salt	Salt
10. Line Focus, Distributed Receiver Track Collector	Central Rankine	Oil	Oil
11. Line Focus Distributed Receiver Tracking Collector	Central Rankine	Oil	Oil
12. Low Concentration Non-Tracking	Central Rankine	Water	Water

Source: John Thornton, et. al. Final Report - A Comparative Ranking of 0.1 - 10.0 New Solar Thermal Electric Power Systems (1980)

collector focusses on the line. (See Part Two, Chapter Nine, Heating Buildings and Part Three, Chapter Thirteen, Industrial Process Heat.) The other generic type of distributed receiver is a parabolic dish that focusses sunlight on a point where a transfer fluid is heated. Generally, the effectiveness of these collectors can be maximized by adding one- or two-axis tracking that allows the collector to follow the sun's path both seasonally and daily.

Neither water nor air is suitable for use as a transfer medium if temperatures are to be high enough to operate a steam boiler or heat engine. Instead, most thermal-electric system designs use a molten salt solution or an organic oil for heat transfer. For energy conversion, they make use of a steam boiler or turbine connected to a generator or an advanced heat engine-electric generator configuration. Many such systems use excess heat from power production for process, space, or water heating or for absorption cooling, in effect creating a "solar total energy system." Of the various conversion systems available, the Rankine cycle steam turbine and heat engine will probably be on the market first. The interface between advanced heat engines, such as the Brayton and Stirling units, and solar thermal electric systems still needs additional research and development.(56)

In general, distributed receiver systems would transport collected or stored heat to a central conversion point. However, some distributed system designs include heat engines and generators at each collector. This arrangement cost more because additional equipment is needed, but it involves no thermal storage and the heat engines get the highest possible inlet temperatures since no heat is lost in transport or storage.

None of the on-site solar thermal electric systems designed so far is operating outside of controlled research environments,(57) so predictions of energy and dollar savings are conjectural, as are technical problems. Experiences with higher-temperature collectors in industrial process applications do, however, give rise to concern about durability (which may not exceed five years at present)(58) and vulnerability to heat loss. (See Part Two, Chapter Eleven, Community Heating and Cooling Systems.) Finally, in solar thermal-electric systems the interaction between a high temperature solar energy system, the high temperature backup fuel source, a boiler or heat engine, and a generator configuration is complex, and "solar total energy" systems will be even more complex. Accordingly, design and operation must be painstakingly careful.

Economics

Any conclusions about the economics of these prototypical systems must be highly provisional. But, their overall economic appeal will depend on the extent to which system reliability can be improved and system costs lowered, on the location of the plant, on the nature of its thermal/electric load,, on the costs of competing energy sources, and on applicable sell-back rates.(59)

One strategy for reducing system costs includes lowering the costs of collecting heat. Another is finding the most economical configuration of solar and energy conversion systems--whether it be lowering effective system costs or using more expensive equipment that is more efficient. The precise costs of different solar/energy conversion arrangements are not well known, although some estimates of the relative costs of different designs are available. Relative cost estimates should be evaluated along with other factors influencing overall system performance including reliability and state of commercial readiness. (Table One Hundred Thirty.)

Facilities in sunny areas with high year-round needs for heating or cooling and for electricity can probably make the most economical use of these systems. In other areas, system economics will depend on how much system costs can be lowered and how much competing electricity costs.

City Applications

On-site solar thermal-electric systems are best applied where electrical (and thermal) loads are heavy and enough land area is available to accommodate many solar collectors. The load requirements probably confine the use of these systems to selected industries with huge demands for medium-temperature heat, while the land-use requirements restrict the number of potential inner city industrial applications greatly. Consequently, industrial parks may be the most feasible setting for this technology,(60) though concern about system effectiveness outside in the sunbelt is bound to arise.

Institutional Constraints

Land-use questions will surround any efforts to use solar thermal-electric systems inside city limits. Even where open space is adequate, only extensive land-use controls can ensure solar access. Consequently, these systems can probably be used only in very low density industrial areas that have strict height limitations and little surrounding vegetation.

TABLE ONE HUNDRED THIRTY

COMMERCIAL READINESS CHARACTERISTICS OF SELECTED SOLAR THERMAL/ELECTRIC TECHNOLOGIES

<u>System¹ Number</u>	<u>Relative State of Development</u>	<u>Relative Technical/Cost Risk</u>	<u>Relative R&D Required</u>
1	High	Low	Low
2	Medium	Medium	Medium
3	Low	Medium	Medium
4	Low	High	High
5	Low	Medium	Medium
6	Low	Medium	High
7	Low	Medium	High
8	Low	Medium	High
9	Medium	High	High
10	High	Low	Low
11	Low	High	Medium
12	Low	Medium	Medium

1. See Table 126

Source: Thornton (1980)

Utilities' responses to these systems will be determined by the utilities' financial health and the state's method of implementing PURPA. (See Part One, Chapter Six.) More particularly, because most solar-thermal electric systems will be accompanied by on-site, fossil-fueled electric generating equipment, utilities are likely to view these applications much as they do cogeneration systems that obtain some of their thermal input from solar energy. However, since solar thermal electric systems will probably be able to provide most of their electrical output when the demand for electricity is highest, utilities might find it difficult to justify higher back up and lower sell-back rates for solar thermal-electric systems.

Socio-Economic Considerations

Conceivable, solar thermal-electric systems could be used to reduce beleaguered industries' energy bills. But the high costs of these systems mean that struggling industries will need financial help to buy them without assistance. Additionally, the lack of operationing experience with the systems, coupled with the availability of other industrial heating and electrical conservation alternatives, means that these systems are not ready for immediate use.

PHOTOVOLTAICS

Technical Approaches

Photovoltaics (or solar cells) produce electricity directly as sunlight strikes them, providing "instant electricity."

Currently, most solar cells are made of single-crystal silicon a material which is both a good absorber of light and a good semi-conductor.(61) Two separate layers of silicon, each of which contains "impurities" that form an electrical barrier between the layers, make up a manufactured cell. When light strikes the cell, one of the layers accumulates freed electrons that can be channelled to the other layer only by a wire. This flow is an electric current that can be tapped to run appliances or to be fed back to the grid.

A photovoltaic system consists of an array of panels containing a number of these cells wired together. The size of the array depends upon climate conditions, cell efficiencies, the size of the building's electrical load, power sell-back arrangements with the utility, and other factors. Besides cells, each system also has an inverter (which converts the DC output of the cells to AC for use in homes or for sell back to the grid) and controls to regulate voltage and monitor usage. If the system is not grid-connected or if the owner wishes to take advantage of the highest sell-back rates, some means of storing electricity (usually batteries) is also required.

Climatic Context

The output and cost-effectiveness of any photovoltaic system depend heavily on the intensity of available sunlight--a function of geography, seasonal changes, cloud cover, pollution, and other factors. Generally, the more intense the sunlight, the better the photovoltaic potential. Accordingly, the sunbelt can usually obtain a larger electrical output than the Northeast from photovoltaic arrays of equal size, and the Northeast has better photovoltaic potential in the summer than in winter.

Photovoltaic systems are also much more dependent on direct sunlight than are active solar heating systems, so haze or pollution can reduce the amount of electricity that can be produced. Finally, high ambient air temperatures can make solar cells less efficient, so their power output in intensely sunny areas may be somewhat less than expected.(62)

Types of Systems

Most operational photovoltaic systems employ round, single-crystal silicon cells mounted on flat-plate panels. Cell efficiency (the amount of electrical power produced at the cell divided by the amount of potential power in a given level of sunlight) ranges from eight to fifteen percent. While such power conditioning equipment, as inverters and voltage regulators will reduce system efficiency further, as will battery storage, cell efficiencies have by far the greatest impact on system efficiencies. Cells are also the single most expensive component of any photovoltaic system. (See Economics, below.) For these reasons, most strategies for reducing overall systems costs focus on increasing cell output or reducing cell costs while maintaining constant levels of electrical output.

Cell Improvements

One strategy for cost reduction involves changing the shape of solar cells from round to square so that an array can feature more cells per square foot.(63) More fundamental improvements are aimed at boosting the electrical conversion efficiency of the cell itself or increasing the intensity of light on the cell's surface. (For

example, cells made of gallium arsenide are generally more efficient than silicon cells because they can absorb a wider portion of the solar spectrum.(64) But these higher efficiency cells do cost more. The theoretical limit of single-crystal silicon cell efficiency is about 24 percent, however, and the cell's efficiencies much beyond the 15 percent upper limit now available may not be less economical than other cost-reduction strategies.

The amount of sunlight available can be increased by reflecting or concentrating sunshine onto the cell's surface. The parabolic trough collector does this by concentrating sunlight onto a tube containing smaller solar cells. (See Part Two, Chapter Nine, Heating Buildings.) Mirrors or lenses can also be used to focus sunlight on the cell more intensely. One lower cost design of this type surrounds a cell with aluminum cones that can increase the concentration of sunlight on the cell's surface fourfold.(66) Alternatively, incoming sunlight can be split into different wavelengths, each focussed on the cell material that could convert it most efficiently. (At one research laboratory, experiments using dual silicon and gallium arsenide cells achieved combined efficiencies of 30 percent.)(67) All of the above approaches could be enhanced if the photovoltaic array were designed to track the sun.

The other major strategy for array-cost reduction involves using less expensive materials in the cells themselves. For example, silicon that is less pure than single-crystal silicon can be grown at less cost. So called "thin film" cells made of such materials as cadmium sulfide or copper sulfide are also under development. But while these cells will cost far less than single-crystal silicon cells, their output is lower and they may be less reliable.

Combined Heat and Power from Photovoltaics

"Cogenerating photovoltaics" improve the overall energy efficiency of a photovoltaic array by using the cells to produce heat as well as power. As they absorb light and produce power, photovoltaic cells can reach very high temperatures especially in concentrating systems. To prevent damage, they must be cooled naturally or mechanically.

A mechanical cooling system for solar cells would work much the same as an active space heating system, passing a water or air transfer medium behind the cells to collect solar heat. One such combined photovoltaic/thermal system is installed at the Mississippi County Community College in Blytheville, Arkansas.(68) In one large multifamily application near Boston, the aluminum-cone concentrating system uses electricity from photovoltaics to run the pumps of an active solar water heating system and uses the heat collected from the solar cells to preheat the domestic water supply.(69) Although most researchers say that the electric and heating efficiencies of cogeneration photovoltaic systems are not as high as stand-alone systems of either type afford, these systems may make economic sense where heating loads are relatively high and electrical loads somewhat lower.

System Experiences

Photovoltaic systems have been used effectively and reliably for years to provide power to satellites. In terrestrial applications, most of the systems that have been operating for long are in remote locations, unconnected to any utility grid. However, a few demonstration or pioneering systems--most built with government support--are in use on homes or office buildings in dense areas. (See Table One Hundred Thirty-One.) Most monitored systems have performed well, although solid evidence is scant except from many of the more remote installations (which are both reliable and durable).

Economics

Incontestably, the single biggest barrier to the use of photovoltaic systems is their cost. Even assuming continued increases in the costs of conventional electricity, photovoltaic system costs must come down by a factor of ten to compete with existing utility service. Yet, costs have come down and the Department of Energy is working to meet ambitious photovoltaic cost-reduction goals by encouraging mass production and developing cheaper manufacturing techniques.

Photovoltaic systems costs comprise array costs and balance of system (BOS) costs (for power conditioning, storage, etc.). Conventionally, both are given in dollars per peak watt (\$/Wp) of output (system output when the array is exposed to the most intense sunlight available in its area). Thus, a system with an output of five kilowatts that cost \$10/Wp for the array and \$10/Wp for BOS, would cost \$20 times 5,000 watts--\$100,000. (See Table One Hundred Thirty-Two.)

Obviously, at these cost levels photovoltaic electricity cannot possibly compete with utility-produced electricity. However, attaining the U.S. Department of Energy's cost goals (which would mean reducing both cell and BOS costs substantially) could change this picture dramatically. (See Table One Hundred Thirty-Three.) At these cost levels, whenever they are reached, the five peak-kilowatt system that now costs \$100,000 could be purchased for under \$10,000.

TABLE ONE HUNDRED THIRTY-ONE

SELECTED PHOTOVOLTAICS APPLICATIONS IN DENSE AREAS

<u>Location</u>	<u>Application</u>	<u>System Capacity</u>	<u>Capital Costs</u>	<u>Financing</u>
Phoenix ¹	Single-family residence (1500 ft ²)	7.5 Kwp	\$ 260,000	U.S. - DOE
Cape Canaveral ²	Single-family residence (1300 ft ²)	4 Kwp	55,000	Florida Solar Energy Center Florida Power & Light MIT Lincoln Labs
Carlisle, MA ³	Single-family residence (3100 ft ²)	7.3 Kwp	100,000	U.S. - DOE
Quincy, MA ⁴	Multi-family residence		80,000	Private
Beverly, MA ⁵	School (280,000 ft ²)	107 Kwp (9% of annual load)	260,000	U.S. - DOE
Bedford Hills, NY ⁶	Bank (Electric/thermal collectors)	.31Kwp (30% of total energy use including cogeneration)	15,000	Private
Dallas/Fort Worth ⁷	Airport	25 Kw	\$1,000,000	U.S. - DOE/Private
Blytheville, AR ⁸	School	320 Kw	n/a	U.S. - DOE

Sources: 1. Personal Communication, John F. Long Homes., Inc.
 2. Florida Solar Energy Center, Brochure
 3. Don Best, "The Advent of Residential Photovoltaics," Solar Age; June, 1981
 4. Personal communication, Bill O'Connell, Granite Place Apartments.
 5. Personal communication, Richard Addiss, Solar Power Corporation.
 6. Westchester Federal Savings personal communication.
 7. Personal communication, Preston Firk, E-Systems.
 8. Monegon, Inc., Solar Electricity (1981)

TABLE ONE HUNDRED THIRTY TWO

AVERAGE PRICES FOR SOLAR CELLS
(Selected Companies)

<u>Firm</u>	<u>Cell Price (\$/WP)</u>
Solarex	\$10 - \$14
Arco	10 - 12
Solar Power Corporation	10 - 12
Solenergy	11.25
Photon Power	5 - 12

Source: Center for Renewable Resources, A Question of Balance:
Competition in the Photovoltaics Industry (1982)

TABLE ONE HUNDRED THIRTY-THREE

DOE COST GOALS FOR RESIDENTIAL AND INTERMEDIATE SCALE
PHOTOVOLTAIC SYSTEMS

<u>Sub-System</u>	<u>Current Costs (\$/WP)</u>	<u>DOE Cost Goals (1986) (\$/WP)</u>
<u>Residential</u>		
Cells	\$10.00	\$0.70
Bos	10.00	\$.90 - \$1.50
<u>Intermediate</u>		
Cells	10.00	\$.70
Bos	10.00	\$.90 - \$1.90

Source: U.S. DOE.

Detailed economic analyses using current costs seem pointless. Even when total system costs of less than \$10/Wp are assumed, photovoltaic electricity costs too much to use in most applications. (See Table One Hundred Thirty-Four.) Nonetheless, life-cycle cost analyses of prototypical systems using projected DOE cost goals indicate that attractive life-cycle costs are achievable. (See Table One Hundred Thirty-Five.) For example, a simulation done by the Minnesota Energy Agency indicated that a relatively large (10 Kwp) residential system installed in Minnesota could deliver electric energy at competitive prices over twenty years--7.9 cents per kilowatt hour (\$23.03 per MMBTU) without Federal and state tax credits and 5.5 cents per kilowatt hour (\$16.06/MMBTU) with tax credits.(70) A SERI analysis of prototypical single-family systems installed in Boston and Albuquerque indicated that declining life-cycle costs could be anticipated for systems installed from 1985 to 2000.(71)

Two caveats should be noted here. First, when these cost goals will be achieved is still a matter of speculation. Second, attractive life-cycle cost may not be sufficient to encourage individual purchase decisions. City or state governments often employ life-cycle cost criteria in making decisions on capital expenditures, but most other consumers do not. Additional analyses are, therefore, needed to assess paybacks and cash flows--more commonly used criteria.

While this discussion assumes that no major technical breakthroughs that lower costs dramatically will occur, at least one system currently on the market sells for under \$3.00 per peak watt, with costs projected to drop as low as \$1.25 per peak watt with mass production. Employing the aluminum-cone concentrating and cogenerating arrays discussed earlier, this system has reportedly been installed on single-family homes and small commercial buildings for between \$9,000 and \$15,000, with the manufacturer estimating paybacks at nine to twelve years for some systems.(72) The widespread use of this system or others like it could dramatically improve the economic appeal of photovoltaic systems.

City Applications

Photovoltaic systems are much more flexible than either wind or solar-thermal electric technologies. Modular, photovoltaic panels can be used to provide electricity to almost infinitely diverse DC or AC loads, in applications as small as cathodic corrosion inhibitors on highway bridges or as large as airports and hospitals.

The on-site requirements for photovoltaic systems are simple--adequate space, proper building or lot orientation, and solar access. While these are the same basic requirements needed for an effective active solar heating system, the nature of photovoltaic systems may make their impacts more severe. (See Part One, Chapter Four Land Use and Energy and Part Two, Chapter Nine, Heating Buildings.)

As for land, the minimum photovoltaic array area required is a function of the electrical demand that will be met by the system and the availability of sunlight. Demand calculations should begin with an estimate of the total annual (and seasonal) electrical demands of the building, which can be obtained by calculating the wattage requirement for each system or appliance and the number of hours each will be used per year.

The costs of photovoltaic arrays depend on the number of cells used, so the system designer or building owner will have to determine the optimal size of the system very carefully. Unlike active space heating systems, photovoltaic systems are capable of providing their highest output when demand is highest. But it is still unwise to size the system to meet peak cooling loads if the resulting system would be oversized for the rest of the year unless favorable sell-back rates are available from the utility. Therefore, a better tack is to base the load design on a monthly average of kilowatt hour consumption.

Whatever the design electrical load chosen, the size of the array needed to meet it will vary by city because of regional differences in the availability of sunshine. With equal cell efficiencies, it takes more space (and costs more) to meet a given electrical load in New York than in Phoenix. (See Table One Hundred Thirty-Six.)

The information in the Table underscores the importance of reducing system size or using highly efficient cells in northern climates. The "worst case" occurs in Seattle. There, a heavy electrical load met with relatively inefficient cells would require almost 1,400 square feet of photovoltaic panels. But these array space requirements could be cut by over two-thirds if the load were reduced either by conservation or by downsizing the system and if more efficient cells were used. Even in more southerly climates, heavy loads met with inefficient cells would require over 700 square feet of collector but reducing the load and using more efficient cells would cut the required roof or ground area to a more manageable size.

A related consideration is potential competition for space between active solar space or water heating systems and photovoltaics. Since few cities obtain much space-heating energy from electricity, most urbanites who want to obtain both heating and electrical energy from sunshine may have to use two solar energy systems. Because there may not be enough room to accommodate both, in many denser cities it may be necessary to

TABLE ONE HUNDRED THIRTY-FOUR

LIFE CYCLE COSTS OF DELIVERED ELECTRICITY FROM PROTOTYPICAL PHOTOVOLTAIC SYSTEMS AT \$10/WP

<u>Location</u>	<u>System Capacity</u>	<u>System Costs</u>	<u>Annualized Life Cycle Costs of Delivered Electricity¹</u>	<u>kWh</u>	<u>MMBtu</u>
Boston	4 Kwp	\$ 39,810		55¢	\$161.15
Albuquerque	4 Kwp	39,680		41¢	120.13

1. Includes costs of mortgage money at 12%. Assumes 3% real discount rate and 2.5% real escalation in electricity prices.

Source: SERI, Cost of Energy From Some Renewable and Conventional Technologies (1981)

TABLE ONE HUNDRED THIRTY-FIVE

ECONOMIC ANALYSIS OF RESIDENTIAL PHOTOVOLTAIC SYSTEMS USING DOE COST GOALS

<u>System</u>	<u>Boston¹ 1985</u>	<u>Boston¹ 1990</u>	<u>Boston¹ 2000</u>	<u>Albuquerque¹ 1985</u>	<u>Albuquerque¹ 1990</u>	<u>Albuquerque¹ 2000</u>	<u>Minnesota²</u>
<u>Capacity</u>	4 KW	4 KW	4 KW	4 KW	4 KW	4 K	10 KW
System Cost	\$10,000	\$6,400	\$5,600	\$10,000	\$64,000	\$56,000	\$19,000
\$/wp	\$2.50	\$1.60	\$1.40	\$2.50	\$1.60	\$1.40	\$1.90
Financing	12%	12%	12%	12%	12%	12%	n/a
System efficiency	8.0%	8.1%	8.2%	7.9%	8.0%	8.1%	
Annual Output (KWH)	5535	5590	5672	9683	9779	9875	17000
Levelized Cost - twenty years (¢/kwh)	13.0	7.9	5.8	9.4	5.6	4.1	7.9

Source: 1. SERI, Cost of Energy From Some Renewable and Conventional Technologies (1981)

2. Minnesota Energy Agency (1981)

TABLE ONE HUNDRED THIRTY-SIX

SPACE NEEDED FOR PHOTOVOLTAIC ARRAYS UNDER DIFFERENT DESIGN CONDITIONS

City	Insolation (Btu/ft ² /Day)	FT ² OF COLLECTOR NEEDED								
		Load 1 - 15 kWh/Day			Load 2 - 20 kWh/Day			Load 3 - 25 kWh/Day		
		System Efficiency			System Efficiency			System Efficiency		
		(6.5%)	(8.1%)	(12%)	(6.5%)	(8.1%)	(12%)	(6.5%)	(8.1%)	(12.0%)
Boston	1105	800	643	421	1065	957	562	1331	1072	702
New York	1099	803	647	423	1071	863	565	1339	1078	706
Washington, D.C.	1208	731	589	385	974	785	514	1218	981	642
Atlanta	1345	656	529	346	875	705	461	1094	881	577
Miami	1473	599	483	316	799	644	421	999	805	527
Chicago	1215	726	585	383	969	780	1511	1211	975	638
Minneapolis	1170	754	608	398	1006	810	530	1257	1013	663
Denver	1568	563	453	299	751	605	396	938	756	495
Houston	1351	653	506	344	871	702	345	1089	877	574
Phoenix	1869	472	380	249	630	507	332	787	634	415
Los Angeles	1594	554	446	292	738	595	389	923	743	487
Seattle	1053	838	675	442	1118	900	589	1397	1125	737

Source: Derived via a formula used in Maycock, Photovoltaics, (1981)

employ concentrating systems, perhaps with simultaneous heat collection. For example, the lower-cost "cone" concentrating system might be very appealing even though it requires the addition of retrofit piping and storage tanks. Alternatively, community photovoltaic and/or thermal systems could be considered.

Shading--especially in summer when deciduous trees cast their fullest shadows and electrical demands and system outputs are highest--can also have a much more detrimental effect on photovoltaic than on active heating systems. Most photovoltaic systems are wired in two types of connections--series and parallel. Series cell connections allow voltage (or quantity) increases with constant current (or flow), while parallel cell connections allow current increases at constant voltage. Overall, both voltage and current levels can thus be maximized. But, shading even one cell in a series connection can reduce current, and, therefore, power output substantially.(73)

The need for space and solar access suggests that the most promising applications for on-site photovoltaic systems may be in new developments or in low-density residential or commercial areas.(74) Unless concentrating or cogenerating systems are used, photovoltaic applications in denser areas might be confined to community-scale systems. New buildings can be oriented for maximum solar exposure, and some companies now produce shingles combined with photovoltaic cells so that the additional costs of the photovoltaic systems can be partially subsumed in roofing costs in new construction. Nevertheless, photovoltaic retrofits are physically much easier to make than active space or water heating retrofits because the photovoltaic panels weigh much less, and no storage tank is necessary (unless the system is cogenerating). Indeed, it would be fairly simple to mount photovoltaic panels vertically on the sides of taller apartment or office buildings.

Institutional Constraints

Land-use issues surrounding on-site photovoltaic applications will be similar to those involved in the use of active space-heating or water-heating systems. Steps that cities can take to provide solar access protection to on-site solar energy collectors are discussed in Part One, Chapter Four, Land Use and Energy.

Owners of photovoltaic systems will, like other small power producers, be able to sell power back to local utilities. Photovoltaics cannot meet brief on-site peaks very well because the power output of the system is limited by the availability of sunlight,(75) but nearly all photovoltaic systems will produce most electricity in summer, when most utilities experience peak demands--an advantage for utilities as well as consumers. In areas with large amounts of sunshine, photovoltaic systems may be as or more reliable than thermal power plants.

Socio-Economic Considerations

Even if DOE cost goals are reached, the photovoltaic cell does not promise to be a "cheap" technology. Poor people will simply not be able to use these systems on their homes without subsidy. But cities could help the poor by developing intermediate-scale or small community-scale photovoltaic systems, perhaps in cooperation with a municipal utility. People on low incomes could also benefit from the addition of photovoltaic systems to public utility grids if electricity costs increased less rapidly throughout the service area as a result.

Photovoltaics may also hold real promise for local business development. For example, the San Bernadino West Side Community Development Corporation now manufactures photovoltaics(76). If the use of "lower cost" systems like the one using aluminum cone reflectors become more widespread, local businesses could benefit.

II. COMMUNITY-SCALE APPLICATIONS

Introduction

Energy conservation and renewable energy technologies can be employed in centralized, as well as dispersed, applications to provide relatively cheap, non-polluting, and reliable power to large numbers of customers. These systems could be developed and owned by public utilities. Alternatively, city government, local industries, or public-private partnerships can become profit-making electricity producers. Indeed, a collection of small, centralized power-production facilities could include a utility-operated "wind farm" incorporating several large wind energy conversion systems, an industrial cogeneration system selling power to the grid, and a low-head hydroelectric facility at a dam renovated by a city government.

ADVANTAGES OF SMALLER-SCALE CENTRALIZED ELECTRIC GENERATION

Many community-scale systems are economically competitive with larger thermal power plants right now. More will become so as the construction, financing, and safety-related

costs of large coal- or uranium-fueled facilities continues to escalate relentlessly. Current estimates put the costs of a 1,000-megawatt nuclear plant, beginning construction in 1981 at between \$2 and \$3 billion.(77) The total costs of Nine-Mile, Unit Two, a nuclear plant currently under construction in New York state, will exceed \$5.5 billion (or \$5,500 per kilowatt of capacity).(78) Many cogeneration or renewable energy electrical systems can be brought on-line for half that price right now.

Smaller-scale power facilities are also more reliable than larger plants. A single non-scheduled outage can severely disrupt service in a large plant, but where power is supplied by many smaller facilities, shutdowns of one or a few will affect overall levels of service less drastically. Indeed, an electric grid supplied by many small generating stations and backed up by a reasonable reserve margin could be virtually outage-proof.

A third advantage of a network of smaller-scale electric generating facilities is flexibility in response to fluctuations in demand. When rates were cheap, electricity demand rose steadily, partly because utilities helped market electrical appliances and heating systems. During this period, utility planners assumed that demand would continue to grow. Now, however, utility industry analysts are not so sure: some are uttering jeremiads about electrical supply shortfalls in the next twenty years,(79) while others contend that large-scale growth projections have already led to the construction of unneeded plants and excess capacity.(80) Part of the problem is that the predicament varies by region. Certain parts of the South and West are experiencing far greater demand increases than developed regions, and where electric rates are still relatively cheap, immediate market pressure to stabilize demand patterns is low. Even in high-growth areas, the long-term effects of future price increases cannot be easily predicted, especially since advantages in appliance efficiency may reduce utility's capacity needs even if end-use demands increase.

Uncertainties about demand can devastate a utility since, according to a Harvard study, it takes an estimated 13 years to bring a 1,000-megawatt nuclear plant on line. While regulatory changes could cut this time by a third, nearly a decade would still be needed. In contrast, smaller-scale power production facilities both take less time to build and make "tracking" demand easier. Projected rapid increases in demand could be met much sooner. Overestimates would not be as costly.

Smaller-scale power production also increases opportunities for local control over a community's electricity supply. Smaller scale generation is within the financial capability of city governments, particularly if favorable sell-back rates are available under the state's implementation of PURPA 210 or a similar program. Moreover, localities would have special opportunities to tap local primary energy sources such as waste heat, waste wood, wind, sunlight, or water.

A last advantage is that small power production facilities that make use of renewable energy pose fewer environmental threats than large-scale thermal power plants. While the long-term health effects of low-level radiation from coal or nuclear facilities remain unknown, the hazards and the costs of controlling air pollution and water pollution, and of nuclear waste disposal are already well established. Then too, the nuclear industry's ability to predict, prevent, and deal with a catastrophic accident is by no means assured.(82)

Technical Approaches

Modular Integrated Utility Systems

A modular integrated utility system (MIUS) is a centralized block- or neighborhood-scale utility unit capable of providing heat, power, potable water, sewage treatment, and wastewater treatment.(83) Theoretically, a MIUS can reduce capital and delivered service costs by integrating the operation of several utility services. It could, for instance, take advantage of the economies of scale offered by cogeneration, and at the same time use solid waste as input fuel to a combustion or gasification energy system. According to their proponents, MIUS also produce fewer emissions than the various systems they replace.

While MIUSs are too new to evaluate in detail, they are obviously major capital projects that can probably be justified when new facilities are needed or when existing facilities are due for replacement anyway. Logically, their economic benefits to either private users or city government are probably affected by many of the same factors--including the costs of the utility services they replace--that influence the economics of cogeneration strategies. Where even one relatively low-cost conventional service delivery system is available, it should probably be considered first. And where a MIUS is the preferred option, private users will need to be able to reduce their use of conventional utility services without penalty (either outright disconnection or rate increases for back up services). Their widespread economic and environmental benefits would come only if they appeared on a widespread basis.

Clearly, more site experience is needed with MIUSs to ensure that they will work as advertised. They may be heir to the technical and environmental problems encountered by many "garbage to energy" plants, and it may take time to learn to manage so many and such

diverse utility operations smoothly.

Advanced Cogeneration Techniques

Combined Cycles

A combined-cycle cogeneration unit employs both a topping and a bottoming cycle to obtain substantially greater electrical outputs than topping or bottoming cycles alone with relatively small increases in fuel inputs. First, a combustion turbine produces both electricity and steam. The steam is fed to a waste heat recovery boiler where temperatures are raised high enough to run an extraction/condensing or backpressure turbine that cogenerates heat and power. (See Part Two, Chapter Eleven.)

Combined cycle equipment could be installed or retrofit onto a cogeneration system.

Some utilities calculate that using a combined cycle could increase the amount of economical cogeneration potential in their service areas several-fold. (Arkansas Power and Light estimated that with conventional techniques about 100 megawatts of electricity could be cogenerated economically by industries in its service area. But with combined cycles, the potential could reach 1,700 megawatts.)(84)

While combined cycles can be much more economical and efficient than topping or bottoming cycles alone, combined-cycle combustion turbines must be run on oil or gas. Obviously, combined cycles will hold less appeal as these fuels become more expensive or scarce. However, this problem is at least somewhat offset by the very high efficiencies of these units.

Fuel Cells

In fuel cells, the hydrogen gas in a fuel is combined with air in a chamber. In the chemical reaction between the air and hydrogen, both DC electricity and heat are produced. If converted to AC, the electricity can be used for low-temperature (330 degrees F or less industrial processes, water and space heating, absorption cooling, or other purposes.

Fuel cells represent a cleaner and more efficient way than fossil-fuel combustion to produce electric energy. In conventional generating plants using oil or gas, fossil fuels are burned to produce mechanical energy that, in turn, runs electric generators. With the fuel cell, combustion is unnecessary, as are turbines or heat engines and generators. Although fuel cells will not be commercially available on a wide scale until at least 1985, they offer substantial promise for use in small power-producing and cogeneration facilities, especially those located in or near urban areas.(85)

Fuel cells can be more efficient than conventional power production in both electric-only and cogeneration modes. By one estimate, fuel cells can generate electricity at 40 percent efficiency--compared to 25 to 33 percent for conventional thermal power plants--and cogenerate heat and power at an overall efficiency of 90 percent.(86) These cells are also more efficient supporting partial loads than conventional generators are, and they can respond to dramatic increases in demand faster.

Fuel cells are also projected to be available in a range of sizes, and their operation gives rise to relatively little pollution. Indeed, a study of a projected 4.8-MW fuel cell cogenerating unit for a paper mill in Santa Clara indicated that replacing on site boilers with fuel cells would reduce nitrous and sulfur oxide and particulate emissions by over 100 pounds per day and pollution caused by electric generation by over 1,000 pounds per day.(87)

A demonstration fuel cell facility of 4.8 MW capacity is scheduled to begin operating in New York City in 1982. Built to operate initially in a power-only mode, it will eventually cogenerate heat for preheating feedwater entering the East River Power Plant next door. (Coal-derived fuels may also be burned at this plant experimentally.)

ALTERNATIVE III: RENEWABLE ENERGY TECHNOLOGIES

Wind energy conversion systems, solar thermal electric systems, and photovoltaics can all be used in community-scale, while numerous other renewable electricity technologies can be used only in a partially centralized fashion: small hydroelectric and biomass-fueled systems in cities; geothermal resources and solar ponds outside city boundaries.

LARGE WIND ENERGY CONVERSION SYSTEMS

As noted earlier, wind energy conversion systems with between 70 and 100 KW of rated output can be used to provide electricity to larger buildings or to neighborhoods, while systems with over 100 KW of rated output can be used expressly to produce electricity for the grid. While most of these larger units cannot be located within city limits, they could be used to provide electricity for cities. For example, Los Angeles is currently examining plans to establish "wind farms" in nearby mountains to provide power to the city.(88)

Obviously, larger-scale wind systems will feature wider blades and higher towers than smaller ones. But the difference can be striking. A small wind system with a rated output of less than 10 KW will have rotors of from 8 to 25 feet in diameter and towers of 50 to 60 feet. Larger systems (200 KW to 2.5 MW) can have rotors with diameters of 150 to 300 feet and towers of 100 and 200 feet.(89)

Larger systems require more land than small systems, not only because the machines are bigger, but also because they are more vulnerable to turbulence caused by surrounding obstructions.

Thus, a single large wind turbine (1 MW) could require acres of land and clusters of large wind systems would need far more so that one windmill does not "disturb" another. Indeed, many planned "wind farm" projects include many smaller machines, rather than a few larger units. One pilot project at Crotched Mountain, New Hampshire, gets 1 MW of peak power from 20 machines with rated outputs of 50 KW each.(90)

Larger wind systems also pose more environmental and safety-related problems than smaller ones. For instance, some larger-scale systems have caused continuous, low-level vibration in surrounding areas, so blade rotation speeds have had to be cut or steel turbine blades replaced with fiberglass blades. Larger wind systems also require ice sensors since ice flying off large blades could injure people and buildings.

Few wind systems of over 100 KW are in use, though the Bonneville Power Administration (BPA) recently finished building three 2.5 MW units in Goodnoe Hills, Washington, that will be closely monitored to establish the effects of turbulence in groupings of larger machines, the reliability of clusters of larger machines, the "match" between electricity production and demand patterns, and environmental impacts.(91)

SOLAR THERMAL-ELECTRIC

Solar thermal-electric systems can be used to help "repower" existing utility service areas by replacing outmoded or expensive power plants. Most current plans for repowering projects (all DOE funded and, thus, vulnerable to budget cuts) are for areas with large amounts of insolation available year-round.(92)

Solar thermal repowering projects could make use of distributed receiver systems, though central receiver systems are often favored. In central receiver systems, a series of distributed mirrors (heliostats) reflect sunlight onto a central point where the collected heat is used to run (or help run) a heat engine connected to an electric generator. This arrangement keeps both heat losses and energy requirements to a minimum.

Some central receiver designs include a thermal storage system, others employ battery storage and still others use collected heat for electricity generation immediately. Where storage is used, system output can be matched more closely to peak demands, but storage does add to capital costs and entail some heat loss.

Currently, one central receiver plant is under construction in Barstow, California. Others are planned,(93) but experience is limited. Theoretically, with central receiver systems cities would not have to worry about collector durability or heat loss in transport that may be expected in distributed receiver systems. But some heat loss always occurs if storage is integrated into the system, and the long-term durability of heliostats is still largely conjectural. Finally, interconnecting central receiver systems with the auxiliary heating system and the heat engine can be complex.

Community-scale solar thermal-electric systems require far too much land area--five to eight acres of land per megawatt of capacity--to be used within most cities.(94) Curtailing development in surrounding areas to protect solar is another access problem. Most likely, therefore, community-scale solar thermal electric systems will be sited in open areas and contribute "imported" electricity to cities.

PHOTOVOLTAICS

Photovoltaic arrays can be configured in large modules to provide electric power to community grids. Aside from costs (see Economics, above), the one impediment to the widespread urban use of these systems may be spatial requirements. The panels are so light weight that they could be installed atop flat buildings or the flat roofs of parking areas to save space, but protecting solar access for these systems in inner cities could still be difficult.

SMALL-SCALE HYDROELECTRICITY

Hydroelectric systems use falling water to power turbines whose mechanical energy is, in turn, used to run electric generators. Currently, hydroelectricity accounts for about 11 percent (59,000 MW) of total U.S. generating capacity for about six percent of total U.S. energy consumption.(95) Most hydroelectric power generation takes place in relatively large (15 MW to 2,000 MW) facilities but substantial untapped capacity exists at smaller (under 15 MW) sites, many in or near small- to medium-sized cities, especially in the Northeast.

Determining Small Hydro Potential

The size of a hydroelectric project is determined mostly by the amount of water available at the dam site. Water resources can be assessed in terms of three features (1) the flow-rate, or the gallons of water that pass a fixed point on the bank each minute; (2) the consistency of stream flow or the daily or seasonal variations in flow rates; and (3) the head, or the distance of vertical drop available at a given dam site. Larger hydro projects are located in areas with relatively great flow rates, while smaller projects are on streams with relatively smaller ones. All large-scale hydro projects are "high head," though not all small hydro projects are "low head." (Small streams featuring long vertical drops (high heads) but low flow rates can be used to produce hydroelectricity.)

The amount of "head" at a given hydroelectric site is a function of terrain and dam structure (storage or run-of-the-river). Storage dams are relatively tall. Usually, they are located in deep valleys so they can form large, deep reservoirs with a highly dependable capacity. Most good sites for large storage dams in this country are already developed, and few unexploited sites are near large cities.

Run-of-the-river dams are much more common where waterways are relatively flat. (Thus most "low head" hydrofacilities are on run-of-the-river dams, many of them in cities.) The Army Corps of Engineers has estimated that over 57,000 MW of power potential is available at 2,100 sites, 32 percent of which are located in the Northeast.(96) The New York State Energy Research and Development Authority recently estimated that 1,507 MW of undeveloped small hydro capacity existed at 468 in-state sites with dams already in place. Another 1,519 MW could be obtained by building dams at 286

additional sites.(97) A few cities are beginning to develop or redevelop their hydroelectric potentials. (See Table One Hundred Thirty-Eight.)

System Operation

In all but the smallest (100 KW or less) hydro projects, a dam is needed to direct the flow of falling water. Briefly, the major components of a hydroelectric project are:

Dam - In larger projects, the dam may hold water for later use. In general, the primary function of the dam is to create additional "head" at the site and direct water through a dam's penstock(s) to its turbine(s).

Spillway - A concrete structure, the spillway allows water to overflow a dam during times of high stream flow.

Intake and Penstock - The intake guides water from behind the dam into the penstock, which is a pressurized conduit that carries the water to the turbine in the power house.

Powerhouse - The powerhouse contains a turbine (which is turned by water flowing out of the penstock), an electric generator (which is connected to the turbine), control equipment (including a transformer, circuit breakers and switch gear) and the tailrace (frequently a concrete structure that channels water from the powerhouse back into the stream.) Depending on available head and dam design, the power house may be an integral part of the dam or may be located some distance downstream.

The difference between low-head and high-head applications is critical to turbine selection. In high-head applications, water tends to reach the turbine at a very high velocity. ("Impulse turbines" utilize such a stream by letting it strike each turbine blade serially.) Water passes through a low-head system at a low speed and great pressure. Reaction, propeller, and crossflow turbines operate optimally in response to water pressure rather than velocity. (These turbines operate by letting water flow over a number of blades simultaneously.)(98)

Overall, hydroelectric plants are extremely efficient--about 86 percent of the kinetic energy in water can be converted to electricity. The efficiency losses that do occur result from friction on the water as it flows through the penstock, incomplete transfer of energy from water to the turbine, and energy lost as heat or friction in the operation of generating equipment. These losses aside, hydroelectric facilities obtain efficiencies two or three times higher than those of thermal plants.

Planning a Low-Head Hydro Plant

To investigate hydropower potential within its boundaries, a city needs to determine how much power can be produced with existing resources, how much structural rehabilitation is needed on existing dams and other facilities, the industries and businesses adjacent to it. More commonly, however, hydropower facilities will transmit power to customers via utility lines.

At least two considerations influence the ease with which hydroelectric power produced at a retrofitted dam can be integrated into a public utility distribution network. One is the accessibility of transmission lines, since adding lines adds to capital costs. (See Economics, above.) Still, in most urban hydropower sites, power lines are close by.(99)

Perhaps a larger issue is cooperation with the local utility. Some public utilities are encouraging, even financing, the private development of low-head hydro sites. And private developments initiated without the blessing of the local utility are still protected by PURPA from "discriminatory" rates and treatment.

Sell-back rates will be determined in part by the reliability of hydro sites and in part by the match between their output and the demand patterns in the utility service area. Unless average annual flow rates are extremely variable, most low-head hydro facilities can be expected to provide power reliably. However, the amounts of power available will vary by season, as and how easily power can be transmitted to utilities or to other customers.

TABLE ONE HUNDRED THIRTY-EIGHT

SELECTED EXISTING OR PLANNED SMALL HYDRO PROJECTS

<u>City</u>	<u>Capacity of Completed Project</u>	<u>Project Status</u>	<u>Necessary Adjustments To Existing Dam</u>	<u>Capital Costs</u>
Idaho Falls, ID	26.6 MW	First of 3 turbines now on line. Other two in spring of '82.	Replacement of 3 Kalan Turbines w/ Bulb Turbines. Dam renovation.	\$58.0 Million
Paterson, NJ	7.5 MW	Construction due to begin early '82. Power on line in '84.	Replacement of penstocks, trash racks, gates, generators, and turbines.	\$ 8.8 Million
Lowell, MA	15 MW	License request still awaiting approval.	15 MW plant added to system.	\$28.7 Million
Philadelphia, PA	3.5 MW	Undergoing feasibility study by Penn. Hydro. Has not yet received FERC license.	Flat rock dam rebuilt.	\$ 6.2 Million
Benton, ME	3.4 MW	Under construction. Due on line in October of '82.	Two tube turbines added to existing Shawmut Dam	\$ 5.8 Million

TABLE ONE HUNDRED THIRTY-EIGHT

SELECTED EXISTING OR PLANNED SMALL HYDRO PROJECTS

Columbus, OH			
- Griggs Dam	2.0 MW	Awaiting favor- New turbines. able FERC	\$ 3.62 Million
- O'Shaughnessy Dam	5.0 MW	license ap- roval	\$ 4.1 Million

Power Potential

Only a qualified engineering firm can assess a location's hydropower potential--the site's capacity (the number of kilowatts that can be generated at peak flow rate) and average annual output (the number of kilowatt hours of electricity that can be generated in a year). City officials also need estimates to ranges of potential output and indications of daily and seasonal output peaks to make sure the system is predictable enough to warrant investment. This output schedule also affects the system's contribution to shaving peak loads, the need for storage batteries, and the amount of money that can be obtained via sell back to the local utility.

Conditions of Existing Facilities

Where power generation appears attractive, whether a dam exists at the site already is the most important factor influencing the economics of system development. In most cases, it is uneconomical to build a new dam on a small-scale hydro site. (An exception would be a small stream with a high head or at a relatively wide stream with large potential capacity, neither of which is common in cities.) Probably most economical are old hydroelectric facilities. If dams, spillways, penstocks, and powerhouses are already in place, only renovation is needed. If the dam was never used to produce hydropower, retrofitting it may or may not be economical. (See Economics, above.) A key factor here is how power production affects the structure's integrity, since the flow of water through a penstock and turbines can cause potentially damaging vibrations.

One of the most common problems encountered in renovating all old dams is sedimentation. Silt deposited over years behind a dam may block intake gates or severely diminish water storage capacity. Dredging is a simple, though costly, remedy. (See Table One Hundred Thirty-Nine.)

Power Marketing and Transmission

In a few isolated cases, hydropower can be used directly without being transmitted through the public utility grid. A retrofitted dam located in a rehabilitated textile mill complex in the Northeast could, for example, provide all of its power to the industries and businesses adjacent to it. More commonly, however, hydropower facilities will transmit power to customers via utility lines.

At least two considerations influence the ease with which hydroelectric power produced at a retrofitted dam can be integrated into a public utility distribution network. One is the accessibility of transmission lines, since adding lines adds to capital costs. (See Economics, above.) Still, in most urban hydropower sites, power lines are close by. (99)

Perhaps a larger issue is cooperation with the local utility. Some public utilities are encouraging, even financing, the private development of low head hydro sites. And private developments initiated without the blessing of the local utility are still protected by PURPA from "discriminatory" rates and treatment.

Sell-back rates will be determined in part by the reliability of hydro sites and in part by the match between their output and the demand patterns in the utility service area. Unless average annual flow rates are extremely variable, most low-head hydro facilities can be expected to provide power reliably. However, the amounts of power available will vary by season, as steam flow rates increase or decrease, and most flow rates do not peak in summer, when utilities' demands do. (See Table One Hundred Forty) Where maximum flow rates are compatible with demands for service lighting in nearby business or industrial sites, hydropower developers may find it profitable to sell their power directly to users.

Licensing Concerns

The environmental impacts associated with small or low-head hydro projects are generally far less severe than those associated with conventional power plants or even large dams. Nonetheless, resolving questions about the effects of dams on water quality and fish migration, as well as settling disputes over water rights, can take years. In general, the time and money needed to obtain a license for a hydroelectric plant will vary with stream and project size and will involve many Federal and state agencies. However, as a result of recent efforts to reduce the Federal role in licensing small projects, dams under 1.5 MW are now only required to go through a "short form" licensing process, and some projects under 0.5 MW may be exempt from Federal licensing entirely. Only new hydro projects with dams above 1.5 MW still require the full FERC application process.

ELECTRICITY FROM BIOMASS RESOURCES

Steam boilers powering turbines connected to electric generators can burn wood, crop wastes, municipal solid wastes, and other biomass fuels. All can be used for cogeneration or in small "power only" facilities, and methane gas recovered from landfills can also run turbines in electric generating facilities. (See Part Three,

TABLE ONE HUNDRED THIRTY-NINE

SAFETY CHECKLIST FOR RETROFITTING EXISTING DAMS
FOR HYDROPOWER PRODUCTION

<u>Dam Type</u>	<u>Potential Problems</u>
Earth & Rockfill	• cracking • slope and foundation stability • settlement at crest • excessive seepage at abutment, toe • excessive hydrostatic pressure • changes in alignment or geometry • bulging at toe or beyond • loss of freeboard • surface erosion
Concrete	• cracking • displacement or offsets • tilting • sliding • excessive seepage • excessive hydrostatic pressures • deteriorated concrete • concrete erosion • downstream erosion • undermining
Abutments, channels, tunnels	• stability of slopes • stability of tunnel wall or lining • seepage • erosion • excessive hydrostatic pressures

Source: Leslie Pruce, "Power from Water." Power, April 1980.

TABLE ONE HUNDRED FORTY

PATTERNS OF STREAM FLOW-RATES BY REGION

<u>Region</u>	<u>Months of High Flow</u>	<u>Months of Low Flow</u>
North Atlantic	March, April	August, September
South Atlantic-Gulf	February, March	September, October
Great Lakes	April	January, August, September
Ohio	March	September, October
Tennessee	March	October
Upper Mississippi	March, April	January, September, October
Lower Mississippi	March	October
Souis-Red-Rainy	April	January, February
Missouri	March, June	January
Arkansas-White-Red	April, May, June	January, September
Texas-Gulf	March, May	August, October
Rio Grande	May	June
Upper Colorado	June	January, February
Lower Colorado	March, April	June, November
Great Basin	June	September, January
Columbia-North Pacific	February, April, May	January, February, August, September
California	April, May	September, October, December

Source: D.K. Todd (Ed.) The Water Encyclopedia, Water Information Center, Port Washington, New York 1970.

Chapter Fourteen.

Various equipment capable of burning biofuels is now available. Spreader-stoker boilers, for instance, can burn wood with a moisture content up to 65 percent, in some cases producing 100,000 to 300,000 pounds of steam per hour on site.(100) In Stockton, California, Diamond Walnut Growers are firing this type of boiler with ground walnut shells to produce electricity and industrial process heat.(101) Some spreader-stoker boilers can also burn both solid (coal or wood) and liquid (usually oil) fuels.

Another versatile boiler is the fluidized bed combustion unit, which burns wood or other biomass fuels (including those with a high moisture content) in a mass of mineral particles kept in motion via forced air. Because it has a much higher heat transfer rate than a stoker-fired boiler, a smaller sized boiler of this type can produce relatively more steam--up to 10,000 pounds of steam per hour in some wood-burning units now on the market. (Larger wood-burning systems have been demonstrated, but not widely marketed.) Many California Canneries now use fluidized-bed boilers to produce process heat from pits, shells, and other wastes.

One of the simplest technologies for wood-burning is the suspension or cyclone burner. This type of burner can be incorporated into a new wood-fired boiler or retrofitted onto an existing boiler that produces less than 50,000 pounds of steam per hour. These burners can burn only very fine, dry fuel--planar shavings, sawdust, ricehull fines, sunflower seed fines, and the like. In 1978, more than 200 of those units were being used in industry.(102)

Burning municipal solid wastes usually requires larger boilers than burning crop wastes does. Numerous technologies--most of which must be field-erected--are available for burning municipal wastes. In waterwall combustion, a furnace jacketed with water-filled tubes burns unsorted unshredded wastes or shredded wastes from which glass and metals have been removed ("refuse-derived fuels"). (See Part Two, Chapter Eleven, and Part Two, Chapter Thirteen.)

Facilities that now use gas or oil may find boiler retrofitting to burn wood or biomass difficult and costly. An alternative is to produce a medium-BTU gas on site with a small "package" wood gasifier coupled to the existing boiler kiln. (Once particulates are removed, medium-BTU gas is a close substitute for oil or gas.)

Besides new combustion equipment, electric generation facilities converting to wood may require additional handling, storage, and pollution-control equipment similar to that used in coal-burning facilities. New unloading equipment, processing equipment, conveyors or loaders, and storage devices will be needed in most cases, while processing- and storage-equipment needs vary with the type of combustion equipment chosen. For example, hammermills may be needed to grind such coarse fuels as nut shells for use in suspension burners, or silos may be needed to keep fuels dry enough to be used in moisture-sensitive technologies. Simple cyclones or (for larger boilers) electrostatic precipitators or baghouses may be needed to control air pollution.

Over 2,000 automated, wood-fired boilers are operating in the U.S. today, many of them for several years. The Weyerhaeuser Company joined with Oregon's Eugene Water and Electric Board (in Eugene, Oregon) in 1951 to install a multifuel boiler capable of burning coal, wood, or oil. For over thirty years, Weyerhaeuser and other utility customers have bought steam and electricity generated at the plant.

Wood gasification systems, like direct combustion systems, are well-proven. Commercially available since the turn-of-the century, these systems lost popularity in the 1950s and 60s but may be ripe for a comeback in the 80s. (Retrofitting boilers to use medium-BTU gas produced on-site by gasifiers requires replacing burners and expanding ductwork and fan capacity.)

Technologies for gasifying other renewable fuels are not yet commercially proven. A pilot gasifier installed at the Diamond Walnut Growers plant in 1976 with funding from the California Energy Commission produced a clean low-BTU gas from walnut shells when it was operating but suffered chronic mechanical problems, primarily due to clogging. In 1977, management decided to shut the gasifier down and pursue direct combustion instead.(103)

Overall, five considerations govern the viability of using biofuels. First, they are more flexible than other renewable sources of electricity to demand since they can easily be stored. Thus, small power producers can "time" operations so as to obtain the most favorable sell-back rates available.

Second, facilities that use biofuels must be near the fuel sources so as to minimize transportation costs. In facilities that generate energy from waste wood or solid waste produced on site--say, in furniture-manufacturing or waste treatment--transportation costs nothing, but biofuel sources are heavy and bulky so these (and storage costs) can mount up quickly with distance. Indeed, a good rule of thumb is that transporting biomass fuels much more than fifty miles to the point of use is uneconomic.(104)

Third, a biomass electrical generating facility must secure reliable commitments for the delivery of adequate and predictable raw materials. Supply interruptions or inadequacies can ruin the economics of these systems.

Fourth, using biomass resources in retrofitted power plants that previously burned oil or coal nearly always involves derating the plant's capacity unless remedial measures are taken. For example, retrofitting boilers to use medium-BTU gas produced on-site can cause derating of five percent to 25 percent in the existing boiler, depending on its design.

Finally, using biomass in electric generation entails some environmental penalties. Wood is high in particulates, although low in sulfur and nitrous oxides. Refuse-derived fuel is high in metallic content. Moreover, improved forest management is needed to avoid serious, long-term environmental impacts. Burning garbage for electricity without prior recycling is shortsighted.

ELECTRICITY FROM GEOTHERMAL RESOURCES

Geothermal energy can probably be used for electricity production in this country only in the West where high-temperature resources are available. But such large cities as Los Angeles, Salt Lake City, and Albuquerque could make use of geothermally produced electricity.(105)

Conceptually similar to conventional power production using heat engines or steam turbines, geothermal electric generation differs primarily in that the heat or steam used to run the turbines comes from the earth itself instead of from coal or fossil fuel, so no (or fewer) boilers are needed. (For example, Pacific Gas and Electric's Geysers Plant in Sonoma County, California uses high-temperature dry steam as a power source instead of boilers.(106) Of course, plants that use pressurized, high-temperature hydrothermal resources would need equipment to "flash" the hot water to steam, heat exchangers would be needed where heat engines are employed.(107)

The rated capacity of geothermal plants ranges widely. The Geysers facility--the largest in the world--has 906 MW of output. But it was developed incrementally between 1960 and 1980, and the smallest "unit" supplies only 11 MW of power while the largest supplies 135 MW.

Economically attractive, geothermal electricity production does have potential problems. At the Geysers, for example, substantial pollution-control equipment is needed to remove hydrogen sulfide, a polluting impurity in the stream. More generally, the long-term environmental effects stemming from the intensive exploitation of a geothermal store are not well understood.(108)

ELECTRICITY FROM SOLAR PONDS

The least suitable for city use of all of the "renewable electric" technologies discussed here is the solar pond. Most analysts agree that solar ponds capable of producing electricity can be located only in natural bodies of water on vast tracts of open space in the sun belt, since ponds capable of producing electricity must be several times larger than ponds supplying the same amount of energy as low-temperature heat.(109) Good examples of potential solar pond sites are the Salton Sea in California and the Great Salt Lake in Utah.

ECONOMICS OF COMMUNITY-SCALE SYSTEMS

The economics of the different electrical generating technologies discussed here are best compared in terms of capital costs per kilowatt of rated capacity and in terms of the delivered cost of the electricity (cents per kilowatt-hour). Capital cost is probably the best indicator when capital, fuel, and operation/maintenance costs represent roughly the same proportion of total costs for each system--especially if equipment costs, installation costs, and financing charges constitute the major element of total system costs. By the same token, this measure is far less useful when capital, fuel, and operating costs make up very different shares of the systems being compared. For example, oil-fired power plants cost less to build but far more to fuel than nuclear plants. Nuclear plants have low fuel costs, but very high construction and operation/maintenance costs. In hydropower and photovoltaic facilities, capital costs may be higher than in thermal plants but fuel and operating costs are far lower. (See Table One Hundred Forty-One.) To compare these different types of generating systems, information on the delivered costs of the power from each is needed.

CAPITAL COSTS PER KW OF CAPACITY

The estimated capital costs per kilowatt capacity for a number of smaller-scale electric-generating technologies are included in Table One Hundred Forty-Two. The numbers are given for general reference and comparison only. They should be interpreted cautiously since they have been supplied by various sources and reflect different base years. Moreover, the estimates do not include financing charges, which will increase the actual costs significantly, often by a factor of two or more.

Right now, the renewable technologies with the most operating experience are municipal solid waste systems, wood-fired systems, small hydro projects, and larger geothermal plants. Capital costs for many of the others--especially photovoltaic systems, solar thermal-electric facilities, and solar ponds--are more speculative.

The need for caution aside, these general figures suggest that some small-scale renewable technologies are competitive in capital costs with some conventional alternatives now. Even such expensive technologies as photovoltaics and central-receiver solar thermal-electric systems are expected to become competitive as DOE cost goals are met or approximated.

WOOD-SYSTEMS

The capital costs of wood-fired electric generating systems depend heavily on whether the wood-burning facility is new or retrofit onto a fossil fuel plant. In general, it takes more capital to construct a new wood-fired system than a coal- or oil-fired plant. At the least, larger boilers and fuel-handling systems are needed to obtain the same capacity rating because (non-pelletized) wood has a lower BTU content than oil or coal. (See Part Three, Chapter Fourteen.) However, coal-fired plants can often be retrofit to burn wood at relatively low cost.

WOOD VS. COAL

Capital costs for coal-fired facilities will vary with the sulfur content of the coal. Compared to a low-sulfur coal plant, a wood-fired plant has substantially higher capital costs, mainly because a larger boiler is needed to obtain the same output. But wood-fired systems are far more competitive with coal plants using high-sulfur Eastern or Mid-western coal, since these plants need expensive pollution-control equipment. (Wood-fired systems emit particulates, but no sulfur oxides and relatively little nitrous oxide.

Retrofits

Retrofitting a coal-fired boiler to burn wood can be inexpensive because the conversion technologies are similar. In some cases, wood can be substituted for coal with few modifications to the plant, although with significant capacity losses.

TABLE ONE HUNDRED FORTY-ONE

RELATIVE CONTRIBUTIONS OF CAPITAL, OPERATING,
AND FUEL COSTS TO TOTAL COSTS OF DIFFERENT THERMAL POWER PLANTS

<u>Plant Type</u>	<u>Capital Costs</u>	<u>Operating Costs</u>	<u>Fuel Costs</u>
Oil-fired	Low	Low	High
Coal-fired	Medium	High	Medium
Nuclear	High	Medium	Low
Wind	High	Medium	Low
Photovoltaics	High	Low	Low
Hydropower	High	Low	Low
Solar Thermal/ Electric	High	Medium/Low	Low
Solar Ponds	High	Medium/Low	Low
Waste-to- electricity	High	Medium	Low-to-medium
Geothermal	Medium	Medium	High

TABLE ONE HUNDRED FORTY-TWO

COSTS/KW OF CAPACITY FOR SMALLER-SCALE RENEWABLE
ENERGY ELECTRIC POWER TECHNOLOGIES

<u>Technology</u>	<u>Capital Costs/KW</u>
<u>Wood-fired systems</u>	Under \$10.00 in some installations (retrofits - coal)
(New - 25-60 MW) ¹	\$1,000 - \$1,900
<u>Small Hydroelectric Plants</u> (retrofit) ²	\$ 820 - \$2,358
(new) ³	\$ 3,200
<u>Photovoltaics</u>	
(current)	\$20,000
(DOE cost goals - 1986 ⁴ intermediate and central station applications)	\$1,100 - \$2,600
<u>Large wind systems</u>	
(100th unit - 200 KW) ⁵	
(100th unit - 2.5 MW) ⁶	\$ 1,717
<u>Solar Thermal Electric</u>	
(current)	
Barstow - 10 MW ⁷	\$14,990
Crosbyton- 5 MW ⁸	\$ 4,400
<u>Solar Ponds</u>	
(Assuming \$30/m ² ⁹ pond costs)	\$14,800 - (Southwest) \$27,300 - (Northwest)
<u>Geothermal</u>	
55 - 135 MW (1980) ¹⁰	\$203 - \$315
Sources:	1. Hewett and High (1978) Rocket Research Company (1980) SERI (1980) 2. U.S. DOE 3. <u>A New Prosperity</u> (1981) 4. U.S. DOE 5. U.S. DOE 6. U.S. DOE 7. U.S. DOE, <u>Project Summaries</u> (1980) 8. Monk (1979) 9. Edessess, (1980) 10. Dippio (1980).

Converting a 10-MW unit at the Moran generating station in Burlington, Vermont cost only \$25,000 (or \$2.50/KW).(110) Converting a 92-MW coal-fired plant to use wood residues as a supplementary fuel at Lake Superior District Power's Bay Front generating station cost under \$10/KW.

WOOD VS. OIL OR GAS

New Plants

Where wood-fired plants compete with facilities using oil or gas, results are very different than when coal is the alternative. Compared with an equivalent oil or gas system, new wood fired plants can require up to 250 to 700 percent higher capital investments.(111) Most additional costs are for boilers and more complicated handling and storage systems.

Retrofits

Converting an oil- or gas-fired plant to use wood is also much more complicated and expensive than converting a coal-fired plant. Boilers must be revamped and pollution control equipment to remove particulates from the flue gasses added. Given the expense of boiler conversions, a second retrofit option might be to replace the existing boiler with a wood boiler (which must be larger to provide the same rated capacity output). A third option might be to install an on-site wood-gasification system that could provide a low-BTU gas to the existing boiler, thus eliminating the need to replace or overhaul the existing equipment.

MUNICIPAL SOLID WASTE SYSTEMS

Assessing the capital costs/KW capacity of waste plants that produce steam for sale to power producers is difficult. Easier to gauge are the costs per input ton of waste per day. (See Part Two, Chapter Eleven.)

Few municipal waste plants generate electricity on-site. According to a recent survey, of 67 waste-to-energy projects, only eight were designed to produce on-site electricity and seven of these were not yet operating.

Differences between two systems currently under development illustrate how much costs/KW can vary. A plant in Columbus, Ohio, scheduled for completion in 1983 is slated to generate 90 MW of power from an 80 percent trash-20 percent coal mixture at a capital cost of \$152 million (or, less than \$1,900/KW).(112) An "all biomass" plant being developed for Plymouth, Massachusetts, is tentatively rated at 25 MW with a capital cost of \$124 million (\$4,100/KW) by the completion date in 1985.(113) While this is expensive, the region's heavy dependence on foreign oil and the steadily climbing costs of nuclear power may justify the expense.

HYDROPOWER

Almost all small-scale hydro development has been the conversion and renovation of existing dams, which costs only about half as much as building entirely new facilities.(114) Since capital costs can represent 90 percent of the total costs of a hydropower system, converted dams can generally provide electricity at cheaper rates than can new projects.

Costs of adding power-producing facilities to existing dams vary with the amount of head at the site, the planned rated capacity, and the condition of the existing facility. For a given capacity, costs will increase as height decreases. Below 65.5 feet of head, costs per KW begin to climb dramatically for a given capacity; and turbines used in low-head projects cost more per KW capacity than those used in higher-head applications because they have to be bigger to extract the same amount of power.(115) Finally, renovating facilities (dam, intake, penstock, powerhouse, etc.) can represent from 20 percent to over 60 percent of project costs. Some require adding generators in existing power houses, while others require construction work on the dam. (See Table One Hundred Forty-Three.)

Geothermal

Since 1960, Pacific Gas and Electric invested over \$159 million in 906-MW of geothermal resources at its Geysers Plant in Sonoma County, California. Taken together, the cumulative average capital cost for fifteen units of varying capacity ratings (11 MW to 135 MW) is \$175/KW. Predictably, the oldest units cost less and the newer ones more because of inflation and expenses related to meeting pollution control requirements aimed at eliminating hydrogen sulfide. (See Table One Hundred Forty-Four.)

Nonetheless, in 1976 PG&E reported that their geothermal plants were the least expensive to construct--26 percent cheaper than oil-fired plants, 50 percent less than coal-fired facilities, and 62 percent less than nuclear plants.(116) Costs are less

TABLE ONE HUNDRED FORTY-THREE

RANGES OF PROJECTED COSTS/KW FOR
PROPOSALS SUBMITTED TO DOE'S SMALL HYDRO PROGRAM

<u>Cost Range</u> <u>(\$/KW in 1980 \$)</u>	<u>Number of Projects in Range</u>
\$ 500 - \$1000	13
1000 - 1500	18
1500 - 2000	9
2000 - 3000	<u>5</u>
Total	45

Source: U.S. DOE

TABLE ONE HUNDRED FORTY-FOUR

COSTS PER KW FOR EACH UNIT IN GEYSERS GEOTHERMAL FACILITY

<u>Unit</u>	<u>Megawatts</u>	<u>Year of Commercial Operation</u>	<u>PG&E Capital Investment</u>	<u>\$/KW</u>
1	11	1960	\$ 4,010,000	167
2	13	1963		
3	27	1967	7,610,000	141
4	27	1968		
5	53	1971	12,756,000	120
6	53	1971		
7	53	1972	10,982,000	104
8	53	1972		
9	53	1973	13,520,000	128
10	53	1975		
11	106	1976	14,404,000	136
12	106	1979	21,473,000	203
13	135	1980	28,934,000	214
14	110	1980	27,966,000	254
15	55	1979	17,339,000	315

All figures in current dollars; capital investments figures for units 12-15 are estimates.

Source: DiPippo (1981)

because no boilers and accompanying control equipment are needed with a dry steam resource. (See Technical Approaches.)

OTHER TECHNOLOGIES

The capital costs of other renewable energy technologies are much more uncertain because operating experience is so limited. Many of the cost estimates of photovoltaics, solar-thermal systems, and (to a lesser extent) large wind systems reflect the assumption that cost goals will be reached in the late 1980s. The most dramatic improvements are expected to occur in photovoltaics development: costs per KW of capacity should drop from about \$20,000 to under \$2,000 with improved production techniques. As for the more "familiar" technologies--including wind energy conversion and hydropower--costs will drop as equipment goes into mass-production, though increases in the costs of materials and labor could offset this advantage.

Capital expenditures for most of these other renewable energy technologies will include substantial land costs--a key factor many analyses fail to take into account. Of course, photovoltaic and solar thermal-electric systems' collectors can be installed on the roofs of buildings or parking lots, and "wind farms" could be located on public lands, but realistic capital cost estimates for these systems must always include land costs.

DELIVERED COSTS PER KWH

Predicting the busbar (generated) costs of electricity for most of these technologies involves even more guesswork than projecting capital costs. Busbar costs are a function not only of capital and financing charges but also of fuel costs, both operating and maintenance expenses, and the electric generating system's capacity factor over its useful life. For renewable energy electric generating technologies, the availability of resources is important too, even when most other factors remain constant. For example, feasibility studies of potential small hydropower retrofits on the Scioto River near Columbus, Ohio, indicated that delivered costs of electricity would be 3.1 cents/KWH for one but 5.6 cents/KWH for the other, despite the similarity of development costs, because the higher head at one dam allowed the generation of about twice the electricity so capital costs could be spread out over a larger output range.(117)

Predictions about when renewable resource-dependent power will be generated also figure into any comprehensive economic analysis: power that offsets the need for peaking facilities is clearly more valuable than power that reduces the baseload. Finally, sell-back rates established under PURPA 210 will complicate things further both for small power producers and for consumers. With higher sell-back rates, small power producers can generate electricity at a lower cost per KWH because investments are "repaid" faster than the same capital investment would be where sell-back rates are lower. However, higher sell-back rates will not immediately reduce prices for consumers since the utility is paying small power producers the equivalent of avoided energy costs and capital costs and recapturing that payment in the rate base.

These complications notwithstanding, some provisional attempts have been made to estimate the busbar costs of renewable electric technologies. While they reflect different technological, financial, and economic assumptions, the two analyses summarized in Table One Hundred Forty-Five indicate that many centralized renewable electricity sources constructed between 1980 and 1990 could provide cheaper electricity (as calculated on a life-cycle cost basis) than many conventional electric generating technologies. Indeed, SERI work found that all six technologies surveyed here would cost less (on a life-cycle cost basis) than conventional alternatives if construction began in 1990. The California Energy Commission study suggests that all the five technologies listed in the table would generate electricity at lower life-cycle costs than oil-fired generation systems. Two (wind and wood) systems would produce cheaper electricity than generation technologies using natural gas, and all the rest would generate electricity at about the same costs as natural gas systems.

Of course, predictions cannot be verified without experience, most of which has so far been with biomass, small hydro, or geothermal projects.

BIOMASS SYSTEMS

Wood-Fired Systems

Besides the extra capital expense of a wood energy system, operation and maintenance costs can be significantly higher than those of an oil-fired system. Numerous firms currently using wood boilers conservatively estimate that annual O&M costs are approximately 15 percent of the capital costs.(118) Operating costs are also approximately 20 percent higher for wood energy systems than for oil-fired boilers, mainly because of the increased labor costs and operating energy connected with the storage and fuel-handling systems. Maintenance costs for wood energy systems can be as

TABLE ONE HUNDRED FORTY-FIVE

COSTS PER kWh OF VARIOUS RENEWABLE ELECTRIC TECHNOLOGIES (PROJECTED)

<u>Technology</u>	<u>Levelized Busbar Costs per kWh (¢/kWh) (1980 \$)</u>	<u>Assumptions</u>
<u>Group One¹</u>		
A. Large wind energy conversion system	10.7 (1980 - 2010) 7.9 (1985 - 2015) 4.7 (1990 - 2020)	• 25 wind machines rated at 2.5 MW at 27.7 Mph. • Total energy output at capacity factor of 38% equal to 208 million kWh per year. • Wind system life of 30 years. • Capital costs of \$1,900/kW (1980 \$) declining to \$829/kW (\$1980) in 1990. • Annual o & m costs = 1% of capital costs. • 50% financed from debt at 14% interest. • General inflation rate of 7.5% per year. • 10.5% nominal discount rate.

TABLE ONE HUNDRED FORTY-FIVE

COSTS PER kWh OF VARIOUS RENEWABLE ELECTRIC TECHNOLOGIES (PROJECTED) (CONTINUED)

<u>Technology</u>	<u>Levelized Busbar Costs per kWh (¢/kWh) (1980 \$)</u>	<u>Assumptions</u>
B. Solar thermal electric system-central receiver	20.0 (1980) 16.0 (1985) 12.0 (1990)	• 100 MW rated capacity. • Total energy output at 35% capacity factor equal to 303.5 million kWh per year • System life of 30 years • Capital costs of \$2811/kW (1980 \$) in 1980 declining to \$1650/kW (\$ 1980) in 1990. • Annual O & M costs = 2% of capital costs.
Centralized		
C. Photovoltaics	67.0 (1980) 32.0 (1985) 8.4 (1990)	• 10 Mw rated capacity. • Total energy output at 24% capacity factor equal to 21 million kWh per year. • System life of 25 years. • Capital costs of \$10,851/kW (1980 \$) in 1980 declining to \$1,800/kW (1980 \$) in 1990.

TABLE ONE HUNDRED FORTY-FIVE

COSTS PER kWh OF VARIOUS RENEWABLE ELECTRIC TECHNOLOGIES (PROJECTED) (CONTINUED)

<u>Technology</u>	Levelized Busbar Costs per kWh <u>(¢/kWh) (1980 \$)</u>	<u>Assumptions</u>
D. New wood-fired electrical generation	4.9 (1980)	● Annual o & m costs = 1% of capital costs
	5.0 (1985)	● 50% financed from debt at 14% interest
	5.0 (1990)	● General inflation rate of 7.5% per hour
		● 10.5% nominal discount rate
		● 61 MW rated capacity
		● Total energy output of 374 million kWh per year at 70% capacity factor
		● System life of 20 years
		● Capital costs of \$1,208/kW (\$ 1980) in 1980 increasing to \$1,447 (\$ 1980) in 1990.
		● Annual o & m costs = 4.5% of capital costs
		● 100% of costs financed by debt at 10.5% interest
		● 7.5% inflation rate
		● 10.5% nominal discount rate

TABLE ONE HUNDRED FORTY-FIVE

COSTS PER kWh OF VARIOUS RENEWABLE ELECTRIC TECHNOLOGIES (PROJECTED) (CONTINUED)

<u>Technology</u>	<u>Levelized Busbar Costs per kWh (¢/kWh) (1980 \$)</u>	<u>Assumptions</u>
E. Retrofit low head hydroelectric facility	6.0 (1980) 5.0 (1985) 4.0 (1990)	• 3.4 mW rated capacity at head of 20.4 ft. and average mean annual flow of 2370 CFS • Total energy output at 60% capacity factor equal to 18 million kWh per year • System life of 40 years • Capital costs of \$1,320/kW (\$ 1980) in 1980 declining to \$1003/kW (1980 \$) in 1990 • Annual o & m costs = .15% of capital costs
F. Geothermal		• 50 MW capacity from hydrothermal resource supplying 92,500 lb/hr 464°F. • Total energy output at capacity factor of 90% equal to 16.4 million kWh per year. • Life of wells, 10 yrs.; distribution system, 20 yrs.; electrical conversion equipment, 30 yrs. • Capital costs of \$1664/kW (1980 \$) in 1980; increasing to \$1704/kW (\$ 1980) in 1990. • Annual o & m costs = 3.2% of capital costs.

TABLE ONE HUNDRED FORTY-FIVE

COSTS PER kWh OF VARIOUS RENEWABLE ELECTRIC TECHNOLOGIES (PROJECTED) (CONTINUED)

<u>Technology</u>	<u>Levelized Busbar Costs per kWh (¢/kWh) (1980 \$)</u>	<u>Assumptions</u>
		• 60% of well costs, 50% of plant costs financed from debt at 11.5% • 7.5% inflation rate • 10.5% nominal discount rate
<u>Group two²</u>		
A. Utility wind systems	7.5 (1990 - 2020)	• System operates for thirty years starting in 1990, at 35% capacity factor • Capital costs of \$880/kW (1980 \$) in 1990 • Annual o & m costs account for 7% of levelized costs • Levelized costs include yearly inflation rate of 6.5% between 1990 and 2020 • Nominal discount rate of 12% • Interest rate of _____
B. Photovoltaics - central station	31.7 (1990 - 2020)	• System operates for 30 years starting in 1990 at 22% capacity factor • Capital costs of \$1894/kW (1980 \$) in 1990 • Annual o & m costs account for 5% of levelized costs

COSTS PER kWh OF VARIOUS RENEWABLE ELECTRIC TECHNOLOGIES (PROJECTED) (CONTINUED)

<u>Technology</u>	<u>Levelized Busbar Costs per kWh (¢/kWh) (1980 \$)</u>	<u>Assumptions</u>
		● Levelized costs include yearly inflation rate of 6.5% between 1990-2020 ● Nominal discount rate of 12% ● Interest rate of —
C. Wood-fired power plants	14.4	● System operates for 30 years starting in 1990 at a 80% capacity factor ● Capital costs of \$1033/kW (\$ 1980) in 1990 ● Annual o & m costs account for 1.4% of levelized costs ● Levelized costs include 6.5% yearly inflation 1990 - 2020 ● Nominal discount rate of 12% ● Interest rate of —
d. Conventional hydroelectric	32.5 (1990-2020)	● System operates for thirty years (1990-2020) at capacity factor of 20% ● Capital costs of \$1,300/kW (1980 \$) in 1990

TABLE ONE HUNDRED FORTY-FIVE

COSTS PER kWh OF VARIOUS RENEWABLE ELECTRIC TECHNOLOGIES (PROJECTED) (CONTINUED)

<u>Technology</u>	Levelized Busbar Costs per kWh <u>(¢/kWh) (1980 \$)</u>	<u>Assumptions</u>
E. Geothermal (Flash steam)	30.1 (1990 - 2020)	• Annual o & m costs account for 3.1% of levelized costs • Levelized costs include 6.5% yearly inflation (1990 - 2020) • Nominal discount rate of 12% • Interest rate of — • System operates for thirty years at 70% capacity factor. • Capital costs of \$1130/kW (1980 \$) in 1990. • Annual o & m costs account for 3.7% of levelized costs • Levelized costs include 6.5% yearly inflation (1990 - 2020)

Sources: Group 1: SERI, Cost of Energy from Renewable and Conventional Technologies, (1981)

Group 2: California Energy Commission, (1981)

much as 200 percent of those for a comparable oil-fired system. Any economic advantages of wood-fired systems must thus stem from lower fuel costs.

Although it is impossible to derive "one" cost for wood, the comparison in Table One Hundred Forty-Six indicates that wood costs per BTU are generally significantly lower than fossil fuel costs--in many cases lower enough to more than offset the higher capital and maintenance costs of a system. (See Table One Hundred Forty-Seven.) In practice, wood costs vary with the kind of wood used, the distance it must be transported, and the nature of the local market for wood and wood products. (See Fuels from Renewable Resources.)

Plant ownership also affects the delivered costs of electricity from wood-fired plants. All other things being equal, publicly owned utilities can probably produce the lowest-cost electricity for a given fuel cost because they can use tax-free bonds for 100 percent debt financing, they are exempt from Federal income tax payments, and they do not need to return profits to investors. (See Table One Hundred Forty-Eight.)

It is worth noting that the financing assumptions used in these analyses may be optimistic. All assume long-term bond financing at 10.5 percent interest or less, whereas the New York Times reports that the Bond Buyer's Index of 20 average municipal bond yields hit 12.97 percent in August of 1981. Still, even the highest estimates of delivered costs are roughly competitive with current delivered electricity prices in many areas. So resource availability or environmental constraints are greater potential problems than economic feasibility.

MUNICIPAL SOLID WASTE SYSTEMS

Since very few MSW systems generate electricity on-site, precise assessments of the costs per KWH from such systems is premature. The prices of electricity produced from steam or RDF sold to utilities will depend in part on the prices charged for the input steam or RDF, but also on such other features as the plant's capacity factor, the capital costs of any adjustments needed to allow the use of RDF, and whether the plant is a base-, intermediate-, or peak load.

Fuel and maintenance costs influencing the prices of steam and RDF are discussed in Chapters Eleven and Thirteen, respectively. It should be remembered that such costs are affected both by the reliability of refuse supplies and the operating patterns and the efficiency of the refuse-processing facilities.

The costs of steam and electricity production from these plants can also be offset by the tipping fees charged for dumping refuse. For example, the Office of Technology Assessment has found that some landfills currently charge tipping fees as high as \$15 to \$18 per ton as available land decreases. Tipping fees this high could help make solid waste plants economical.

HYDROPOWER

As noted, capital costs account for most of the costs of hydroelectricity. But low operation and maintenance costs and free fuel more than compensate. Still, the importance of capacity factors cannot be overemphasized. For example, the SERI analysis shows that a small hydro facility operating at a 60 percent capacity factor can produce electricity far more cheaply than many conventional alternatives. However, the California Energy Commission finds that the levelized costs of a conventional hydropower facility operating at only 20 percent of capacity are far higher than those for most thermal power plant alternatives except where oil is the primary fuel.(119) Nonetheless, the relatively low busbar costs from existing or planned hydroelectric facilities suggest that existing dams with reliable levels of sufficient power potential should be considered for retrofits to produce hydroelectricity. (See Table One Hundred Forty-Nine.)

GEOHERMAL

Fuel costs--the prices that the power producer must pay for the steam--represent the largest fraction of busbar electricity prices from geothermal plants. Unlike capital and operating and maintenance costs, steam costs are highly variable. The formula that PG&E uses to buy steam for the Geysers units is determined in part by the amount and cost of electricity produced from fossil and nuclear facilities during the previous year and the development costs of the field. (A surcharge to cover the cost of reinjecting spent geofluid is also added.) Consequently, the cost of steam will rise and fall with the prices of fossil fuel prices and electricity from conventional sources. Indeed, in 1969, the price of Geysers' steam sold to PG&E was \$.0026/KWH (MMBTU). By 1978, it had increased sixfold to \$.016/KWH (\$4.69/MMBTU).(120)

At the Geysers, PG&E has found maintenance requirements to be somewhat greater than those in conventional fossil fuel-fired power plants. Turbine blades and electrical equipment fail more frequently at geothermal stations because of the corrosive nature of

TABLE ONE HUNDRED FORTY-SIX

WOOD & FOSSIL FUEL COSTS IN SOUTHEASTERN UNITED STATES - 1979

<u>Fuel</u>	<u>Unit Costs</u>	<u>\$/MMBTU</u>
Coal (25% moisture content)	\$55 per ton	\$2.63
Wood pellets (10% moisture content)	\$35 per ton	2.94
Wood chip (47% moisture content)	\$12 per ton	1.99
Wood residue . (47% moisture content)	\$ 8 per ton	1.33
Oil	\$.60 per gallon	5.00
Natural gas	\$.03 per cubic foot	3.86

Source: Levi & O'Grady 1980.

TABLE ONE HUNDRED FORTY-SEVEN

SIMPLIFIED COMPARISON OF OIL AND WOOD-FIRED BOILERS
(16.7 MMBtu/hr. Capacity)

<u>Capital Investment</u>	<u>Wood-Fired</u> <u>(Green wood fuel)</u>	<u>#2 Oil-Fired</u>
Boiler, installed with fuel handling and limited storage	\$300,000	\$ 60,000
Incremental capital investment for wood		-\$240,000
<u>Annual fuel cost (at 40 percent utilization of full capacity)</u>		
Oil at \$5/million Btu (in steam) wood at \$1/million Btu (in steam)	59,572	297,662
Gross annual savings using wood		+\$238,090
Incremental operating costs for wood fuel		<u>-\$ 60,000</u>
Net annual savings on operations		\$178,900

TABLE ONE HUNDRED FORTY-EIGHT

DELIVERED ELECTRICITY COSTS OF SIMILAR WOOD-FIRED COGENERATION PLANTS UNDER DIFFERENT OWNERSHIP PATTERNS
\$/MMBTU (Mills/KWH)

<u>Ownership</u>	<u>\$2.50/1000 lbs. Steam</u> <u>\$7.13/BDT Wood</u>	<u>\$4.55/1000 lbs. Steam</u> <u>\$7.13/BDT Wood</u>	<u>\$2.50/1000 lbs. Steam</u> <u>\$14.26/BDT Wood</u>	<u>\$4.50/1000 lbs. Steam</u> <u>\$14.26/BDT Wood</u>
Private In- dustry	\$16.19 (55)	\$14.10 (48)	\$18.28 (62)	\$16.40 (56)
Investor- Owned Utility	\$15.25 (52)	\$13.47 (50)	\$17.44 (59)	\$15.60 (53)
Municipal Utility	\$ 7.93 (27)	\$ 5.95 (20)	\$10.33 (35)	\$ 8.35 (28)

Source: Rocket Research (1980)

TABLE ONE HUNDRED FORTY-NINE

BUSBAR COSTS OF ELECTRICITY FROM EXISTING OR PLANNED LOW-HEAD HYDRO PROJECTS

<u>Project</u>	<u>Ownership</u>	<u>Hydraulic Head</u>	<u>Capital Costs</u>	<u>Financing</u>	<u>Capacity Factor</u>	<u>Busbar Costs/kWh</u>
Great Falls ¹ (Paterson, NJ)	Municipal	70 ft.	\$800/kW (1978 \$)	Tax exempt revenue bonds at 7% and 40 year term		2.1¢ (1981)
Boott Mills ² (Lowell, MA)	Private	34	\$1900/kW	Bank loan at 14% - 30 years	62%	6.2¢
Idaho Falls ³	Municipal	19	\$1500/kW (1981 \$)	Electric revenue bonds at 6.7% - 30 years		2.5¢
Columbus ⁴ Griggs Dam	Municipal		\$1800/kW	bonds at 6% - 25 yrs		5.6¢
Columbus ⁴ O'Shaugnessy Dam	Municipal		\$800/kW	Bonds at 6% - 25 yrs		3.1¢

Sources:

the rock- and dust-laden steam, and maintenance shutdowns have resulted in higher forced outage rates than expected at the plant.

OTHER TECHNOLOGIES

Computing the costs of delivered power from technologies not in widespread use is even more conjectural, though a few general points can be safely made. First, estimates of delivered energy costs depend heavily on future cost reductions in equipment. Second, for all of these technologies fuel costs will amount to little or nothing since sunlight and wind are free. However, developers may need to purchase solar access or wind access easements, which could be very expensive. Third, there is no reason to assume that operating and maintenance costs for these systems will be inordinately high. In general, photovoltaic and wind power applications would appear to have lower maintenance requirements than the higher-temperature and more complex solar thermal-electric and solar pond systems. Fourth, ownership patterns will affect delivered costs of electricity from these systems. For example, the California Energy Commission has found that the levelized costs of electricity from all of these technologies are considerably cheaper under municipal than under private ownership. (See Table One Hundred Fifty.)

TABLE ONE HUNDRED FIFTY

<u>Technology</u>	<u>Levelized Costs (¢/kWh) (1990-2020) (IOU Ownership)</u>	<u>Levelized Costs (¢/kWh) (1990-2020) (Municipal Ownership)</u>
Utility wind system	7.5	5.0
Photovoltaics - Central Station	31.7	20.9
Wood-Fired Power Plants	14.4	11.6
Conventional Hydro- electric	32.5	16.6
Geothermal (Flash steam)	30.1	16.1

Source: California Energy Commission (1981)

DEVELOPMENT OPTIONS

Even relatively small-scale community electrical systems require large capital investments. (For example, the Minnesota Energy Agency calculated that a 2.5 MW wind system would cost over \$1.7 million in 1980.)(121) Consequently, these systems will have to be planned and financed by organizations with access to relatively large amounts of capital--utility companies, industries, private developers, city government, or some combination of these investors.

Utilities

Utilities--the most likely potential investors--will be encouraged to invest in renewable sources of electric power if those resources can provide cheaper and more reliable electric capacity than thermal power plants, if the utilities are allowed adequate returns on investment, and if institutional restrictions do not channel investments away from renewable energy technologies and toward conventional facilities.

As noted, a few utilities are beginning to recognize the economic advantages of some solar electric technologies. But these examples by no means signal a complete turnaround on investment policies in the industry as a whole. Some utilities have access to relatively cheap fuel mixes and/or have excess capacity already. (See Part One, Chapter six, Energy Supply and Distribution Systems, pp. xx-xx.)

And most utilities are often reluctant to make substantial renewable energy investments because of a number of countervailing factors--fear of the untried and unfamiliar for example. San Diego Gas and Electric, in spite of its dependency on oil and gas, still apparently views renewable energy technologies as too risky and prefers to allow larger neighboring utilities such as Southern California Edison to absorb many of the development risks.(122) Still other utilities seem to be waiting for improved technologies or for the fairly substantial cost reductions for equipment that may occur in the next few years. Uncertainty about the reliability of technologies dependent on climate and natural resources--however unfounded--also govern utility's investment decisions.

One way for utilities to reduce perceived risks would be for them to form partnerships with industrial or private developers. (Arkansas Power and Light's cogeneration marketing strategy and New England Electric's "wind farm" project exemplify this approach.) Yet, some observers believe, utilities shy away from "third party" partnerships because they are reluctant to sacrifice control over development decisions for what they believe to be minimal benefits.(123)

Finally, many of the subsidy, tax, and regulatory barriers that impede utility involvement in on-site conservation may keep them from investing in small-scale supply technologies. For example, utilities' creation of subsidiaries to market cogenerating solar electric technologies is restricted by Federal law.(124)

Given these factors, much of the impetus for developing community-scale renewable electric systems may come either from private developers who plan to sell power to large individual users or to utilities or from city governments working through municipal utilities or with private partners.

Private Developers

The private concerns most likely to develop community electrical systems are such companies with some fuel resources already at hand--such as industries with large amounts of waste heat that could be used to run generators or with large volumes of waste products that could be used to fire steam boilers. Alternatively, the Boott Mills Complex in Lowell, Massachusetts, is using its own water resources and dam to generate hydroelectricity, most of which will be sold to industrial customers in the mill complex itself.(125)

Prevailing financial conditions and the investment criteria applied by most private firms clearly constrain private development. Private companies are less likely to obtain below-market financing and they have fewer tax advantages than city governments or municipal utilities. Indeed, one study of potential cogeneration projects found that private developers' costs per KWH produced were somewhat higher than the costs for investor-owned utilities and much higher than those for municipal utilities.(126) At the same time, private firms have the strictest criteria for evaluating investments, often requiring annual rates-of-return exceeding 20 percent. Under such circumstances, private small power producers would not invest without guarantees of fairly high purchase rates from reliable private users or from the local utility.

Private developers could enter into partnerships with utilities or city governments: the private firm could provide the development expertise or the resource, and the utility or city government could provide access to less costly capital or a reliable market for the power produced. For example, a steam-producing resource recovery plant in Saugus, Massachusetts, was developed by two private companies--a construction company that owned a landfill site slated for closing and an engineering firm brought on as technical consultants. The new refuse-to-energy company they formed secured commitments for refuse supply from surrounding municipalities, while the "host" community, Saugus,

posted revenue bonds when it learned that the facility would provide substantial tax revenues for the town.(127)

City Governments

Finally, renewable energy-based electric generating facilities could be developed by cities themselves, especially those with municipally owned utilities and readily accessible resources. Thus, Idaho Falls is currently developing 24.6 MW of hydroelectric capacity on the Snake River(128) and the utility at Burlington, Vermont has retrofit one 10-MW power station to burn wood and plans to build another with 50 MW of rated capacity.(129) Columbus, Ohio's municipal utility plans to stop purchasing power from an investor-owned utility and to start generating most of its power from a city-owned resource recovery plant.(130) Los Angeles' Energy/LA Plan directs the Department of Water and Power to investigate regional wind energy potential.

Cities without municipal utilities could also develop their own generating facilities to produce electricity for use within their own borders or for sale to the local utility, particularly if there is ready access to "free" resources, either in the form of municipally owned waterways or municipally owned land in areas with good sunlight or wind access.(131) In one such application, Paterson, New Jersey, is investigating developing 7.5 MW of hydroelectric capacity on the Passaic River.(132) Well-planned resource recovery plants using nonrecyclable urban wastes represent another possibility.

Of course, the large capital investments required for such projects may prevent even those cities with readily available resources from developing on their own. In such cases, partnerships with private developers or investor-owned utilities may work.

Chapter Thirteen

Industrial Process Heat

BACKGROUND

Industry uses a large share (39.3 percent in 1980) of the U.S. energy budget and presents enormous potential for improved energy efficiency and increased renewable energy use. Some 43 percent of industrial energy goes for process heating,(1) the focus of this chapter. The rest is used for machine driven electric power and such feedstocks as construction asphalt and metallurgical coal.

Current Energy Use

In many cities, industries rely heavily on scarce or expensive fuels. As shown in Table One Hundred Fifty-One, the percentage of energy consumed by industry is substantial in many cities. The types and amount of fuels used by local industry depend largely on fuel availability and the industrial mix. (See Tables One Hundred Fifty-Two and One Hundred Fifty-Three.) Urban industries that rely heavily on expensive, scarce, or imported fuels may be particularly concerned with decreasing this dependency. Uncertainties about price and availability of oil may encourage industry managers to work with city officials to increase energy efficiency and the use of renewable fuels. For example, St. Paul began city-wide energy planning efforts in 1979 at least partly because of such uncertainties.

Relying heavily on electricity, which is getting even more expensive, also poses problems for industries. Portland's aluminum industry uses 25 percent of the city's industrial energy in processing, and 89 percent of that energy is electric. While the abundance of cheap hydroelectric power in the Pacific Northwest initially attracted the aluminum industry, the increasing electrical demands that accompanied regional growth have now made the aluminum industry, the city, and regional utilities concerned about the high monetary and environmental costs of constructing new coal and nuclear generating facilities. Both the Bonneville Power Authority and the City of Portland are now encouraging industrial conservation.

Southern Florida faces great uncertainty about the future of its industrial energy supply. The area's industry is very electricity-intensive, with local utilities supplying 66 percent of its industrial energy. Some 36 percent of electricity generation uses oil as the primary fuel. Local utilities, already faced with high oil costs, are trying to avoid adding expensive new generating capacity. Among other measures, Florida Power & Light, a local utility, is offering lower (so-called interruptible) rates to industrial customers willing to stop consuming electricity during peak demand periods.

Energy and Employment

Many of these same cities face industrial employment problems that can be exacerbated by energy price increases or shortages. In Northeastern and Midwestern cities, where manufacturing employment has declined 0.1 percent annually for the past decade(2) and industry relies heavily on imported oil, city officials may be particularly concerned about how energy price hikes and shortages affect local employment. Bridgeport, Connecticut, is such a city. Between 1971 and 1975, energy consumption in Bridgeport's industrial sector declined 28.6 percent.(3) The point is not that consuming mere energy would create more jobs for cities like Bridgeport but that a carefully planned program of conservation and the increased use of renewable energy could help local industry avoid slow downs, lay-offs, production cuts, and plant closings next time oil prices escalate rapidly. As discussed below, conservation and renewable energy investments could also help create new jobs in manufacturing, installation, and maintenance.

While manufacturing employment in the South and West is in much better shape (increasing 2.4 percent annually from 1971 through 1980 and expected to keep growing during the next ten years),(4) job benefits will still result from industrial conservation and renewable energy improvements in these regions. For example, the Los Angeles Energy Management Advisory Board expects that city's historical overall job growth to continue. Still, it is trying to make sure that job losses in such sectors as construction, agriculture, mining, transportation, and trade can be made up with new jobs created by the "Energy/LA" Action Plan--a comprehensive, citywide program calling for \$1.2 billion in conservation and renewable energy investments. Fully implementing the action plan's provisions for industrial conservation improvements would alone create 326 new construction jobs over eight years and 840 new permanent jobs in operation and maintenance. At the same time, it would create secondary jobs by keeping money in the local economy.(5)

Energy Saving Potentials

A growing body of literature identifies great potential for improving industrial energy efficiency.(6) For example, after ranking its 18 member countries, the International Energy Agency found that U.S. is the most energy-efficient manufacturer of aluminum only. Industrial energy efficiency in the U.S. ranks 13th in steel, 13th in cement, 9th in pulp and paper, and 9th in petroleum production.(7)

TABLE ONE HUNDRED FIFTY-ONE
PERCENTAGE OF LOCAL ENERGY USE CONSUMED BY INDUSTRY

<u>City</u>	<u>Percent Total Energy Used by Industry</u>
Boulder	8.9%
Dayton	49.4%
Greenville, NC	17.0%
Dearborn	47.2%
Lawrence, Mass.	37.1%
Knoxville	15.3%
Bridgeport, CN	21.3%
South Florida*	14.8%
Los Angeles	12.4%
Miami	6.3%
Portland (1971)	39.0%
Philadelphia	20.0%

* Miami, Broward, Dade, and Monroe Counties

Source: Comprehensive Community Energy Management Plans developed by Cities 1978-1980.

TABLE ONE HUNDRED FIFTY-TWO

INDUSTRIAL ENERGY CONSUMPTION BY MAJOR INDUSTRY GROUP AND FUEL TYPE, 1978

Industry (SK Code)	Total Energy Consumer (10 ¹² Btu)	Electricity (%)	Fuel Oil (%)	Coal & Coke (%)	Natural Gas (%)	LP Gas (%)	Other Fuels (%)
Food and kindred products (20)	980.5	14.1	20.7	11.0	43.6	0.0	10.1
Tobacco Products (21)	20.8	20.8	34.6	-	10.8	0.0	33.8
Textile Mill Products (22)	326.6	28.1	28.8	9.0	23.0	1.0	10.2
Apparel and other textile products (23)	69.1	33.3	12.5	2.1	22.3	0.0	29.3
Lumber and wood products (24)	231.1	24.6	20.5	-	26.4	1.0	27.5
Furniture and fixtures (25)	55.3	26.3	14.0	5.0	33.7	1.0	19.9
Paper and allied products (26)	1301.1	12.0	39.2	16.7	27.0	0.0	5.0
Printing and publishing (27)	91.5	38.6	9.1	-	30.8	0.0	21.0
Chemicals and allied products (28)	2905.3	17.1	13.8	12.0	50.8	0.0	6.0
Petroelum and coal products (29)	1122.7	9.2	6.4	-	78.7	0.0	5.4
Rubber and misc. plastics (30)	261.0	30.0	21.5	7.5	28.7	0.0	11.7
Leather and leather products (31)	21.6	22.0	34.1	6.6	26.1	0.0	10.9
Stone, clay and glass products (32)	299.8	8.6	12.3	29.6	42.4	0.0	10.9

TABLE ONE HUNDRED FIFTY-TWO

(Continued)

Industry (Sic Code)	Total Energy Consumer (10 ¹² Btu)	Electricity (%)	Fuel Oil (%)	Coal & Coke (%)	Natural Gas (%)	LP Gas (%)	Other Fuels (%)
Primary metal in- dustries (33)	2710.9	21.0	12.9	24.7	37.5	0.0	3.6
Fabricated metal pro- ducts (34)	400.2	22.5	11.8	2.8	49.9	1.0	11.8
Machinery, except electrical (35)	350.7	29.3	11.1	6.6	39.9	1.0	11.9
Electric and ele- ctronic equipment (36)	254.9	34.9	12.6	5.4	26.1	1.0	10.9
Transportation equipment (37)	397.7	27.3	12.6	13.6	38.0	1.0	7.5
Instruments and related products (38)	79.0	24.5	16.7	-	23.3	0.0	35.2
Miscellaneous man- ufacturing industries	49.0	27.8	18.2	-	31.0	2.0	21.6

TABLE ONE HUNDRED FIFTY-THREE

PRINCIPAL INDUSTRIES AND INDUSTRIAL FUEL MIX BY CITY

		Fuel Mix (Percent Industrial Energy Use)							
<u>City</u>	<u>Principal Industries</u>	<u>Total Industrial Energy Use (10⁹ Btu)</u>	<u>Electricity</u>	<u>Fuel Oil</u>	<u>Natural Gas</u>	<u>Propane</u>	<u>Coke & Coal</u>	<u>Steam</u>	<u>Other</u>
Boulder	Computers; paving & gravel; aircraft	1,838	23		77				
Dayton	Transportation Equip- ment; machinery, food	16,246	24.7	8.7	45		16.9	4.7	
Greenville	Light manufacturing & assembly; food processing, agri- business, pharmaceuticals	815	41	42	18				0.2
Wayne County, MI	Motor vehicles; steel machinery; fabricated metals	133,270	19.9	10.3	40.8		23.5		5.5
Knoxville	Apparel; textile mills; food processing, machinery	7,893	28.7	11.1	46.3	1.4	11.2		1.3
Bridgeport	Fabricated metals; transportation equip- ment; electrical equipment	11,980	20.9	54.9	24.5				
South Florida	Food processing; stone, clay & glass	13,682	66	.03	30				

Source: Comprehensive Community Energy Management Plans developed by Cities 1978-1980

TABLE ONE HUNDRED FIFTY-THREE

(Continued)

<u>City</u>	<u>Principal Industries</u>	<u>Total Industrial Energy Use (10⁹ Btu)</u>	<u>Electricity</u>	<u>Fuel Oil</u>	<u>Natural Gas</u>	<u>Propane</u>	<u>Coke & Coal</u>	<u>Steam</u>	<u>Other</u>
Los Angeles	Petroleum refining; food processing; stone, clay & glass; transportation equip- ment	44,700	29.5	24.6	45.6				
Portland	Paper & allied products; primary metals (aluminum); construction; lumber & wood; food processing	98,821	28.4	17.4	43.9				10.3
Philadelphia	Food processing; apparels & textile products; printing & publishing; textile mills	47,900	17.1	65.9	15.4			1.5	

Renewable energy's potential in industry is also underutilized. Direct plant-site combustion of such readily available renewable fuels as scrap wood at lumber mills is increasing, and technologies to convert renewable fuels to easily used gases and liquids are also becoming increasingly widely accepted. (See Chapter Fourteen.) The use of active solar collectors for industrial process heating is more expensive and less immediately economically and technically feasible. But 27 percent of industrial process heating requirements nationally are for temperatures less than 550 degrees F, which solar collectors can supply.(8) Using solar heat for preheating and using improved collectors to supply higher-temperature heat should increase solar energy's potential for meeting industry's process heating needs.

Such "theoretical" potential is verified by real-world improvements. Nationally, industry's energy efficiency can be measured by its energy consumption per "gross product." Also called the "energy-value added" ratio, this measure of industry's productivity relative to its energy consumption rose sharply from 1967 and dropped equally sharply from 1970 to 1979. Accordingly, the Solar Energy Research Institute says that "the energy productivity of American industry increased rapidly during the 1970s."(9)

Industry's interest in energy conservation is manifested in its voluntary participation in the Department of Energy's monitoring program. In 1977 manufacturing corporations participating in the program accounted for 53 percent of total U.S. industrial energy consumption. As Table One Hundred Fifty-Four indicates, five of the industry groups had already exceeded their 1980 targets by 1979. Overall, these ten industry groups reduced their energy consumption per unit of output by an average of 15.4 percent between 1972 and 1979.(10) Since most of the industry groups increased output during that period, overall energy efficiency in the ten industries actually increased an average of 17.6 percent, primarily because of low- and no-cost conservation measures.(11)

The success of the voluntary monitoring program has been widely reported through industry trade associations and publications. Some cities have used this information to develop industrial conservation programs and efficiency goals. For example, the Los Angeles Energy Management Advisory Board urges the city to work closely with utilities and industry to reach by 1985 the state goal of 15 percent (above the 14 percent Los Angeles already achieved) improvement over 1979 consumption levels.(12) Staff of the Los Angeles energy office also searched through issues of "Energy User News," the files of local gas utility, and information provided by the American Institute of Plant Engineers for case studies of successful industry conservation projects. They subsequently used these to evaluate the technical and economic feasibility of industrial conservation improvements and disseminated that information to local industries. A typical case history describes Firestone Tire's manufacturing plant in Akron, Ohio.(13) Firestone invested some \$4 million between 1972 and 1981 to redesign its rubber-curing process to recover waste heat. It also improved its boilers and added insulation. Energy consumption declined about 20 percent.

Industry has also begun to use renewable energy. Besides the increased use of wood and renewable fuels described above, both Federally- and privately-funded solar energy systems are supplying process heat to a variety of industries.(14)

Barriers to Increased Efficiency

Great improvements in industrial energy efficiency do face formidable barriers, success stories aside. First, few firms have the economic incentive to make major investments in energy efficiency since even in the most energy-intensive industries, energy comprises only 2.8 percent of total operating costs.(15) Even industry managers who are convinced of the need to spend money for conservation improvements may have difficulty obtaining the necessary capital. For example, the steel, aluminum, and cement industries experienced an average return on sales of only 3.9 percent in 1979.(16) Since most industrial investments (including energy conservation investments) are financed internally, these low returns discourage any additional expenses.

Even when investment capital is available, most industrial managers first make investments in facilities that will expand production. Next in line are required investments in pollution control and industrial health and safety. Conservation improvements thus compete with other uses of the remaining "discretionary capital."(17) These economic barriers to conservation are exacerbated by Federal tax laws, which allow conventional energy costs to be deducted from taxes as an annual operating expense.

A second barrier keeping industry from investing more heavily in conservation and renewable energy technologies is the lack of reliable information on the technical performance and cost savings associated with these systems. Because of declining profitability, industrial investment in research and development has been decreasing since 1964. Where operating experience is scant, industry managers are reluctant to make major investments. The technical and economic information that is available is most easily used by large companies with in-house engineering expertise. In mid-sized firms, engineers tend to focus on production rather than energy-conservation improvements, while most smaller firms lack any information on energy costs or energy-saving options.(18)

TABLE ONE HUNDRED FIFTY-FOUR

ENERGY-EFFICIENCY IMPROVEMENT PROGRESS
FOR TEN MAJOR ENERGY-CONSUMING INDUSTRIES (1972 Base Year)

<u>SIC</u>	<u>INDUSTRY</u>	<u>1980 TARGET</u>	<u>PROGRESS THROUGH 1979</u>
20	Food and kindred products	12%	15.3%
22	Textile mill products	22%	17.7%
26	Paper and allied products	20%	16.9%
28	Chemicals and allied products	14%	22.0%
29	Petroleum and coal products	12%	14.7%
32	Stone, clay and glass	16%	12.9%
33	Primary metal industries	9%	7.8%
34	Fabricated metal products	24%	21.5%
35	Machinery (except electrical)	15%	24.7%
37	Transportation equipment	16%	23.4%

Source: DOE, 1980, Annual Report to the Congress and the President on the Industrial Energy Efficiency Improvement Program.

For example, a city-run survey of industries in Seattle found that the ten largest firms were tracking energy consumption and starting to make conservation improvements, while only three of 18 mid-sized firms surveyed were monitoring their energy use and none had increased their energy efficiency through plant changes.(19)

The Role of Government Programs

Local government programs can greatly help industry overcome barriers to investments in conservation and renewable energy technology. For example, Los Angeles predicted that its energy-management efforts could save 50 percent more industrial energy than market forces alone would prompt industry to save. Seattle estimated that an energy-conservation package combining information, regulations, and incentives would reduce industrial energy use by ten to 30 percent in each facility.(20)

Local government programs directed toward industries can take several forms. In areas currently attracting new industries, development policies should attract industries that use energy efficiently.(21) For example, cities could award business licenses and review development plans on a priority basis for industries able to show that they would use energy frugally. Alternatively, zoning provisions could be structured so that industries expending large quantities of waste heat of potential use in cogeneration or district heating locate near large residential and business complexes. (See Part II, Chapter Eleven.)

For established industries, cities could develop information, incentive, or regulatory programs to encourage or require conservation efforts. For example, Los Angeles' city-owned Department of Water and Power provides on-site audits for large industrial and institutional electricity customers, identifying relatively inexpensive conservation improvements. On average, 60 percent of the identified conservation measures are being implemented. The audit program, along with seminars and printed information for smaller customers, is expected to cut projected electricity consumption by 6.5 percent by the year 1990.(22) Seattle's Energy, Ltd. plan would require all firms to conduct a walk-through energy audit.(23)

In many Northeast and Midwestern cities, the problem is not attracting new industries but retaining old ones. And in any area, levying energy-conservation mandates on industries, particularly those in bad financial shape, could compel them to close or relocate. In such situations, cities could combine regulatory requirements with financing programs. In Seattle, for example, the Energy Ltd. plan also included provisions for the city to help finance audits and technical assistance.

This chapter provides some of the technical information city officials need to help develop an effective conservation and renewable energy program for local industries. First, conservation approaches ranging from relatively inexpensive housekeeping measures to potentially expensive process changes are considered. Then, renewable energy's potential in industry is discussed.

Housekeeping and Maintenance Improvements

The Department of Energy estimates that the average industrial plant can reduce energy consumption three to seven percent through administrative or informational programs and an additional five to ten percent through small incremental investments in improved equipment. However, the potential savings of low-cost conservation programs may be greater still. Indeed, the average 15.4 percent savings achieved by major industries in the DOE voluntary monitoring program was attributed largely to such low-cost measures as energy-management training, insulation, and better fuel-use controls.(24) And the Los Angeles Department of Water and Power anticipates 35 percent savings at industrial plants that implement the low-cost housekeeping improvements that L.A. Water and Power suggests.(25)

Technical Approaches and Issues

Numerous inexpensive approaches can be used to reduce energy consumption at industrial plants. One of the least expensive is to train employees to turn off lights and equipment when not in use. (Hughes Aircraft in Tucson, Arizona, claims to have saved \$100,000 per year between 1972 and 1979 through an "Employee Energy Watch" program.) Typically, such training programs are incorporated into a larger conservation program. For example, a chemical plant in Lynwood, California, owned by Cargill, Inc., trained employees to shut off gas and electric equipment when not in use as part of a larger effort that included changing steam lines and adding a new heat exchanger.(26)

Another approach to improving energy efficiency in industry is to improve fuel combustion in boilers, kilns, and other heaters. By measuring the oxygen content of gasses expelled from industry burners, energy engineers can determine whether the fuel-air combustion mix contains the right amount of air. Simple boiler or furnace adjustments can optimize the ratio of air to fuel to improve combustion. For example, one Union Carbide plant saved 97 million BTU per year by carefully controlling combustion.(27) In the petroleum industry, 72 percent of the corporations reporting energy savings between 1972 and 1979 under DOE's voluntary monitoring program saved

significant amounts of energy by making combustion improvements in their process heaters. Besides optimizing air-to-fuel ratios, combustion efficiencies can be improved by keeping burners free of soot and other deposits.

Many inexpensive industrial maintenance improvements are aimed at making process steam use more efficient since 36 percent of all industrial fuel is used to produce steam. Improvements can range from plugging leaks to improving steam distribution to the recovery of steam condensate. A common problem in distribution systems is malfunctioning steam traps. When these traps, which remove water condensed in the pipes, stick open, steam is lost. The Union Carbide plant is reported to have saved 78 million BTUs of energy annually by training personnel to inspect, maintain, and replace defective steam traps. Because of the high costs of water purification for use in steam boilers, steam systems are usually closed loops, recirculating the steam condensate to the boiler. And losses in the condensate return system waste energy since more heat will be needed to purify makeup water and the heat in the condensate is lost, so careful maintenance is critical.

Another low-cost approach to improved industrial energy efficiency is to time equipment use--shutting off equipment when not in use or changing overall production timing. To optimize production scheduling, the relationship between energy use and product output must be carefully analyzed. For companies that consume approximately the same amount of energy at lower and higher rates of output, operating 24 hours in a "batch" production mode for several days and then shutting down entirely for several days may be the most energy-efficient path. (The Union Carbide plant referred to earlier saved 175 billion BTU in six months by switching to batch production.)(28) Other companies may be better off operating fewer pieces of energy-consuming equipment at full capacity, rather than more lower capacity. (DuPont reports saving the equivalent of 10,000 barrels of oil per year by shutting down some of its chemical-refining columns operating at partial capacity and operating others at full load.)(29)

A final "housekeeping" approach is to insulate boilers, pipes, and other heat-transfer equipment. Indeed, a 1975 study by the Federal Energy Administration estimated that if all U.S. industrial plants made maximum use of insulation, the equivalent of 3.5 billion barrels of oil could be saved between 1976 and 1990.(30) Among the improved industrial insulating materials now becoming available is ceramic fiber, which is easier to store and install and has a higher R-value than firebrick formerly used on industrial furnaces. A forging company in Fontana, California, insulated its ovens with ceramic fiber and saved 55,440 therms of natural gas in the first year. In Pasadena, a plumbing-manufacturing plant reduced overall annual energy use by 25 percent by lining its furnaces with \$225,000 worth of lightweight fiber insulation which paid for itself in one year.

Insulation can have especially great energy saving impact when added to steam-distribution systems. One study reports that an uninsulated eight inch diameter steam pipe carrying steam at 350 psi loses approximately three billion BTU per 100 feet.(31) Larger pipes operating under higher pressure lose even greater amounts of heat. Along with other low-cost improvements at a manufacturing plant in Southgate, California, insulating steam lines reduced annual gas bills by 67 percent.(32)

Urethane foam is also increasingly popular for industrial applications, particularly the easy-to-install spray-on type. Like other organic materials, urethane burns at high temperatures, releasing toxic combustion gasses. It may also crack and shrink at high temperatures below the flash point. Consequently, urethane is used to keep the cold in or out of an industrial process. For example, the owners of the Hunts Point Cooperative Market in New York City added urethane foam and PVC outer jackets to 1.5 miles of brine-carrying steel pipes that connect chillers in a utility building to the warehouse and market buildings, making possible the use of an innovative heat-recovery system that can save 220,000 gallons of fuel oil annually.(33) At the American Can Company plant in Ashland, Wisconsin, two inches of sprayed-on urethane foam added to a clarifier tank greatly reduced plant down-time due to freeze-ups in the tank. At a cost of \$4,600, the insulation saved \$10,000 in reheating costs during the first winter.(34)

Economics

Low-cost administrative and housekeeping changes generally have very rapid paybacks. (See Table One Hundred Fifty-Five.) These measures can thus be attractive to even the most skeptical plant manager since in terms of payback they can compete with investments in production equipment.

However, not all simple conservation improvements are inexpensive. Insulating steam pipes or tuning up gas burners may be undertaken by plant employees at the cost of materials, but employee-training programs or large repair programs may entail high labor costs. However, even very expensive programs may have rapid paybacks. For example, a medium-sized Union Carbide plant that initiated a program to inspect, maintain, and replace defective steam traps at a cost of \$15 million per year saved \$175 million in fuel costs during the first year.(35)

TABLE ONE HUNDRED FIFTY-FIVE
ECONOMICS OF INDUSTRIAL "HOUSEKEEPING" MEASURES

<u>Firm</u>	<u>Location</u>	<u>Description of Measure</u>	<u>Annual Savings</u>				<u>Simple Payback</u>
			<u>Cost</u> <u>Materials</u>	<u>Labor</u>	<u>Therms</u>	<u>\$ (@30¢/therm)</u>	
Hughes Aircraft	Tucson	Employee Energy Watch				\$100,000	
Cargill	Lynwood, CA	Insulate steam pipes	\$ 3,000	\$ 0			
		Install heat exchanger	\$ 7,000				
		Fine tune gas burners	\$ 0	\$ 0			
		Employee energy awareness training program	\$ 0	\$ 0			
		Reduce time required for process cycles	\$ 0				
		<u>Total</u>	\$10,000			\$ 78,000	.13 year
Forging Co.	Fontana, CA.	Install ceramic fiber insulation on a furnace	\$ 4,000	\$1,000	55,400	\$ 16,600	.30 year
Ceramic Company	San Fernando Valley, CA	Install ceramic fiber insulation on three kilns	\$ 2,550	\$ 650	25,271	\$ 7,500	.50 year
Plumbingwear manufacturer	Pasadena, CA	Line furnaces with lightweight fiber insulation		\$225,000	745,000	\$223,500	1 year
Juice Company	Orange County, CA	Install insulation on pasteurizer	\$ 1,300	\$ 425	2,026	\$ 608	3 years

Source: Case Histories of Energy Savings in the Industrial Sector, Pat Lang, 1981.

WASTE HEAT RECOVERY

The potential for reducing industrial energy consumption by recovering waste heat is quite large--up to 25 percent of industrial process energy consumption, according to expert consensus.(36)

Waste heat is available from a variety of sources at various temperatures. Direct firing of furnaces produces byproduct heat at 1,200 to 3,000 degrees F. Exhaust temperatures from boilers, gas turbines, reciprocating engines, and heat treating furnaces range from 450 to 1,200 degrees F. In addition, many low-temperature sources such as steam condensate, cooling water from furnace doors and engines, and air conditioning and refrigeration condensers produce heat and hot water at 90 to 450 degrees F.

Technical Approaches

Various techniques can be used to recover waste heat.(37) If the hot air or exhaust gas is relatively clean, it can be used directly for another process. A more common approach is recuperation, in which a heat exchanger is used continuously to transfer the heat content of waste gasses, air, or hot water to another medium, rather than using it directly. In regeneration, heat from exhaust gasses is conducted to a heat exchanger and stored before being used to preheat combustion air. Finally, waste heat boilers use a recuperation system in which waste heat is used to help produce process steam, heat water, or generate electricity.

In non-industrial applications, heat exchangers operate an average of 80 percent efficiency. However, in industrial applications scale build-up and corrosion caused by hot gases reduces their ability to transfer heat. Other limitations are relatively high costs and restrictions on the type of waste heat streams with which they can be used.(38) Metal and ceramic recuperators (or "economizers") used to recapture heat from exhaust for use in preheating combustion air currently operate at only 30 to 40 percent efficiency at best.(39) Heat wheels can be used to exchange both heat and the latent heat contained in water vapor between exhaust and entry gas streams. (See Part Two, Chapter Nine.) A newer, more efficient heat-exchange technology uses heat pipes to transfer exhaust gas heat to combustion air. Working much as a simplified air conditioner does, a heat pipe circulates an organic working fluid between intake and exhaust air ducts. As the fluid passes through a hot exhaust duct, it absorbs heat and vaporizes. As it circulates to the cooler inlet duct, it loses heat and recondenses. Some types of heat exchange equipment (finned tube generators, for example) can transfer heat from a gas to a liquid or vice versa.

All of these industrial heat exchangers are commercially available, while more efficient recuperators that can be used in various high-temperature applications are being developed privately and by the Department of Energy. However, the currently available systems are popular despite their limitations. The chemical industry has made major capital investments in waste heat recovery and industrial cogeneration. Two thirds of the corporations participating in DOE's industrial energy monitoring program claimed to have made significant investment in heat-exchange and improved waste-heat recovery equipment.(41) In the cement industry, where 80 percent of industrial process heat is used for firing kilns, conservation efforts are focussing on recovery of heat from kiln exhaust gasses.(42) The glass industry is also increasing investment in heat recovery from its natural gas-fired furnaces, and the paper industry is increasingly using waste heat for cogenerating and for heating both buildings and process water.

Examples of individual plants that have successfully installed heat recovery equipment abound.(43) Cargill, Incorporated, installed a \$7,000 heat exchanger in its plant in Lynwood, California. The heat exchanger uses waste heat from plant processes for two purposes--to preheat combustion air for the incinerator and to maintain a "hot room" for chemical processing. In Baldwin Park, California, a foundry installed a boiler blowdown heat recovery system on five boilers that saved almost 316,000 therms of natural gas in the first year, showing a payback of only a few months. A smelting operating in Los Angeles installed a recuperator to preheat combustion air with exhaust gas from the furnace, saving nearly 90,000 therms of natural gas per year. A paper plant in Oxnard, California, installed an economizer that uses waste heat from the boiler to preheat boiler feedwater to 230 to 273 degrees F and preheat air for a hot air dryer. In a polystyrene products manufacturing plant in Southgate, California, a blowdown heat recovery unit was installed at a steam boiler, preheating the boiler feedwater from 60 to 110 degrees F and thus allowing a reduction in boiler steam pressure. At the same time steam lines were insulated, steam traps to improve condensate return were installed, and a better-insulated condensate collector tank added. As a result, annual gas bills at the plant fell by 67 percent.

A final case study illustrates both the large theoretical potential for reduced energy consumption and some of the technical difficulties of recovering waste heat in

industrial processes. A Solar Energy Research Institute team studying the energy inputs and exhaust energy outputs of an aluminum can manufacturing company found that about 48 percent of the total energy input leaves in the waste gasses. Investigating the feasibility of recovering this lost energy, the team found that the most important factor affecting gas recycling at this plant is maintaining an adequate air-to-gas ratio for combustion.(44) Since, no more than 25 percent of the exhaust gasses could be recycled without affecting the current ratio, either the 25 percent limit would have to be observed or some means of generating adequate temperatures at a lower air-to-gas ratio would have to be found. Theoretically, the most important limiting factor on gas recycling under the second option would be maintaining a safe concentration of vaporized organic solvents, which is not a problem unless more than 55 percent of the exhaust gasses were to be recycled. At the 55 percent level, it turns out, exhaust gasses would supply 27 percent of total process heat requirements, thereby greatly reducing natural gas consumption.

While heat recovery systems make use of lower-quality waste energy "cascaded" from high-temperature industrial processes, another approach involves using waste heat from cogeneration. (See Part Two, Chapter Eleven and Part Three, Chapter Twelve.)

The potential for using excess heat from electrical power production for industrial process--clearly exists.(45) All of the many technical approaches for recapturing waste heat produced by on-site power generation involve so-called "topping cycles," in which steam is first used to drive a turbine or generator and then recaptured for process heat. The type of topping cycle cogeneration used at an individual factory depends largely on the type of electric generating system in place. Some factories use gas or diesel turbine generators, which are relatively inexpensive, easy to maintain, and can be arranged in modules to meet changing electricity demand. For smaller generating requirements, reciprocating heat engines can be used.

The most commonly used industrial cogenerating system, the steam turbine, is also the most expensive and least efficient, producing electricity at an overall efficiency of only ten percent.(46) High capital costs aside, though, such systems can burn coal, wastes, or other less expensive fuels. Moreover, their overall efficiencies can be improved by cogenerating.

A final approach to industrial cogeneration is the so-called "combined cycle," in which a gas turbine is used to generate electricity and hot exhaust. As in the gas turbine topping cycle, turbine exhaust gasses are used to heat a working fluid in a boiler. Steam (or organic vapor) thus created drives a second electric generator which gives off waste heat that is used for process needs.(47)

Economics

The economic appeal of waste heat recovery depends on the costs of purchased fuels, the amounts and temperatures of available waste heat, such design details as the distance that waste heat must be transported, and other factors. That appeal is also relative, so plant managers should compare waste heat recovery with temperature reduction strategies. In 1977 researchers estimated the cost of a gas-to-gas heat exchanger recovering four MMBTU per hour from a 500 degrees F heat source at \$120,000 to \$200,000.(48) If the system operated at 80 percent effectiveness for half the year and replaced natural gas costing \$1.50 per MMBTU (\$0.15/therm), it would pay for itself in 4.6 - 7.7 years. If the costs of such a system rose ten percent by 1980, it would have cost \$159,720 to \$266,200 in 1980, by which time industry was paying \$2.12 per MMBTU of natural gas. Hence, payback by 1980 would have fallen to between 4.3 and 7.2 years. If the heat exchanger replaced deregulated natural gas (which cost \$6.80/MMBTU at the marginal price in January of 1980),(49) it would pay for itself in 1.3 to 2.3 years.

In 1977 a gas-to-gas heat exchanger capable of delivering 12 MMBTU per hour from a higher-temperature heat source would have cost \$260,000 to \$450,000 and had a payback of 3.25 to 5.6 years.(51) Given January, 1980, equipment costs and energy prices, the system would cost \$346,060 to \$598,950 and pay for itself in 3.06 to 5.3 years when displacing regulated natural gas or industrial distillate.

Since 1980, regulated natural gas prices have risen still further to \$3.00/MMBTU or higher, and heat recovery equipment has become less expensive. As a result, paybacks at some factories may well be shorter now. As Table One Hundred Fifty-Six indicates, the paybacks on heat recovery equipment are often rapid enough to spur investment.

Improved paybacks aside, many economic barriers remain. Some firms may require energy conservation equipment to pay for itself more rapidly than investments in improved production equipment on the assumption that conservation investment is more technologically risky. For such firms, even a heat exchanger that pays for itself in six months may seem worth the price.

IMPROVED ENERGY EQUIPMENT AND CONTROLS

TABLE ONE HUNDRED FIFTY-SIX
ECONOMICS OF WASTE HEAT RECOVERY IN INDUSTRY

<u>Firm</u>	<u>Location</u>	<u>Description of Measure</u>	<u>COST</u>		<u>Annual Savings</u>		<u>Simple Payback</u>
			<u>Materials</u>	<u>Labor</u>	<u>Therms</u>	<u>\$ (@ 30¢/therm)</u>	
Beverage Manufacturer	San Fernando Valley	Install economizers on four boilers plus a blowdown heat recovery unit	\$190,000	\$47,500	337,000	\$101,000	2
Ceramic Manufacturer	Commerce, CA	Install a recuperator on a kiln	\$ 32,000	\$ 8,000	148,700	\$ 44,610	.7
Smelter	Los Angeles	Install a recuperator on a furnace	\$ 46,000	\$11,500	89,615	\$ 26,880	2
Foundry	Baldwin Park	Install boiler blowdown heat recovery unit on 5 boilers	\$ 10,819	\$ 2,700	315,511	\$ 94,650	.1
Cardboard Container Corp.		Install blowdown heat recovery unit on a boiler	\$ 3,100	\$ 800	37,800	\$ 11,304	.33
Carpet cleaning/dyeing firm		Install counter flow heat exchanger	\$ 12,000	\$ 2,000	19,543	\$ 5,800	3
Foundry	Anaheim, CA	Install recuperator on furnace	\$ 3,245	\$ 800	4,500	\$ 1,350	4

Source: Lang, 1981, Case Histories of Energy Savings in the Industrial Sector

Technical Approaches

Rather than recapturing heat wasted because combustion is inefficient or because equipment and load are mismatched, industry managers may choose to replace or add newer, more efficient equipment and control systems to reduce heat losses. Since almost every industry has many "unit" processes (e.g., generation and distribution of steam), they can be improved incrementally. Substantial energy savings can be realized in this way, especially if computerized control systems that optimize fuel use in a number of different processes are installed.

Unit changes can be as simple as replacing one machine or as complicated as redesigning a system. For example, turbulators costing only a few thousand dollars can be installed in boilers to slow water flow, thus increasing heat transfer. One fertilizer producer in California realized savings of 12,000 therms of natural gas per year after adding turbulators.(51) Similarly, a can-manufacturing plant in Pasadena, replaced its old burner system with a new system that could be controlled more precisely to maintain the correct gas-to-air ratio. This system costs only \$12,000 and paid for itself in two years.(52) In a more complex improvement costing \$39,140, a forge in Santa Ana replaced its existing furnace with an indirect-fired recirculating air furnace, saving \$34,934 therms of natural gas per year.

In some cases, factory managers may find adding new energy-recovery equipment more economical than simply replacing inefficient units. In Lynwood, California, a synthetic resin manufacturing company installed condensate return lines at the same time it insulated its steam lines. Overall, the plant's total gas consumption fell by 47 percent (or 368,800 therms per year.)(53)

The most sophisticated energy control systems are computerized. (See Part Two, Chapter Nine.) In industrial applications, computers can perform such maintenance- and equipment-scheduling functions as monitoring boilers, condensate return systems, and waste heat recovery equipment. The expense, size, and complexity of the computerized control system depends on whether local, central manual, or central automatic control is desired.

New computers now available can be "hard-wired" or they can use software packages to optimize plant ventilation, equipment start-up times, and fuel-use rates and to shed electrical demand during peak loads. In particular, optimizing "enthalpy" (or ventilation) is important since process heating requirements can increase greatly if outside air at low temperatures is admitted. A Winnebago-manufacturing plant in Forest City, Iowa, recently wired its chassis preparation room, the most energy-intensive section of the plant, for computer control of fuel use. The system cost \$160,000 and saved \$166,900 in the first year.(54) In Taft, Louisiana, a Union Carbide plant installed a computer system to monitor plant operations, schedule environmental maintenance, and control the use of steam, by-product gasses, and raw materials. The firm now uses 12 percent less energy than in 1972, while productivity has increased 30 percent.(55)

Economics

Improved energy equipment and control systems vary widely in cost. As Table One Hundred Fifty-Seven indicates, most such equipment is slightly less economically attractive than the waste heat recovery systems discussed previously. While some measures have paybacks of only one or two years, such improvements as replacing furnaces and kilns have four- or five-year paybacks. Few firms are, thus, likely to make these investments unless the equipment was due for replacement anyway.

As Table One Hundred Fifty-Eight shows, the costs of computer systems installed at industrial and commercial facilities varies with the degree of sophistication--from a \$10,000 mini-console to over \$250,000 for a "dedicated computer."(56) Varying installed costs reflect the different number of points in the building monitored, labor rates, the plant's design, and the location of equipment. Wiring and communication expenses can account for more than one half of the computer system's installed cost.(57) In fact, the wiring is very difficult to remove and its resale value is almost nothing so a company that invests in a system and then wishes to replace it will take a large loss. Overall the higher costs and longer paybacks of these sophisticated systems compared to those of simpler "housekeeping" and heat recovery measures may restrict investments, especially given lingering uncertainty about these technologies potential effectiveness.

The most common source of industrial financing for any type of conservation improvement is internally generated capital. Industrial firms with little internal capital may seek bank loans to finance conservation equipment. But high interest rates (17 to 22 percent), and short terms (three to five years) may foreclose this option.

To spur reluctant industry managers to invest in computers and other sophisticated conservation equipment, a growing number of engineering firms and equipment manufacturers are offering innovative financing plans. These allow industries to install and use the conservation equipment without tying up their capital in what they view as unproven

TABLE ONE HUNDRED FIFTY-SEVEN
ECONOMICS OF IMPROVED EQUIPMENT AND CONTROLS

<u>Firm</u>	<u>Location</u>	<u>Description of Measure</u>	<u>Cost</u>		<u>Annual Savings</u>		<u>Simple Payback (year)</u>
			<u>Materials</u>	<u>Labor</u>	<u>Therms</u>	<u>\$ (@ 30¢/Therm)</u>	
Steel Company	Alhambra, CA	Install ladle preheater on 6 ladles	\$ 17,700	\$ 4,400	110,000	\$33,300	.7
Forge	Santa Ana, CA	Replace direct fired furnace with indirect recirculating air	\$ 31,340	\$ 7,800	34,933	\$10,480	4
Can manufacturer	Passadena, CA	Replace old burner system with newer, more easily controlled burners		\$12,000	21,000	\$ 7,508 (@35¢/therm)	2
Appliance Manufacturer	Los Angeles, CA	Install fiber insulation in ovens and furnaces add hot air duct returns to furnaces		\$62,000	519,552	\$15,500	4
Tile Manufacturer	Pomona, CA	Replace 2 existing kilns with 1 more efficient kiln	\$459,000	\$100,000	302,000	\$90,600	5
Barrel Refiner	Montebello, CA	Replace boiler with waste heat boiler	\$ 40,000	\$ 10,000	190,000	\$57,000	1
Cattle Feed Company	Riverside, CA	Install turbulators in boiler	\$ 1,700	\$ 425	2,558	\$ 767	3

Source: Lang, 1981

TABLE ONE HUNDRED FIFTY-EIGHT
ECONOMICS OF COMPUTERIZED ENERGY-MANAGEMENT SYSTEMS

<u>Firm</u>	<u>Location</u>	<u>Functions</u>	<u>Cost</u>		<u>Annual Energy Savings</u>	<u>Simple Payback</u>	<u>Financing</u>
			<u>Computer</u>	<u>Wiring</u>			
R. H. Macy Properties	Paramus, NJ	Peak load reduction at electrically heated shopping center	\$ 30,000		About 1/3		internal cash flow
Rouse Corporation	Throughout U.S.	Climate control at 10 shopping centers	\$ 12,000 - \$ 18,000	\$38,000 - \$57,000	12-15%		lease-purchase
Winnebago	Forest City, Iowa	Controls fuel use in chassis preparation room (distributed processing system)	\$160,000		\$166,900	1 year	
Schlosser Forge	Cucamonga, CA	Control of high-temperature forging process	\$400,000		\$199,000	2 years	
Union Carbide	Union Barbidge	Controls fuel use, scheduled maintenance, use of steam, exhaust gasses, raw materials			\$500,000		
Goodyear Tire	Albany, NY	Temperature control in 300,000 ft ² warehouse	\$ 7,302		\$9,000 + \$9,000 savings in maintenance costs	0.4 years	

Sources: Interviews with Rouse Corp., R. H. Macy (3/81); Lang, 1981

technologies. All such alternatives which range from leasing to "shared savings" and "guaranteed cash-flow," cost more over five years than a purchase financed with a five-year, 18 percent loan. But many plans would require no capital investment and most include maintenance and engineering services. With little or no capital investments to offset, monthly payments for equipment leasing or rental are immediately compensated for by utility bill savings. Some arrangements even guarantee a certain level of savings.(58) (See Tables One Hundred Fifty-Nine and One Hundred Sixty.)

PROCESS CHANGES

All of the conservation improvements described so far make improved use of energy in existing industrial processes. Another approach to decreasing industrial energy consumption is to redesign or restructure the manufacturing process. Depending on the industry, new processes can reduce energy use per unit of output by 20 to 90 percent.(59)

Technical Approaches

In the past, new industrial processes were developed primarily to produce a needed product more efficiently and cheaply. Today, however, process improvements may be triggered by rising fuel prices. Chances are that most such efforts will take place in the five major manufacturing categories that presently account for 75 percent of total industrial fuel purchases.(60)

Pulp and Paper

The pulp and paper industry is the third largest energy user among manufacturing industries. Purchased fuels, which account for half of the energy this industry uses, include oil (39 percent), natural gas (27 percent), coal and coke (18 percent) and electricity (18 percent). The other half of this industry's energy needs are met by such on-site byproducts as bark, waste wood, "white liquor," and "black liquor."

Many process improvements being developed in the pulp and paper industry are aimed at reducing unnecessary drying operations. Currently, pulp is dried at the pulp mill and then shipped to a paper mill, where it is moistened before being formed into paper. Integrating the two operations would eliminate the need to dry the pulp, thus reducing total energy required to produce paper by about 10 percent.(61) Alternatively, the separate processes could be made more energy efficient. In Oxnard, California, a pulp mill installed a \$300,000 "Hi--Pli" press to reduce moisture content of the pulp slurry, thus reducing drying energy needs. Along with other improvements, the new press is credited with reducing natural gas consumption by 14.3 percent and electricity use by 8.2 percent annually since 1979.(62) At paper plants, new paper-forming processes that require less drying fuel are being developed. In one, water is mechanically removed from the paper web before it is steam-dried.

Within the pulping process (which accounts for 42 percent of all energy consumption in the industry)(63) are numerous opportunities for making energy use more efficient, primarily by increasing the use of waste byproducts. The two commonly used processes for pulping are mechanical pulping and the draft (or sulphate) process. Because it makes greater use of byproduct liquors, the Kraft process requires much less energy. Yet, 25 percent of the pulp produced in the U.S. in 1978 was still processed mechanically. Completing the transition to the Kraft process could reduce energy consumption in pulping by six to ten percent.(64) Purchased energy use can be reduced even further by increasing use of the "black liquor" byproduct, a condensate of pulping vapors. In theory, the pulp and papermaking industry's purchased energy requirements could be reduced to almost nothing by increased use of waste byproducts.(65) A final area of energy efficiency improvement for pulp and paper-making lies in the development of oxygen-bleaching technology, which uses much less energy than current bleaching techniques.

Overall, new processes have the potential to reduce energy consumption at new paper plants by 30 to 40 percent in the near term and by as much as 80 percent over the long term.(66) But achieving this potential will be difficult since the industry is highly capital-intensive and slow to change. In the DOE voluntary conservation program, which was aimed primarily at relatively inexpensive housekeeping-, heat-recovery, and control improvements, pulp and paper manufacturers failed to meet their 1980 goal of a 20 percent improvement in energy efficiency. In 1976, the industry spent only 12 percent of its profits on research and development, compared with a 16.4 percent average among other energy-intensive industries.(67) However, some firms have begun to increase drying efficiencies, reclaim fibers, and make other process changes.(68) Then too, once the industry has met pollution-control requirements, it may intensify its efforts to develop, demonstrate, and use more energy-efficient processes.

Primary Metals

Manufacturing of primary metals requires large amounts of high-temperature thermal energy. To meet that energy need, a modern integrated iron- and steelmill typically uses

TABLE ONE HUNDRED FIFTY-NINE

SIX METHODS OF FINANCING ENERGY CONSERVATION PROJECTS

ASSUMPTIONS:

\$100,000 Energy Conservation Project

\$ 50,000 Per Year Energy Savings

10 Percent Prime Interest Rate

50 Percent Tax Bracket

Purchase Using 5-Year \$100,000 Bank Loan	5-Year Lease-Purchase at 20 Percent	Guaranteed Cash Flow 5-Year Contract	Shared Savings with 5-Year Contract	Energy Services 5-Year Contract	Five-Year Lease at 18 and 25 Percent Interest
		(Note: Spokesmen of companies offering this plan said their firms must borrow money at prime rate or higher, so must charge higher rates than prime.)			(Note: Leasing rates can vary. Some lessors of- fer prime rate to lessors, others and up to 7 points to prime rate.)
Payments toward equity \$100,000	Payments toward equity \$100,000	Payments toward equity \$100,000	Payments toward equity None with most plans	Payments toward equity None with most plans	Payments toward Equity 0
Capital outlay \$100,000	Capital outlay 5-10% of Equip- ment cost	Capital outlay Estimated \$15,000 for feasibility study	Capital outlay 0	Capital outlay 0	Capital outlay 5-10% of equip- ment cost
Total payments \$152,360.40	Total payments \$156,000	Total payments \$160,143	Total payments \$125,000	Total payments 0	Total payments \$150,000 at 18% \$172,500 at 25%
Energy cost savings to user over 5 years \$250,000	Energy cost savings to user over 5 years \$250,000	Energy cost savings to user over 5 years \$250,000	Energy cost savings to user over 5 years \$125,000 (half of \$250,000 savings over 5 years)	Energy cost sav- ings to user over 5 years \$100,000 (if energy ser- vices firm takes tax advantages \$40,000 if user takes tax ad- vantages	Energy cost sav- ings to user over 5 years \$250,000

TABLE ONE HUNDRED FIFTY-NINE

SIX METHODS OF FINANCING ENERGY CONSERVATION PROJECTS (CONTINUED)

Purchase Using 5-Year \$100,000 Bank Loan	5-Year Lease-Purchase at 20 Percent	Guaranteed Cash Flow 5-Year Contract	Shared Savings with 5-Year Contract	Energy Services 5-Year Contract	Five-Year Lease at 18 and 25 Percent Interest
Tax Benefits Not Applicable to non-profit institutions	Tax Benefits	Tax Benefits	Tax Benefits	Tax Benefits	Tax Benefits
Depreciation \$100,000	Depreciation \$100,000	Depreciation \$100,000	Depreciation 0	Depreciation \$100,000 if user elects to take it	Depreciation 0
Interest Deduction \$52,360.40	Interest Deduction \$56,000	Interest Deduction \$69,143	Interest Deduction 0	Interest Deduction 0	Interest Deduction User can write off 100% of lease pay- ments, in this case either \$150,000 or \$172,500, depend- ing on leasing rate
Total Deductions \$152,360.40	Total Deductions \$156,000	Total Deductions \$169,143	Total Deductions 0	Total Deductions \$100,000 if user elects to take it	Total Deductions \$150,000 at 18% \$172,000 at 25%
Credits \$10,000 invest- ment tax credit (ITC) (10%), \$10,000 energy conservation tax credit (ECTC) (10%), if applicable)	Credits \$10,000 invest- ment tax credit (ITC) (10%), \$10,000 energy conservation tax credit (ECTC) (10%), if applicable)	Credits \$10,000 invest- ment tax credit (ITC) (10%) plus \$10,000 energy conservation tax credit (ECTC) (10%), if applicable)	Credits 0	Credits \$10,000 invest- ment tax credit (ITC) (10%) and \$10,000 energy conservation tax credit (ECTC, if ap- plicable) if user elects to take them	Credits If available, user can negotiate for \$10,000 investment tax credit (ITC) (10%) and \$10,000 energy conserva- tion tax credit (ECTC) (10%).

TABLE ONE HUNDRED FIFTY NINE

SIX METHODS OF FINANCING ENERGY CONSERVATION PROJECTS (CONTINUED)

Purchase Using 5-Year \$100,000 Bank Loan	5-Year Lease-Purchase at 20 Percent	Guaranteed Cash Flow 5-Year Contract	Shared Savings With 5-Year Contract	Energy Services 5-Year Contract	Five-Year Lease at 18 and 25 Percent Interest
Net tax benefits 50% bracket \$86,180.20 plus \$10,000 ECTC, if applicable.	Net tax benefits \$38,000. plus \$10,000 for ECTC if applicable	Net tax benefits \$94,571.50 plus \$10,000 for ECTC if applicable	Net tax benefits 0	Net tax benefits \$60,000 if user elects to take them, add \$10,000 for ECTC, if ap- plicable	Net tax benefits \$75,000 at 10%, \$86,250 at 25%, without ITC or ECTC. (if user takes credits, lease payments increase.)
NET BENEFITS (SAVINGS PLUS NET TAX BENE- FITS MINUS COSTS OVER 5 YEARS) \$183,819.80 (Without ECTC) \$193,819.80 (With ECTC) PLUS OWNERSHIP	NET BENEFITS OVER 5 YEARS \$182,000, plus \$10,000 for ECTC if ap- plicable. PLUS OWNERSHIP	NET BENEFITS OVER 5 YEARS \$175,428.50, PLUS OWNERSHIP	NET BENEFITS OVER 5 YEARS \$125,000, PLUS OWNERSHIP WITH SOME PLANS	NET BENEFITS OVER 5 YEARS \$100,000 WHETHER OR NOT USER TAKES TAX BENEFITS	NET BENEFITS OVER 5 YEARS \$175,000 AT 18% \$163,750 AT 25% WITHOUT ITC OR ECTC, ADD \$10,000 FOR ITC AND \$20,000 FOR ITC AND ECTC.

TABLE ONE HUNDRED SIXTY
FIRMS OFFERING ENERGY MANAGEMENT FINANCING

Aegis Energy Systems, Inc., Doylestown, PA
Aircon Service Inc., Sacramento, CA
American Lodging Systems Inc., Norcross, GA
Associated Energy Consultants Inc., Northampton, MA.
Associated Funders Corp., Marietta, GA
Cogenic Energy Systems Inc., New York, NY
Combustioneer Energy Management Corp., Washington, D.C.
Corporate Energy Management Inc., Richmond, VA
CSL Energy Controls Inc., Los Angeles, CA
Diversified Energy Systems Consulting Engineers Inc., King of Prussia
PA
Ebasco Services Inc., New York, NY
Energy Management Inc., Chestnut Hill, MA
Energy Management Services, Salt Lake City, UT
Energy Resources and Planning Inc., Chicago, IL
Honeywell Inc., Minneapolis, MN
International Energy Conservation Services, Atlanta, GA
Johnson Controls Inc., Milwaukee, WI
Leasing Services Inc., Boston, MA
Natkin Service Co., Englewood, CO
New England Energy Management Services Inc., Westborough, MA
Northern Energy Corp. Boston, MA
Parsons Brinckerhoff, New York, NY
Pequod Associates Inc., Boston, MA
Scallop Thermal Management, New York, NY
Worldwide Energy Systems Inc., Atlanta, GA

Source: Baum, 1981.

about 30 percent purchased natural gas, 14 percent purchased oil, and 38 percent coal-derived coke oven gas. Another 18 percent of energy consumption is supplied by reclaimed blast furnace gasses, tars, creosote, and other energy-rich byproducts. The aluminum industry, in contrast, relies on electricity for 78-percent of its energy needs.

Steelmaking involves several steps with varying energy requirements. On average, raw materials preparation consumes six percent of total energy; coke making, 18 percent; iron making, 35 percent; steel making, 13 percent; and rolling and finishing, another 18 percent.(69) New processes in iron and steelmaking already in use in Japan and Europe cut energy use in some of these steps. Dry quenching coke after it leaves the coking ovens, for example, saves 20 percent of the net energy used in the coking process--one million BTU per ton of coke produced. This process is gaining acceptance in the U.S. after wide use in Europe. Much less polluting than the present water-quenching(70) process, the technology is expensive, however.

Ironmaking in blast furnaces is the most energy-intensive step in steelmaking. Unfortunately, U.S. industry has shown little interest in the one new process--direct reduction of iron ore--that could make iron production more energy-efficient. Advances in steelmaking are more promising. U.S. steel plants are gradually switching from the open hearth furnace (a technology fundamentally unaltered since 1867) to the basic oxygen furnace, which increases the oxygen input to combustion, and cuts energy needs by as much as 90 percent of energy consumed per ingot ton of steel produced. By 1974, over half (56 percent) of all U.S. steel was produced in basic oxygen furnaces. Despite this improvement, we still lag far behind the Japanese, who use the open hearth furnace for only one percent of production (compared with 24 percent in the U.S.) and the basic oxygen furnace for 81 percent of output.(71)

DOE is also sponsoring demonstrations of more energy-efficient steel-forging processes.(72) For example, a high-performance slot forge furnace recycles hot exhaust gasses, ensures uniform heat distribution through the use of recirculation burners, reduces heat losses through closures, and features improved insulation and controls. Already tested and demonstrated, this furnace can easily be retrofit at existing steel plants.

The rolling and finishing steps in steelmaking offer considerable potential for increased energy and production efficiency. At present, energy is wasted at several points. For example, in specialty steel production, reheating furnaces used 40 to 80 hours per week may be kept at high temperature 24 hours per day. In these furnaces, steel is oxidized and about four percent of total plant output is lost as a result.(73) Lightweight furnaces that could quickly be heated to the required process temperature and that heated and formed the steel under pressure or a vacuum would be much more energy efficient.

Energy is also wasted in ingot casting. Most U.S. steel plants cast steel into ingots, allow it to cool, and then reheat it to roll into the final product. An alternative, the continuous casting process, both reduces energy requirements by about 1.4 million BTU per pound of steel output and increases total output by about 10 percent.

At present, however, only about six percent of the nation's domestically produced steel is continuously cast.(74) A final technique to reduce energy waste allows steel slabs to be inspected and surface defects removed at temperatures over 1,000 degrees F. This technology, now being developed by DOE, is expected to save over one third of the energy now used for reheating.(75)

Like the paper industry, iron and steel manufacturers are slow to change because their processes are capital-intensive. By late 1979, the primary metals group as a whole had not met its 1980 energy conservation target of only nine percent savings over 1972 consumption levels. On average, U.S. steel plants are 15 to 30 percent more energy-intensive than their foreign competitors. According to DOE, the iron and steel industry's difficulties in reducing energy use stem from a low profit margin: little capital is available for replacing inefficient production equipment.(76)

Prospects for increased energy efficiency in the relatively well-capitalized aluminum industry are somewhat brighter. Indeed, a high percentage of research and development spending within the industry is dedicated to conservation research on, for example, electrolysis cells that operate with lower current density and smelting processes that require from 30 to 90 percent less energy than the Hall-Heroult electrolytic reduction process now in use.(77)

Cement Manufacturing

Stone, clay, and glass manufacturers comprise the fourth largest energy-consuming industry grouping. Cement production alone accounts for over one third of total energy consumption in this sector and 1.5 percent of total annual industrial energy use in the U.S. The industry relies primarily on natural gas (44.3 percent) and coal (34.7 percent), secondarily on fuel oil.(78) Eighty percent of these fuels are consumed by kilns, where limestone and clay are "calcined" at 2,700 degrees F to form cement clinker. Another 13 percent is used for grinding.

The greatest potential for increasing energy efficiency lies in switching from the present "wet process" to dry process kilns. In the wet process, ground cement is mixed with water to form a slurry that is pumpable and thus easy to transport. Later, however, the cement must be dried out at a great energy cost. In the dry process, no water is added after grinding, combustion heat is recaptured from the kilns and used to preheat lime entering the kilns, and there is no need to pump wet cement first to holding tanks and then back to the manufacturing plant. Consequently, dry process plants, on average, are 20 percent more energy efficient than wet process plants, using roughly one million BTU less energy per ton of cement output than the wet process.(79)

The cement industry predicts that by 1985 about one third of its 1976 capacity will be replaced with dry-process kilns.(80) But U.S. industry still lags behind its European and Japanese counterparts, ranking thirteenth in energy-intensity among cement industries in the 18 International Energy Agency Member countries.(81)

In concrete-block manufacturing, another energy-intensive industry, cement and aggregate are mixed with a small amount of water and compacted into "green" bricks that must be cured before they are shipped from the factory. At the turn of century, the blocks were simply left outdoors under a tarp to cure to "28-day strength." To increase inventory turnover, however, manufacturers soon began to speed the curing process by floating the blocks in high-pressure steam or using "bubble" curing--processes that require large amounts of oil and electricity.

A new technique in concrete block curing makes use of the heat given off by the block itself as cement, aggregate, and water combine. By putting the green block into a kiln to trap this "exothermic" heat and adding only small amounts of heat and moisture, the block quickly reaches "28-day strength" with much less input energy. In the humid southern states, no additional energy is needed in the kiln, so energy use per pound of cement production is reduced by about 80 BTU.(82) This technique is now in widespread year-round use in Florida. Elsewhere, it is used during the summer months. When kiln insulation techniques improve, the method could be used throughout the U.S. even in the winter.

Petroleum Refining

Petroleum refining, which uses energy both as a feedstock and for process heat, is the fourth largest industrial consumer of energy. Using a measure of energy use per dollar value added, the petroleum industry group is the most energy intensive. In this industry, 60 percent of all energy is used for direct process heat, and 25 percent for process steam. (Another 15 percent is consumed in byproduct streams.) In 1978, almost four-fifths of this energy was supplied by natural gas, with a small amount of electricity and fuel oil supplying the rest.

Petroleum refining separates crude oil into constituent products through chemical reactions. Many of these reactions require high-temperature heat. The first step in refining, crude oil distillation, requires temperatures of about 650 degrees F. When naptha, one of the end products of this step, is later treated before it is formed into still other products, a temperature of about 650 degrees F is again needed. Vacuum distillation requires temperatures above 750 degrees F, and the "catalytic cracking" operation temperature uses around 1,200 degrees F.

While present refining techniques make extensive use of waste heat recovery and heat exchange, further improvements can be made. For example, few distillation techniques can greatly reduce heat losses, and a new fluidized-bed process now installed at 90 percent of all oil refineries uses about 200,000 fewer BTU per barrel of output in the catalytic cracking step than the old moving-bed process did.(83) Like many other energy-efficiency improvements, the fluidized bed cracking technique also improves productivity--in this case by a factor of ten.

Another promising new technology that could greatly increase energy efficiency in catalytic cracking is the Advanced Cracking Reactor (ACR). Now being demonstrated at a Union Carbide facility in Seadrift, Texas, this system makes waste heat recovery more efficient. Heat exchangers are located so they will not be fouled by coke and tar, so much of the heat from the 2,000 degrees F product stream is recovered and returned to the process. The ACR can use naptha, vacuum gas oil, kerosene and even some undistilled crude oils as feedstocks.(84)

The petroleum and coal products industry is profitable enough to research, develop, and invest in the energy and process improvements described here. However, only 7.6 percent of the industry's profits are spent on research and development. To date, most industry energy-conservation efforts have been focussed on process heater modifications, waste heat recovery, steam system improvements, and insulation of equipment.(85) Such less capital-intensive conservation improvements did improve the industry's net energy efficiency by 14.7 percent between 1972 and 1979, and further gains in productivity and energy efficiency can be expected from improvements in distillation and catalysis techniques.

Chemicals

Chemical and allied companies make up the largest energy-consuming group in U.S. industry. These industries rely primarily on natural gas (51 percent) and electricity (17 percent) for their processing needs, with smaller amounts of energy supplied by fuel oil (14 percent) and coal and coke (12 percent).

Like the petroleum refining industry, the petrochemical industry relies on oil and gas as feedstocks as well as fuels. However, as gas liquids become increasingly expensive, the industry is making increased use of crude oil and other less refined oil products (a task made easier by development of the Advanced Cracking Reactor described above.)

The chemical industry uses distillation techniques extensively, so many conservation efforts will be focussed on distillation. Currently, very high-temperature heat is added to the bottom of the distillation column and various products are recovered as vapors or liquids at different points along the column. Because it demands temperatures high enough to cause the "lightest" component of the mixture to vaporize at the top of the column, this approach is very energy inefficient. Because the heat is used just once, many chemical plants waste as much as 95 percent of the input energy used in distillation.(86)

A more energy-efficient approach to distillation is to begin with a lower temperature input heat and to use heat pumps to boost the temperature as required at various stages in the process. A variation of this approach called "multiple reboiling distillation," uses multiple heat levels, added at several points along the distillation columns, rather than simply at the bottom. Another alternative is chemical (or liquid-to-liquid) extraction, whereby a chemical additive that has a high affinity for one component of the mixture combines with that component and sinks to the bottom of the tank where it can be removed. DuPont claims to be saving the equivalent of 40,000 barrels of oil per year by using this process to recover a solvent used in manufacturing synthetic fibers.(87)

Another technique for increasing the energy efficiency of chemical production is vapor recompression--a technique for recapturing the latent heat contained in vaporized chemicals at the top of the column and using it to supply heat elsewhere along the column. In this approach, feed liquids are passed through an evaporator into a vapor/liquid separator, where concentrated liquids are drawn off. Some of the vapors are recycled and compressed so that they give off their latent heat, via a heat exchanger, to the evaporator.

Like the petroleum refining industry, the chemical industry has enough discretionary capital to make conservation investments. In 1976, chemical and allied industries spent 39.7 percent of their profits on research and development (compared to the 16 percent average R&D investment of energy-intensive industries.)(88) As one result, the industry had by 1979 exceeded its 1980 goal of a 14 percent improvement in energy efficiency by eight percent, largely because of major process changes and housekeeping improvements.(89)

Environmental Impacts

Few potential industrial energy-efficiency improvements are stalled for want of vacant land. Adding waste heat recovery equipment or improving boiler maintenance at urban factories will not affect adjacent land uses adversely and may well improve air and water quality.

In many cases, pollution problems have spurred industrial improvements that also conserve energy. For example, Europe embraced dry quenching in coke production partly because wet quenching causes pollution problems. One Midwestern corn wet-milling plant that began recycling process water to meet environmental regulations realized considerable energy savings.(90) In Milwaukee, Wisconsin, a coil-coating plant was ordered to clean up its emissions of toxic paint solvents or shut down. The plant installed a thermal oxidation system that burns pollutants as fuel, meeting emissions regulations and simultaneously reducing its process gas consumption by 30 percent.(91)

Institutional Constraints

Electric utilities' reactions to increased industrial energy efficiency are likely to be minimal. Most energy-intensive industries rely primarily on fossil fuels, rather than electricity, and where industry is highly dependent on electricity, many electric utilities appear to be supporting conservation efforts. Where utilities have excess generating capacity and industries are large users of electricity, utilities may discourage industrial conservation efforts by issuing declining block rates or attempting to sell large amounts of electricity at cut rates.

Socio-economic concerns

Much less energy efficient than their European and Japanese counterparts, U.S. industries will operate at a competitive disadvantage in world markets as energy prices continue to rise. For the U.S. steel industry and others that are already beleaguered by foreign competition, continued energy waste could be disastrous. On the other hand, major capital investments (whether publicly or privately financed) in new and improved equipment could better U.S. industry's competitive position and help create jobs.

By the same token, local conservation investment would help local urban economies. By reducing factories' energy costs, conservation improvements could increase profit margins, thus allowing them to stay open or expand. For older plants in the Northeast and Midwest, many of which are either sinking fast or barely staying afloat, energy conservation could make the difference between survival and economic dislocation.

RENEWABLE SOURCES OF INDUSTRIAL PROCESS HEAT

DIRECT SOLAR ENERGY

The Conservation/Solar Interface

The use of direct solar energy for industrial process heat is less technically developed and frequently more expensive than industrial energy conservation improvements.

But city officials should not dismiss solar applications. Instead, these two technically and economically compatible options for reducing local industries' reliance on scarce, expensive fossil fuels should be considered in tandem.

Energy-conserving improvements to a city's industrial plants may actually help make solar process heat more viable. For example, to reduce energy consumption, the food processing industry is converting some of its steam boilers to high-temperature hot water heat-delivery systems, which are more compatible than steam with solar industrial process heat. Industrial solar systems using hot water as the heat delivery mechanism are cheaper, better developed, and more efficient than those designed to produce steam.(92) Industrial efforts to make better use of lower-quality heat--such as reducing processing temperatures and recovering waste heat--also help make the use of solar energy more feasible. Because solar industrial heating technologies providing relatively low-temperature (less than about 200 degrees F) heat are best developed, solar energy's contribution grows as industries learn to make better use of low-temperature heat.

Conversely, solar heating contributions can make greater conservation improvements possible. At one aluminum can manufacturing plant, a SERI study team found that using solar energy instead of natural gas to preheat incoming combustion air was less economical than combining solar preheating with air preheating from the can cooler exhaust air and partially recycling exhaust gasses.(93) With the solar contribution to preheating combustion air, less gas was needed for combustion, less combustion air was needed to maintain the existing oxygen-to-fuel ratio, and greater amounts of oxygen-depleted exhaust gasses could be recycled.

In some plants, solar energy may be more economically attractive than energy efficiency improvements. A crude oil de-watering plant in Wyoming, the same SERI researchers found, used propane very inefficiently because the separator tank was poorly designed. Since reducing the tank's energy consumption would require redesigning the entire facility, the team identified three solar system configurations that could preheat the oil/water mixture. With paybacks of seven years or less, these systems afforded a less expensive means of reducing the plant's propane use.(94)

Technical Approaches

Solar industrial process heaters include two essential components: a collector to absorb solar heat and a transfer medium to carry that heat to the process equipment. Some systems also include a heat exchanger, storage medium, and distribution system.

Several types of collectors that supply industrial heating needs are now commercially available. Which will work best in a particular plant depends on which type of heat is needed--hot water, process steam, or hot air--and at what temperature.

Flat-plate collectors, typically manufactured in modular panels of about 20 square feet, can provide low-temperature heat to a maximum of about 150 degrees F. (See Part Two, Chapter Eight.) In industrial applications, where higher temperatures are needed, flat mirrors or concentrators designed to capture more sunlight can be used to boost temperatures further--by 1.45 to six times.(95)

Evacuated tubes absorb more energy per unit area than flat-plate collectors, providing output temperatures of 150 to 200 degrees F. (See Part Two, Chapter Nine.) These collectors are popular for industrial applications in the North and East because their efficiency varies less with temperature and insolation than that of flat-plate collectors. Evacuated tube collectors, too, can be "boosted" by silvering the bottom half of the glass tube or adding reflectors or reflective troughs.

Still another type of industrial collector uses multiple reflectors. The absorber pipes of this collector are covered with a black selective surface to increase absorption. Mirrored reflector blades concentrate the sunlight onto the tubes in a 24-to-1 ratio.

Parabolic trough collectors for industrial use are being manufactured by several companies. The most common type is a one-axis tracking collector, which can either follow the sun from east to west each day or face south and tilt up and down. These collectors produce temperatures of 200 degrees F and above, with a maximum temperature of about 600 degrees F.(96)

Still in the development stages are linear fresnel lens and heliostat systems, 2-axis tracking collectors, parabolic dishes, and other high-temperature collectors. These systems are designed to supply heat at temperatures above 572 degrees F for use in heat engines connected to electric generators or to supply process heat directly. (See Part Three, Chapter Twelve, Electricity.)

Industries installing solar collectors can choose from a number of alternative heat delivery systems--direct hot water, hot water exchange, direct hot air, hot air exchange, steam flash systems, and steam generation systems. The simplest, direct hot air or hot water systems, require only pumps or blowers to move the heat. More complex systems may include heat exchangers, expansion tanks, and storage. The collectors themselves may be mounted either on the roof or walls of the factory. They can also be mounted on the ground, though most ground-mounted systems require more extensive piping networks, insulation, and controls than roof-mounted systems, and heat losses tend to be greater.

A sketch of some installed systems indicates the range of alternatives available. With DOE funding, 4,455 square feet of flat-plate collectors and 2,880 square feet of stationary parabolic troughs have been mounted on a warehouse roof at the Campbell's soup plant in Sacramento, California. Potable water from a well is first preheated in the flat plates and then heated up to 195 degrees F in the parabolic troughs for use in can washing. A 19,000-gallon steel tank stores solar-heated water over the weekend shut down, and a gas-fired steam heat exchanger boosts the water temperature to 195 degrees when solar energy alone is not enough. The system supplies all of the heat that one of twenty parallel can-washing lines needs on a day of peak insolation in June--the equivalent of 74 percent of the washing line's annual needs.

In Dallas, the owners of a Mary Kay cosmetics factory installed a solar heating system at their own expense after a study showed that their demands for hot water coincide with the availability of solar energy. Some 600 square feet of flat-plate collectors mounted on the factory roof in late 1978 now produce about 3,000 gallons of hot water per day for sanitizing process equipment, preheating boiler feedwater, and cleaning up. A DOE-funded system at the Gold Kist soybean plant in Decatur, Alabama, includes 13,104 square feet of flat-plate collectors supported above ground at a 15 degree angle by a massive steel structure designed but never used for parking. Ambient air is preheated in the collectors to 140 degrees F and then carried 150 feet in a 4 ft. by 4 ft. insulated duct to the dryer house. There it is mixed with combustion air for soybean drying.(97)

A more complex system is in use at a Johnson & Johnson manufacturing plant in Sherman, Texas.(98) Pressurized water circulates through 1,070 square feet of reflecting parabolic trough collectors, reaching temperatures up to 420 degrees F. This hot water is then throttled to a 5,000-gallon insulated flash boiler, which supplies steam to the plant's steam main at 345 degrees F. The system supplies about 1.5 BBTU of energy annually.

Since solar industrial process heat technologies are so new, evaluating their performance is difficult. In 1980, a SERI research team analyzed the performance of six low-temperature (less than 212 degrees F) systems operating one year or more.(99) In 1979, another researcher interviewed owners of four systems about system performance.(100) Presented here, their findings and impressions must be considered tentative.

SERI found that solar systems performed less well than expected. (See Table One Hundred Sixty-One.)(101) Both DOE-funded field tests and private installations encountered such problems as excessive thermal losses from piping in large ground-mounted systems, collector degradation, performance losses due to trial emissions coating collector glazings and concentrating mirrors, and control system malfunctions. In some systems, these problems led to stagnation, thermal shocking, and the breakage of evacuated tubes and mirrors. Finally, operating energy requirements in forced air systems were high, so net system efficiencies were not.

Experience is the answer to many of these problems. Incremental improvements in the design, engineering, and installation of industrial systems should improve performance. Meantime, simple roof-mounted hot water systems hold the most near-term promise since they entail lower costs and lower thermal losses than ground-mounted systems and require less electricity to operate than forced-air systems. For now, the industry best suited to use solar energy may be the food industry, which uses low-temperature hot water.

TABLE ONE HUNDRED SIXTY-ONE
PREDICTED AND ACTUAL ENERGY DELIVERY OF SOLAR
INDUSTRIAL PROCESS HEAT FIELD TESTS

<u>Project</u>	<u>Annual Energy Delivery</u>			
	<u>Predicted</u>		<u>Actual</u>	
	<u>(MBtu/yr)</u>	<u>(Btu/yr)/ft²</u>	<u>(MBtu/yr)</u>	<u>(Btu/yr)/ft²</u>
Campbell Soup	2156	290,000	-	-
Riegel Textile	1400	210,000	370	55,000
York Building Products	1500	160,000	364	39,000
Gold Kist	3700	280,000	788	60,000
LaCour Kiln Services	900	360,000	370	147,000
L and P Foods	2300	110,000	1035	39,000

Source: Kutscher & Davenport, Preliminary Operational Results of the Low-Temperature Solar Industrial Process Heat Field Tests (1980).

Drying processes may also be well suited to the use of solar process heat.(102) As field-tested by DOE, solar drying added to the quality of the final product. A lumber-drying company in Canton, Mississippi, that added solar preheating equipment to the kiln found that the wood cracked less than when exposed to the hot combustion gasses produced by gas heat.(103) The same principle could apply to the drying of food products.

Economics

For numerous reasons, solar industrial process heating in most locations is still only marginally cost-effective at best. First, system efficiencies have been low--only eight to 33 percent in DOE field tests. Luckily, prospects for the higher operating efficiencies and improved performance needed to help solar systems offset high costs with high output levels appear quite good. For example, parabolic troughs now operate at annual average efficiencies of 29 percent in the Southwest, but researchers at Sandia laboratories expect efficiency to improve to 44 to 47 percent.(104)

Given present efficiencies, solar industrial process heat will probably be most immediately economical in the southwestern states, where today's collectors can deliver at least twice as much energy per square foot as they can in New England or the Pacific Northwest.(105) Indeed, of the 61 industrial systems designed or operational in 1981, most were located in California, the rest in Texas and the Southwest.(106)

A second major factor governing the economics of solar industrial process heat is the cost of fuel displaced by the system. While operating efficiencies in the Northeastern states are lower, oil costs are higher and gas supplies less certain, so solar process heating may be economical in some industrial settings. In the Midwest and Mid-Atlantic states today a handful of systems are now operating.(107) As fuel costs rise, more may come to seem wise buys.

A key factor in the economics of solar industrial process heating is the total installed cost of \$20 more per square foot than expected. Clearly, expected economies of scale have failed to materialize, and thermal storage costs are in many cases too high to allow solar energy to be used continuously at an attractive price.(108)

Future increases in energy prices alone will not make solar industrial process heat economically attractive. total installed system costs must come down as the cost of displaced fuel increases. According to SERI, installed system costs must fall by half from the current costs of \$40 to \$50 per square foot before solar process heating finds widespread acceptance,(109) and such cost breaks are not likely to occur until considerably more design and operating experience accrues.(110)

Solar process heat economics are also hurt by the strict payback criteria most plant managers apply to investment decisions. Many view solar technologies, like conservation improvements, as unproven "risky" technologies. Thus, they will not invest unless paybacks of six months or less can be guaranteed. Yet, as Table One Hundred Sixty-Two illustrates, the present paybacks of solar applications for industrial use all exceed five years, and some are longer than the 20-year assumed life of the solar system. Moreover, the collector costs assumed in these case studies are relatively low (most are less than \$50 per square foot) so paybacks may be even longer than indicated.

Of course, innovative financing plans could help make solar investments somewhat more attractive. Then too, the accelerated depreciation provisions in the Economic Recovery Tax Act of 1981 (P.L. 97-34) allow industries to depreciate purchases of energy-saving (among other) equipment over five years, reducing their taxes and improving cash flows. (One analysis indicated that the new depreciation provisions could improve the net present value of a flat-plate industrial process system by over \$2,000.)(11) Nonetheless, costs and paybacks must both come down before solar process heating will draw many industrial investors.

Finally, the economics of solar process heating applications could be improved by conservation improvements at each potential solar site. For example, case studies of a bakery in Denver and of an aluminum container manufacturing plant indicate that solar systems alone were not cost-effective. (See Table One Hundred Sixty-Two.) However, when combined with waste heat recovery at both locations, the solar systems paid for themselves within the system lifetimes.

City Applications

Many analysts argue that solar industrial process heating's potential in cities is severely limited by land-use and other constraints. In fact, the unavailability or high cost of land in dense cities may prevent factories there from adding solar equipment, for solar process heating does require quite large collector areas. For example, the Gold Kist soybean plant in Decatur, Alabama, had to construct a massive steel I-beam structure to support 13,104 square feet of collectors.(112)

At L&P Foods in Fresno, California, 21,000 square feet of collectors were ground-mounted, and additional land area was required for a shed providing rock bin

TABLE ONE HUNDRED SIXTY-TWO

ECONOMICS OF SOLAR INDUSTRIAL PROCESS HEAT: CASE STUDIES

Type of Industry	Application	Collector Type	Total Installed Collector Cost (\$ ft. ²)	Fuel Displaced	Fuel Cost (\$/MMBtu)	Payback (Years)	Location
Group 1: Hooker, et al., 1980 1979\$;							
Crude oil dewatering	Pump oil through collector for pre-heat	Flat-plate	\$48	Propane	\$5.62	4.5	Wyoming
	Pump oil through external heat exchangers attached to collectors	Parabolic troughs	\$71	Propane	\$5.62	6.6	
Aluminum container manufacturing	Supply hot water for can washing	Parabolic trough	\$40	Natural gas	\$2.00	less than 20	
	Preheat combustion air, with gas recycling	Parabolic trough	\$35	Natural gas	\$2.00	greater than 20	
Corn wet milling	Preheat corn steep water	Flat plate	\$27	Fuel oil	\$3.92	greater than 20 13	Midwest El Paso
Polymeric resin manufacturing	Supply hot water to heat storage tanks	Flat plate	\$26	Natural gas	\$2.80	greater than 20	
	Supply steam for low-temperature reactors	Parabolic trough	\$33			greater than 20	Chicago
Milk processing Fluid	Provide hot water for clean-up	Flat plate	\$28	Natural gas	\$2.38	less than 20	Southwest
	Provide heat for pasteurization via heat exchanger	Parabolic trough				less than 20	

TABLE ONE HUNDRED SIXTY-TWO

(Continued)

<u>Type of Industry</u>	<u>Application</u>	<u>Collector Type</u>	<u>Total Installed Collector Cost (\$ ft.²)</u>	<u>Fuel Displaced</u>	<u>Fuel Cost (\$/MMBtu)</u>	<u>Payback (Years)</u>	<u>Location</u>
Bread and bun bakery	Preheat makeup water, with heat recovery					10	Denver
	Preheat oven air, with heat recovery					less than 20	
Meat processing	Preheat truck washing water	Flat plate		Natural gas	\$1.87	less than 20	
	Preheat boiler feedwater	Flat plate		Natural gas	\$2.23	less than 20	
Group 2: Clark & Studstill, 1981; 1980-81 \$							
Processed food	Heat vegetable oil	Flat plate			\$3.50	13.2	Georgia
Meat processing	Hot water	Evacuated tube			\$3.50	16.7	Georgia
Bakery	Preheat hot air for ovens	Evacuated tube	\$48		\$3.50	16.1	Georgia
Group 2: Clark & Studstill, 1981; 1980-81 \$ (cont.)							
Small carpet manufacturing	Heat dye water, with heat recovery	Evacuated tube			\$3.50	9.2	Georgia
Broadloom Carpets	Heat dye water, with heat recovery	Flat plate	\$24		\$3.50	8.5	Georgia
Apparel Fabric	Preheat process Water	Flat plate	\$33		\$3.50	17.3	Georgia

thermal storage.

In older inner-city factories, an additional limitation on using solar applications is that the factories' plant and processes are likely to be energy inefficient. More than new energy-conserving plants, most of which are in suburbs or rural areas anyway, older plants may require major engineering overhauls to become energy efficient or to make use of solar process heating. Engineering a retrofit is, obviously, expensive; and integrating solar features into the plant's basic structure is difficult.

Another constraint to using solar industrial process heat in large cities is industrial pollution, which can degrade collector and mirrored surfaces. The high levels of industrial and auto emissions found in some urban industrial areas could make collectors perform less efficiently there than in suburban or rural areas.

None of these constraints present is unsurmountable, however. Solar collectors require space at the factory site, but not necessarily land. In many settings, they can be mounted on the walls or roofs of existing buildings. For example, 4,600 square feet of collectors were mounted on the roof of an Anheuser Busch beer-pasteurizing building in Jacksonville, Florida. No structural modifications of roof supports were required in this building, which was based on a prototypical design that many future Anheuser facilities will employ.(113) Owners of a photo-processing laboratory in Richmond, Virginia, found that mounting flat-plate collectors vertically on the side of the lab was much more cost-effective than ground-mounting them because hardware needs were less. Roof- or wall-mounted systems also have lower "parasitic power" requirements than ground-mounted systems do. As Table One Hundred Sixty-Three indicates, just to operate, ground-mounted solar systems at Gold Kist in Decatur and L&P Foods in Fresno required 8.7 and 9.5 percent, respectively, of the solar energy they collected. Thus, the roof-mounted systems with the greatest potential for urban use can also be the most efficient.

While solar process heat may have its greatest potential in new, suburban factories, retrofitting urban factories is certainly feasible. Indeed, most existing solar process heating systems are retrofits, and many are in large cities.

As for the greatest near-term potential for using solar process heat, the likeliest candidates are textile manufacturers, food processors, and chemical industries. All use low-temperature heat, and the textile industry is concentrated in the Southeast, where insolation levels are high. The challenge, of course, is designing systems to accommodate the changing technology of the industry. For instance, the DOE-funded solar retrofit at Riegel Textile Corporation's plant in La France, South Carolina, supplies heat to a batch-type dyeing tank that is now being replaced by a continuous-dyeing technology that can dye more fabric more quickly. solar demonstrations will have to accommodate changing industrial settings.

Most of the heating needs in food processing are for temperatures less than 350 degrees F, which commercially available collectors can provide, and many food-processing plants are located in urban areas, to take advantage of the labor force and markets there. Dairies and beverage plants, which have a high conservation potential and process temperature requirements within the range of flat-plate collectors, appear to be particularly well-suited to urban solar applications.(115) Conservation improvements at these plants would help make solar more economically attractive by reducing required collector areas, thus alleviating land-use constraints.

As discussed in the conservation section above, the highly energy-intensive chemical industry is already making major investments in energy efficiency. Like the food-processing industry, chemical plants tend to locate close to a large labor force, usually a city. Most also require process temperatures in the range produced by parabolic trough, evacuated tube, and flat-plate collectors. These factors--plus the fact that chemical industries are already heavily concentrated in the South--combine to make solar process heating applications at chemical plants quite promising in southern cities. Northern cities that produce industrial chemicals may also be able to use solar process heat, too, since producing industrial inorganic chemicals requires temperatures in the range produced by evacuated tube collectors, whose performance varies less with climate than other types of collectors.

Just as some industries can make better use than others of solar process heating applications, so can some cities. In Lawrence, Massachusetts, high oil prices have led the city and the local textile industry to examine the feasibility of conservation, industrial cogeneration, and district heating and to begin developing local hydropower. Once these opportunities have been exhausted, the possibility of using direct solar energy still remains. In Los Angeles, the food-products industry is the second largest energy-consuming industry, and the chemicals industry ranks seventh. Obviously, high insolation and a mild climate there favor solar applications.

Land Use

As noted, shortages of collector space in dense cities can be partially overcome by mounting collectors on roofs and walls. Then too, at the city's edge, relatively more land may be available for collectors. Industries there will have to weigh the value of

TABLE ONE HUNDRED SIXTY-THREE

PERFORMANCE OF SOLAR INDUSTRIAL PROCESS HEAT FIELD TESTS

<u>Project</u>	<u>Location</u>	<u>Collector Area (ft.²)</u>	<u>Mounting Type</u>	<u>Net System Efficiency</u>	<u>Parasitic Fraction (%)</u>
Campbell Soup	Sacramento, CO	7335	Warehouse roof	-	4.2
Riegel Textile	LaFrance, SC	6680	Ground	8.1	3.4
York Building Products	Harrisburg, PA	9216	Integral part of roof	8.6	3.9
Gold Kist	Decatur, AL	13104	Special structure	19.7	8.7
La Cour Kiln Services	Canton, MS	2520	Storage building roof	32.5	1.0
L&P Foods	Fresno, CA	21000	Ground	14.2	9.5

Source: Kutscher & Davenport, 1980.

that land for plant expansion against its potential use for solar energy collection.

In many ways, current-generation industrial design--including flat roofs, one-story construction, and development on flat terrain--favors solar retrofits at existing factories.(116) A recent study of 200 industrial plants found that 87 percent had over 25,000 square feet and 55 percent had more than 100,000 square feet of flat roof or south-facing wall suitable for collectors.(11) Additional flat roof area is available at warehouses, most of which are located close to industrial areas, and few of which require much heat or encounter solar access problems.

In planning solar industrial process heat applications, cities should first encourage industries to cluster so as to be able to share process heat and electricity. The large potential for recapturing industrial waste heat is even greater when several industries using different types and temperatures of process heat can exchange heat and electricity. Then too, industrial parks have other economic advantages--including cost savings associated with shared parking and storage facilities and joint site selection--that combine with the appeal of reducing industrial noise and pollution to make energy-efficient "clustering" even more desirable.

More specifically, at industrial parks collector areas could be combined. A further step would be to combine collector space and thermal storage areas, which would save factories both money and energy. The large landscaped areas surrounding industrial parks ensure solar access, and, in some cases may prove fit for ground-mounted collectors or producing biomass energy crops. Uniform building height and setback requirements for new construction can further protect access, and new buildings can also be designed with roofs of adequate load-bearing capacity to support collectors.(118)

Environmental Impacts

Using solar energy to supply industrial process needs can reduce air pollution in two ways. Besides enhancing the feasibility of energy-conserving improvements that reduce emissions, as discussed above, using solar energy can reduce the need for fossil fuels, thus bringing down the absolute level of emissions.(119) To implement Prevention of Significant Deterioration (PSD) regulations, Federal and state air quality planners now follow a "bubble concept": they allow firms that reduce emissions at one smokestack to exceed emission standards at another. Accordingly, plant managers who want to expand one part of a process might add solar equipment to another part to trade off emissions (if, that is, the solar addition cost less than meeting tightened emissions controls, which is usually not the case).(120)

A similar regulatory approach, the emissions offset policy, is used to regulate new sources of pollution in already polluted areas. Under this approach, state air-quality officials will allow a new plant to open in a non-attainment area only if the projected emissions from the proposed new plant offset greater emission levels from existing sources. In effect, new industries in a non-attainment area must shoulder the costs of helping other industries in the area reduce their emissions in exchange for the economic advantage of locating there.

City officials determined to encourage both industrial development and the industrial use of solar process heat can make the most of this policy by promoting solar offsets. For now, the costs of solar equipment are too high to make solar offsets feasible. But, if costs of solar industrial process heat decline while costs of pollution control increase, such trade-offs might become feasible.

Utilities

Electric utilities should have little opposition to increased use of solar industrial process heat, since most industries now rely on coal, oil, and gas. However, as noted, utilities in areas where industry relies heavily on electric process heat might oppose solar installations if they have excess capacity. Utilities trying to avoid having to add new capacity might work with city energy planners and local industries to encourage solar process heating.

Socioeconomic Factors

Since solar industrial process heat costs more than most industries are willing to invest today, its use will not create many new jobs in the near future. However, if costs come down and the prices of competing fuels increase, new jobs will open up in collector manufacturing, installation, and maintenance. In particular, maintaining solar industrial process systems is especially important, and maintenance requires both skilled and unskilled labor.

Increased use of solar industrial process heat could also help maintain existing urban jobs by providing an affordable, reliable energy source for urban industries. Despite its present high costs, solar energy equipment appeals to owners of industrial plants as a potential long-term, reliable energy source. For example, managers at York Building Products in Harrisburg, Pennsylvania, decided to participate in the solar demonstration with DOE because they were concerned about the future availability of fuel.

The solar system they incorporated into their new plant now supplies 30 percent of the energy needed by the most energy-intensive part of their process--concrete-block curing. Owners of L&P Foods in Fresno, California, another DOE solar industrial process heat demonstration site, are concerned about possible future gas curtailments and view their system as a potential alternative. For these and other industries, the solar alternative could provide a means of staying in business in the future, thus avoiding the job losses plant closings cause.

BIOMASS FUELS FOR INDUSTRIAL PROCESSES

The potential for producing fuels from biomass and municipal waste is covered in Part Three, Chapter Fourteen. Here, the focus is on the feasibility of using these fuels for industrial process heat.

Technical Approaches

Biomass fuels could supply much of the energy American industry needs. Currently, nearly half of the energy the forest products industry uses is supplied by wood and wood wastes. As fossil fuel prices increase, industry's wood consumption is expected to grow too. By the year 2000, SERI projects, 70 to 80 percent of industry's needs will be met by wood.(121) Increasingly, the food-processing industry, which also has a ready supply of biomass available, is burning or gasifying peach pits, walnut shells, and other byproducts. By the year 2000, these byproducts could supply 10 percent of the energy the food processing industry uses.(122) Other urban industries can put energy from municipal solid wastes to use, as the General Electric plant in Lynn, Massachusetts, now does.(123)

Industrial product wastes can be used to produce various fuels. Gasifying or directly burning wood and food-processing wastes are obvious options. Industries can produce liquid fuels, though rarely to provide industrial process heat. (See Chapter Fourteen.)

Most technologies for supplying industrial process heat from renewable biomass resources rely on direct combustion. (See Part Three, Chapter Twelve, Electricity.) In smaller industrial plants, "package" (or factory-assembled) biomass boilers capable of producing 60,000 pounds of steam per hour and burning various solid fuels in small sizes (3" or less) can be used. Wood-fired package boilers, about 100 of which were operating in North America in 1978,(124) can heat water or produce low- or high-pressure steam.

Economics

The economic attractiveness of converting or retrofitting boilers to use biomass depends on numerous factors. One of the most important is the initial capital cost. New wood-fired boiler systems (including handling and storage equipment) cost from \$10,000 to \$100,000 per MMBTU per hour of output capacity. Retrofits of existing boilers vary even more in cost. A coal-fired boiler may need little or no retrofit, while retrofit of an oil- or gas-fired boiler would be much more extensive and costly. Installing a package gasifier at a cost of between \$40,000 and \$90,000 and with the capacity to produce 2 to 10 MMBTU of heat per hour is an intermediate-priced alternative for plants now using oil or gas.

The capital costs of wood-fired boilers must, of course, be compared with those of an existing or competing boiler. Typically, wood-fired systems cost 250 to 750 percent more than oil or gas-fired combustion systems, largely because larger boilers and more complicated handling and storage systems are required. For the same reason, wood systems are generally more expensive than coal-combustion equipment. However, if the competing boiler burns high-sulfur eastern coal, the wood system may be more competitive because the coal-burning system would require expensive pollution-control equipment while the wood-based system would not. (See Chapter Twelve.)

Operating and maintenance costs, like capital costs, are higher for biomass combustion than for fossil-fired process heating, especially if the biomass must be pulverized, dried, or treated.

The big advantage to biomass combustion, of course, is low fuel costs. In most of the country, wood costs less than fossil fuels; and at many plants, wood or food wastes are essentially free. Their bulk and low heating value do make transporting these fuels long distances uneconomical, but opportunities for using such wastes near where they are generated are great. (At the Tri-Valley Growers plant in Modesto, fruit pits are transported to an airfield at the edge of town for drying and then retrieved for combustion, but this transportation loop greatly adds to fuel costs.)

A final factor affecting the economic attractiveness of biomass combustion or gasification is system performance. Fossil-fired boilers retrofitted to burn or gasify wood can lose overall capacity since wood has a lower heat content than coal. Boilers thus derated by five to 25 percent may perform quite well, but will not pay for themselves as quickly as improvements that do not derate the plant.

City Applications

While the wood products industry is primarily rural, many food-processing plants are found in cities. Still, a shortage of space for storing and handling bulky biomass fuels could restrict retrofits at factories in crowded urban industrial areas, as could a lack

of space for the larger biomass boiler in smaller factories.

One renewable fuel source that is more available in urban than rural areas is municipal solid waste. The Saugus, Massachusetts, resource recovery plant discussed above is guaranteed a fuel supply through 30-year contracts with 13 participating cities. In Chicago, the city's northwest incinerator produces process steam for sale to the nearby Branche Candy Company factory.

Land Use

As noted, plants converting to make use of biomass fuels will need additional space at or around the plant site. For example, a spreader-stoker boiler system requires between six and seven times as much space as the equivalent oil-fired system and four times as much area as a coal system with the same energy output. Small urban factories might not have this additional space available, either within or outside the factory. Increased use of biomass, like increased use of solar energy may thus hold more potential in new industrial parks on the urban fringe. The parks could use nearby greenbelt areas for biomass production or purchase the rights to nearby wood or agricultural wastes. Then too, land could also be set aside in the industrial parks to accommodate centralized fuel storage and handling equipment

Environment and Safety

Mishandling biofuels for industrial process heat can pose health and safety hazards. Such mass sources as loose sawdust or fruit pits and nut shells must be carefully stored to prevent spontaneous combustion. Another potential hazard is ignition of biomass on conveyor belts. Electrical equipment must be carefully maintained to keep sparks from flying and flammable biomass from starting a fire.

Storing and transporting finely-ground sawdust or nutshells can endanger the health of workers inhaling the dust, and incomplete combustion of biomass in boilers can produce a highly explosive gas mixture. In addition, the medium-BTU gas produced by wood gasifiers may contain toxic pollutants. (The gasifier is generally closely coupled to the boiler or kiln, but even small leaks could be dangerous.) Finally, the tars and oils produced as gasification byproducts may also be carcinogenic and require careful handling. None of these problems presents an insurmountable barrier to the use of biomass fuels, but an industrial manager considering biofuels should take them into account.

Air pollution is seldom a problem if biomass combustion and gasification systems are equipped with efficient particulate controls.(126) In fact, centralized biomass combustion involves less air pollution than fossil fuel combustion. Emissions of nitrous oxides and sulfur dioxide are naturally low when shells, pits, wood, organic materials, or municipal refuse are burned. Emissions of carbon monoxide and organics can be higher than in coal combustion, but these pollutants can be controlled by maintaining high combustion efficiency.

To meet air quality laws, wood-burning boilers producing more than 10,000 pounds of steam per hour will have to undergo a Federal Prevention of Significant Deterioration (PSD) regulatory review. Generally, boilers with outputs smaller than 20,000 pounds of steam per hour can meet the PSD requirement with the addition of simple cyclones, while larger facilities may require electrostatic precipitators or baghouses to control particulate emissions. In the southeast, many industries with large coal-fired boilers use wet venturi scrubbers, which collect particulates in water. In highly polluted areas ("non-attainment areas"), industries that want to add new biomass-fired boilers may have to obtain emissions offsets from other nearby plants.(127)

Liquid effluents created in biomass combustion or conversion can also cause problems if controls are not adequate. Effluents produced by wet scrubbers used for particulate control and by cleanup of medium-BTU gas produced by wood gasifiers are high in oxygenated hydrocarbons and must be treated before disposal. These effluents may also contain heavy metals, sulfides, and thiocyanates.(128)

Institutional Constraints

Electric utilities are unlikely to oppose increased use of biomass as a source of industrial process heat since forest products industry and other industries most likely to increase their use of biomass already use large amounts of biomass and relatively little electricity. Yet, owners of wood-fired industrial cogenerators may encounter problems obtaining an adequate sell-back rate if they wish to sell electricity to the local utility. (See Part Three, Chapter Twelve.)

Another institution that could affect whether the use of wood as a fuel source increases is the wood-contracting and delivery business. If better and more reliable wood-supply systems become available, various industries in forested areas might use wood as a fuel source. In the meantime, wood's use as a fuel will be largely confined to the forest products industry.

Chapter Fourteen

Fuels from Renewable Resources

Most of the renewable energy technologies discussed so far can be used to substitute for conventional liquid, solid, or gaseous fuels. In addition, renewable resources can be used as feedstocks in the production of these fuels. For example, crops can be converted to ethanol for use in gasohol. Wood or municipal wastes can be turned into solid fuels that can be burned to produce heat or steam or to generate electricity. A variety of biomass resources can be converted into gas capable of meeting various end-use needs.

With respect to fuels produced from renewable resources cities can assume any or all of the following roles: consumers, production facilitators, or producers. As consumers they could, for example, use gasohol in city-owned vehicle fleets or purchase pelletized wood for use in municipally owned power plants. As production facilitators, they could encourage industries with available resources to develop fuels-production facilities or to sell their products as feedstocks to other fuel producers. Finally, cities themselves could become fuel producers, by for example, extracting methane from landfills.

Whether or not the city can encourage local production or enter the fuels production business will depend on the accessibility of local feedstocks. All cities have access to a waste stream, but the availability of such feedstocks such as wood, crops, or other biomass is confined to specific locations. Even to become consumers of biofuels, cities must be located fairly close to fuel-production facilities. Otherwise, excessive fuel transportation costs will make the urban use of those fuels uneconomical. Transportation from production points of use poses fewer problems with liquid than with solid fuels. Nearly always, gaseous fuels produced from renewable feedstocks must be very close to points of production.

In general, fuels produced from renewable energy will probably play a smaller role in large cities than in smaller ones. Their greatest potential is in rural or exurban areas. Nonetheless, even our largest cities have some options open to them. Los Angeles extracts user biogas from one of its sewage-treatment plants to fuel on-site sewage-treatment processes and still has enough left over to sell to a neighboring power plant owned by the municipal utility.(1)

This chapter provides city officials with some of the technical, economic, and environmental information needed to discuss the urban use or production of fuels from renewable resources.

LIQUID FUELS

Cities use liquid fuels primarily for heating and transportation. While heating oil can be replaced by gas, wood, coal, electricity, or solar energy, the only alternative to liquid fuels in transportation is electricity, whose use in vehicles is promising but constrained by costs and energy-storage problems. Accordingly, cities will probably use liquid renewable fuels--ethanol and methanol--mainly in transportation.

All but a negligible fraction of the 105 million gallons of fuel ethanol produced in the U.S. in 1980 was consumed in transportation as gasohol--a one-part ethanol, nine-parts gasoline blend used as an automotive fuel.(2) Another 95 million gallons of domestic ethanol (and 22 million gallons imported primarily from the United Kingdom) was used in the manufacture of pharmaceuticals and other chemicals.(3) About 1.1 billion gallons of methanol was also produced for use in chemical industries. Another million gallons of ethanol was produced by farmers for on-farm use.(4) No significant use of alcohol fuels was made in cities except in chemical manufacturing and vehicles.

Other urban uses for alcohol fuels are theoretically possible. In particular, alcohol could be used in boilers for space heating, for process steam, and in electrical power generation where environmental factors rule out the use of cheaper coal-fired generators. Methanol can also be used in fuel cells and in the gas turbine engines utilities use for peak-load generation and industry uses to produce electricity. (See Chapter Twelve.) As of 1981, however, alcohol fuels could not compete economically with conventional fuels in any of these applications.(5)

In transportation, the story could be quite different, particularly since fixed demands for transportation fuels account for roughly one fourth of many cities' total energy budgets.(6) (See Table One Hundred Sixty Four.) However, before substituting alcohol fuels for conventional liquid fuels, cities must grapple with numerous technical, social, and economic issues. Complicated in itself, this task is all the more difficult because the analyses and information available to cities relate primarily to rural opportunities for making and using alcohol fuels. Also, cities must consider that both the short-term and long-term production or use of alcohol fuels will depend upon federal and state production incentives and regulations over which the city has no control.

These caveats aside, cities' interest in liquid fuels is sure to rise along with the prices of conventional liquid fuels, and general technical and economic information on alcohol fuels is proliferating. Whether and how to become involved with alcohol fuels are decisions cities can now make with some reliable evidence in hand.

BOX ITEM NUMBER ONE

ALCOHOL FUELS

Ethanol. (C_2H_5OH) - also called ethyl Alcohol or grain alcohol, ethanol is the product of fermentation based on grain or other forms of biomass.

Methanol. (CH_3OH) - also called methyl alcohol or wood alcohol, methanol is the product of the destructive distillation of wood or other lignocellulosic or carboniferous biological materials. Volatile, flammable and poisonous, it can be used as motor vehicle fluid, a denaturant for ethanol, a solvent, antifreeze, or base in the manufacture of chemicals.

TABLE ONE HUNDRED SIXTY-FOUR
ENERGY USAGE FOR TRANSPORTATION
 (Selected Cities)

<u>City</u>	<u>Yearly Transportation Energy Use (BTU)</u>	<u>Percent Total Energy Use</u>
Bridgeport	15,100	26.9
Boulder	3,657	28.2
Dearborn	5,820	22.0
Knoxville	24,922	31.5
Los Angeles	173,400	47.9
Seattle	34,122	33.0

Sources: CCEMP Audits

TABLE ONE HUNDRED SIXTY- FIVE

BIOMASS RESOURCE BASE FOR ALCOHOL PRODUCTION

(1990 and 2000)

<u>Raw Material</u>	Potential Alcohol Production (Billions of Gallons)	
	<u>Ethanol</u>	<u>Methanol</u>
Grain		
1990	4.0	
2000	4.0	
Cellulose*		
Wood**		
1990	3.2	6.2
2000	1.9	3.7
Municipal Solid Waste		
1990	3.7	9.8
2000	4.3	11.5
Crop Wastes		
1990	1.5	3.4
2000	1.5	3.4
Subtotal for Cellulose (Wood, MSW, Crop Wastes)		
1990	8.4	19.4
2000	7.7	18.6
Sugar Crops		
1990	3.0	
2000	5.0	
Sludge		
1990		0.1
2000		0.1
Food Wastes		
1990	0.5	
2000	0.6	
Total		
1990	15.9	19.5
2000	17.3	18.7

* Cellulose may be converted to either ethanol or methanol. The figure given for each alcohol under any cellulose category is a maximum number, assuming that the particular resource is used only to produce that alcohol. A given amount of cellulose may be converted to a larger volume of methanol than ethanol. Therefore, the total volume of alcohol that may be produced from a given cellulose resource will range from the minimum (ethanol) figure to the maximum (methanol) figure.

** Excludes potential contribution from silvicultural energy farms.

Source: U.S. National Alcohol Fuels Commission (1981)

Resources/Potential

Currently, ethanol is used primarily in gasohol, which is now marketed in over 15,000 gas stations and used heavily where feedstocks are in greatest supply, primarily the Midwest. (See Table 166.) According to the Renewable Fuels Association, alcohol production will reach 500 million gallons by 1985 (the national goal established by the Carter Administration) if gasoline prices continue to rise and the Federal production incentives set forth in the 1980 Energy Security Act are not withdrawn.(7)

Theoretically, ethanol's potential equals that of total U.S. gasoline use--110 billion gallons per year. But the 500-million gallon goal is obviously more realistic. The chief obstacle to meeting even this lower goal is the difficulty of bringing ethanol plants on line by 1985.(8) Lesser concerns are modifying car engines slightly so they can burn methanol or fuel mixtures that contain more than ten percent ethanol, finding ways to maximize pollution controls, and making sure that ethanol use at this level does not (as it need not) drive up agricultural commodities prices.

As for the strictly urban potential of ethanol, likely uses are in passenger cars, public buses, and municipal vehicle fleets. Indeed, the city of Tulare in California is conducting a feasibility study of a 250,000 gallons/year ethanol plant that could meet all the fuel needs of its 96-vehicle fleet.(9)

Commercial-scale methanol production for transportation use will not be a reality until a plant now under construction in Winchester, New Hampshire, begins operating.(10) Although the theoretical potential of methanol equals that of ethanol and the amounts of methanol feedstocks available greatly outstrip ethanol feedstocks, the practical near-term potential is much less since the technology for converting biomass to methanol still requires improvement.(11) Yet, its present status as a newcomer on the automotive fuels market does not rule out the use of methanol in cities, only its near-term availability and its rapid acceptance. Efforts like that of Los Angeles County, which teamed up in mid-1981 with the California Energy Commission to launch an experimental methanol program, should make available sound data on the use of pure alcohol in transportation.

Technology

Ethanol production takes place in three stages. First, the feedstock (usually sugary or starchy plants) is cooked. During cooling, carbohydrates are converted into fermentation sugars (usually glucose) with the aid of liquefying and saccharifying enzymes. Second, these simple sugars are converted through fermentation into ethanol and carbon dioxide. Finally, the dilute ethanol is concentrated through distillation and separated from the water so it will burn. Non-fermentable materials such as distillers grains can be recovered (usually, for use as an animal food) either before, or more commonly, after the fermentation step.

While no facilities for converting wood and other forms of cellulose to methanol are operating in the U.S., the process is well understood. First, the wood or other feedstock is gasified, then the gas and water effluents are separated and cleaned, and finally the synthesis gas is converted by high pressure and condensation processes to methanol. In methanol production, unlike ethanol production, most of the process energy is obtained from the heat generated during the production process itself.

Which fermentation technology a private producer or city decides to use will depend in part upon which feedstock is available in quantity at affordable prices. One model is that in use at the Archer-Daniels-Midland plant in Decatur, Illinois. This grainbelt plant was opened in mid-1979 to produce for use in beverages and industry some five million gallons of high - (192 to 200-) proof alcohol from corn syrup, damaged corn, and wheat starch. In 1979, the plant tripled its output by abandoning the beverage-grade standard and switching to the exclusive production of fuel-grade alcohol. It also tightened its operation by tying it more closely with a company-owned corn-processing facility so as to extract and market nutrients from the corn feedstock.

Among the country's largest, the Archer-Daniels-Midland facility produces 150,000 gallons of ethanol per day. Scale affords the operation many economies and relatively great efficiency. Other special technical features also improve the plant's economics: the fermentation cycle has been reduced to twelve hours, separation of the yeast from the beer has been simplified, and only one distillation column is needed in the process. Also of note, the plant makes use of waste heat from the adjacent corn-processing facility to meet some of its energy needs. (Steam generated in a boiler fired by natural gas meets the rest.)(11)

A second model is the Milbrew plant in Juneau, Wisconsin. Built in 1978 and expanded in 1979, this plant reportedly produces over five million gallons of 193-proof ethanol annually from cheese whey. Fired by a combination of natural gas, propane, and fuel oil, the facility produces high-protein yeasts and condensed fermentation solubles as by-products.(12)

A third example of ethanol-production technology is that employed in a Georgia-Pacific plant in Bellingham, Washington, to convert the waste liquor from a

TABLE ONE HUNDRED SIXTY-SIX
REGIONAL PRODUCTION OF POTENTIAL FEEDSTOCKS

	Corn ¹	Milo ¹	Wheat ¹	Oats ¹	Barley ¹	Rice ²	Potatoes ²				Sweet Potatoes ³	Sugar Beets ³	Sugarcane ³
							Winter	Spring	Summer	Fall			
New England	0	0	2	2	0	0	0	0	0	31	0	0	0
Midatlantic	208	0	22	35	12	0	0	0	3	18	1	0	0
Southeast	373	22	73	18	9	56	1	8	5	0	9	0	33
Cornbelt	3,462	68	259	142	2	1	0	0	2	4	0	1	0
Lake states	1,077	0	166	257	56	0	0	0	3	40	0	7	0
Great Plains	1,090	662	1,044	270	137	23	0	1	2	23	1	5	2
Western States	136	36	462	20	199	18	1	14	6	187	1	13	0
Hawaii	0	0	0	0	0	0	0	0	0	0	0	0	20
Alaska	0	0	0	0	0	0	0	0	0	0	0	0	0
United States	6,346	788	2,026	744	415	98	2	23	21	303	12	26	56

¹Units: 10⁶ bushels

²Units: 10⁶ hundredweight

³Units: 10⁶ tons

Source: U.S. Department of Agriculture, Agricultural Statistics, U.S. Government Printing Office, Washington, 1978.

sulfite pulp mill into alcohol. Interesting technical features of this six-million-gallon-per-year stainless steel plant include the capacity for continuous fermentation and the reuse of yeast (which is separated from the beer via a centrifugal separator), the use of diethyl ether (instead of the more commonly used benzenes) to dehydrate ethanol so that simpler equipment and less steam and water will suffice, and a mechanism for siphoning off salable methanol from the incoming waste liquor. Drawing its operating energy from a combination of wood waste, fuel oil, and natural gas, and selling its spent fermentation liquor to manufacturers of such products as artificial vanilla and herbicides, this plant represents an integrated approach to alcohol fuels production.(13)

These three prototypes are based on ethanol technologies that are well understood and no longer patentable. Cities may also soon have at their disposal several new technologies. Besides relatively advanced membrane and vacuum technologies and improved hydrolysis technology, which are expected to be viable in ethanol production by the late 1980s, are several that could be in use soon. These include a pressure-cascading technique (called the Katzen process) that allows process heat to be recovered and reused, a twin-tower distillation system that reuses ether vapor at considerable energy savings, and a thermally integrated production complex that combines the equipment for fermentation, distillation, and distillate concentration. Two other noteworthy new production breakthroughs are an ultraefficient industrial heat exchanger and a continuous fermentation process (the "Chemapec" process) based on energy recovery and the use of relatively low-temperature process heat.(14)

Technical Issues

Besides hardware, cities with an interest in producing, using, or marketing alcohol fuels will want to consider several other technology-related issues. These include the performance characteristics of alcohol fuels, their efficiency ratings, the operating problems associated with the use of methanol and ethanol, and the net energy gained in alcohol fuels production.

The importance to cities of performance characteristics is twofold. First, their own investments and commitments will be influenced by the utility and versatility of the fuel. Second, cities acting as distributors or promoters of alcohol fuels may have to launch information campaigns aimed at helping people overcome their reluctance to use unfamiliar fuels.

The performance of ethanol in vehicles is generally considered superior to that of gasoline (though ethanol/gasoline blends do not test as well as pure ethanol, and methanol/gasoline blends perform less well still in standard tests).(15) In general, alcohol fuels give off fewer carbon monoxide and hydrocarbon emissions than gasoline but more aldehydes (which are highly photochemically reactive) and evaporative emissions. Alcohol combustion is smokeless, odorless, and (compared to gasoline) octane-rich. However, alcohol fuels are also more corrosive than gasoline to engine parts. They are also less dependable in temperature extremes, though temperature-related problems (such as vapor lock and phase separation) can be reduced greatly if additives are used and the alcohol-burning vehicle's carburetor is modified (a relatively simple adjustment.) As for mileage, alcohol fuels tend to get more miles per BTU, but since they contain fewer BTU per gallon, a tank of alcohol will not go as far as a tank of gasoline.

For cities financing or manufacturing alcohol fuels themselves, another consideration is the debate over the net energy gained in alcohol fuels production. Critics of alcohol fuels contend that more energy is required to produce a gallon of ethanol than the ethanol contains. Proponents take the view that efficient production does not result in net losses of energy and that the liquid fuels produced have more applications than the energy contained in the feedstock or used to fuel the process. This issue is too complicated to more than outline here.(16) But it is obvious that some processes do allow net energy gains. One critical factor here is monitoring all production variables closely to make sure that each step and input is energy-efficient. Another is renewable resources in the production process to tip the energy balance in a positive direction.

A final technical issue cities must consider is the relative merits of getting involved with ethanol, as opposed to methanol, production. The choice here may be between a more modest near-term pay-off with well-established technologies and a potentially larger pay-off over the long term (as methanol-conversion technologies are perfected). In any event, the lack of precedents for the commercial production of methanol as a transportation fuel makes further investigation of this issue imperative.

ECONOMICS

Introduction

Overall, the economics of alcohol fuel production look to be improving with production technology improvements and increases in the costs of competing fuels. Yet, some of the economic variables are out of cities' control, and experience with large-scale plants is scant and confined primarily to the farm belt. Further, both price and demand will fluctuate with the availability of feedstocks and changes in farm commodities prices.

Uncertainty abounds over the economics of alcohol production. But there is widespread agreement on two points. First, the cost of the feedstock and the commercial value of the byproducts of alcohol production are the primary determinants of price. While capital costs for plant construction can require sizable investments, they are less important than the first two factors to the economics of alcohol fuels production.(17) Second, the price of the finished product relative to that of the competing fuel (in most cases, gasoline at the refinery gate) is the main determinant of salability.

Factors Affecting Alcohol Costs

If corn is used as the feedstock and the byproducts of the grain-to-ethanol process (corn oil, corn syrup, distillers dried grains, etc.) are sold at market value, ethanol can be produced for as little as 96 cents, but more typically for between \$1.30 and \$1.65 per gallon.(19) If corn prices remain stable, new ethanol-production processes are commercialized, and prices for distillers dried grains (protein-rich byproduct used as a livestock feed supplement) hold, the costs of ethanol derived from corn should fall to about \$1.20 per gallon within five years.(20)

Other feedstocks besides corn can be used in ethanol production. Indeed, there is no single best feedstock. Wheat, grain sorghum, oats, sweet sorghum, sugar cane, and other food crops can all be used. Food-processing wastes (such as cheese whey) and both spoiled and substandard grain could also make good feedstocks. Accordingly, cities that want to encourage alcohol fuels production within their boundaries should begin by taking an inventory of these kinds of feedstocks available close by.

For biomass-to-methanol production, various feedstocks could also be used. Timber, wood refuse, wood-processing residues, and municipal solid wastes are the likeliest choices. Each of these costs considerably less than ethanol feedstocks. For example, methanol made from wood costs an estimated 52 to 95 cents per gallon at the plant gate; methanol from a municipal solid waste feedstock even less.(21) However, there is little hard data on operating experience to back up these cost estimates. Moreover, methanol's relatively lower heat content and performance profile make it a less valuable vehicle fuel than ethanol, even though methanol has a higher octane rating and the United States has 50 years of experience producing methanol from natural gas.

Plant construction costs will be determined by the type of feedstock, the grade of alcohol to be produced, the heat source the plant employs, the type of feedstock used, the costs of labor, the environmental or safety controls in place, and the costs of money. The research so far suggests that plant costs will also vary fairly consistently with plant capacity. For example, in a 1981 report by the Solar Energy Research Institute's Strategic Planning Branch, the building costs of a new, energy-efficient fifty-million-gallon-per-year, coal-fired distillery using corn as the feedstock were estimated at \$89.6 million (\$1.79 per annual gallon output.)(22) An independent study conducted a year earlier reached a consistent conclusion, estimating the cost of a 25-million gallon per year coal-fired plant at \$41.4 million (\$1.66 per annual gallon output.)(23) Capital costs could be substantially reduced if a city could use an existing facility for production. For example, the National Commission on Fuel Alcohol estimates that the idle capacity of local breweries is about 100 million gallons nationally.(24)

Besides feedstock costs, the resale value of byproducts, capital costs, and transportation costs are several other economic considerations that affect the costs of fuels. Chief among them are federal and state subsidies to alcohol fuel users. Also important is the impact of feedstock production on the prices of agricultural commodities--an issue that has already become controversial.

Federal subsidies to alcohol production now amount to four cents per gallon of gasohol (which is one tenth ethanol) or forty cents per gallon of alcohol. In addition, twelve states also offer subsidies ranging from 10 to 95 cents per gallon of alcohol. Such subsidies usually exempt the product taxes.(25) While the alcohol producer does not receive these subsidies directly, they do allow the fuel to compete economically with unleaded gasoline. Of course, the payback on investments in alcohol fuel plants will be longer if these subsidies are eliminated before petroleum prices rise sufficiently or alcohol fuels production costs fall.

As for the potential for competition between food crops and fuel crops, and the impact of that competition on food and fuel prices, the key issue is the production level of alcohol fuels. Without production controls, commodities prices will certainly rise

with demand. Fairly pessimistic on the subject, agricultural economist Lester Brown contends that "in the absence of any governmental limitations on the conversion of agricultural commodities into fuel, the price of oil could eventually set the price of food." (26) Yet, by using crop wastes and non-agricultural forms of biomass as the alcohol feedstock, recycling the protein that remains once the sugars in the feedstock are converted to fuels, and keeping production low enough to avoid triggering grain-price inflation, competition between food and fuel can be managed. For cities interested in alcohol fuels, the overriding questions are thus whether federal and state governments will set and enforce such policies and how trustworthy the feedstock market will be if they do not.

Comparison with Conventional Fuels

In a direct comparison with gasoline prices, ethanol at the distillery in late 1979 at \$1.60/gallon appeared far from competitive with the average refinery-gate gas price of \$0.65 - \$0.75. While methanol at \$0.70 per gallon would have been competitive, no methanol from biomass was on the market then so the comparison is moot. In addition, methanol's poor performance characteristics in existing cars suggest that it cannot be compared directly to gasoline as engine fuel.

However, most researchers argue that the cost of ethanol and methanol should not be compared to the average cost of gasoline, but with the "marginal" costs of imported crude oil. (27) By late 1979, the spot market price of crude oil was \$45 to \$50 per barrel. According to one study, at \$45 per barrel, the refinery gate price of unleaded gasoline would be \$1.65 per gallon. (28) With unleaded gasoline at this price, ethanol at \$1.60 per gallon would be an attractive alternative.

Numerous other factors may make ethanol more economically competitive than straight price comparisons indicate. First, as discussed above, newer ethanol processes could bring the delivered price of ethanol down to about \$1.20 per gallon. As crude oil prices rise, ethanol and refinery gate gasoline prices should become more competitive. Second, OTA suggests that ethanol's true economic value may lie in its octane-boosting properties. Thus, refiners might be willing to pay more for ethanol because they could mix it with a commensurately less octane-rich (and less expensive) gasoline. (29) In addition, retailers may be willing to pay more for ethanol because they can charge more for ethanol-gasoline blends (gasohol) than for less octane-rich gasoline.

ENVIRONMENTAL IMPACTS

Three types of environmental impacts are associated with alcohol fuels. Environmental problems can stem from the growth of the feedstocks, from fuel production, and from the use of alcohol fuels in vehicles. Of these, the impacts of feedstock production are by most accounts the most serious over the long term, while vehicle-related pollution is relatively less important. (30) Pollution from the production process can be expensive to control, requiring expenditures at plant-construction time of roughly one eighth the total capital costs (of a 50-million gallon per year facility.) (31) For perspective, consider the U.S. Congressional Office of Technology Assessment's view that these aggregated environmental impacts are a "significant" drawback to alcohol fuels' production and use, but less important overall than conversion inefficiencies in the production process. (32)

The most serious problem related to feedstock cultivation is one that cities until now have not worried about except with respect to the loss of prime farmland to urban sprawl. That problem is cropland degradation or conversion. (33) Either increasing the intensity of agricultural production or the amount of land under cultivation (as opposed to using surplus or spoiled crops) paves the way for soil erosion, which increases the need for fertilizer and pesticides to sustain the soil's productivity. In turn, agricultural run-off rich in these chemicals (many of which are expensive and resource-intensive to produce) can contaminate creeks, rivers, and water supplies, even as the sediment that transports them silts up or eutrophies waterways.

Cultivating fallow acreage or forests and other virgin lands can cause other pressures too. Expanding agriculture's demand for water can have a devastating effect on water tables, which are already alarmingly low in several Western states. (34) In particular, increasing irrigation needs can exacerbate "water wars" between up-river and down-river farmers, as well as between agriculture and fossil-fuel developers. It can also increase salinity.

As for pollution from the production process, emissions from the heat source and from distillery wastewaters generally pose the greatest problems. Beyond that, the level, type, and seriousness of the damages depend upon which type of boiler and which feedstock are used. (See Table 167.) Coal-fired boilers tend to generate the most harmful emissions and solid wastes (including coal dust, fly ash, and bottom ash), though control technologies for coping with these emissions are well established.

The major air emissions arising from ethanol production are grain dust (which can be contaminated by fungus and pesticides), carbon dioxide, oxygenated compounds (primarily

TABLE ONE HUNDRED SIXTY- SEVEN

BIOCONVERSION OF GRAIN TO ETHANOL - EMISSION AND EFFLUENT SOURCES

<u>Operation</u>	<u>Emissions to Atmosphere</u>	<u>Liquid Effluents</u>	<u>Solid Wastes</u>
Feedstock Storage	Transfer operations (fine dust)		Grain, dirt
Milling and Cooking	Mechanical collectors for milling operations (particulates)	Wash water (dissolved and suspended solids, organics, pesticides, alkali) Flash cooling condensate dissolved and suspended solids, organics)	Grain dust from mechanical collectors)
Hydrolysis and Fermentation	Fermentation vents (CO ₂ , hydrocarbons)	Wash water (dissolved and suspended solids, organics, alkali)	
Distillation and Dehydration	Condenser vents on columns (volatile organics)	Rectifier bottoms (organics), dehydration bottoms (organics)	
Storage	Storage tanks, (hydrocarbons)		
Coproduct Recovery	Dryer flue gases (NO _x , SO _x , CO, particulates, hydrocarbons). Evaporation condenser vents (hydrocarbons)	Evaporator condensate (dissolved and suspended solids, organics)	Grain dust (from direct-contact dryers)
Steam Production (coal-fired)	Flue gases (NO _x , SO _x , CO, particulates)	Boiler blowdown (inorganics), cooling water blowdown (dissolved and suspended solids, organics)	Coal dust, ash (bottom ash and fly ash)
Environmental Control Systems	Evaporation from biological treatment ponds (organics)	Scrubber blowdown (dissolved and suspended solids, organics)	Sludge (from flue gas treatment), biological sludge (from wastewater treatment)

Source: R.M. Scarberry and M.P. Papai, "Source Test and Evaluation Report: Alcohol Synthesis Facility for Gasohol Production," Radian Corporation, January, 1980.

acids, alcohols, and aldehydes), and volatile organic fermentation products. In the recovery of co-products, some commercial distilleries also emit sulphur dioxide, carbon monoxide, and nitrous oxides. While "scrubbers" and other environmental control systems can neutralize some of these contaminants, pollution-control equipment can itself generate secondary wastes, so no perfect solution to the emission problem exists. Thus, it may be difficult to site alcohol production facilities in urban areas with existing air pollution problems.(35)

Environmentally hazardous effluents from the fuel-production process are discharged in distillery wastewaters. The alcohol plant's wash waters are high in biological oxygen demand (BOD). Some also contain both dissolved and suspended solids, trace chemicals, and pesticide residues. Stillage from alcohol plants is high in alkali salts and BOD. Since a 50-million-gallon-per-year distillery generates over a million gallons of wastewater a day, commercial alcohol plants must either install water purification systems (which are readily available on the market) or--the cheaper alternative in some cases--pipe the wastewater to publicly owned treatment works with enough spare capacity to handle the large volume of wastewater ethanol production entails.

The environmental impacts of using alcohol fuels on a large scale are not well understood simply because ethanol and methanol as yet make up only a small fraction of U.S. liquid fuels use. But it is known that the exhaust and evaporative emission from pure alcohol fuels contain roughly the same amount of carbon monoxide and hydrocarbons as gasoline emissions, less nitrous oxide, and more aldehyde. (With blends, the evidence is more ambiguous with respect to hydrocarbon and nitrous oxide).(36)

An advantage of pure ethanol use is the absence of sulfur dioxide and combustion particulates. According to the Office of Technology Assessment, it may actually be possible to "engineer an unambiguously beneficial environmental effect by channelling gasohol to certain urban areas with specific pollution problems (for instance, high carbon monoxide concentrations but no smog problems)."(37)

A final environmental concern is compliance with the regulations that govern alcohol fuels production. Numerous federal laws (among them, the Clean Air Act and amendments of 1977, the Clean Water of 1972 Act, and the Resource Conservation and Recovery Act of 1976) contain provisions covering alcohol production, and at the state level even more stringent environmental regulations can be imposed on fuels manufacturers. Moreover, any large project receiving Federal funds or loan guarantees must complete environmental or impact statements to receive aid. Yet, government will be hard-pressed to monitor small commercial operations as their numbers multiply. For cities involved in alcohol fuels production, one risk is that of shut-down or fines. Another is unwillingly damaging the local environment. Whether or not they become co-partners in production, cities may also want to revamp land-use regulations in view of these Federal laws or to monitor informally the effects of nearby alcohol-fuels production on the urban environment.

The cost of reducing or eliminating these environmental impacts depends on how big the plant is and whether pollution controls are built in or added on. (Direct-control systems for new ethanol facilities equal an estimated 13 percent of the initial fixed investment.)(38) While the control technologies have been fully developed and have stood the test of time in many chemical and food-processing industries, some are quite expensive. (See Table One Hundred Sixty-Eight.)

TABLE ONE HUNDRED SIXTY-EIGHT

CAPITAL COSTS OF ENVIRONMENTAL
TECHNOLOGIES : 1981
(for a 50-million-gallon-per-year
(ethanol production facility)

Flue gas scrubbing system	\$4.2 million
Wastewater treatment system	\$2.0 million
Fire protection system	\$.6 million
Ash collection package	\$.17 million
Vapor-controlled storage tanks*	\$.16 million
Vent condensers	\$.13 million

*(incremental cost beyond that for cone-roof tanks)

SOURCE: The Gasohol Handbook, V. Daniel Hunt, Industrial
Press, Inc., 1981.

SOLID FUEL USE IN CITIES

When we speak of solid fuels, we usually mean coal, which supplies about 19 percent of U.S. energy.(39) Here, a discussion of coal is also the starting point because renewable fuels will generally be used to replace or supplement coal. Even when wood is used in an oil-burning system, it is as an alternative to coal. Seventy-seven percent of the coal burned in the United States is used to produce electricity, providing 48 percent of U.S. electricity.(40) Most of the remaining coal produces steam and industrial process heat, and a little is used for home heating.

Cheaper than oil or natural gas, abundant in the United States, and more reliable than nuclear power, coal seems an ideal answer to America's energy woes. But coal has its disadvantages. Transporting coal is expensive, and coal contributes to carbon dioxide build-up, acid rain, and other forms of air pollution. Mining can also harm the environment and workers.

The renewable forms of solid fuel that offer an alternative to coal represent the very old and the very new--wood and refuse derived fuel. Wood, the world's first fuel, is now used extensively in the wood products industry and is gaining popularity, especially in New England, for home heating. Burlington, Vermont is using wood to generate part of its electricity. Refuse derived fuel (RDF) is a newly developed fuel that is produced by separating energy-containing materials from garbage and chemically converting that waste into a form suitable for transport, storage, and burning. RDF can be prepared in various forms and can be burned alone or in combination with coal (and sometimes) oil. Although several pilot plants are making RDF, the technology is still in the development stage.

WOOD

Resources/Potential

Wood currently supplies about 1.4 to 1.7 quads of energy a year in the United States. Of this, about 1.2 to 1.3 quads is used by the forest products industry and 0.2 to 0.4 quads is burned in home stoves or fireplaces. The equivalent of about two quads of energy is returned to the soil through decomposition or burned at the logging site, and some of this energy could be used commercially.(41) Wood, of course, has other uses than energy that must be considered. The equivalent of 1.7 quads of energy is contained in forest products such as paper and lumber. The U.S. Office of Technology Assessment (OTA) estimates that with widespread intensive forest management wood could provide between five and ten quads of energy per year by 2000 without depleting our forests.(42) The Solar Energy Research Institute (SERI) sets nine quads as the upper figure.(43) The forest products industry is likely to be using three to four quads of wood energy in 2000 according to industry estimates,(44) and the remainder of the projected use would be in homes, electricity generation, and other industries.

No generalizations can be drawn about the practical and economic feasibility of using wood as an energy source. In every case, the local forest conditions, the quality of the wood, transportation costs, wood prices, and the extent to which forest management techniques are applied will be different. All of these variables must be considered in planning wood energy use, a process each city must carry out with its specific needs and applications in mind.

The technology for using wood fuel is already in operation at forest products facilities throughout the country, and especially in New England, the South and the Northwest. In most cases, wood waste is burned to produce process steam, but dozens of operations are designed to cogenerate both steam and electricity. The forest products industry currently gets between 45 and 55 percent of its energy from wood.(45) Because the wood does not have to be bought or transported, these on-site wood-energy systems are very economical. (The major expense is forgoing the profit that could be made by selling the waste or using it to make other products.) The industry is finding new ways to use wood waste for making such products as fiberboard, and in the future a smaller percentage of the total wood harvest will be considered waste.

Several utilities are using wood-fired boilers to generate electricity. Vermont's Burlington Electric adapted two 10-megawatt oil/coal boilers to burn a mixture of 75 percent wood and 25 percent oil. New plans call for a 50-megawatt wood-fired generator.(46) The Eugene Water and Electric Board in Oregon operates a 33.8-megawatt wood-fired boiler that provides space heat, industrial process heat, and electricity.(47) Lake Superior District Power's Bay Front Generating Facility in Wisconsin burns wood as a supplemental fuel in an adapted coal boiler.(48) (See Chapter Twelve, Electricity.)

The high moisture content of wood residue and wood chips (about 50 percent) makes it impossible to burn them in a boiler designed for coal without adjustments. Increased moisture leads to slower combustion and a change in the composition of the exhaust gas, necessitating adjustments in the pollution-control system. Wood pellets, in contrast, are only ten percent water and can be burned in coal systems without any special

BOX ITEM NUMBER TWO

Wood residue is the sawdust, wood chips, and bark remaining after trees have been processed to produce lumber, paper, or other wood products. The cheapest wood fuel, wood residue is uneven in composition and energy content.

Dirty green wood chips are the two-inch pieces of wood produced by chipping whole trees or as a byproduct of certain wood processing operations. The chips are "dirty" because they include bark, which is relatively low in energy.

Clean green wood chips are two-inch pieces of wood that are free of bark.

Wood pellets are made by drying and compressing wood. The pellets are lower in moisture and higher in energy than other forms of wood and therefore more economical to transport.

adjustments.

Boilers can be built specifically to burn wood, but adapting an existing coal-fired boiler costs less. Even when it is necessary to purchase a new boiler, buying a system that burns both wood and coal is advisable because of possible variations in the wood supply. Unless wood is an integral part of the energy supply system, supply can be unreliable and it pays to have a system in which coal can be substituted for wood.

Besides needing different pollution-control techniques, wood-fired boilers require more storage area and a larger combustion chamber than equivalent coal-fired boilers. The largest wood-fired plants would be about 50 megawatts (compared to 1,000 megawatts for large coal plants) because wood would have to be transported more than 50 miles to supply a larger plant, and the transportation costs would make the increased size uneconomical. As a rule of thumb each mile wood must be transported adds 1.25 cents to the costs per million BTU.(49)

Economics

Most studies have suggested that wood-fired steam or electric-generating plants will be higher in capital and operating costs than oil or coal-fired plants, but much lower in fuel costs. (See Table One Hundred Sixty-Nine.) In many cases, wood costs will be low enough to make wood-burning plants the most economical alternative. (See Chapter Twelve, Electricity,

However, variability in the price of wood makes fuel cost projections tentative at best. In Burlington, Vermont, for example, during 1978 and 1979, the price ranged from \$12 per ton to \$26 per ton and back to \$16 per ton.(50) The future price of wood is likely to be even more mercurial. If wood becomes increasingly popular as a fuel, competition with other uses of wood could raise prices. Ultimately, the supply of wood and the sustainability of our forest resources depends on how widely and well intensive forest management is practiced.

With so many variables to juggle, urban energy planners should focus primarily on energy systems in which wood can be used in combination with other fuels. If wood prices go up, coal or oil can be used instead. Another advantage is that retrofitting existing systems to burn wood as a supplemental fuel costs less than converting completely to a wood-fired boiler. Wood use is economic in many parts of the country right now, though the situation may change radically in ten years.

Part of the higher operating costs of wood-fired systems is the expense of hiring extra workers, which can be considered a social investment. Even if oil and wood systems cost exactly the same, the wood system would have the advantage of keeping the money in the community rather than exporting it. Compared to coal, wood requires more labor to harvest per unit of energy and more labor to convert to a useful form.(51)

Environmental Impact

Using wood for energy could significantly affect the health of our forests and the quality of our air. Without proper forest management, wood is not a renewable resource. If wood use increases and industry's forest-management practices remain shortsighted and wasteful, precious topsoil will erode, rivers will fill with silt, flooding will occur, forests will deteriorate, and U.S. wood reserves will be quickly depleted.

The aim of forest management is the effective use of forests for all their attributes--as a home for wildlife, as a place of quiet and beauty, as a source of materials for buildings, furniture, and paper, as a source of energy--without depleting the woodlands. Forest management entails studying the soil and topography to learn what trees will grow and how many can be harvested. Managers must make such decisions as whether selective cutting or clear cutting is most appropriate, whether timber waste should be cleared or left, and if fertilizer is necessary. And they must make certain that new trees that will prosper are planted.(52) No set rules exist for managing forests, so specialists will have to monitor the effects of any strategy chosen. To maintain productive forests, government and private landowners will have to work to guarantee that forests remain a renewable resource and fulfill their other purposes as well.

According to the Office of Technology Assessment, however, intensive forest management will enable us to double or triple the energy yield of our forests without destroying any forest land. Indeed, it may be possible to use less wooded land for commercial production.(53) Although cities will not execute forest management policies--rural counties, state authorities, or the Federal government will--city officials nevertheless need to make sure that their wood supplies are sustainable and that local forests and rivers are not sacrificed to save a few dollars.

City officials will be directly involved in protecting air quality. Compared to coal combustion, wood burning produces less sulfur and nitrogen oxides and therefore contributes less to the creation of acid rain. Emissions from wood burning, however, contain more particulate matter and more polycyclic matter (POM), which is known to cause cancer in animals.(54)

TABLE ONE HUNDRED SIXTY- NINE

WOOD AND FOSSIL COSTS IN THE SOUTHEASTERN U.S., 1979

<u>Fuel</u>	<u>Price/Unit</u>	<u>Price/Million BTU</u>
coal	\$55/ton	\$2.63
oil	\$.60/gal	5.00
natural gas	\$.003/ft ³	3.86
wood pellets	\$35/ton	2.94
wood chips	\$12/ton	1.99
wood residues	\$8/ton	1.33

Source: Mr. Levi and M.S. O'Grady, "Decisionmaker's Guide to Wood Fuel for Small Industrial Energy Users," (1980).

Air-tight wood stoves are particularly high in POM emissions. Controlling emissions from wood combustion will not be difficult at large industrial or utility facilities, but home wood stoves are too numerous to regulate. Wood also leaves more ash than coal does, and this ash must be landfilled. The danger here is that the ash, which has a high heavy metal content, will adversely affect water quality if the heavy metals leach from the landfill.

REFUSED DERIVED FUEL

Resource/Potential

The average U.S. city dweller produces 3.5 pounds of solid waste a day, of which approximately 75 percent contains energy--the equivalent of 1.5 pounds of coal.(55) Few cities make use of this energy. Indeed, most devote considerable labor, energy, and land to dispose of the waste in landfills. Several methods of using the energy in municipal waste are already being used. Direct combustion of waste to produce steam is the most common method. (See Chapter Eleven.) It is not, however, necessarily best. Direct burning requires a large capital investment and a nearby market for the heat or process steam produced. Conversely, converting the waste to solid fuel that can be transported involves a smaller capital investment and allows greater flexibility in plant siting.

The cost of a refuse derived fuel (RDF) plant is about 30 percent that of a direct-burning plant,(56) and the RDF can be marketed outside the immediate vicinity of the plant. These considerations could make RDF an attractive alternative to a direct-burning operation for many cities. The RDF can be sold to industries or utilities that can burn it in combination with coal or alone in specially designed boilers. Or the city itself can use the RDF. Ames, Iowa, manufactures RDF that its municipal utility burns to produce electricity.(57)

Technology(58)

Several processes exist for separating the combustible portion of municipal waste and converting it to RDF. Some also separate recyclable materials, such as glass, iron, and aluminum from the trash mix before it is used for energy purposes. The most common forms of RDF are fluff, wet, densified, and dust. (See Table One Hundred-Seventy.)

Fluff RDF is produced by shredding the waste into particles about four to eight inches across and passing it through an air classifier that separates the light materials (the 50 to 85 percent that contains the energy) from the inorganic and heavy organic material. The light portion is then passed over a screen or trommel to remove small pieces of glass. After screening, the RDF is shredded again into pieces of 1/4 to 2 inches.

Fluff RDF can be burned in combination with coal in many boilers. For the user, however, handling fluff RDF is difficult. It hangs up in the tops of hoppers, it can bind like papier-mache if left standing for a few days, and it can become explosive if stored too long.

Wet RDF is produced by mixing the waste with water and passing it through a hydropulper that separates out large, heavy items. The remaining slurry is passed through a liquid cyclone to remove such heavy materials as glass, metals, thick plastics, and wood. The remaining slurry, mostly paper, is then dewatered for burning. Removing the water is expensive and requires energy: to reduce moisture by only ten percent uses between four and eight percent of the slurry's energy content.

Wet RDF cannot be combined with coal in most boilers because it contains so much moisture. Instead, it must be burned alone in specially designed boilers.

Densified RDF is an experimental product that could be produced by pelletizing, briquetting, or extruding fluff RDF. The densified RDF would be easier to handle, store, and transport than fluff RDF.

Dust RDF goes through the same initial shredding and air classification as fluff RDF. But instead of being shredded a second time, the material is treated with an embrittling agent and then pulverized to dust. Dust RDF has a higher energy and lower moisture content than other forms of RDF, but it costs more to produce and can easily become explosive in storage. It can be burned with coal or mixed with oil. Dust RDF is still in the development stage so its economics and practicality remain matters of conjecture.

Technical Concerns

One of the advantages usually associated with the production of energy from wastes is the recovery of reusable resources such as glass, iron, and aluminum. Resource recovery, however, has not been highly successful, either in RDF or bulk-burning facilities.(59) In many cases, the glass recovered is unusable because the content of ceramics that remain after mechanical separation is so high. Aluminum and iron are often mixed with other metals in products and cannot be separated mechanically, and mixed metals are less useful than pure metals to recycling operations. Finally, recovered

TABLE ONE HUNDRED SEVENTY

COMPARISONS OF VARIOUS FORMS OF RDF AND COAL

<u>Fuel</u>	<u>% Moisture</u>	<u>% Ash</u>	<u>BTU/lb</u>	<u>Net Energy</u>	<u>Advantages</u>	<u>Problems</u>
Fluff RDF	20-30	19	5,000-6,500	49%	best known technology	production: poor resource recovery use: difficult to handle can be explosive
Wet RDF	50	20	3,500	48%	least cost to produce	prod: poor resource recovery use: can only be used in special equipment
Dust RDF	2	10	6,900	63%	easy to handle can be mixed with oil	prod: still developmental expensive use: can be explosive
Densified RDF	2-30	10-20	5,000-6,500		easy to handle	prod: still developmental requires more money and energy to make
Coal	3-12	3-11	11,500-14,300			

Source: Tania Lipshutz, "Garbage-to-Energy - The False Panacea" (1979).

material may be too sullied to have much commercial value.

More important, garbage-to-energy systems can discourage the more economical and effective practice of source-separation recycling by individuals. For a garbage-to-energy system to work economically, a steady and reliable supply of waste must be available for processing. Individual recycling efforts could significantly reduce the garbage flow. In particular, paper recycling would be set back. Comprising 40 to 60 percent of a city's garbage, paper accounts for most of its energy content. Without paper, the waste stream's energy potential would be drastically reduced.(60)

Even though cities might be only indirectly involved in the production of RDF, they must consider how RDF is used in order to determine whether a sufficient and stable market for the product exists. RDF can be used alone or to supplement coal in producing steam or electricity. Burned with coal, RDF can provide between five and 25 percent of total primary energy. RDF is currently being used to supplement coal to produce electricity in Ames, Iowa, and Madison, Wisconsin. Baltimore, Maryland, produces RDF pellets that it sells to a local industry to mix with coal to produce steam.(61)

Several problems exist for using RDF, which is still a developing technology. RDF contains materials that can corrode the elbows of boiler equipment, which increases the need for repairs and increased maintenance. The plastic in RDF can leave a residue that clogs the machinery. RDF also contains some glass, which can stick to boiler walls or emission systems or block the openings in the combustion grate.

RDF cannot be burned in all boilers. Its lower energy content and higher ash content makes it unsuitable for systems with small combustion chambers or limited ash capacity. Because RDF contains less energy than coal, the boiler will operate at a lower capacity when RDF is burned with coal. If fluff is substituted for 25 percent of the coal, for example, the output of the boiler will be reduced by approximately 12.5 percent.

Handling RDF also presents many difficulties. The tendency of fluff RDF to hang up in hoppers and not fall when material below it is removed makes its use troublesome for mechanical systems. The tendency of fluff and dust RDF to become explosive when stored means that they pose hazards if the equipment breaks down and the RDF cannot be burned immediately.

Economics

With so few RDF plant operations, conclusions about their economics must be broad and tentative. (Information from new or planned facilities is included in Table 171. Capital costs are affected in part by whether the RDF facility pays for the boiler modification that makes burning RDF possible. For example, the two plants with the highest capital costs per output, Ames and Madison, both include costs of boiler modification in total capital costs. There are also apparent economies of scale. The two smallest plants, again Ames and Madison, cost the most per output ton, even if boiler-modification costs are excluded.

The cost of operating a plant also varies according to where it is located, how far RDF must be transported, the composition of the waste, and the tipping fees charged to waste haulers. If a plant must be located in a relatively developed area, land will be expensive and extra precautions must be taken to control emissions. If a production plant is located far from the point of use, transportation costs will be high. The energy content of the waste and the difficulty of separating out the energy-containing materials will also affect the ultimate cost of the RDF.

Although the prices charged for RDF are often competitive with coal prices, few RDF plants are actually operating economically. With its product selling at \$25.00 per ton, the Madison Plant does not operate in the black because until markets expand, the plant will have idle capacity.

Each city will have to determine the economies of building or operating an RDF plant in its area. The key is to compare the costs of the RDF operation to various other strategies for waste disposal or waste-to-energy production.

Is RDF cheaper than direct combustion to waste? Although an RDF plant costs only about 30 percent as much to build as a waste-burning plant, it could be much easier and more profitable to market steam or heat than RDF. A private company would be more likely to buy steam, which it can use directly, than RDF, which cannot be used in most boilers unless modifications are made. Then too, to sell RDF, the city might have to agree to take the loss if users experience technical problems. Overall, steam technology remains more reliable than the still-developing RDF systems.(62)

How does the cost of an RDF facility compare with the current cost of garbage disposal? The answer cannot be precise because the cost of waste disposal and the problems of landfilling vary tremendously. In many cities, land is extremely limited and the cost of new landfill sites very high. If landfills are located near homes or water, extra care must be taken so that dangerous substances do not leak from the landfill. If only distant landfill sites can be found, transportation costs will be high. Each city must decide how much it has to gain by changing its disposal system.

TABLE ONE HUNDRED-SEVENTY - ONE
ECONOMICS OF OPERATING RDF FACILITIES

<u>Plant Location</u>	<u>Plant Capacity (Ton RDF Produced Per Day)</u>	<u>Capital Costs</u>	<u>Price of RDF (\$/Ton)</u>	<u>RDF Heat Content (BTU/lb)</u>
Baltimore	250	\$ 8.4 million (1975)	\$27.00	6500-7000 BTU/lb
Ames, IA	110	\$ 6.3 million	N/A	5625 BTU/lb
Madison	30	\$ 3.8 million	\$25.00 *	7000-8400 BTU/lb
Albany	N/A	\$11.6 million (1975)	N/A	4650 BTU/lb
Tacoma	300	\$ 2.4 million (1977)	\$ 8.00- 12.00	5000-6000 BTU/lb

Sources: Center for Renewable Resources Interviews with RDF Facility Engineers.

Most important, is an RDF plant preferable to source separation recycling? Unfortunately, the major government studies of waste-to-energy systems do not include comparisons of the economics of large plants with that of comprehensive recycling operations.(63) Recycling potentially saves more energy resources and provides more jobs than waste-to-energy plants, however--an important advantage cities must weigh in view of their employment profiles and resource bills.

What other economic effects will result from a RDF plant? Cities need to monitor and control air quality to protect public health. No doubt, cities will tolerate some air pollution to keep industry operating and workers employed, but urban officials must ensure that those activities that lower air quality provide compensatory economic benefits. The production and burning of RDF creates air pollution and few jobs. Recycling, on the other hand, creates no pollution and could create many jobs.

None of these considerations necessarily means that RDF plants are uneconomical. In any particular instance, producing solid fuel from waste could be the most efficient and economical method of waste management. But the value of an RDF system cannot be known without a thorough study of local conditions and comparisons with alternatives. Moreover, technology for producing and burning RDF is still developing. Though no major breakthroughs are expected, gradual improvement is likely. Still, many questions about the economics of RDF remain unanswered, the cities that experiment with this fuel source will be exploring largely uncharted territory.

Environmental Impact

RDF proponents often list reduced air pollution as an advantage of garbage-to-energy systems, and it is true that waste contains less sulfur than the coal it would replace. But sulfur is not the only pollutant. Compared to coal, RDF has much greater concentrations of heavy metals--copper, sodium, lead, and zinc--and produces substantial amounts of nitrogen oxides, carbon monoxide, and hydrochloric acid.(64) In addition, waste can contain polyvinyl chloride from plastics, PCBs from fluorescent lightbulbs, and pesticide residues, all of which could enter the atmosphere as the waste is processed or burned.

To guarantee safety, an RDF production facility should have a baghouse (a series of filters). And special measures must be taken to control emissions from RDF combustion. The electrostatic precipitators commonly used in coal plants work effectively when adjusted for the moisture content of the fuel burned, but RDF's variable moisture content hinders emission control by precipitators. Some engineers recommend baghouses for RDF burning, but the molten plastics could clog the filters. The ash residue remaining after RDF burning can also be dangerous. In fact, California considers RDF ash a hazardous waste product requiring special care in disposal.(65) RDF ash contains a high concentration of heavy metals, which can leach out of a landfill site unless preventive measures are taken. (Leaching is a problem with any landfill and most operating sites do not include sufficient safeguards. RDF ash, however, may be especially troublesome since it contains a higher percentage of heavy metals than ordinary waste.)

The production of RDF can enable a city to control more carefully the dangerous materials in urban waste through the use of baghouses, emissions control, and secure landfills. But without these extra measures, RDF could be an environmental hazard.

GASEOUS FUELS FROM RENEWABLE ENERGY

Gas produced from renewable resources (such as wood, wastes, or manure) can be burned to heat space or water or to produce steam. It can also be used as primary fuel in electricity generation or converted to liquid fuel.

Since most gaseous fuels produced from renewable resources must be used fairly close to where they are produced, gaseous fuels probably cannot be used in cities unless they are produced within cities as well.

Cities can initiate the production of gaseous fuels within their boundaries in several ways. They can help or encourage local industries that have available resources (such as waste wood or food-processing wastes) or high energy needs to install gasification equipment. The city itself could become a gas producer by using gasification equipment at facilities where appropriate resources are concentrated (at, for example, waste or sewage treatment plants) or by extracting methane from landfills. Municipal electric generating facilities could sometimes be retrofit to use biomass more easily if gasifiers were used. For example, turning wood into gas could obviate the need for extensive retrofits of boilers that previously burned fossil fuels.

Resource Potential

The Office of Technology Assessment estimates that with maximum Federal support and private development, biomass gas could provide nine quads of energy by 2000.(66) In reality, the contribution is likely to be far lower since the optimum combination of market-driving forces will probably not occur.

Gaseous fuel resources are generally concentrated in specific areas. For example, regions with an abundance of wood resources or lots of farms are probably the only areas where wood gasification and anaerobic digestion from manure are feasible. All cities, however, have potential resources at hand at municipal sewage-treatment plants or landfills.

The different types of renewable gaseous fuels vary according to the fuel input (feedstock), the gasification process used, and the most feasible end uses. As a frame of reference, natural gas has a BTU content of 1,000 BTU per cubic foot (CF). Low-BTU gas (100-200 BTU/CF) can be produced from wood or other biomass resources by gasifiers coupled to boilers. Medium-BTU gas (300 - 500 BTU/CF) is made by gasifying municipal solid waste or biomass resources. This gas can be used in industrial process heating or in electricity via gas turbines. It can also be synthesized into liquid fuels. (At an intermediate stage in the production of methanol, methane is produced.) Biogas (600 - 900 BTU/CF) can be produced by anaerobically digesting manure or sewage sludge, or through the natural decomposition of wastes in landfills. It can be used for process or space heating or electricity generation. In addition, it can be upgraded to pipeline quality by removing impurities or, in some cases, by boosting its BTU content with propane.

TECHNOLOGICAL APPROACHES/ISSUES

Thermal Gasification

Direct combustion of a feedstock results in heat, gas, ash, and other byproducts. Applying heat to a feedstock in a highly controlled environment can allow better control over the type and quality of conversion outputs. In gasification systems, the gas output of a thermal-conversion process is maximized.

The most commonly used thermal gasification system is the so-called air-blown gasifier, which blows air through a prepared feedstock at a rate that allows partial combustion. This accelerates the gasification of the remaining feedstock. The product is a low-BTU gas that can be used almost immediately as in gas-or oil-fired boilers. Indeed, this gas must be used quickly because the residual oils, char, and tar in the gas would clog valves and fuel lines if the gas cooled. Consequently, these systems are usually close-coupled to boilers so that gas can be used while it is still hot.

Air-blown gasifiers can be highly efficient since both the heat generated during gasification and the output gas can be used in the boiler. The U.S. Office of Technology Assessment estimates that properly working systems could achieve efficiencies (energy delivered to the boiler divided by the energy content of the feedstock) of 80 to 90 percent.(67) However, some system development is needed to reduce tar and oil production first.

Most currently installed air-blown gasifiers are relatively small-scale models (2 to 10 MMBTU/hour output) in use in industry. Most are used in forest products industries, where feedstocks in the form of wastewood are readily available. Such units could also be connected to retrofitted industrial boilers that formerly burned oil. Wood gas is an almost perfect substitute for oil, so boiler retrofits are simple. Some firms are also producing larger models (up to 100/MMBTU/hour output) that can be field-erected near where energy feedstocks are harvested. At present, smaller-sized units that could be used in residential or commercial applications are not cost-effective because the lower demand for gas means that recovering capital and fuel costs would take much longer.(68)

In general, thermal gasification systems work best with dry feedstocks. Although some of the larger models use municipal solid waste, wood is the preferred fuel for most air-blown gasifier applications, partly because waste wood is often the most accessible feedstock. Then too, some technical problems attend the use of other biomass feedstocks in air-blown gasifiers. For example, the bulkiness of grasses and crop residues can cause clogging. Experiments using denser agricultural wastes as feedstocks have had more promising although not problem-free, results. The California Energy Commission has developed a small gasifier based on a Swedish technology that converts any type of dry agricultural or wood waste to a low-BTU gas. A test unit at the Diamond-Sunswet walnut factory near Stockton, California, produced a clean, low-BTU gas of about 155 BTU/cu ft. from walnut shell feedstocks. Early performance (in 1976 and 1977) was so successful that the company planned to build a much larger, 130 MMBTU/hour gasifier, producing gas at less than \$1.00/MMBTU. Since then, however, mechanical difficulties have kept the equipment off-line too often to make expansion commercially feasible. Instead, the company is using direct combustion of walnut shells.(70)

Another technology similar to air gasification is the oxygen gasifier. This system limits biomass combustion by controlling the oxygen content in the chamber, allowing the gas given off during combustion to remain confined. The result is a medium-BTU gas that can be used for industrial process heating or methanol production.

Various feedstocks can be used in oxygen gasification. For example, one demonstration unit in a union Carbide Plant in South Charlestown, West Virginia, has produced medium-BTU gas from 200 tons per day of municipal solid waste.(71)

Despite its potential, the oxygen gasification process has not attracted as much commercial interest as air gasifiers. This may be due in part to the high organic quality of the gas produced which requires extensive clean-up.

Fundamentally, different gasification processes use the so-called pyrolysis technique, which involves applying high heat to a feedstock in the absence of oxygen(72) to produce oil, charcoal, and medium BTU-gas. More oil and charcoal are produced when the process is slowed; while a faster pyrolytic reaction at higher heat produces more gas. The process can make use of various feedstocks including wood, other biomass resources, and municipal solid waste.

Interest in the pyrolysis process is substantial because a variety of feedstocks can be used and products produced. Moreover, in this process outputs produced at one stage of the process can be used as input fuels in subsequent stages, and some of the environmental problems that plague other fuel-production processes are avoided. Indeed, pyrolysis makes sense for use in municipal solid waste facilities in urban areas: it takes care of both waste disposal and energy production, and because the waste is burned in an oxygen-free environment air pollution is minimal. However pyrolytic materials do give off pollutants when they are burned.(739)

For all these theoretical advantages, however, the technology remains in the developmental phase. And some remaining problems may be difficult to solve. A municipal solid waste treatment plant using pyrolysis in Baltimore had so many operational problems that the original developer withdrew leaving the city to manage the plant.(74) Some analysts claim the process is too costly, given the energy it delivers and that the oil and gas produced have relatively restricted uses.(75)

Anaerobic Digestion

When bacteria consume feedstocks in an airless environment, "biogas," a mixture of carbon dioxide and methane with a heat content of 500-900 BTU/cu ft., is released. Biogas can be produced from manure, selected biomass resources, municipal wastes, and many other feedstocks using any of several methods. The two principal technologies used are constructed digestors and direct methane-recovery from landfills.

Constructed Digestors

Anaerobic digestion units can be added to feedlots where livestock are confined or to facilities that treat municipal sewage. Smaller units can produce gas that can be used on-site to produce heat, steam, or electricity. Facilities with access to larger resources can also produce gas for delivery to pipelines.

Manure

Manure can be converted into biogas. If it is kept in a digester tank for several weeks, gas can be drawn off as it is produced. This process can be combined with the recovery of other resources. For example, manure released from the digester can be stored in an effluent lagoon where enriched liquid can be drawn off to make fertilizer and other byproducts.

Perhaps the largest impediment to using aerobic digestors with a manure feedstock is matching feedstock output and digester size with demand levels. Most confined livestock operations are relatively small, and few produce enough manure to make digester use continuously and (thus) economical.(76) Conversely, the manure available from large-scale feedlots could produce much more gas than would be needed on-site, particularly since these feedlots typically use liquid fuels to drive tractors and run other machines. Relatively low in energy, biogas cannot be stored effectively either. Therefore, some other solution to the supply/demand imbalance must be found--perhaps purifying the gas and selling it to a pipeline or using the gas to generate electricity for on-farm uses or sale to the utility. (See Economics, below.)

Since there are far more small than large feedlots, most analysts expect that the use of manure-fed anaerobic digestors will be confined to on-farm uses for the foreseeable future.(77) Except in relatively rare cases, then, they will not be producing much energy for cities.

Municipal Sewage

Unlike manure-based biogas operations, municipal sewage treatment plants do hold considerable promise for urban use. Even small-scale applications could help reduce urban energy consumption by making sewage treatment plants more energy self-sufficient. In 1973, some 70 percent of all municipal sewage treatment plants in the U.S. contained an anaerobic digestion unit in the sewage-treatment chain.(78) Still, most biogas produced by these digestors is burned off. According to analysts from the Solar Energy Research Institute, if all this gas were used it could supply all or most of the energy needed for sewage treatment in the county.(79)

The attractiveness of adding on-site gas-recovery systems is illustrated by the experiences of several communities. Cranston, Rhode Island, has been capturing biogas and converting it to pure methane since 1941. About 75,000 cubic feet of pure methane is

produced per day and used both to fuel the digestion process and to heat a city administration building.(80) In Los Angeles, the 350-million-gallon-per-day Hyperion Plant produces four million cubic feet of (60 percent methane) gas daily. One-quarter of this gas is sold to an adjacent electric generating plant owned by the city. The rest fuels on-site sewage treatment processes, principally via electricity generation.(81) A 23-million-gallon-per-day plant in Winston-Salem, North Carolina, gets 70 percent of its on-site energy from the 350,000 gallons of biogas it produces daily.(82)

A newer approach to combined sewage treatment and gas production may soon be tested in Hercules, California. In early 1980, the city opened a sewage treatment facility that grows water hyacinths and duckweed as part of the wastewater treatment process. Now the city plans to add a digester and electric generator to the facility, since these plants are excellent feedstocks for anaerobic digestion.(83)

Direct Recovery from Landfills

As municipal waste is compacted in sanitary landfills, natural anaerobic digestion occurs. The biogas thus produced can migrate from the landfill, causing fires and killing vegetation.. But it could be recaptured on-site, solving these environmental problems and providing energy.

Landfills can be "tapped" for methane gas by digging collection wells, installing piping systems, and using processing equipment to remove contaminants or to bring the gas up to pipeline quality. Such wells consist of perforated pipes vertically sunk at calculated intervals either in the landfill itself or nearby. Generally, the pipes are imbedded in gravel or cracked stone and spaced to maintain maximum gas-flow rate, a process aided by a pressurized pumping system that maintains a slightly negative pressure within the landfill. Both the wells and the pumping system are linked by a manifold piping system that delivers the gas to the processing facilities, where the water, solids, carbon dioxide, and other contaminants are extracted. Finally, if pipeline-quality gas is required, the heating value of the landfill gas can be increased by adding small amounts of propane.(84)

The growing interest in this technology is indicated by the number of cities that have started landfill-tapping projects. A March, 1980 listing by the National Center for Resource Recovery showed seven demonstrations of commercial-scale landfill gas-recovery systems operating or under construction. By September of 1981, the number had grown to 19.(85) (See Table One Hundred Seventy-Two. Some cities are using the recovered gas in their own buildings or power stations, while others are developing projects in cooperation with local utilities. In Los Angeles, for example, gas obtained from the Sheldon-Arleta Landfill in Los Angeles is used in a nearby city-owned generating plant. Under a royalty agreement with the city of Mountainview, California, Pacific Gas and Electric is recovering 1.2 million cubic feet of landfill gas (45 to 50 percent methane) per day, purifying it for use in PG&E's pipeline.(86)

Experiences with currently operating landfills are providing some valuable lessons for future projects. For example, the Sheldon-Arleta Landfill operation in Los Angeles had to close temporarily when it was discovered that the contaminant-control system was not large enough to handle the gas supply and that corrosive impurities left in the gas caused cooling coils in the compression system to corrode. The facility will reopen after the scrubbers are resized and the cooling coils replaced with coils made of non-corroding stainless steel.(87)

The extraction of methane gas from landfills has led to some experimentation with integrated systems--combined landfill-recovery operations and sewage treatment plants. These facilities mix municipal solid waste with sewage sludge in a controlled, airless environment. While gas production in landfills may take twenty to forty years, the same process could occur in five to thirty days in an integrated plant. Since June of 1978, DOE has operated a pilot plant to test this process (called REFCOM) in Pompano Beach, Florida. Currently, the Florida plant is operating at about half capacity and processing about 46 tons of refuse per day, producing some 10,000 cubic feet of 50 percent methane gas per ton.(88)

ECONOMICS

Thermal Gasification

Medium-sized air-blown gasifiers with outputs from two to ten MMBTU per hour should cost between \$40,000 and \$90,000 according to an analysis prepared by Booz-Allen-Hamilton.(89) This estimate squares with OTA's assessment that such units should cost about \$10,000 per MMBTU per hour of capacity.(90) Using these cost levels, Booz-Allen-Hamilton has calculated one representative payback for an industrial facility substituting wood gasification for oil. (See Table 173.) Even with \$40,000 capital costs and relatively high operating and maintenance costs, the ready availability of wood fuel means a rapid payback because wood costs so much less than oil. Granted, this calculation is somewhat dated in terms of oil prices and wood costs and it fails to take interest and taxes into account, but it does illustrate the economic appeal of a retrofit

TABLE ONE HUNDRED SEVENTY-TWO

PROJECTS TO RECOVER METHANE FROM LANDFILLS

Location and Major Participants	Output or Gas Produced Million ft ³ /day	Capital Costs (\$ millions)	Status
<u>CALIFORNIA</u>			
<u>Azusa</u> Azusa Land Reclamation Co. (wholly owned subsidiary of the SW Portland Cement Co.)	Low Btu gas	N/A	Operational
<u>Carson</u> Watson Biogas Systems; SCS Engineers	Medium Btu gas to power generators, producing electricity for sale to utility	N/A	Collection system complete; operations expected in Feb.1982
<u>City of Industry</u>	Medium Btu gas; .5 (Approx.)	.45	Operational
<u>Duarte</u> Watson Biogas Systems Lockman and Assoc.	Medium Btu gas to power generators, producing electricity for sale to utility	N/A	Collection system under construction; operata- tions expected in Feb. 1982.
<u>Los Angeles</u> (Bradley East Landfill)	Medium Btu gas; 2.4	N/A	Operational
<u>Martinez</u> Getty Synthetic Fuels, Inc.	Medium Btu gas	N/A	Operations expected in late 1981.
<u>Monterey Park</u> Getty Synthetic Fuels, Inc. Operating Industries, Inc. Southern Calif. Gas Co.	High Btu gas; 4.0	N/A	Operational
<u>Mountain View</u> City of Mountain View; EPA; Pacific Gas & Electric Co.; Dept. of Energy	High Btu gas; 0.3	.85	Demonstration plant; operating and produc- ing 0.3 MMSCFD of treated gas with a HHV of 850-950 Btu/SCF; expansion under inves- tigation.
<u>Palos Verdes</u> Getty Synthetic Fuels, Inc. Los Angeles Co. Sanitation District; So. Calif. Gas Co.	High Btu Gas; .75	N/A	Operational
<u>San Fernando</u> Getty Synthetic Fuels, Inc.	Medium Btu gas	N/A	Operations expected in late 1981.
<u>San Leandro</u> Getty Synthetic Fuels, Inc. Oakland Scavenger Co.	Medium Btu gas	N/A	Operational
<u>Sun Valley</u> (Sheldon-Arieta Landfill Gas Recovery Project) City of LA Departments of Public Works and Water & Power	Low Btu gas; 2.8	2.5	Compressor station undergoing equip- ment modifications; operations expected to resume Fall 1981.
<u>Wilmington</u> Watson Biogas Systems, Inc. SCS Engineers	1.5	N/A	Operational

TABLE ONE HUNDRED SEVENTY-TWO

PROJECTS TO RECOVER METHANE FROM LANDFILLS (Cont)

Location and Major Participants	Output or Gas Produced Million ft ³ /day	Capital Costs (\$ millions)	Status
ILLINOIS			
Calumet City Getty Synthetic Fuels, Inc. Waste Management, Inc. Natural Gas Pipeline Co.	High Btu gas to power generators, producing electricity for sale to utility	N/A	Operational
MICHIGAN			
Riverview Watson Biogas Systems; SCS Engineers	Medium Btu gas to power generators, producing electricity for sale to utility	N/A	Contracts with city signed; applications for construction submitted; utility negotiations proceeding
NEW JERSEY			
Cinnaminson Sanitary Landfill, Inc. Public Services Electric & Gas Co.; Hoeganaes Corp.	Medium Btu gas (570 Btu/ SCF); 1 (Used in-plant by Hoeganaes Corp.)	N/A	Operational; modifica- tions planned to im- prove service relia- bility and add other customers.
NEW YORK			
Staten Island (Fresh Kills Landfill) Brooklyn Union Gas Co.; New York City Office of Resource Recovery & Waste Disposal; N.Y. State Energy Research & Development Authority; US Dept. of Energy; Leonard S. Wegman, Inc.	0.05	.33	Test began in Feb.1981 using raw landfill gas in an internal combus- tion engine generator to produce 100 Kw of electricity; 2000 hrs. logged on unit as of July 11, 1981.
Staten Island (Fresh Kills Landfill) Getty Synthetic Fuels, Inc. City of NY; Brooklyn Union Gas Co.	High Btu gas	N/A	Operations expected to begin in early 1982
NORTH CAROLINA			
Winston-Salem City	Medium Btu gas (burned to generate electricity to power sewage treat- ment plant)	Less than \$25,000 for wells and pipeline	Operational

TABLE ONE HUNDRED SEVENTY-THREE

PAYBACK FOR SUBSTITUTING WOOD GASIFICATION
FOR OIL IN MEDIUM-SIZED INDUSTRIAL FACILITY

Cost of Oil (75¢/gallon) without gasifier	\$75,000/year
Cost of Wood (\$26/dry ton) with gasifier	<u>-40,000/year</u>
Fuel Cost Savings	\$35,000/year
Increase in O&M with gasifier	- 6,000/year
Net Savings	\$29,000/year

Capital Costs of Gasification Unit \$40,000

Simple Payback:
$$\frac{\$40,000 \text{ (capital Cost)}}{\$29,000/\text{year (savings)}} = 1.4 \text{ years}$$

Source: Booz-Allen-Hamilton, Assessment of Industrial Activity
in the Utilization of Biomass for Energy (1980).

gasifier to an oil-using industry with a readily-available feedstock. Obviously, economics would be somewhat less attractive if the system were competing against a natural gas system.

The economics of similar systems installed in residential or commercial facilities are far less promising, principally because capital costs are offset by lower yearly fuel savings due since the load factor or utilization rate is low. Table 174 summarizes OTA comparisons of dollars per MMBTU of delivered energy for industrial and commercial wood gasifiers. With a higher load factor (90 percent versus 25 percent for the commercial user), industry can offset the capital costs with a higher level of annual energy production.

Compared to the small-scale gasifiers discussed so far, large field-erected gasifiers would cost proportionately much more. Indeed, OTA estimates that energy from field-erected units could cost four to five times more per unit output than gas from the smaller units.

Anaerobic Digestion

Estimates of the costs per BTU of energy produced by anaerobic digestion range widely. In the following discussion, the focus is on general influences on system economics. For perspective, some specific examples are also included.

Manure

The economics of biogas production from manure depend on whether the gas is used on-site or sold to a utility and whether the gas is used to produce thermal or electrical energy. An additional variable is the value of non-energy byproducts.

So far, using biogas at the production site has proved to be more economical than selling it to utilities, even for large production facilities. For example, one company in Guymon, Oklahoma, had been selling purified methane from its 100,000-head beef feedlot to Peoples Gas for transmission to Chicago at \$1.97 per MMBTU. However, in 1980, the company instead began using the gas on-site to process residual protein products into finished feeds. This in-house use proved more economical than selling to the pipeline company.

The economic feasibility of on-site electrical production depends heavily on utilities' willingness to purchase excess electricity whenever it is available. OTA predicts that most utilities would be willing to purchase electricity generated from biogas only at low wholesale rates, so biomass production combined with electricity generation will be economically attractive only for livestock operations with a high baseload electricity demand. Thus, large poultry farms in the Northern U.S., which use large amounts of expensive electricity for heating, lighting, and mechanical operations, may be the first to use electricity from biogas on a large scale. Some large beef feedlots with high electricity use might also find this approach attractive, OTA contends. And, although too small to realize economies of scale, swine operations that use electric self-feeding systems might also be able to make economic use of a combined digester-generator system.(92)

If PURPA provisions are effectively implemented, OTA's expectations may prove too pessimistic. If small farm-scale or medium-sized feedlot generators were paid true "avoided costs" for excess electricity sold to utilities, these generators in many cases may be very cost-effective particularly where electricity costs are high. One Missouri farmer four years ago installed a digester and electric generator fueled by cropwastes. (The electric generator cost \$350, and the engine was donated.) This system has proven so successful that the farmer has patented the "meter beater"--a small engine generator that can run on either biogas or methane. To date, he has sold seven of the units to farm and industrial users in California, the Midwest, and the U.S. Naval Academy in Annapolis.(93) Clearly, at least some farmers expect to make economical use of electricity from biogas, either on-farm or through resale to utilities.

The economics of producing methane from manure also vary with the value of byproducts--a fact too few economic analyses take into account. Valuable liquid fertilizers are produced in the digestion process, and solid byproducts are being tested as cattle feed.

Municipal Sewage

Plants currently producing gas from sewage enjoy favorable economics. The Hyperion Plant in Los Angeles produces four million cubic feet of biogas daily for only \$2.42 per MMBTU.(94) The Archie Elledge plant in Winston-Salem produces 350,000 cubic feet per day for only \$1.60 per MMBTU. However, these costs do not include costs for upgrading gas to pipeline quality,(95) which could add another \$1.04 to \$1.79 per MMBTU. But even including these costs, gas produced from such facilities would still be very competitive with natural gas at current prices.(96)

Gas from Landfills

TABLE ONE HUNDRED SEVENTY- FOUR

COMPARATIVE COSTS/MMBTU OF INDUSTRIAL
AND COMMERCIAL WOOD GASIFIERS

	<u>Total</u> <u>Cost</u>	<u>Delivered</u> <u>Feedstock</u> <u>(\$40/ dt)</u>	<u>Capital</u> <u>Cost</u>	<u>Operating</u> <u>Cost</u>
1. Medium-sized industrial user				
250 dry tons green-wood/day	\$3.60	\$2.95	\$0.40	\$0.25
90% load factor				
85% energy efficiency				
2. Smaller, commercial user				
30 dry tons green-wood/day	\$5.50	\$3.60	\$1.40	\$0.50
25% load factor				
70% energy efficiency				

Source: Office of Technology Assessment, Fuels from Biological Processes (1981).

Based on its experience with methane recovery in Mountain View, California, Pacific Gas and Electric has developed a detailed economic analysis of landfill gas collection, treatment, and compression. Cost data from the Mountain View system completed in May 1978 at a cost of \$840,000, indicates that a larger plant producing 96,100 MMBTU of raw gas annually and purifying it to pipeline quality methane would cost \$3.3 million to construct. If financed 50 percent with debt at 16 percent interest and 50 percent with equity at 20 percent return on equity, the system could produce gas at \$12.02 per MMBTU (in 1981 dollars). These costs are competitive with the marginal cost of oil (\$10.90/MMBTU) and, according to PG&E, with the current cost of liquified and synthetic natural gas.(97)

PG&E's projected costs for gas produced from a large new facility are higher than present costs of gas from the Mountain View facility. In July, 1980, PG&E charged \$4.43 for pipeline-quality gas from that system. However, both capital and operating costs are expected to increase over the lifetime of the facility, partly because more and more wells will have to be dug to maintain desired output as gas production falls with continued extraction. Thus, the costs of gas for landfills should be differentiated in terms of short-term costs and the much-higher lifetime costs.

ENVIRONMENTAL IMPACTS

Both the production and use of gaseous fuels derived from renewable resources are expected to have relatively benign environmental impacts compared to those of fossil fuels. With new gasification and end-use conversion systems that do not replace existing fossil-fueled facilities, of course, environmental problems will increase.

Little solid evidence exists about pollution-creating potential of gasifiers. But OTA has made some general observations and identified areas requiring further study. First, air pollution emissions vary greatly with feedstock composition, conversion technology, and the degree of pollution control exercised. Most gasification technologies will emit fewer sulfur or nitrogen compounds and less carbon dioxide or carbon monoxide than oil-fired boilers. But oil-burning facilities will emit fewer particulates and hydrocarbons.(98) In most cases, a wood gasification unit retrofit onto an oil boiler will emit far less carbon monoxide, particulates, or hydrocarbons than a direct wood combustion unit.

Second, environmental assessments cannot ignore the impacts of using or disposing of gasification byproducts--pyrolytic oil or char. Burning char can emit nitrous and sulfur oxides, while high levels of particulates can be emitted when pyrolytic oils are burned in the gasification process. Some studies have also suggested that the waste effluent from pyrolysis contains a very high organic content, potentially damaging to water quality.(99) However, where waste is the feedstock, the pollution-related costs (including those of clean-up) will have to be balanced against the environmental costs and disturbances associated with other methods of waste disposal or energy production.

Most anaerobic digestion or landfill recovery operations can have positive environmental impacts. For example, tapping accumulations of methane in landfills can help prevent dangerous gas build-up that could lead to explosions or to land- or water-pollution. Similarly, confining animal wastes for gas production could reduce environmentally damaging runoff from cattle feedlots.(100)

Potential environmental problems of anaerobic digestion are mostly those of waste disposal. Digestion reduces the amounts of toxic wastes requiring disposal but does not eliminate them. However, the technologies for anaerobic waste treatment are fairly well understood.

NOTES

1. See, for example, the reports of energy audits conducted under the U.S. Department of Energy's Comprehensive Community Energy Management Planning (CCEMP) Program. Published reports include documents from Bridgeport, Boulder, Greenville (North Carolina), Los Angeles, and Seattle. For their availability see Appendix I.
2. Energy demand figures are based on the proposed rule for the Building Energy Performance Standards (BEPS). Insolation data in BTU are derived from information assembled by the National Oceanic and Atmospheric Administration (NOAA).
3. Theodore B. Taylor, "Long Term Storage of Heat and Cold," Princeton/SERI Report #21, Princeton Center for Energy and Environmental Studies, June 28, 1981.
4. Cf. V. Daniel Hunt, *Windpower* (New York: Van Nostrand Reinhold Company, 1981), pp. 21-1; Jack Park, *The Wind Power Book* (Palo Alto: Chesire Books, 1981), pp. 44 ff.
5. City of New York, "Initial Brief, Submitted to New York State Energy Planning Board," December 3, 1981, pp. 32-3.
6. Energy Task Force, *Windmill Power for City People* (Washington, D.C.: Community Services Administration, 1977), p. 5.
7. New England River Basin Commission, *Potential for Hydropower Development at Existing Dams in New England*, January, 1980; New York State Energy Research and Development Authority, *An Action Program for the Development of Small Hydropower in New York State*, (undated), pp. 2-7; General Accounting Office, *New England Can Reduce Its Oil Dependence Through Conservation and Renewable Resource Development* (Washington, D.C.: U.S. General Accounting Office, 1981) vol. 1, pp. 7, 8-9;; vol.2, pp. 26-7; Resource Policy Center, *The New England Energy Atlas* (Hanover, N.H.: 1980), pp. 20-28.
8. Much depends on how deep the water resource is. Ground water temperatures close to the surface can vary substantially with ambient temperatures. Fluctuations are less likely with deeper reserves. Cf. Southern Tier Central Regional Planning Board, *Renewable Energy Resource and Technology Assessment* (Washington, D.C., U.S. Department of Energy, 1978,), pp. 25-6.
9. For a general overview of different hydrological configurations see U.S. Department of Energy, *Institutional Constraints on Alternative Water for Energy: A Guidebook for Regional Assessments* (Washington, D.C.: U.S. Department of Energy, 1980), pp. 8-10; Southern Tier, op. cit. p. 26.
10. James M. Calm, "Heat-Pump-Centered Community Energy Systems: Systems Development Summary," Argonne National Laboratory, February, 1980, p. 7.
11. See, for example, City of St. Paul, *Energy Committee of 100+: Large Energy Users Subcommittee Report*, January, 1980, p. 10.
12. Cf. Hampshire College, *Energy Self-Sufficiency in Northampton, Massachusetts* (Washington, D.C.: U.S. Department of Energy, 1979), pp. 126-130; Donald L. Kirkpatrick, et. al. "A Unique, Low-Energy Air Conditioning System Using Naturally-Frozen Ice," presented at the Solar Rising Conference of the International Solar Energy Society, Philadelphia, PA, May 26-30, 1981.
13. Michael Edesess, "Solar Ponds Resource Potential," *Non-Convecting Solar Pond Workshop Summary* (Boulder City, Nevada: Desert Research Institute, 1980), pp. 2-8.
14. Conversations with Mel Lezburg, Boot Mitts; George Tutte, Director of Finance, City of Paterson, N.J.: Jeffrey Paine, Chief City Engineer, City of Idaho Falls, Electric Division, Summer, Fall, 1980; Summer, 1981.
15. Edesess, op. cit., pp. 2.7-2.8.
16. City of Burlington, *Report for the Electric Department for the Year Ending June 30, 1978*; Timothy S. Cronin, "New Wood Fired Generating Unit Brings Savings," *Public Power*, January-February, 1978, pp. 32-33.
17. Office of Technology Assessment, *Energy from Biological Processes* (Washington, D.C.: Office of Technology Assessment, 1981), p. 4; City of Portland, *Energy Conservation Choices for the City of Portland, Oregon*, Volume 3D: *Industrial Conservation Choices*

(Washington, D.C.: U.S. Department of Housing and Urban Development, 1977), p. 14: Michael P. Levi and Michael J. O'Grady, Decisionmaker's Guide to Wood Fuel for Small Industrial Energy Uses (Golden, CO: Solar Energy Research Institute, 1980); John Lohnes, Potential Industrial Wood Boiler Users in New England (Hanover, NH: Resource Policy Center, Dartmouth College, 1979)

18. City of Lewiston, Cooperative Agreement/Applications District Heating/Cooling Systems Study, January 16, 1981, Section 5,B.

19. Charles Hewett and Colin High, Construction and Operation of Small Dispersed Wood-Fired Power Plants (Hanover, NH: Resource Policy Center, Dartmouth College, 1978), p. 21.

20. OTA, Energy from Biological Processes, op. cit., pp 78-9.

21. Cf. Colin J. High and S.E. Knight, Environmental Impact of Harvesting Non-Commercial Wood for Energy. (Hanover, N.H.: Resource Policy Center, Dartmouth College, 1977); C.G. Wells and J.R. Jorgenson, "Effect of Intensive Harvesting on Nutrient Supply and Sustained Productivity." Proceedings: Impact of Intensive Harvesting on Forest Nutrient Cycling (Syracuse: State of New York, 1979); Resource Policy Center, op. cit., p. 17.

22. N. Bhagat, H. Davitian, and R. Pouder, Crop Residues As A Fuel for Power Generation (Upton NY: Brookhaven National Laboratories, 1979), pp. 1-2.

23. Solar Energy Research Institute, Fuel From Farms - A Guide To Small-Scale Ethanol Production (Golden, CO: 1980), pp. A.2-A.3.

24. Lester R. Brown, Food or Fuel: New Competition for the World's Cropland (Washington, D.C.: Worldwatch Institute, 1980).

25. Mueller Associates, Biomass Availability for Highway Vehicle Fuels: A Resource and Availability Survey (Washington, D.C.: U.S. Department of Energy, 1979), pp. 21 ff.

26. Ibid., Bhagat et. al., op. cit., p. 2; See, however, OTA, op. cit., pp. 119-20.

27. Mueller Associates op. cit., p. 21.

28. Eric Leber, "Golden Garbage, Public Power, March/April, 1980, pp. 14-17; U.S. Conference of Mayors, Economic Development and Resource Recovery (Washington, D.C.: U.S. Conference of Mayors. October 1979) (Draft). In addition see the series of case studies prepared by the Conference on Cities that have implemented resource recovery plants.

29. Even where waste is burned for heat or steam, landfills may still be needed, however, to dispose of ash from garbage incineration and items in the waste stream that cannot be recovered. The extent to which landfills are still needed will offset the economics of garbage-to-energy plants significantly. See Tania Lipshutz, Garbage to Energy - The False Panacea (Santa Rosa, California: Sonoma County Recycling Center, 1979).

30. Environmental Protection Agency, Resource Recovery Plant Implementation: Guides for Municipal Officials, Vol. 3 Markets (Washington, D.C.: U.S. Environmental Protection Agency, 1979).

31. U.S. Geological Survey, Assessment of Geological Resources in the United States - 1978, Geological Survey Circular 790, (Washington, D.C.: U.S. Department of the Interior, 1979). Much of this has to do with differences in the geothermal gradients in the two areas. In the west, reserves get hotter fairly quickly as one goes into the earth, whereas in the east, temperatures increase more slowly with depth. Since porosity tends to decrease with depth, the hotter resources closer to the surface in the western region are more easily recoverable via drilling. Personal Communication, William J. Toth, Supervisor, Technology Transfer, EG&E, Idaho, Inc., December 11, 1981.

32. "DOE Moves Ahead with Geothermal." Epri Journal, March 1980, pp. 28-32.

33. For an excellent technical discussion of geothermal resources see Direct Utilization of Geothermal Energy: A Technical Handbook (Davis, California: Geothermal Resource Council, 1979).

34. Epri Journal, op. cit.

35. U.S. Department of Energy, Geothermal Energy: Program Summary Document (Washington, D.C.: U.S. DOE, January, 1980) pp. 32-33; Stahrl W. Edmunds, "The Government's Role in Developing Geothermal Energy Policy in Imperial County, California," Joel T. Werth, ed. Energy in the Cities Symposium, PAS Report no. 349, (Chicago: American Planning Association, 1980) pp. 37-42.
36. The standard method used to calculate wind speed distributions on the basis of average wind speed measurements is the so-called Rayleigh distribution described by Park, op. cit., p. 54.
37. Epri Journal, June, 1981.
38. Cf. U.S. Army Corps of Engineers, Feasibility Studies for Small Scale Hydropower Additions: A Guide Manual (Washington, D.C.: U.S. Department of Energy, 1979); Tippetts-Abbett-McCarthy-Stratton, Evaluation of Small Hydroelectric Potential (New York: 1979) available from T-A-M-S office, 655 Third Avenue, New York, New York 10017.
39. For a more detailed discussion see: Resource Recovery Plant Implementation, op. cit., vol 1, Planning and Overview.

CHAPTER FOUR - NOTES

1. Compact Cities: Energy Saving strategies for the Eighties, Report together with Dissenting Views by the Subcommittee on the City of the Committee on Banking, Finance, and Urban Affairs, House of Representatives, (Washington, D.C.: U.S. Government Printing Office, 1980), p. 15.
2. City of Boulder, Community Energy Management Plan, vol. 1, Energy Case Study, 1980, pp. 54-62.
3. Compact Cities, op. cit., pp. 13-14.
4. Ibid, p. 15; City of Portland, Energy Conservation Choices for the City of Portland, Oregon, vol. 3B, Transportation and Land Use Conservation Choices (Washington, D.C.: U.S. Department of Housing and Urban Development, 1977), p. 32.
5. City of Los Angeles, Solar Envelope Zoning: Application to the City Planning Process (Golden, Colorado: Solar Energy Research Institute, 1980), p. A-35.
6. City of Boulder, op. cit., pp. 45-7. Some growth management programs, however, are potentially discriminatory and may be struck down judicially because of it. See Compact Cities, p. 60.
7. City of Portland, op. cit., pp. 25-34; Los Angeles Energy Management Advisory Board, The Energy/LA Action Plan, 1981, p. 48.
8. John Alschuler found that political impediments to these changes were perhaps the strongest barrier. See Community Energy Strategies: A Preliminary Review (Draft) May 1980, pp. 37-8. Cf. The Energy/LA Action Plan, op. cit.
9. For example, the Philadelphia Solar Planning Project calculated that almost 80 percent of the housing units in the city were in row homes. See Philadelphia Solar Planning Project, Working Papers. Applications, May, 1980, p. 7.
10. Robert Twiss, et. al., Land Use and Environmental Impacts of Decentralized Energy Use (Washington, D.C.: U.S. Department of Energy, 1980) pp. D.18-D.28.
11. Cf. George E. Peterson, et. al., "Urban Development Patterns" (Washington, D.C.: The Urban Institute, 1980).
12. City of Boulder, op. cit., p. 35.
13. Greater Bridgeport Region, 1980, p. 15.
14. City of Portland, op. cit., p. 32; Compact Cities op. cit., p. 57; James Ridgeway, Energy Efficient Community Planning (Emmaus, PA: J.G. Press, 1979), pp. 57-61.
15. Testimony of Marion Hemphill, Energy and the City, Hearings before the Subcommittee on the City of the Committee on Banking, Housing, and Urban Affairs, House of Representatives, (Washington, D.C.: U.S. Government Printing Office, 1977), p. 94-95.

16. Energy/LA, op. cit., p. 48.
17. Office of Energy Conservation, State of Colorado, Energy Conscious Planning, 1979.
18. City of Portland, op. cit., vol. 1, Preliminary Energy Data and Analysis, pp. 67; 78.
19. Energy Audit - Greater Bridgeport Region, op. cit., p. 24.
20. City of Philadelphia, Pre-Application for a U.S. Department of Housing and Urban Development Innovative Grant for Community Energy Conservation, June 19, 1980.
21. Ibid.
22. City of Portland, op. cit., Volume 3D, Industrial Conservation Choices, pp. 66-7.
23. Figures based on F-Chart calculations using home energy efficiency and collector performance assumptions employed by Roger Bezdek, et. al., "Economic Feasibility of Solar Water and Space Heating," Science, 23, March, 1979, pp. 1214-1220.
24. For an excellent discussion of the technical and land use issues involved in assuring solar access see Martin Jaffe and Duncan Erley, Protecting Solar Access for Residential Development: A Guidebook for Planning Officials (Washington, D.C.: U.S. Department of Housing and Urban Development, 1979), esp. pp. 82-98.
25. Ibid, p. 83; Winslow Fuller, "Collector Location: No Taboos an East or West," Solar Age, December, 1980, pp. 26-7.
26. Twiss, op. cit., p. D-3.
27. Ibid, p. D-48.
28. Jaffee and Erley, op. cit. pp. 10-21.
29. Ibid, p. 99. Cf. Gerald Mara and David Engel, "Institutional Barriers to Solar Energy: Early HUD Demonstration Experiences," Solar Law Reporter, March/April, 1980, pp. 1095-1117 at 1103.
30. Twiss, op. cit., p. D-3.
31. For a partial list of communities proposing or adopting solar shade control ordinances see Jaffee and Erley, Appendix.
32. Philadelphia Solar Planning Project, Working Papers - Neighborhoods, Part II, May, 1980, pp. 27-48; Michael Shapiro, "Boston Solar Retrofits," Discussion Paper E-80-11, Energy and Environmental Policy Center, John F. Kennedy School of Government, Harvard University, December, 1980, p. 21.
33. Twiss, op. cit., p. D-30.
34. Ibid, p. D-76.
35. The best source on solar access protection in existing development is Gail Boyer Hayes' Solar Access Law (Cambridge, MA: Ballinger, 1979).
36. Seattle Energy Office, Energy Ltd., (Draft), October, 1980, pp. 113-115; Jaffe and Erley, op. cit., pp. 46-50.
37. Jaffe and Erley, op. cit., pp. 88-90.
38. Greater Roxbury Development Corporation, Solar Typologies Project: Neighborhood-Scaled Solar Energy Development Strategies for Roxbury, MA., November 1, 1980, p. 8; Cf. Compact Cities, op. cit., p. 10; Solar Envelope Zoning, op. cit., p. 54.
39. Solar Envelope Zoning, op. cit., p. 42.
40. Cf. Energy/LA, op. cit., p. 48.
41. Hayes, op. cit., p. 15-18.
42. Hayes, op. cit.
43. For an extensive discussion of the solar envelope concept see Ralph Knowles and Richard Berg, Solar Envelope Concepts (Golden, CO: Solar Energy Research Institute,

1980).

44. This is truer for some areas than others. For instance, Los Angeles found that applying the solar envelope concept in high density areas would reduce density levels substantially. Still, a solar envelope could be applied in most low- or medium-density areas without adverse impacts. See Solar Envelope Zoning, op. cit., p. 7.

45. This approach is described and critiqued by Hayes, op. cit., pp. 181-192.

46. Cf. Solar Envelope Zoning, op. cit., pp. 35; 43.

47. Philadelphia Solar Planning Project, Neighborhoods, op. cit., Shapiro, op. cit., p. 11.

48. Shapiro, op. cit., p. 10.

49. City of Cambridge, Community Development Department, "Energy Use in Cambridge," (Draft) July, 1980, pp. 4-6.

CHAPTER FIVE - NOTES

1. At last count, 46 states plus the District of Columbia had adopted some form of energy conservation standard. See National Conference of States on Building Codes and Standards, "Draft Report on State Energy Codes for New Building" (Washington, D.C.: October, 1980).

2. See American Institute of Architects Research Corporation, Solar Dwelling Design Concepts (Washington, D.C.: U.S. Department of Housing and Urban Development, 1976), pp. 53-6.

3. Recent practice for new homes features R-19 insulation in ceilings and R-11 in walls, considerable improvements over energy efficiency levels achieved in the early 70's. Still, there is considerable room for improvement. Analyses of energy conservation features used in homes participating in HUD's Residential Solar Demonstration Program indicated that builders regularly used R-30 insulation in the ceilings and R-19 in walls.

4. Michael Andreassi, Lorene Yap, and Olson Lee, "The Impact of Residential Energy Efficiency Standards on Households" (Washington, D.C.: The Urban Institute, June, 1980, pp. 17-19.

5. David R. Kaminsky, "Shelter and Neighborhoods: Indicators of Physical Deterioration in Cities," Robert P. Boynton, ed., Occasional Papers in Housing and Community Affairs, vol. 4 (Washington, D.C.: U.S. Department of Housing and Urban Development, 1979), pp. 126-147 at 138.

6. Douglas Sliger, "Modular Retrofit Experiment (Princeton Project)," June 17, 1980.

7. Kaminsky, op. cit., p. 137.

8. Steven Ternoey, et. al., "Energy Efficient Commercial Buildings: The Effect of Environmental Systems on Architectural Form," Proceedings: The 5th National Passive Solar Conference (Newark, Delaware: American Section of the International Solar Energy Society, 1980), pp. 35-43.

9. Residential Building Standards Development Project, "High-rise Buildings," Building and Appliance Standards Office, California Energy Commission, May, 1980, pp. 3-8.

10. Office of Technology Assessment, Residential Energy Conservation (Washington, D.C.: Office of Technology Assessment, 1979), p. 35.

11. Conversation with Bruce Powell, Institute for Human Development, Philadelphia, PA.

12. Greater Washington Board of Trade, Energy Conservation Manual for Multi-family Dwellings (Washington, D.C.: 1981), p. 65; National Electrical Contractors Association and National Electrical Manufacturers Association, Total Energy Management: A Practical Handbook on Energy Conservation and Management (Washington, D.C.: 1979), p. 27.

13. Philadelphia Solar Planning Project, Working Papers, Economic Impacts, May, 1980, p. 21.

14. Peter Hollander, et. al., Installation Guidelines for Solar DHW in One- and Two-Family Dwellings (Washington, D.C.: U.S. Department of Housing and Urban Development, 1979), p. 18.
15. Gerald Mara and David Engel, "Institutional Barriers to Solar Energy: Early HUD Demonstration Experiences," Solar Law Reporter, March/April, 1980, pp. 1095-1117, at 1106.
16. Robert Twiss, et. al., Land Use and Environmental Impacts of Decentralized Energy Use (Washington, D.C.: U.S. Department of Energy, 1980), p. D-15.
17. Cf. Vivian Loftness and Volker Hartkopf, "Passive Solar Retrofit of All-Glass Office Buildings," Proceedings: The 5th National Passive Solar Conference (Newark, Delaware: American Section of the International Solar Energy Society, 1980), pp. 869-873.
18. Alex Wilson, "Trombe Wall Retrofit," Solar Age, September, 1978, pp. 28-30.
19. Philadelphia Solar Planning Project, Working Papers - Neighborhoods, Part II, May, 1980, p. 28.
20. State of Florida, Model Energy Efficiency Building Code, November, 1978, pp. 5.2-5.8.
21. Andreassi, et. al., op. cit., p. 16.
22. City of Portland, Energy Conservation Choices for the City of Portland, Oregon, vol. 1, Preliminary Data and Analysis (Washington, D.C.: U.S. Department of Housing and Urban Development, 1977), pp. 37-8; St. Paul Energy Committee of 100 +, "Existing Housing and Zoning Subcommittee Report," January, 1980, p. 2.
23. Andreassi, op. cit., p. 22.
24. Philadelphia Solar Planning Project, Working Papers - the Philadelphia Solar Audit, February, 1980, p. 1.
25. Compact Cities: Energy Saving Strategies For the Eighties, Report together with Dissenting Views by the Subcommittee on the City of the Committee on Banking, Finance and Urban Affairs, House of Representatives (Washington, D.C.: U.S. Government Printing Office, 1980), p. 30. Note that much of the power of Executive Order 12185 has been diluted by the change in administrations and the lower levels of funding for HUD housing programs.

CHAPTER SIX - NOTES

1. This would not necessarily be an attempt to make an uneconomical technology look more promising than it is. If accelerated natural gas deregulation occurs, cities heavily reliant on natural gas supplies could be devastated by precipitous fuel price hikes. Encouraging the substitution of solar energy for natural gas could be seen as an effort to cushion the blow.
2. South Florida Regional Planning Council, South Florida Regional Energy Audit (Draft), January 13, 1981, pp. 66ff.
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4. Douglas W. Hooker, E. Kenneth May, and Ronald E. West, Industrial Process Heat Case Studies (Golden Colorado: Solar Energy Research Institute, May, 1980).
5. City of Portland, Industrial Conservation Choices for the City of Portland, Oregon, vol. 1. Preliminary Energy Data and Analysis (Washington, D.C., U.S. Department of Housing and Urban Development, 1977), p. 82.
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Builders Research Foundation, Insulation Manual (Rockville, MD: NAHBRF, 1979), pp. 12-13.

8. City of Portland, op. cit., vol. 1, pp. 53-4;; City of Boulder, Community Energy Management Plan, vol. 1, Energy Use Study, May, 1980, p. 57; Statement of the National Association of Home Builders on Proposed Building Energy Performance Standards (BEPS), March 24, 1980, p. 5.

9. Cf. Hans Landsberg and Joseph Dukert, High Energy Costs: Uneven, Unfair, Unavoidable? (Washington, D.C.: Resources for the Future, 1981), pp. 52-3.

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16. New England Innovation Group, "The Lawrence Economic Development/Energy Program" (undated), pp. 122-26.

17. See Part Two, Chapter Four.

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22. For an excellent, detailed discussion of how cities can become qualified small power producers under the provision of PURPA 210 see David Morris, David Bardaglio, et. al., "Municipalities and PURPA 210: Opportunities for Local Revenue Generation," (Draft), (Washington, D.C., Institute for Local Self-Reliance, 1981).

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27. Cf. City of Philadelphia, Pre-application for a U.S. Department of Housing and Urban Development Innovative Grant for Community Energy Conservation, June 1980. For technical support see C. Lee et. al., "Philadelphia's Gallery II Shopping Center Complex: An Analysis for the Applications of an integrated Community Energy System," two vols. (Chicago: Argonne National Laboratory, 1979).
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31. Harold Lorsch, et. al., "Implications of Residential Solar Space Conditioning on Electric Utilities," Franklin Institute Research Laboratories, Report F-C4209, 1976.
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33. See for example, Southern California Edison, op. cit., p. 13; New England Electric System, NEES Plan, First Update, November, 1980, section two.
34. Cf. City of Los Angeles, the Energy/LA Action Plan, July, 1981, p. 64; See also John H. Alschuler, Community Energy Strategies: A Preliminary Review.
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