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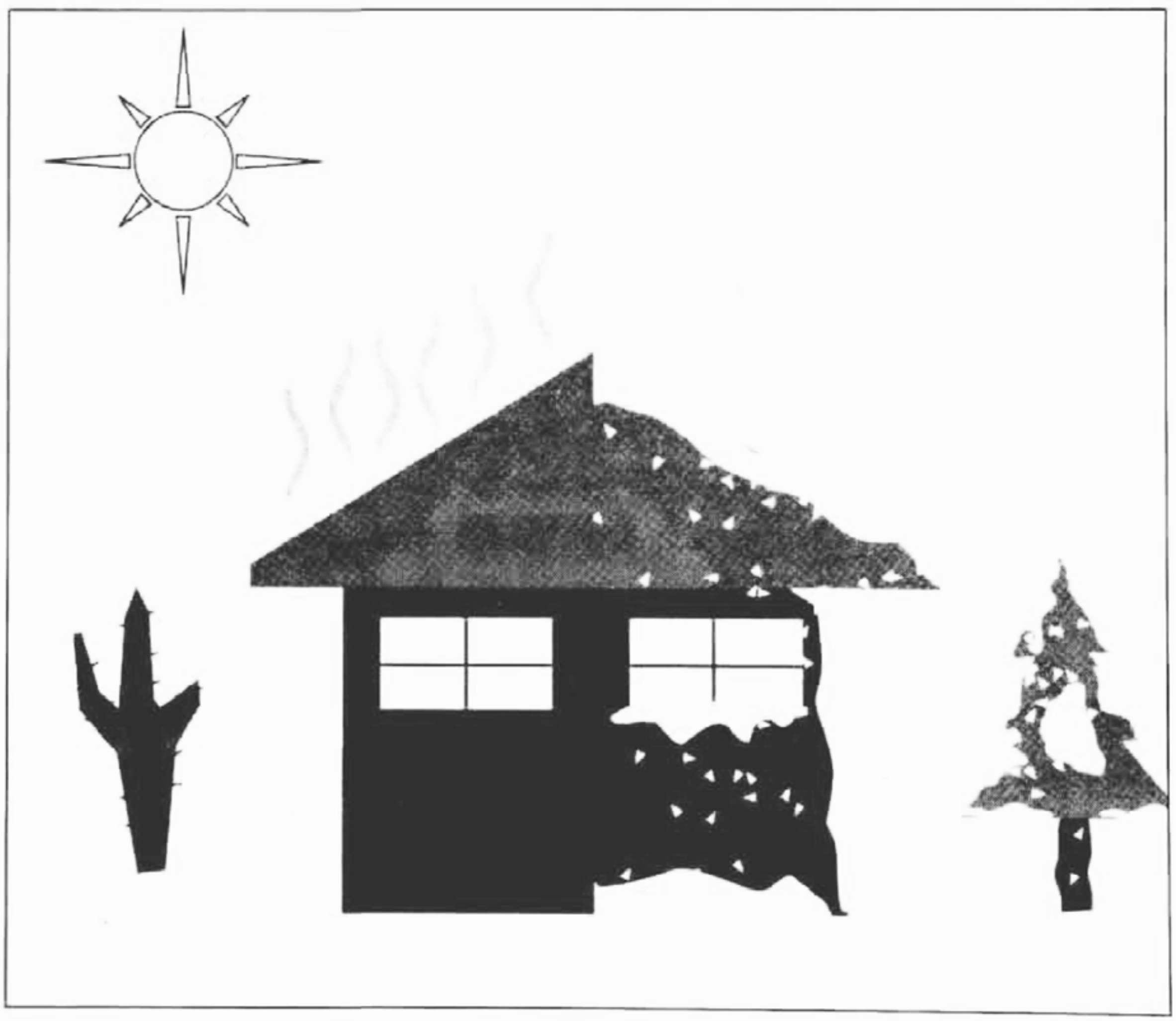
Space Conditioning: The Next Frontier

The Potential of Advanced Residential Space Conditioning Technologies for Reducing Pollution and Saving Consumers Money



Space Conditioning: The Next Frontier

The Potential of Advanced Residential Space Conditioning Technologies for Reducing Pollution and Saving Consumers Money

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TABLE OF CONTENTS

LIST OF EXHIBITS

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DISCLAIMER

Space Conditioning: The Next Frontier
The Potential of Advanced Residential Space Conditioning Technologies for Reducing Pollution and Saving Consumers Money

REPORT'S MAIN FINDINGS

1. Advanced residential space conditioning equipment can save consumers money.

   - In most climates, **EMERGING GROUND SOURCE HEAT PUMPS** and **ADVANCED AIR SOURCE HEAT PUMPS** save consumers hundreds of dollars annually over standard electric technologies, even when their higher first costs are factored in.

   - New, emerging **GAS-FIRED HEAT PUMPS** were also found to have lower total annual costs than **STANDARD GAS FURNACES** in many locations, again despite higher first costs.

2. Advanced residential equipment can reduce emissions significantly.

   - Under most electricity generating scenarios, the **EMERGING GROUND SOURCE HEAT PUMP** had the lowest CO_2 emissions of all technologies analyzed, and the lowest overall environmental cost.
     - Its emissions were 55-60% less than **STANDARD AIR SOURCE HEAT PUMPS**.

   - Among gas equipment, the **GAS-FIRED HEAT PUMP** was the lowest CO_2 emitter, reducing emissions generally by one-fourth to one-third over standard gas furnace and air conditioning combinations.
     - Its NO_x emissions were higher than other gas equipment. The industry will be conducting work to reduce NO_x emissions as this technology is introduced in 1994.

   - If American electric and gas utilities aggressively promoted advanced residential space conditioning technologies, they could reduce national CO_2 emissions by 25 million metric tons, SO_2 emissions by 85,000 metric tons, and NO_x emissions by at least 44,000 metric tons by the year 2000.

3. Advanced residential space conditioning technologies can be highly cost-effective for utility conservation programs.

   - As utility conservation measures, the most advanced **GROUND SOURCE HEAT PUMPS**, **AIR SOURCE HEAT PUMPS**, and the **GAS-FIRED HEAT PUMPS** are all generally very cost-effective when replacing standard technologies, in all areas where they offset needed electricity generation capacity. **ADVANCED GAS FURNACES** were similarly cost-effective everywhere but in the South.

   - By aggressively promoting these technologies wherever they are cost-effective, utilities could save 28 billion kilowatt-hours of electricity and offset the need for 113 typically-sized (300 MW) electric power plants in the year 2000. They could also reduce annual gas demand by over ~~3 billion~~ 825 million therms.

4. Strategic partnerships are the best way to promote advanced residential space conditioning equipment.

   Working together, utilities can most effectively promote advanced space conditioning technologies by:

   - creating coordinated programs in which many utilities target the same efficiency levels;
   - offering incentives that reward continuing efficiency improvements by manufacturers;
   - working with national organizations and universities to develop a competitive, national infrastructure of advanced equipment dealers and contractors.

   EPA and other organizations can compliment these efforts by:

   - helping utilities coordinate their programs, and urging utility commissions to approve them;
   - researching new products with advanced components and alternative refrigerants; and
   - identifying superior equipment through the EPA **ENERGY STAR** product identification program.

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EXECUTIVE SUMMARY

BACKGROUND

Residential space conditioning equipment is responsible for about 9% of total U.S. end-use energy consumption. Through the combustion of fossil fuels, both in the home and at the power plant, space conditioning accounts for 423 million metric tons (MMT) of CO_2 emissions annually. It also results in 1.2 MMT of sulfur dioxide (SO_2) and 830,000 metric tons of nitrogen oxides (NO_x), as well as significant emissions of carbon monoxide, particulates, volatile organic compounds and lead.

Expenditures associated with residential space conditioning are significant; approximately one-half of residential energy expenditures are related to space conditioning, and in 1987 this amounted to about $46 billion.

Due to the long life of space conditioning equipment, the choices that American homeowners, landlords and builders make over the next decade regarding space conditioning equipment will have important environmental and economic ramifications lasting well into the next century. Some existing and emerging technologies hold great promise for significantly reducing the emissions and costs associated with residential space conditioning.

In this report, EPA explores advanced alternative space conditioning equipment and the opportunities each provides for cost-effective energy savings and pollution prevention. Unless existing market barriers are removed, however, these opportunities will not be realized. EPA has identified some methods by which utilities can address the market barriers and improve the productivity of home heating and cooling systems.

COMPARATIVE ANALYSIS OF ALTERNATIVE SPACE CONDITIONING SYSTEMS

EPA compared the performance and cost of emerging high-efficiency space conditioning equipment with equipment already on the market. Since climate affects the performance of space conditioning equipment, comparisons were made for six locations representing the range of major climate zones in the U.S. The six locations analyzed were: (1) Burlington, Vermont; (2) Chicago; (3) the upper New York City metropolitan area; (4) Portland, Oregon; (5) Atlanta; and (6) Phoenix. For the sake of consistency, the same prototypical single-family house was used for each location.

Exhibit ES-1 lists each of the space conditioning technologies that were examined. All comparisons were based on source energy performance taking into account losses associated with all stages of energy use, i.e., energy production, transmission, and distribution. Also, because the advanced heat pumps provide water heating as well as space conditioning, water heating cost and performance were also included in the analysis.

Exhibit ES-1
Space Conditioning Systems Compared in Report

System	Description
Electric Equipment	
Electric Resistance/Standard Air Conditioning	Air Conditioner complies with standard -- has Seasonal Energy Efficiency Ratio (SEER) of 10.
Standard Air Source Heat Pump	SEER of 10, Heating Season Performance Factor (HSPF) of 6.85.
High Efficiency Air Source Heat Pump	Scroll compressor, larger heat exchanger and better controls: 12.5 SEER and 8.1 HSPF.
Advanced Air Source Heat Pump	Variable speed compressor, microprocessor control, better heat exchanger, and demand water heating. 14 SEER and 9 HSPF.
Standard Ground Source Heat Pump	Single speed unit; 13.2 EER at 70° F inlet water temperature and a Coefficient of Performance (COP) of 3.1 at 50° F inlet temperature.
Advanced Ground Source Heat Pump	Single speed scroll compressor, variable speed fans; desuperheater uses waste heat to heat water. EER of 17 at 70° F and COP of 4.4 at 50° F.
Emerging Ground Source Heat Pump	Two-speed scroll compressor; fully integrated demand water heat. Two-speed system saves about 10% heating and cooling energy over advanced technology.
Gas Equipment	
Standard Gas Furnace/Standard Air Conditioner	Typical, 80% efficiency furnace; 10 SEER AC.
Advanced Gas Furnace/ High Efficiency AC	Pulse condensing furnace, 96% efficient, with 12 SEER AC.
Emerging Gas-Fired Heat Pump	To be introduced in 1994; lean-burn, single cylinder engine drives vapor compression and heat recovery cycles. Can perform desuperheating.
Oil Equipment	
Advanced Oil Furnace/Efficient AC	Power oil burner and power vent controller; 85% efficient, with 12 SEER air conditioner.

Some of the high-efficiency technologies listed above, such as two-speed or variable-speed compressors could also be incorporated into central air conditioning systems. However, these and other air conditioner options, including evaporative and dessicant cooling, were not explicitly studied in this report.

PERFORMANCE AND COST

- Source Heating Performance: The **EMERGING GROUND SOURCE HEAT PUMP** had the highest source heating season performance factor (SPF) in all locations[1]. The next-best performers, the **GAS-FIRED HEAT PUMP** and the **ADVANCED GROUND SOURCE HEAT PUMP**, had similar source heating performance in all locations.

- Source Cooling Performance: The **EMERGING GROUND SOURCE HEAT PUMP** also had the highest cooling SPF in all locations, followed by the **ADVANCED GROUND SOURCE HEAT PUMP** and then the **ADVANCED AIR SOURCE HEAT PUMP**. The **GAS-FIRED HEAT PUMP** and the **ADVANCED AIR SOURCE HEAT PUMP** had comparable performance.

- Water Heating Performance: The **GAS-FIRED HEAT PUMP** had a performance advantage in water heating mode in all locations except for Portland, OR (where its performance was closely matched by the **ADVANCED AIR SOURCE HEAT PUMP**).

- Annual Operating Costs: In all locations either the **EMERGING GROUND SOURCE HEAT PUMP** or the **GAS-FIRED HEAT PUMP** had the lowest annual operating costs, since they were the best-performing equipment. In order to get a more accurate view on costs, however, annualized capital costs had to be factored in. In milder climates or in areas where energy costs are low, the higher capital cost of more efficient equipment often negated the operating cost advantage.

- Comparison of Electric Equipment Annualized Costs: The **EMERGING GROUND SOURCE HEAT PUMP/SLINKY™ LOOP** system had the lowest total annual cost (including operating and annualized capital costs) among all electric equipment, except in Portland, where the **LOW-COST ADVANCED AIR SOURCE HEAT PUMP** had virtually the same annual cost.

- Comparison of Gas Equipment Annualized Costs: Among gas-fired equipment, the **GAS-FIRED HEAT PUMP** had the lowest total annual costs in three locations -- Burlington, New York and Phoenix -- based on current energy prices. In the other locations, (Chicago, Portland and Atlanta) the **STANDARD GAS FURNACE/STANDARD AIR CONDITIONER** system had lower annual costs. The **ADVANCED GAS FURNACE/HIGH EFFICIENCY AIR CONDITIONER** system did not have the lowest cost in any location.

- Opportunities for **ADVANCED AIR SOURCE HEAT PUMPS**: In the three warmest locations -- Portland, Atlanta and Phoenix -- the total annual cost of the **LOW-COST ADVANCED AIR SOURCE HEAT PUMP** was lower than the **EMERGING GROUND SOURCE HEAT PUMP/VERTICAL LOOP** system. Thus, in these warmer locations, there appears to be a clear opportunity for **ADVANCED AIR SOURCE HEAT PUMPS**, especially where ground loops installation are relatively costly or impractical -- if sufficient market demand arises to lower their costs significantly through economies of scale.

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[1] The net SPF is a ratio of the total Btus of energy consumed by an end-use equipment, either directly or indirectly, to the total Btus it delivers into service. The net SPF accounts for losses in the generation, transmission and distribution of energy before it arrives at the end use.

UTILITY COST-EFFECTIVENESS

Cost-effectiveness screening was performed to calculate the net benefits of replacing "standard" technologies with the higher-efficiency emerging technologies. The calculations utilized the Total Resources Cost (TRC) test, which is widely used by utilities and their regulators to screen demand-side management programs. The TRC test compares the incremental cost of an energy-saving technology -- both in terms of its extra market price and the administrative cost that the utility would face in promoting it -- to the energy and capacity benefits that the measure brings to the utility's system. Cost-effectiveness is measured both as a ratio of total benefits to total cost and as a net present value. Whenever the ratio is greater than one, or the net present value is positive, the technology is considered cost-effective.

The value of the electricity savings (kWh) in each location was based on avoided energy costs from representative local utilities. The value of the capacity benefit ($/kW) was assumed to be the same in each location, and was based on the cost to construct a natural-gas-fired combustion turbine power plant. In the four coldest locations -- Burlington, Chicago, New York area and Portland -- it was assumed that the utilities were "dual peaking," i.e., they have roughly equivalent summer and winter peaks. Thus, in these locations the value of the capacity benefit was split between the summer and winter peak.

In the two warmest locations -- Atlanta and Phoenix -- a summer-peaking utility was assumed, and the entire value of the peak benefits accrued from reductions in the summertime. The actual capacity benefits that would accrue in a location are in fact based on the local mix of end uses and the local utility's specific mix of generating resources and capacity needs, which can vary widely.

- **GROUND SOURCE HEAT PUMPS:** The **EMERGING** and **ADVANCED** systems were highly cost-effective in all regions as replacements for **ELECTRIC RESISTANCE** and **STANDARD AIR SOURCE HEAT PUMPS**. They also appeared very cost-effective compared to **STANDARD GAS FURNACES/STANDARD AIR CONDITIONING** in the milder climates (Portland, Atlanta, and Phoenix).

- **ADVANCED AIR SOURCE HEAT PUMPS:** The **ADVANCED AIR SOURCE HEAT PUMP** was cost-effective as a substitute for **ELECTRIC RESISTANCE** and **STANDARD AIR SOURCE HEAT PUMPS** in all locations. Its cost-effectiveness generally increased as the climate became warmer (in colder climates it requires electric resistance back-up). Under the **LOW-COST** scenario, the cost-effectiveness of this technology improved significantly. The **LOW-COST AIR SOURCE HEAT PUMP** had both high benefit/cost ratios and net present values relative to all other equipment in Atlanta and Phoenix. In the coldest locations, however, its net present value was not nearly as high as other advanced equipment.

- **GAS-FIRED HEAT PUMP**: The **GAS-FIRED HEAT PUMP** was cost-effective as a substitute for standard technologies in all locations, though its results were not as strong in the three warmer locations (Portland, Atlanta, and Phoenix) as in Burlington, Chicago and the New York area. In those latter locations, it produces a very high net present value, no matter which standard technology it is replacing.

- **ADVANCED GAS FURNACE/HIGH EFFICIENCY AIR CONDITIONER:** This system was most cost-effective in colder climates as a substitute for standard technologies. In warmer climates it was often only marginally cost-effective or not cost-effective. While the system as a whole has a benefit/cost ratio that is greater than 1 when replacing the **STANDARD GAS FURNACE** system in Atlanta and Phoenix, closer analysis reveals that the advanced gas furnace fails in these locations when considered alone.

ENVIRONMENTAL IMPACTS AND TOTAL SOCIETAL COSTS

EPA estimated and compared the CO_2, SO_2 and NO_x emissions resulting from the various alternative space conditioning systems. Four different generating scenarios were analyzed to estimate the air emissions in each region: (1) a regional generating mix based on a weighted average of the actual fuel mix in each area;[2] (2) a natural gas combined cycle generating plant as the marginal unit; (3) an advanced fluidized bed coal plant as the marginal unit; and (4) a natural gas combustion turbine. In order to make cross-pollutant comparisons and get a clear view of overall impacts, EPA assigned "externality" costs to each pollutant. These costs are assigned, on a dollar-per-kilogram basis, using estimates of the cost to control each pollutant, as compiled by the Union of Concerned Scientists et al in America's Energy Choices. Some of the key findings of this analysis were:

- **EMERGING GROUND SOURCE HEAT PUMP EMISSION BENEFITS OVER OTHER ELECTRIC EQUIPMENT:** Depending on the location, **EMERGING GROUND SOURCE HEAT PUMPS** can reduce energy consumption and, correspondingly, emissions by 23-44% compared to the **ADVANCED AIR SOURCE HEAT PUMPS**, and by 63-72% compared to **ELECTRIC RESISTANCE/STANDARD AIR CONDITIONING** equipment.

- **REGIONAL FUEL MIX SCENARIO:** Under **REGIONAL** utility generating fuel mixes as projected for 2000, the **EMERGING GROUND SOURCE HEAT PUMP** generally had lower CO_2 emissions than all other equipment. The only exception to this was the coal-intensive Midwest (Chicago), in which the **GAS-FIRED HEAT PUMP** had the lowest CO_2 emissions. In all locations, except for Chicago and Atlanta, the **EMERGING GROUND SOURCE HEAT PUMP** had the lowest overall environmental "costs" under the projected **REGIONAL** utility fuel mixes.

- **ADVANCED FLUIDIZED BED COMBUSTION (AFBC) SCENARIO:** If the marginal electric generating plant is assumed at all times to be an **ADVANCED FLUIDIZED BED COMBUSTION** coal plant, then **GAS-FIRED HEAT PUMPS** have the lowest CO_2 emissions.[3] However, this relative environmental advantage for the **GAS-FIRED HEAT PUMP** was offset by significantly higher NO_x emissions.

- **NATURAL GAS COMBINED CYCLE (NGCC) SCENARIO:** When it was assumed that the marginal generating plant was **ADVANCED NATURAL GAS COMBINED CYCLE**, (the lowest-cost option for new baseload electricity generation in most areas of the country), **GROUND SOURCE HEAT PUMPS** and the **ADVANCED AIR SOURCE HEAT PUMP** had the lowest CO_2 and NO_x emissions.

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[2] Since the regional fuel mix scenarios utilize a weighted average of all fuels used in a particular region, the average emissions are relatively low for regions which rely heavily on baseload nuclear or hydro resources (e.g., the northwest). To the extent DSM programs reduce electricity consumption during peak periods, when coal or fossil plants are running, the actual emissions reductions would be greater than the "average" numbers represented in this report.

[3] If a conventional pulverized coal steam plant were the marginal unit, the relative CO_2 savings for the **GAS-FIRED HEAT PUMP** would be even greater.

- <u>NATURAL GAS COMBUSTION TURBINE (NGCT) SCENARIO</u>: When it was assumed that the marginal generating plant was a typical modern natural gas combustion turbine, the **EMERGING GROUND SOURCE HEAT PUMP** had the lowest CO_2 and NO_x emissions. The **ADVANCED GROUND SOURCE HEAT PUMP** also had lower or comparable CO_2 emissions than advanced gas equipment in most locations, while NO_x emissions were comparable to the **ADVANCED GAS FURNACE**. The **ADVANCED AIR SOURCE HEAT PUMP** had higher CO_2 and NO_x emissions than advanced gas equipment in the three coldest locations under this scenario.

- <u>COMPARISON OF GAS EQUIPMENT EMISSIONS</u>: The **GAS-FIRED HEAT PUMP** can reduce CO_2 emissions by 23-36% over **STANDARD GAS FURNACES** and by 7-25% over **ADVANCED GAS FURNACES**, assuming the **REGIONAL** electric fuel mix. However, because of relatively high NO_x emissions, the **GAS-FIRED HEAT PUMP** had higher environmental costs than advanced gas furnaces in several locations under various generating scenarios.

THE MARKET POTENTIAL FOR ADVANCED SPACE CONDITIONING EQUIPMENT

Based on the performance and cost analysis at representative locations, EPA estimated the potential for coordinated utility and other promotional programs to affect the space conditioning market. From the results of this analysis, EPA projected energy savings and emissions reductions that could accrue from such an effort. <u>No fuel switching between gas and electric heating was assumed</u>. The major findings include:

- <u>REGIONAL OPPORTUNITIES</u>: Most of the opportunities for **EMERGING GROUND SOURCE HEAT PUMPS** and **ADVANCED AIR SOURCE HEAT PUMPS** occur in warmer climates, reflecting the much higher historical penetration of electric resistance and heat pumps in these regions. Conversely, most of the opportunities for **GAS-FIRED HEAT PUMPS** and **ADVANCED GAS FURNACES** occur in colder climates, given high historical levels of gas penetration.

- <u>MARKET POTENTIAL FOR ADVANCED ELECTRIC HEAT PUMPS</u>: With aggressive utility conservation incentives, total U.S. market demand for **EMERGING GROUND SOURCE HEAT PUMPS** and **ADVANCED AIR SOURCE HEAT PUMPS** could increase from present sales levels of under 50,000 units annually to over 700,000 (about 300,000 **GROUND SOURCE HEAT PUMPS** and 420,000 **ADVANCED AIR SOURCE HEAT PUMPS**) by the year 2000. With increased consumer awareness and acceptance the market for **EMERGING GROUND SOURCE HEAT PUMPS** could grow further to over 400,000 by the year 2005 (with a corresponding reduction in demand for **ADVANCED AIR SOURCE HEAT PUMPS** to just under 400,000).

- <u>ENERGY AND CAPACITY SAVINGS FROM ADVANCED ELECTRIC EQUIPMENT</u>: **EMERGING GROUND SOURCE HEAT PUMPS** and **ADVANCED AIR SOURCE HEAT PUMPS** could save over 23 billion kWh per year and avoid about 18,000 MW of generating capacity in winter and 25,000 MW of summer capacity by the year 2000; by 2005 these savings could increase to 46 billion kWh, 38,000 MW of winter capacity, and 50,000 MW of summer capacity.

- <u>CO_2 BENEFITS FROM ADVANCED ELECTRIC HEAT PUMPS</u>: The potential savings from **EMERGING GROUND SOURCE HEAT PUMPS** and **ADVANCED AIR SOURCE HEAT PUMPS**, if realized, would reduce CO_2 emissions by over 17 million metric tons (MMT)/year in 2000 and by 34 MMT/year by 2005.

- **POTENTIAL MARKET FOR ADVANCED GAS EQUIPMENT**: As a result of utility efforts, demand for **GAS-FIRED HEAT PUMPS** and **ADVANCED GAS FURNACES** could increase by a factor of twelve over the estimated baseline to more than 750,000 units annually.

- **ENERGY AND CAPACITY BENEFITS FROM ADVANCED GAS EQUIPMENT**: Advanced gas technologies could save 5 billion kWh and 825 million therms per year by the year 2000, reducing CO_2 emissions by about 7 MMT/year. These savings would increase to 12 billion kWh and 1.5 billion therms by 2005, reducing CO_2 by 15 MMT.

- **CHALLENGE FOR GAS-FIRED HEAT PUMPS**: While they are competitive in several areas and reduce CO_2 emissions, **GAS-FIRED HEAT PUMPS** increased NO_x emissions. The Gas Research Institute (GRI) plans to undertake additional work to cost-effectively reduce NO_x emissions, either by pollution controls on existing designs or by substituting new, lower-emission technologies.

OPPORTUNITIES FOR ENHANCING THE MARKET FOR ADVANCED SPACE CONDITIONING EQUIPMENT

As the above findings suggest, utility efforts and other promotional programs can play a key role in accelerating the market penetration of advanced space conditioning equipment. Given the unique barriers and challenges that face each technology, however, it will most likely require more than a typical utility rebate program to achieve anything close to full market potential. EPA has identified several steps that utilities could take to effectively enhance the market for space conditioning equipment:

- Form partnerships or coordinated residential programs with other utilities to pool the demand for advanced space conditioning equipment. A coordinated approach can communicate a much stronger market signal to manufacturers than individual utility efforts, and may be more effective at reducing the risk manufacturers face in commercializing new technologies.

- Implement utility conservation programs over a sustained period of time, e.g., 5 years or more. This will demonstrate to manufacturers that there is a stable market for their new products, and will further reduce the risk associated with developing new product lines.

- Expend sufficient effort to develop strong marketing and installation networks in order to improve the local infrastructure. As contractors become more knowledgeable about the new technologies, the cost to install the equipment should fall and the quality of the installations should improve.

- Communicate with the industry to determine in which areas utility incentives would be most effective -- whether paid to the consumer, the dealer, or directly to the manufacturer. Manufacturer incentives might be preferable, since they have the greatest effect on reducing equipment costs. Manufacturer incentives communicate directly to the people who make the decisions about which equipment to produce and in what quantities.

- Structure incentives to allow larger payments for units with higher efficiencies. This would provide an incentive for manufacturers to continuously improve performance and to introduce even more efficient technologies.

- Work to include developers and landlords among the participants in the programs. This could also include housing authorities.

- Explore innovative programs designs, such as equipment leasing or direct utility ownership of ground loops.

- Continue to work with EPA, the Department of Energy, the Electric Power Research Institute (EPRI), GRI, and other research bodies to explore longer-term improvements that utilize more advanced technologies or alternative refrigerants.

INSTITUTIONAL OPPORTUNITIES

Utilities can join together to pool their market strength with each other and with outside organizations. One example is the Consortium for Energy Efficiency (CEE), a public/private partnership of utilities, power authorities, public agencies and conservation groups. Its prime mission is to accelerate the development, commercialization and distribution of new, energy efficient technologies through common utility efforts and partnerships with outside groups. CEE is interested in developing programs centered around aggregate utility buys or common standing rebates designed to increase the market penetration of equipment that already exist or as "Golden Carrots[SM]"[4] that promote the market introduction of the next generation of technology.

In addition, EPA and other organizations can compliment utility efforts to commercialize new technologies in a number of ways:

- by appearing before utility commissions to support strategic, cost-effective demand-side management programs that lead to rapid market transformation;

- by identifying advanced space conditioning technologies under the EPA **ENERGY STAR** product identification program that helps consumers recognize environmentally superior equipment;

- by focusing research on new products and alternative refrigerants;

- by helping utilities build up marketing and installation expertise in their service territories, e.g., EPRI can assist in utility program development, and organizations such as the International Ground Source Heat Pump Association (IGSHPA) can conduct contractor training sessions;

- by developing consortia to accelerate commercialization and market penetration of the advanced technologies, e.g., the American Gas Cooling Center (AGCC) has organized consortia to develop York **GAS-FIRED HEAT PUMPS** and Phillips GAX units.[5]

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[4] "Golden Carrot" is a service mark of the Consortium for Energy Efficiency.

[5] Personal Communication, Richard Sweetser, Executive Director, AGCC, March 8, 1993.

CHAPTER ONE

THE ENVIRONMENTAL IMPACTS OF RESIDENTIAL SPACE CONDITIONING IN THE U.S.

INTRODUCTION

Space conditioning (heating and cooling) uses 5.39 quadrillion Btu ("quads") of energy, 8.82% of total U.S. end-use energy consumption[1]. In 1987, the nation's 90.9 million occupied households consumed a total of 4.93 quads for space heating and 0.45 quads for space cooling. Americans spent approximately $46 billion on space conditioning that year, more than half of total residential energy expenditures.[2]

Residential space conditioning resulted in 423 million metric tonnes (MMT) of carbon dioxide (CO_2) emissions in 1987.[3] When combined with water heating, residential space conditioning contributes more greenhouse gases to total U.S. emissions than all other activities other than driving automobiles -- more than commercial space conditioning and water heating combined, more than light and heavy trucks combined, and more than all industrial machine drives and electrolytics combined. Exhibit 1.1 summarizes the air pollution associated with fossil fuel combustion serving residential space conditioning demand.

The decisions that American homeowners, landlords, developers and builders make about space conditioning over the next decade will have important economic and environmental ramifications lasting well into the next century.

BARRIERS AGAINST EFFICIENCY IN THE HEATING AND AIR CONDITIONING MARKET

Strong evidence exists that several market failures have prevented cost-effective space conditioning products from capturing an economically optimal share of the residential market.

The higher first cost of more efficient equipment has made consumers reluctant to buy efficient products or install conservation measures even though these measures provide higher rates of return than consumers receive for their savings accounts and investments.

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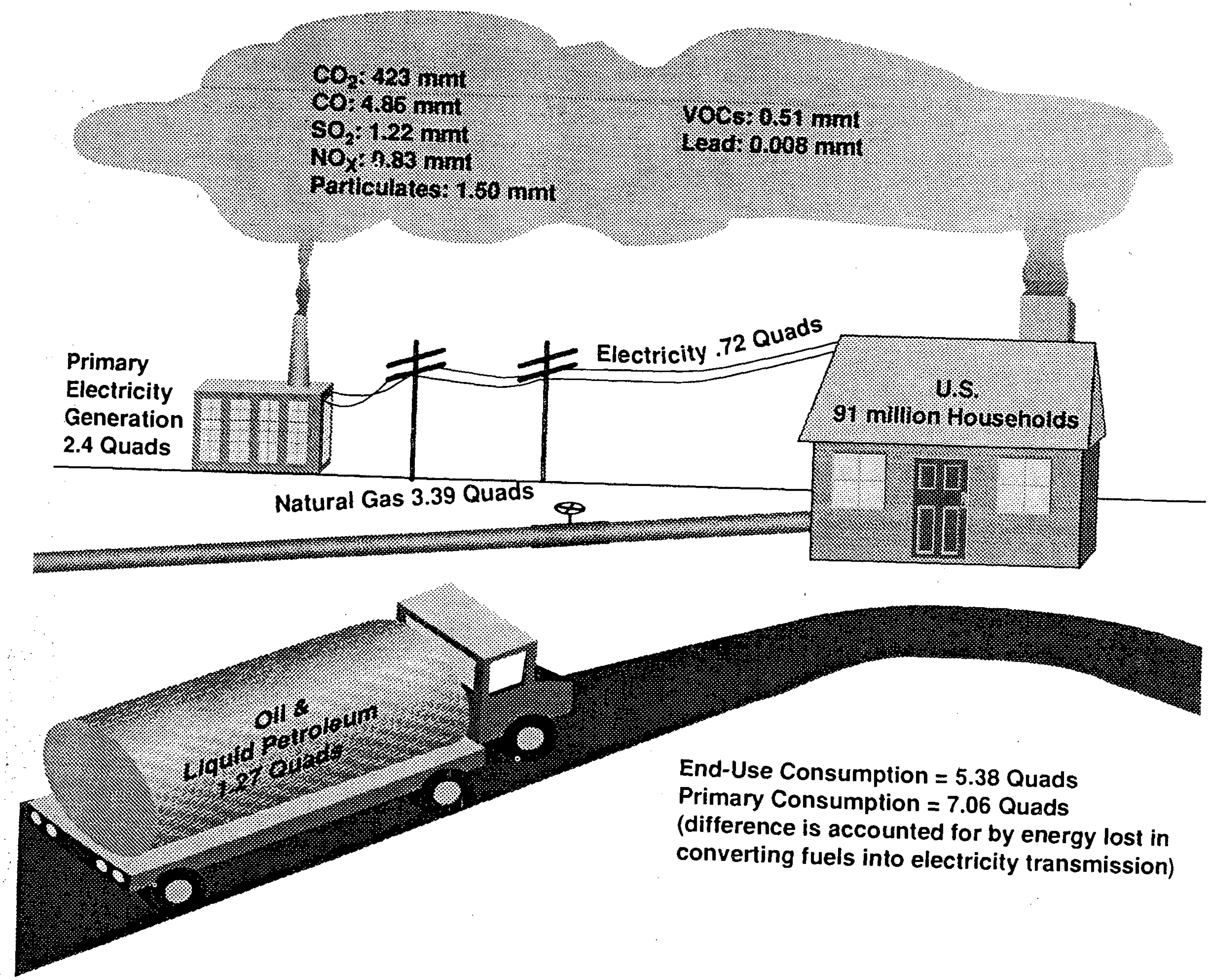
[1] Number of households comes from Bureau of the Census, U.S. Department of Commerce, Statistical Abstract of the United States, 1991, Table 1281. Space heating and electric air conditioning consumption figures come from Energy Information Administration (EIA), Annual Energy Review 1990, Table 17. Space cooling consumption figure presented here also includes 0.01 quads of gas-fired air conditioning, inferred from Table 17. Total U.S. end-use energy consumption (61.1 quads) comes from EIA, Table 7.

[2] EPA estimate derived from Statistical Abstract, 1991, Table 954 and ICF, Inc., 1991 data on the breakdown of energy consumption by residential end-use.

[3] EPA estimate, based on the following rates of CO_2 formation: natural gas, 51.3 kg/MMBtu; electricity, 468.9 kg/MMBtu (based on national average fuel mix for electricity production and national average heat rate); oil, 78.5 kg/MMBtu, and liquified petroleum gases, 63.3 kg/MMBtu. Rates for natural gas, electricity and oil are from ICF Resources, 1991; rate for liquified petroleum gas is taken from EPA, Office of Policy, Planning and Evaluation, "Emissions and Cost Estimates for Globally Significant Anthropogenic Combustion Sources of NO_x, N_2O, CH_4, CO, and CO_2," May 1990, p. 99.

Exhibit 1.1
Energy Usage and Emissions from US Residential Space Conditioning



Another barrier is the landlord-tenant relationship. One-third of households occupy rented housing.[4] Since landlords do not generally pay the heating and cooling bills, they have little incentive to invest in energy efficiency. Tenants are reluctant to make investments when they occupy dwellings for short periods of time.

Recognizing these barriers, policy makers on the federal, state and local level have devised regulatory mechanisms -- building codes and appliance or equipment efficiency standards -- that assure that minimal levels of energy efficiency are attained.

However, developing and implementing regulations is time-consuming, adversarial and politicized. Regulations often lag behind the development of, or fail to reflect, the most cost-effective or environmentally benign technologies. Furthermore, to optimize decisions through regulations would require complexity and raise administrative costs. Non-regulatory mechanisms may be a more efficient way to promote the development and selection of the most efficient technologies.

UTILITIES: THE NEW PLAYERS IN THE SPACE CONDITIONING APPLIANCE MARKET

Utilities have become significant "players" in the purchase decisions of space conditioning and appliances. Utility commissions throughout much of the United States have begun to require utilities to evaluate a full mix of "resources." That is, when a utility decides how to meet its customers' energy services it must now consider conservation and load reducing measures as well as more traditional resources, such as new generating facilities, wholesale power purchases, and transmission and distribution equipment.

In order to fully implement these "least-cost, integrated resource planning" (IRP) policies, many utility commissions have instituted ratemaking procedures that allow utilities to recover the costs of conservation measures and earn an attractive rate of return through their rates.

"Decoupling" of utility revenues from sales is one such mechanism. In traditional ratemaking, the utility would have a rate set for each unit of energy sold within a rate class, such as for each kiloWatt-hour (kWh) sold. Rates would be set based on a forecast of sales, such that the utility's costs would be covered and an allowed rate of return would be earned. The more kWhs sold relative to the forecast, the more profits the utility made. Of course, this means that the converse -- the less kWhs sold, the less profit made -- presented a natural barrier to effective conservation. Decoupling of revenues and hence profits from sales allows utilities to maintain their earnings while actually decreasing the number of kWhs they sell.

"Shared savings" is another commonly employed recovery mechanism for conservation. This approach allows utilities to "share" the savings that have resulted from a particular conservation investment through their rates.

Shared savings recovery mechanisms can be applied broadly throughout entire classes of customers, or they can be applied strictly to program participants. In the latter case, the utility provides the customer with a subsidy for a conservation measure, and then recovers the capital and a profit through an adder on the customer's bill. If effectively implemented, the customer benefits overall because the amount paid back to the utility is less than the reduction in his/her bill.

Whatever the recovery mechanism, conservation measures are justified whenever the cost of implementing them is less than the marginal cost of producing an equal amount of new energy

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[4] Bureau of the Census, Statistical Abstract of the United States, 1991, Table 1281.

supplies (including the cost of transmission and distribution to end users). Marginal cost of new supplies, or the utility's "avoided cost," is the benchmark by which conservation measures are usually evaluated.

THE ENVIRONMENTAL COSTS OF ENERGY

Given the significant contribution of energy usage to air pollution, utility regulators are increasingly -- now in fifteen states -- requiring utilities and other power suppliers to include consideration of the environmental costs associated with power generation in their resource decisions.[5] In fact, some states have even gone so far as to require that utilities include environmental "adders," dollar amounts associated with pollution from different options, in their marginal costs.

In particular, CO_2 emissions associated with the energy industry have come increasingly under scrutiny. In June of 1992, the United States signed an historic international treaty on climate change at the Earth Summit in Rio de Janeiro. Key provisions of the new United Nations Convention on Climate Change include:

2(a) "Each of these Parties shall adopt national policies... recognizing that the return by the end of the decade to earlier levels of anthropogenic emissions will contribute to [the mitigation of climate change]."

2(b) "... each of these Parties shall communicate... detailed information on its policies and measures... with the aim of returning individually or jointly to 1990 levels."

Fossil fuel power generation facilities owned by utilities and non-utility generators (NUGs) now face substantial risk that future policies might be implemented to mitigate CO_2 emissions. This potential risk has not been lost upon commissions practicing least-cost IRP. As the California Public Utilities Commission stated on April 22, 1992:

> "...it is... prudent to adopt future resource procurement policies recognizing that owners of existing coal-fired generation in the future may be required to take actions to abate their carbon emissions significantly, or to pay for emission rights. This raises the concern that the owners may try to pass on the costs for such actions to their customers....
>
> "Given the uncertainty over policy addressing climate change, we ... believe it essential that utilities obtain appropriate assurances from any prospective supplier ... that it alone will bear the cost of meeting any future costs resulting from a carbon tax, acquisition of tradeable emission permits, retrofits, or any other carbon emission control strategy or regulation applicable to the supplier's plant(s)." [6]

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[5] Cynthia Mitchell, "Integrated Resource Planning Survey: Where the States Stand," Electricity Journal, V.5, N.4 (May, 1992), pp. 10-15. "Advanced" IRP was identified by the presence of the following elements: financial incentives to encourage utility demand-side management (DSM) investments; evidence of DSM acquisition; competitive bidding; incorporation of environmental externalities; and gas utility IRP

[6] California Public Utilities Commission, "Interim Opinion, Resource Plan Phase: Bidding for New Generation Resources," Decision 92-04-045, April 22, 1992, pp. 27-29.

The Commission was directing California utilities to follow the example of the Bonneville Power Administration (BPA), which in an October, 1991 solicitation said it would require bidders of fossil fuel generation to assume all carbon-related financial risks; any future costs could not be passed along to the BPA and its customers.[7]

As the risks associated with new, polluting fossil fuel generation increase, demand-side-management (DSM) programs will continue to become increasingly attractive to regulators and utilities.

DSM FOR SPACE CONDITIONING AS PRACTICED BY UTILITIES

Utilities have taken various approaches to implement residential appliance and space conditioning programs. Some have relied on information to change consumer behavior. These have included energy audits, product information and labelling. Other utility programs go further to change behavior by providing financial incentives to dealers and consumers. Such measures as sales person incentive fees ("SPIFs") provide a bonus to a dealer for selling high efficiency equipment. Consumer rebates work on the other side of the transaction by reducing the extra first cost of high efficiency products to the consumer. The utility acts as a co-purchaser with the consumer -- in effect buying the extra energy efficiency. In some cases, utilities have included both SPIFs and consumer rebates in their appliance efficiency incentive programs.

While utility DSM programs have grown, they are not typically designed to promote the most advanced energy-efficient technologies that may be technically feasible. As a result, most programs are failing to capture all of the technically feasible and cost-effective energy-saving opportunities. These "lost opportunities" are occurring because most utility-sponsored DSM programs are short-lived, are not focused on promoting advanced, emerging technologies, and are not coordinated or consistent with programs of other utilities. Manufacturers, in viewing the entire national market, are thus faced with a "crazy quilt" of utility programs that come and go very quickly relative to their own commercialization schedules. As a result, equipment manufacturers are not sufficiently induced to develop the most advanced, energy efficient technologies.

EPA'S POLLUTION PREVENTION STRATEGIES

EPA has launched a variety of programs intended to stimulate market demand for high efficiency, pollution preventing equipment. These programs use different strategies and have been very successful at changing behavior in various markets (Exhibit 1.2).

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[7] Electric Utility Week, June 22, 1992, pp. 3-4.

EXHIBIT 1.2

EPA PROGRAMS AND RELATED EFFORTS FOR ENERGY EFFICIENCY AND POLLUTION PREVENTION

Strategy	Example Program	Success to Date
Change Corporate Purchasing	**Green Lights** Partners Agree To: • survey all domestic facilities • choose lighting upgrades that maximize energy saved while passing economic test • retrofit 90% of all facilities within five years; install efficient lighting in new facilities Vendor and Utility Allies also upgrade facilities and market program	over 800 members and 3 Billion ft^2 in program (over 3% of national office space) 50-75% reduction in consumption underway 81-203 billion kWh saved/yr. by 2000 62-183 million metric tons carbon dioxide avoided/yr. by 2000
Change Consumer Purchasing -- Product Identification	**Energy Star Computer Program** Partners Agree To: • produce high-efficiency personal computers (PCs) and work stations • EPA Energy Star Logo put on efficient products	55% savings expected 26.3 billion kWh/yr. saved by 2000 20 million metric tons CO_2 emission reductions by 2000 Success has led to development of similar initiative for printers
New Technology Acceleration through Long-Term Utility DSM Procurement	**"Golden Carrot[SM]" Super Efficient Refrigerator Program** • supported multi-utility effort to introduce advanced refrigerators through a competitive bid • promotes non-CFC unit that is 25-50% more efficient than 1993 standard • will help make 1998 efficiency standard-setting process less contentious and better-informed	At least 25 utilities participating $28 million incentive pool for manufacturer building best product 150,000 - 500,000 units by Mid-90's Coordinated utility approach better influences manufacturing decisions

WHAT THIS REPORT SEEKS TO ACCOMPLISH

This report assesses a variety of technologies available or potentially available in the residential space conditioning market (Exhibit 1.3). It provides information to different important participants in the process of determining space conditioning choices.

1) Electric utilities may find this report useful for:

   * recognizing the technological and economic potential of ground source heat pumps and other advanced technologies as featured DSM technologies;

   * deciding on key elements that are needed for an effective program; and

   * gauging the appropriate magnitude of investment.

2) Gas utilities may find this report useful for:

   * realizing the importance of similarly nurturing new high-efficiency gas heat pumps or other advanced technology through a DSM program approach.

3) Consortium for Energy Efficiency (CEE) or similar groups may find this report useful for:

   * deciding which aggregate or long-term DSM procurement ("Golden Carrot^{SM}") programs to initiate.

4) State Utility Regulators may find this report useful for:

   * evaluating integrated resource plans and rate filings with respect to the adequacy of proposals for advanced space conditioning technologies; and

   * assessing the proper rate treatment for utility Golden Carrot^{SM} programs for advanced space conditioning equipment.

5) Space conditioning equipment manufacturers may find this report useful for:

   * assessing products, prices, and marketing strategies; and
   * developing strategies for Golden Carrot^{SM} partnerships with CEE utilities, conservation groups, EPA and other public agencies.

6) The Gas Research Institute and the Electric Power Research Institute may find this report useful for:

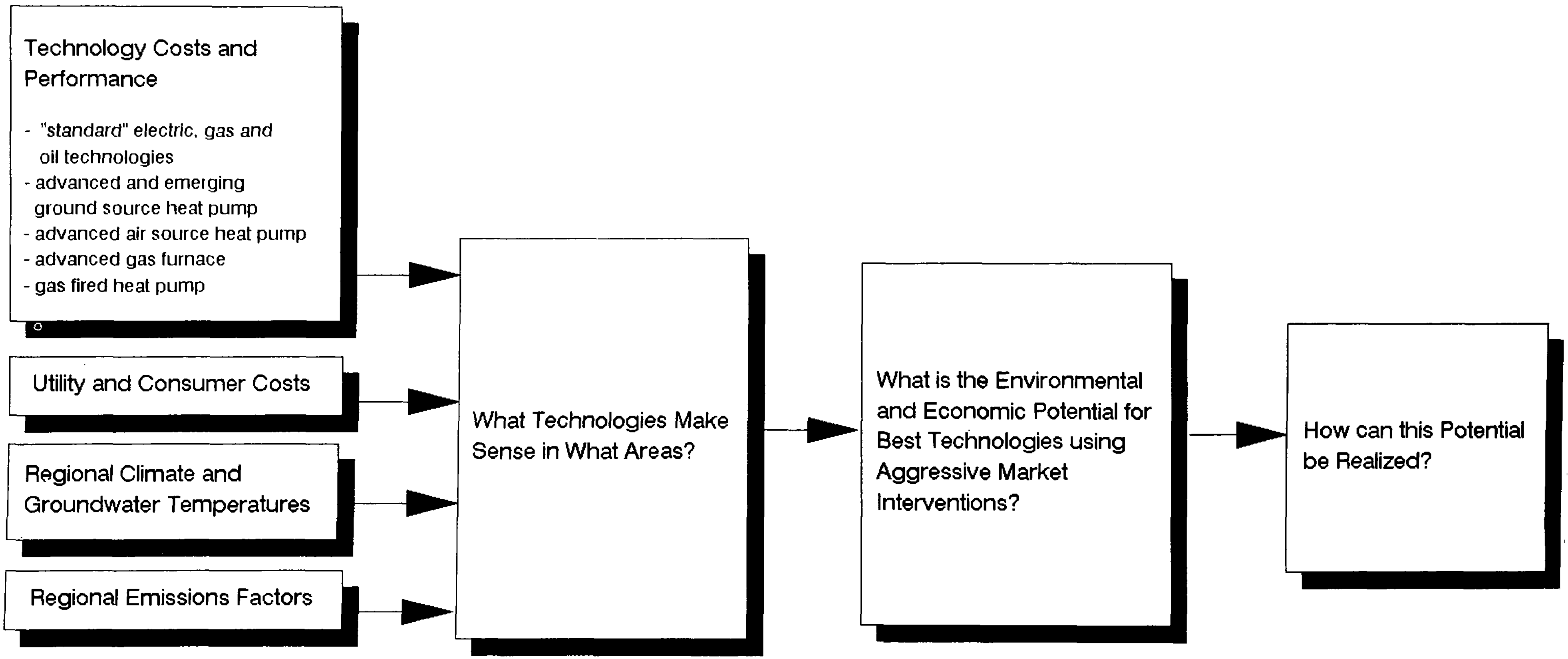
   * fashioning R&D targets in coordination with CEE's Golden Carrot^{SM} program goals.

7) The natural gas industry may find this report useful for:

   * developing marketing strategies for the mid-1990's and well beyond.

EPA hopes the report will initiate a dialogue between various parties that leads to a major shift toward vastly increased sales of higher value added, energy-efficient space conditioning products.

Exhibit 1.3
Analytical Flow Diagram for this Report



CHAPTER TWO

REVIEW OF EXISTING AND EMERGING SPACE CONDITIONING TECHNOLOGIES

This chapter identifies several technologies that currently have or could soon have large shares of the national space conditioning market. These include:

* gas furnaces and heat pumps
* oil furnaces
* central air conditioners
* electric resistance furnaces
* air source heat pumps
* ground source heat pumps

Variations of these technologies -- ranging from standard efficiency equipment that barely comply with minimum federal energy efficiency standards to "super-efficient" equipment -- will compete for the space conditioning market of the 1990's and beyond.

The space conditioning equipment in the categories listed above provides varying levels of service, from furnaces that provide just heating and air conditioners that provide just cooling, to advanced heat pumps that provide heating, cooling and water heating. The latter, triple-function equipment generally costs a lot more than single-function equipment. Of course, it cannot be expected to compete with single-function equipment simply on the basis of any one function. Fair comparison dictates that the single-function equipment be grouped into systems that cover all three functions. Thus, for instance, gas furnaces were grouped with electric central air conditioners and gas water heaters in order to make a system that is comparable to the advanced heat pumps.

After providing an overview of the space conditioning market, this chapter reviews the technologies that were selected and grouped for the comparative analysis. It provides a brief description of each system's technology or groups of technologies, its performance characteristics, and its installed cost.

OVERVIEW OF THE SPACE CONDITIONING MARKET

Approximately 1,025,000 single family homes and 386,000 multi-family dwellings were built in the U.S. in 1989. Seventy-seven percent of the single family homes that were built had central air conditioning (AC); 50% in the Northeast, 60% in the West, 75% in the Midwest, and 95% in the South.[1] The same percentage of multi-family housing built also had central air conditioning installed. 3.9 million space conditioning replacements or add-ons were installed in 1989, including 2 million central air conditioners.[2]

The strong trend in U.S. housing toward the installation of central air conditioning (Exhibit 2.1) implies increasing electricity demand during peak use periods in the summer, when utilities often dispatch "peaking" power plants. These plants are the cheapest to build but use more expensive fuels than "base load plants" that run most of the year.

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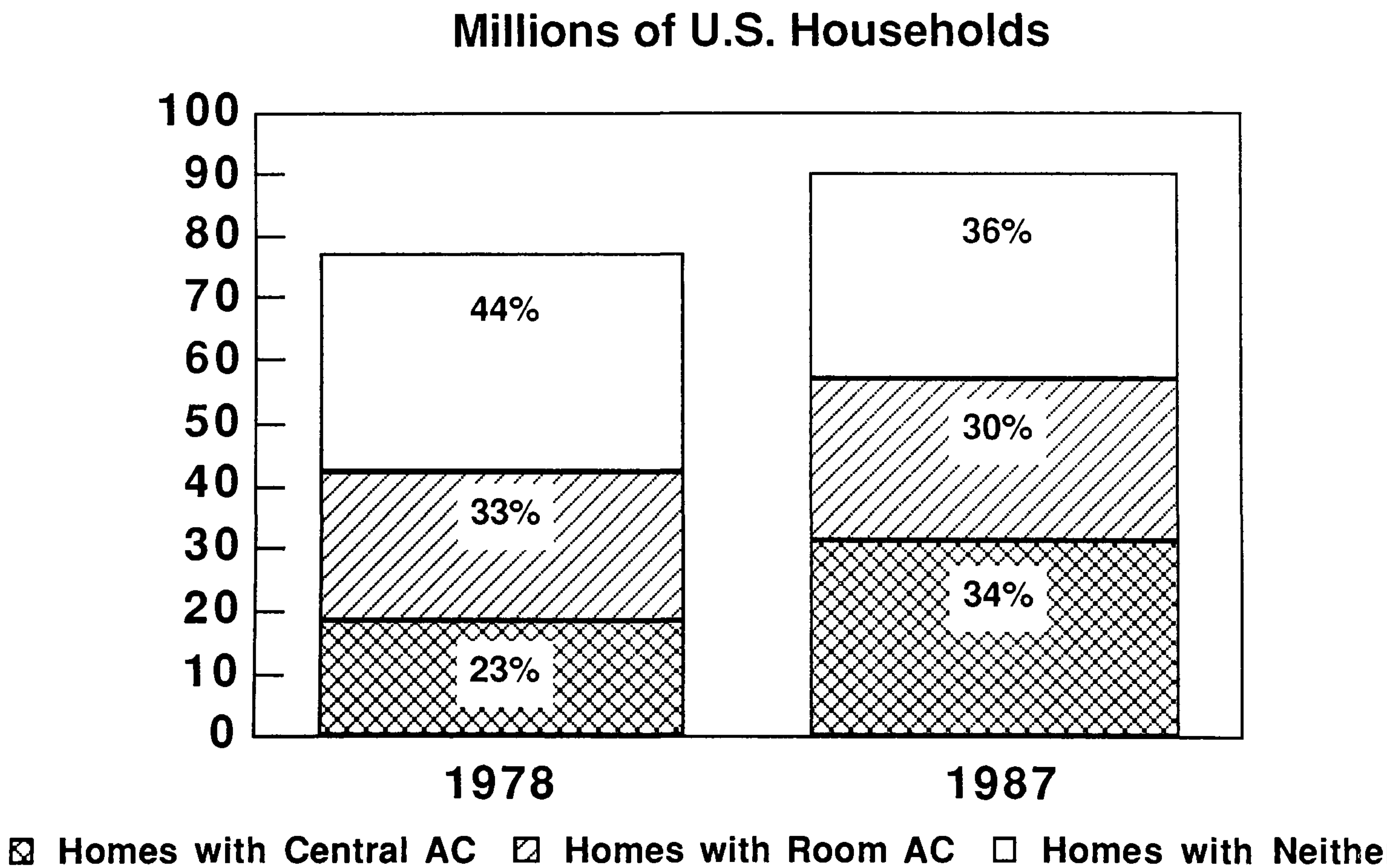
[1] Air Conditioning, Heating & Refrigeration News, "Comfort and Construction (Statistical Panorama Issue), March 30, 1992, p. 22.

[2] Barakat & Chamberlin, 10/21/91 draft report, Exhibits 55-57.

Exhibit 2.1

Growth in Central Air Conditioning



Space heating has also been changing over time, as Exhibit 2.2 demonstrates. This exhibit shows that the percentage of new homes heated by electricity has grown since 1975, at the expense of large decreases in the two other most prevalent heating fuels, natural gas and oil.

Exhibit 2.3 illustrates that the national trend toward electric heating has decreased somewhat in the last five years. This is due to a 40% decline in new home construction in the South, where heat pumps and electric resistance heating have their highest penetrations.[3]

PRESENT AND FUTURE MARKETS FOR SPACE CONDITIONING EQUIPMENT

The Bureau of the Census reports that a total of 2 million gas furnaces were shipped in 1990. This was down about 11% from 1989. Members of the Gas Appliance Manufacturer's Association (GAMA) reported that in 1991 shipments would remain stable at the 1990 level. Of the 2 million units shipped in 1989, about 1.4 million were for the retrofit market.

Looking forward, GAMA members on average see moderate improvement in the gas furnace market, with estimates for 1995 ranging from 2.0 to 2.4 million units. From these figures, one can see that the gas furnace market is large and fairly stable.[4]

The total market for air conditioners is even larger. Central air conditioner shipments totaled 2.92 million units in 1990. This was up from about 2.5 million installations in 1989, of which 2 million were for retrofits, and 0.5 million for new construction. Sales in 1992 were projected to be slightly higher than the 1990 sales, or 2.96 million units.[5]

The heat pump market has a great deal of growth potential. Although the market for air source heat pumps in new construction slowed in the late 1980s due to a slowdown in the building industry in the South (where most air source heat pumps are sold), the number of replacement opportunities for heat pumps is growing. Replacements accounted for only about 100,000 units in 1985; by 1989 they accounted for 313,000 shipments out of a national total of 660,000. This figure grew to 374,000 replacements in 1991.[6]

The growing replacement market for heat pumps results from the vintaging of a great deal of stock installed in the 1970s. EPRI estimates that annual replacements will grow throughout the 1990's, reaching an estimated 485,000 to 735,000 units annually by 2000, and 680,000 to 900,000 units annually by 2005. Total production, including for new construction, will reach an estimated 1.2

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[3] Air Conditioning, Heating & Refrigeration News, "Comfort and Construction (Statistical Panorama Issue), March 30, 1992, p. 22.

[4] U.S. Bureau of the Census and GAMA figures were cited in Air Conditioning, Heating & Refrigeration News, March 30, 1992, p. 14. Data on the split in 1989 between retrofits and new construction provided by Barakat & Chamberlin.

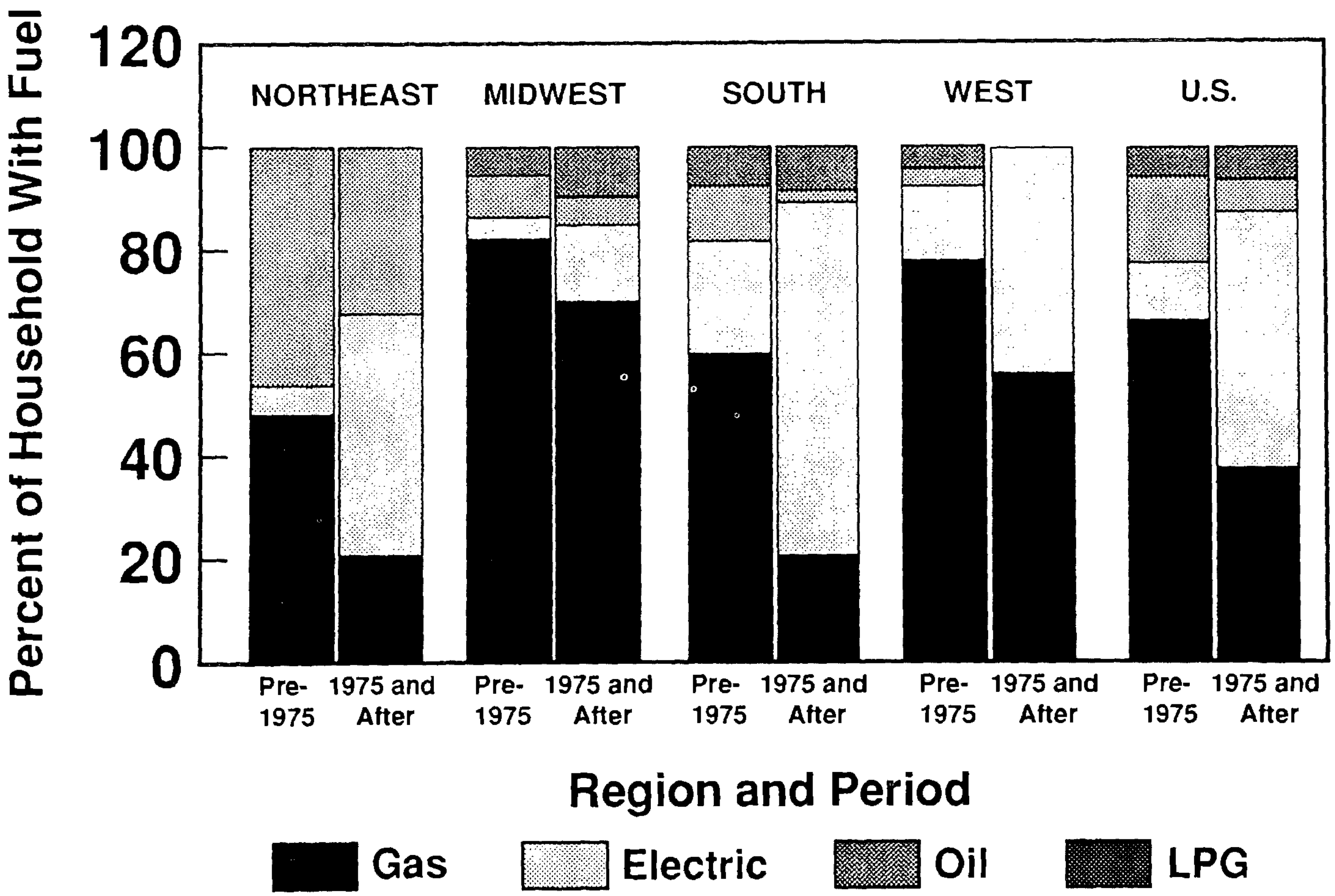
[5] 1990 to 1992 sales figures cited in Appliance Magazine, January 1992, p. 58. 1989 sales figure and split between retrofits and new construction provided by Barakat & Chamberlin.

[6] Figures for 1989 supplied by Barakat & Chamberlin. 1985 and 1991 figures cited in Air Conditioning, Heating & Refrigeration News, March 30, 1992.

Exhibit 2.2

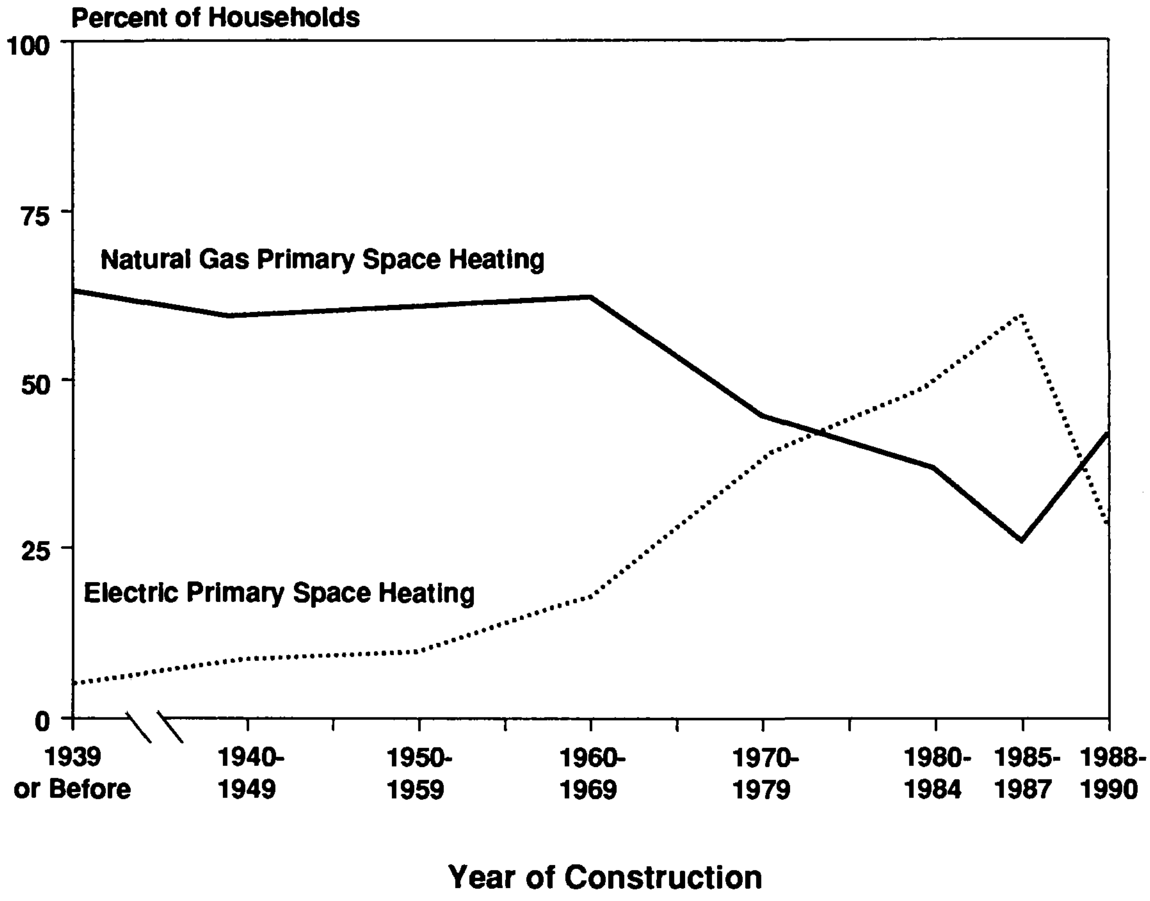
MAJOR HEATING FUEL HOUSEHOLDS

Homes Built Before 1975 VS. Homes Built 1975 or Later



Source: Energy Information Administration, DOE, Annual Energy Reviews, 1990
DOE/EIA 0384 (90), Table 18

Exhibit 2.3
Trends in Space Heating in U.S. Households by Year of Construction



Source: Energy Information Administration, Office of Energy Markets and End Use, Forms EIA-457 A, B, and C of the 1990 Residential Energy Consumption Survey (RECS). Table 32 and RECS Public Use Data File.

to 1.4 million in 2000 and 1.4 to 1.6 million in 2005. EPRI cites research that shows that close to 100% of heat pumps retired from service are replaced by new heat pumps.[7]

The ground source heat pump market is much smaller, and its precise size is very hard to determine, since manufacturers do not release sales figures. The Air Conditioning, Heating & Refrigeration News (March 20, 1992) reports an estimated annual volume for 1991 of about 20,000 shipments, although other estimates are somewhat higher.

However, the superior performance characteristics of ground source heat pumps provide an opportunity for that still very young industry to compete in the growing heat pump market of the next decade.

The following sections review the various space conditioning equipment technologies that were selected for this report's environmental and economic comparisons. A number of combinations of heating and cooling technologies are fairly representative of the standard market. These "baseline" technologies comply with minimum efficiency standards promulgated by DOE pursuant to the National Appliance Energy Conservation Act (NAECA).

Advanced technologies that were selected include some that are already on the market, as well as those which will or can be introduced relatively soon. Future technologies that may emerge within the next decade are also briefly discussed, but there was insufficient cost and performance data to conduct any environmental and economic analysis.

TECHNOLOGIES ASSESSED IN THE REPORT

I. ELECTRIC RESISTANCE FURNACE WITH CENTRAL AIR CONDITIONING

Electric resistance heat is used in a significant number of housing units throughout the U.S. It has a Coefficient of Performance (COP) of 1 (see Exhibit 2.4 for definitions of terms that describe equipment energy performance). The central air conditioning unit is assumed to have a seasonal energy efficiency ratio (SEER) of 10, typically a two and a half-ton unit. Total costs of electric resistance and central air conditioning, including installation, range from $3,300 - $3,500.[8]

II. ELECTRIC AIR SOURCE HEAT PUMP

A heat pump extracts heat from one place and moves it to another. This is the same principle that drives an air conditioner or a refrigerator. In a heat pump, a refrigerant (R22, a hydrochlorofluorocarbon, or HCFC) is circulated through a cycle of evaporation and condensation.

Unlike an air conditioner or a refrigerator, which run this cycle in one direction only, an air source heat pump can either pump heat out of a house to cool the house in the summer or into a house (from the outside) in the winter (see Exhibit 2.5).

Electric resistance is theoretically 100% efficient at generating heat (having a Coefficient of Performance, or COP, of 1). Because air source heat pumps simply move heat from one place to

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[7] Air Conditioning, Heating & Refrigeration News, May 14, 1990.

[8] All equipment costs in this chapter are based on characteristics of a prototypical house described in Chapter 3 and exclude the cost of ducts and water heaters. The size of equipment needed depends upon the climate but is generally in the 2.5 to 3.5 ton range.

EXHIBIT 2.4
GLOSSARY OF EQUIPMENT ENERGY PERFORMANCE TERMS

Coefficient of Performance (COP): energy efficient rating measure determined, under specific testing conditions, by dividing an equipment's energy output (in Btu) by the energy input. The higher the COP value, the more efficient the heat pump.

Degree days: A measure of the severity of the weather. One degree day is counted for every degree that the average daily temperature is below the base temperature of 18° C.

Energy Efficiency Ratio (EER): cooling efficiency rating measure determined by dividing the cooling capacity in Btus per hour by the energy input in watts. The higher the EER value, the more efficient the equipment.

Heating Seasonal Performance Factor: an electric heat pump's total heating output in Btu's during a "normal" heating season, divided by the total watt-hour input during the same period.

kW: one Kilowatt. One kW equals 1000 watts (the electricity demanded by ten 100-watt bulbs).

Seasonal Performance Factor (SPF): measure of equipment energy efficiency over a specific period is similar to COP (in this case Btu of output divided by Btu of input). SPF is used to compare the modeled performance of equipment in this report. It factors in all parasitic energy usage for pumps, fans, etc.

SEER: cooling efficiency rating measure expressed in same units as EER, but which accounts for climate by estimating total performance over a "normal" cooling season.

Ton: A measure of heat pump capacity. It is equivalent to 3.5 kW or 12,000 Btu per hour.

Thermal Balance Point: The lowest ambient temperature at which a system can meet the full heating load of a building.

another, rather than generating heat from electricity, they are more efficient than electric resistance heating. An **AIR SOURCE HEAT PUMP** can achieve an efficiency of about 150% to 300%, or a COP of 1.5 to about 3.[9] In the cooling, or air conditioning mode, the **STANDARD AIR SOURCE HEAT PUMP** is similar in efficiency to a standard central air conditioning system -- 10 SEER -- as described in the previous section.

The current annual sales of air source heat pumps in the new construction and replacement markets for single-family residences is about 450,000, with about 75% of this total occurring in the Southeast.[10]

Electric air source heat pumps have some shortcomings. As the outside air temperature drops, it becomes increasingly difficult to extract enough heat to satisfy the demands of the living space. Current designs for air source heat pumps require electric resistance back-up heat when temperatures fall below their specified "balance point." The balance point will differ from region to region and from model to model, but, generally speaking, it is most economical from the standpoint of the consumer to size the heat pumps to periodically require electric resistance (to size them for full

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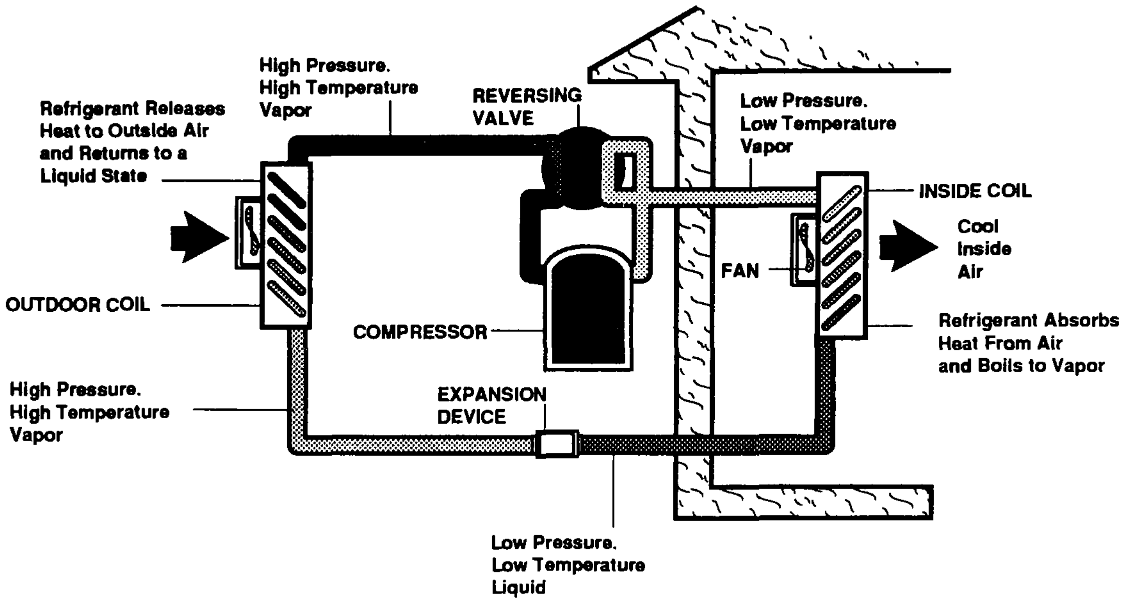
[9] Above the thermal balance point, a heat pump can deliver more heat into a home than an electric resistance furnace.

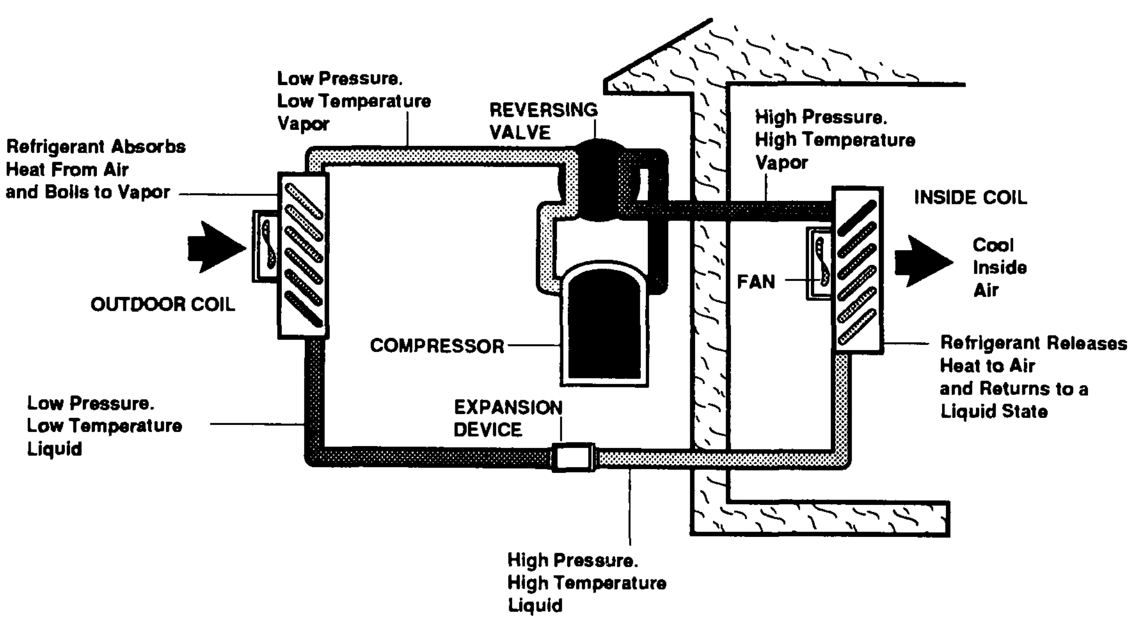
[10] Barakat & Chamberlin, "Market Share Analysis Input Statistics," June, 1992.

Exhibit 2.5

a) Air Source Heat Pump System in Cooling Cycle



b) Air Source Heat Pump System in Heating Cycle



*Adapted from: "Heating and Cooling with a Heat Pump". Minister of Energy, Mines and Resources, Government of Canada. Feb. 1989.

heating load would require very high capital costs). Therefore, the actual operating efficiency of air source heat pumps ranges from a minimum of 100 % to a maximum of 150-300 %. They thus save a significant amount of energy over the course of a heating season relative to electric resistance, but may not reduce demand on the electric system during critical winter "peak" periods. A winter peak-constrained utility thus may be faced with a generating capacity need that is as high as it would be with electric resistance.

Although the **AIR SOURCE HEAT PUMP** can deliver air as warm as 110°F during periods of moderate heating load, during colder periods it delivers much cooler air, sometimes as low as 85°F.[11] Compared to fossil fuel and ground source heat pump systems which consistently deliver air at 90°F or above, air circulated at this lower temperature can lead to some customer discomfort because the air feels chilly.

In addition, with higher efficiency equipment, it can be more difficult to control humidity on peak summer days. The **ADVANCED AIR SOURCE HEAT PUMPS** thus involve some customer comfort tradeoffs in humid climates.

AIR SOURCE HEAT PUMPS currently use 6-7 pounds of hydrochlorofluorocarbon 22 (HCFC 22, as opposed to chlorofluorocarbon, or CFC) for a typical 3 ton system. R22 has 5% the ozone depletion potential (ODP) of CFC-12, which is used in refrigerators. R22 is currently scheduled for phaseout by around 2015 in new equipment.

A. Standard Air Source Heat Pump

The Lennox HP19 was selected to represent standard heat pump technology. It has a single speed compressor, a seasonal energy efficiency ratio (SEER) of 10 and a heating season performance factor (HSPF) of 6.85. Total costs, including installation, range from $3,200 - $4,000. Higher costs in some regions result from the need for a larger unit to accommodate a more extreme climate.

B. High Efficiency Air Source Heat Pump

The Lennox HP22 was chosen to represent **HIGH EFFICIENCY AIR SOURCE HEAT PUMPS**. With a scroll compressor, larger copper tube/aluminum fin coil heat exchanger and improved controls, it has a SEER of 12.5 and an HSPF of 8.1. Total costs, including installation, range from $3,850 $4,810. Higher costs in some regions result from the need for a larger unit to accommodate a more extreme climate.

C. Advanced Air Source Heat Pump

The Carrier Hydro-Tech 2000 was chosen to represent **ADVANCED AIR SOURCE HEAT PUMPS**. The Carrier 2000 integrates heat exchangers and controls to provide nearly all of the domestic hot water supply, often by utilizing "waste" heat, in addition to space heating and cooling.

The Carrier 2000 also utilizes a high-efficiency, variable speed compressor, a microprocessor control module, a high-efficiency refrigerant-to-water heat exchanger, and a water circulation pump. It has a rated SEER of 14 for a three-ton unit and an HSPF of 9, not including the energy benefits from

[11] Energy, Mines and Resources Canada, "Heating and Cooling with a Heat Pump", catalogue #M91-2/41-1989, February, 1989.

hot water heating, which this analysis does consider. Total installed cost ranges from $6,100 - $8,180.

D. Low-Cost Advanced Air Source Heat Pump

Like many other new, advanced technologies, the Carrier Hydro-Tech 2000 has experienced a classic "Catch-22" slowing its penetration on the market. Its cost is high because it doesn't have a high sales volume and can't achieve appreciable economies of scale in production, distribution and pricing. On the other hand, it cannot achieve a very high sales volume because of its high cost.

Carrier estimates that, if deliveries of the Hydro-Tech 2000 increased by a factor of three over its currently low level, its installed cost could come down by 30%.[12] This would result in a total system cost range of $4,270 - $5,726. A similar pricing scenario -- assuming a slightly more conservative 25% reduction -- is included in the cost and environmental comparisons between advanced space conditioning equipment in Chapter Three and Appendix C.

EXISTING AND FUTURE PERFORMANCE IMPROVEMENT OPTIONS

By applying a variety of technical improvements, **AIR SOURCE HEAT PUMPS** could become more competitive in colder, more northern regions. Reduced dependence on electric resistance back-up heat can be achieved by a variety of means, such as vapor extraction sub-cooling, improved compressors and cycles, and thermal energy storage (Exhibit 2.6).

One of these options, thermal energy storage (TES), has already begun to appear on some markets due to utility promotion. The Sacramento Municipal Utility District (SMUD) has recently completed a two year pilot program during which they installed approximately 1,000 TES systems manufactured by Phenix Heat Pump Systems, Inc. by offering not only incentives of $3,500 for 3.5-ton systems and $4,200 for 5-ton systems, but also attractive time-of-use rates. These thermal storage/heat pump systems are attractive to utilities since they allow for peak load reductions by substituting off-peak heating and cooling. Since they run longer in order to store energy during off-peak hours, they suffer from less on-and-off-cycling losses than typical single-speed units; thus, they can achieve high efficiency without the need for two-speed or variable-speed compressors.

Another ETS system more suited for colder climates has been developed by Steffes and marketed by Pennsylvania Power & Light. This system uses off-peak electric resistance heat to heat a ceramic brick "booster" unit. During the on-peak period, the booster negates the need for electric resistance heating. It also provides extra comfort by increasing the temperature of the air delivered into the living space. While this particular technology is beneficial from the standpoint of utility and consumer economics, its use of electric resistance to store heat does not represent an overall energy efficiency improvement or a reduction in electric generation-associated pollution.

THE ROLE OF SUBSTITUTE REFRIGERANTS

Heat pump manufacturers will eventually need to replace R-22. Fortunately, non-ozone depleting substitute work is well underway at EPA, DOE, the National Institutes of Standards and Technology (NIST), EPRI, the University of Maryland, and at some heat pump companies. EPA is also evaluating these substitutes from the standpoint of other important factors such as flammability, toxicity, material compatibility, and global warming potential.

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[12] Nelson McGuire, Product Manager for Hydro-Tech 2000, Carrier Corporation, telephone conversation, August 24, 1992.

EXHIBIT 2.6
Performance Improvements for Air Source Heat Pumps

Technology	Description	Effect
Vapor Extraction	• Additional compressor recompresses some refrigerant as it leaves compressor • Some redesign necessary	Compressing medium temperature refrigerant takes only half the energy
Improved Compressors and Cycles	• Bristol "digital inertia," 2-cylinder compressor • Linear motor/resonantcompression	Increased capacity and efficiency
Electric Thermal Storage (ETS)	• Heat stored in ceramic bricks or water tank	Load-shift to off-peak hours Heat source increased heat pump capacity during cold peak periods

Sources:
Vapor extraction and Bristol compressor: Arthur D. Little, Inc., memorandum on advanced electric air source heat pumps, May 14, 1992.
Linear compressor: Personal conversation with William Kopko, U.S. EPA, July 1, 1992.
ETS: Synergic Resources Corporation, DSM Letter, 1992.
Phenix Heat Pump Systems, Inc., Off-Peak Press, Vol. 1, No. 1, Spring 1990

A binary mixture of R32/R134a has estimated performance increases over R22 of 10-12% in the cooling mode and 6-8% in the heating mode, and may not be flammable in certain blends (R134a is not flammable). Another binary blend, R32/R152a, has estimated improvements of 16-18% in the cooling mode and 7-11% in the heating mode. This mixture has only about one-fourth the global warming potential (GWP) as R22; however, it is slightly flammable.[13] As part of its mission to protect the ozone layer, EPA will continue to work with various organizations to bring safe HCFC alternatives to the market.

[13] Jurgen Pannock and David Didion, "The Performance of Chlorine-free Binary Zeotropic Refrigerant Mixes in a Heat Pump," National Institute of Standards and Technology (NIST), EPA-600-R-92-017, December, 1991, pp. 15-16 and p. 34.

III. ELECTRIC GROUND SOURCE HEAT PUMPS

Ground source heat pumps comprise a very small fraction (about 0.4%) of the entire nationwide heat pump market. Twenty companies manufacture nationwide[14], of which the four largest account for 80% of the market. Even the largest manufacturers, however, distribute only on a local or regional basis.[15] Since there is no single trade association which collects data from manufacturers, estimates of sales have a high degree of uncertainty. According to one estimate, sales of ground source heat pumps appear to have remained fairly stable since 1985, when they were estimated at 20-25,000 units;[16] estimates for 1990 and 1991 remained at 20,000.[17] Others have noted[18], however, that three of the four largest manufacturers have recently moved into new, larger plants leading to the speculation that the market has not remained stable, but rather has increased in size.

In any case, the **GROUND SOURCE HEAT PUMP** market currently remains a niche market that does not enjoy the economies of scale or the level of competition that would minimize installation costs for consumers.

TECHNOLOGY DESIGN: A MIXED BLESSING OF HIGHER PERFORMANCE AND HIGHER COST

GROUND SOURCE HEAT PUMPS work just like air source heat pumps, except that they extract or reject heat to the ground instead of the air, generally by circulating fluid through a pipe buried in the ground. The fluid in this heat exchange loop transfers heat between the ground and another heat exchanger located in the heat pump. Although they are also known as geothermal heat pumps, in many cases much of the heat provided is actually solar energy that has been absorbed by the ground; this depends on the loop configuration. If the ground loop is installed in the ground horizontally (as described below and in Appendix A), solar energy provides most of the heat. If installed vertically, most of the heat provided is indeed geothermal.

Ground source heat pumps have better efficiency than air source heat pumps, especially in relatively wet ground. Ground temperature does not vary over the day or year as much as the ambient air temperature does, providing much more stable operating conditions. In heating mode, today's **GROUND SOURCE HEAT PUMPS** usually deliver air into a house at around 100° F[19] without electric resistance backup. Compared to **AIR SOURCE HEAT PUMPS, GROUND SOURCE HEAT PUMPS** generally have an advantage with respect to air supply temperature. However, air delivery temperatures can be reduced to as low as 90° F in extremely cold weather conditions.[20]

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[14] Dan Ealy, Waterfurnace West, Personal Conversation, May 28, 1991.

[15] Barakat & Chamberlin, report to EPA, January 3, 1992.

[16] EPRI, EM-6062.

[17] Air Conditioning, Heating & Refrigeration News, "Comfort & Construction," v. 185 (April 1, 1991) p. 24+. The same estimate for 1991 was given in an article of the same title published on March 30, 1992, although it is admitted that "there are no reliable statistics."

[18] Jim Bose, Oklahoma State University, Personal Communication, December 1992.

[19] WaterFurnace International, Inc., "Ground Source Heat Pump Marketing Manual", March, 1989, p. 11.

[20] Edison Electric Institute, "Geothermal Heat Pump Options Manual", #07-87-36, p. 8, undated.

Ground loops can be "closed" or "open." The closed system employs a pressurized, sealed loop usually filled with a water/antifreeze mix. A small circulating pump requires little energy to move the fluid. Sixty-five percent of installations use propylene glycol or methanol. Some use sodium chloride, ethanol or no antifreeze at all.[21] Chevron Chemical Co. has also just developed a new ground loop antifreeze, Chevron GS4™, a proprietary compound with a potassium acetate base. Chevron claims that the antifreeze is less toxic than table salt, non-flammable, readily biodegradable and efficient.[22]

An open loop system utilizes water taken directly from a source such as a well or a pond and then discharges it back to the original source or elsewhere in the ground. Because of water quality issues, potential equipment fouling from biological and mineral impurities, the need for larger pumps, and relative lack of open-loop resources, this report only considers closed loop systems.

Use of a ground loop allows **GROUND SOURCE HEAT PUMPS** to use 40%-50% the quantity of R22 that **AIR SOURCE HEAT PUMPS** use[23] and to locate the entire **GROUND SOURCE HEAT PUMP** unit indoors, away from the elements. Although **GROUND SOURCE HEAT PUMPS** can be expected to have a longer lifetime than **AIR SOURCE HEAT PUMPS**, this analysis assumed the same lifetime due to a lack of actual data. **GROUND SOURCE HEAT PUMPS** avoid a large fan and operate quietly, not adding noise to yards in the summertime. Exhibit 2.7 provides a comparison of air source and ground heat pumps.

Exhibit 2.7
GROUND SOURCE HEAT PUMP and **AIR SOURCE HEAT PUMP**
Design and Performance Comparison

3-Ton System	GROUND SOURCE HEAT PUMP	AIR SOURCE HEAT PUMP
Qty of R22 Refrigerant	3 lbs.	6-7 lbs.
Location of Compressor	Inside house	Outside house
First Cost*	$5,599-$8,615	$3,200-$8,180
End-Use Efficiency:** Seasonal Performance Factor - Heating	2.74-5.37	1.56-2.93
End-Use Efficiency:** Seasonal Performance Factor - Cooling	2.82-5.99	2.30-4.33
Temp. of air entering house - heating season	90°- 100° F	80° - 100° F

* Costs are for a range of models and climates, and exclude water heater and duct work costs.
** Efficiency data reflect results of regional analysis presented in more detail in Appendix C.

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21 International Ground Source Heat Pump Association (IGSHPA)Newsletter (October, 1990), p. 4.

22 Chevron Chemical Company, Chevron GS4™ Heat Transfer Fluid, c. 1991.

23 GSHPs use in the order of 3 lbs. of R22 for a three-ton system. Older ASHPs use about 15 lbs. of R22 for a comparably-sized system; lately, however, ASHP manufacturers have been reducing the size of heat exchangers and, consequently, the amount of R22 needed. Consequently, ASHPs use as little as 6-7 lbs. of R22.

Customer satisfaction with **GROUND SOURCE HEAT PUMPS** is extremely high. A survey in Oklahoma found that 97% of the 157 **GROUND SOURCE HEAT PUMP** owners surveyed would buy the system again, and 99% would recommend it to a friend. Eighty-four percent of the people in the same survey said they would allow their names to be used in a testimonial supporting the technology.[24] Buckeye Power, Inc., found a 98-99% satisfaction rate with **GROUND SOURCE HEAT PUMPS.**[25] East Kentucky Power Cooperative claims a 96% customer satisfaction level.[26] The Canadian Earth Energy Association claims a 97% customer satisfaction level.[27] A recent survey of **GROUND SOURCE HEAT PUMP** owners by the Michigan Electric Cooperative Association revealed an overall 97.5% approval of their systems. In addition, customer satisfaction was found to increase with the age of the systems.[28]

From the utility perspective, new dual-speed and variable speed technologies can be economically designed to carry full heating loads in all climates, avoiding higher peak demand from electric resistance back-up heating in extreme winter conditions and providing superior load shapes (Exhibit 2.8).

GROUND LOOP CONFIGURATIONS

Ground loops provide an inherent efficiency advantage over air source heat pumps, but can also increase up-front capital costs by one-third or more.

Ground loops can be configured horizontally or vertically. A horizontal ground loop is placed in a trench 3 to 6 feet deep, depending on climate and size of the system. 400 to 600 feet of tubing per ton of heat pump capacity, with trench lengths of 200 to 500 feet per ton, are required.[29]

Since horizontal systems can require as much as 5,000 square feet of total land space (the "footprint") they are often used on large suburban lots or rural areas where more space is available.[30] However, a new loop configuration -- the SLINKY™ loop -- substantially reduces the amount of horizontal trenching required, opening up the horizontal loop option to homeowners with smaller lots (Appendix A).

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24 Study conducted by AHP Systems for Command-Aire Corporation, within membership of the Red River Valley Rural Electric Association. "Ninety-Seven Percent of Ground Source Heat Pump Buyers Would Buy Again," Marketing Exchange 2:7, National Rural Electric Cooperative Association (NRECA)(August 12, 1988).

25 Woller, Bernie, Director of Facilities and Special Projects, Buckeye Power Inc., Personal Conversation (May 28, 1991).

26 Abnee, William "Conn," Assistant Marketing Manager, East Kentucky Power Cooperative, Personal Conversation, May 17, 1991.

27 Scottsmith, Peter, Canadian Earth Energy Association, Personal Conversation, May 28, 1991.

28 The DSM Letter, "Michigan Co-op Association Surveys Ground Source Heat Pump Customers". May 11, 1992. Vol. 20, No. 10.

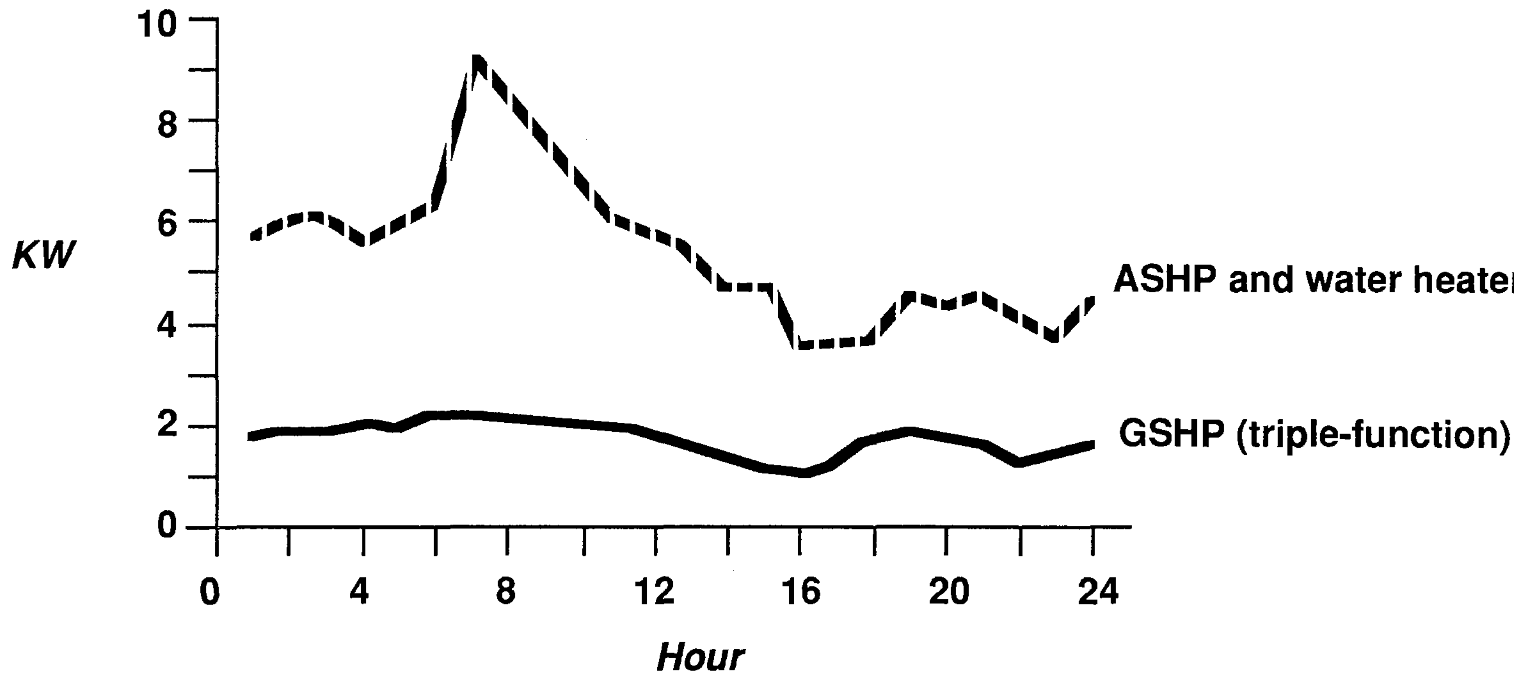
29 Trench/bore size and pipe lengths ranges from "Closed-Loop/Ground-Source Heat Pump Systems -- Installation Guide. NRECA, OSU, IGSHPA. 1988.

30 "The Ground Source Heat Pump -- The Most Energy-Efficient Technology Available Today". Ontario Hydro, undated marketing brochure.

Exhibit 2.8

Typical Demand Reduction from a Ground Source Heat Pump

Capacity Reductions



Source: National Rural Electric Cooperative Association, "Closed Loop/Ground-Source Heat Pump Systems: Installation Guide", NRECA, Research Project 86-1, p. 19

Vertical systems can be installed when land space is limited, as long as there is access for the drilling rig. Four to five loops requiring a footprint of up to 500 square feet are inserted in vertically drilled holes 6 inches or so in diameter. The holes range from 60 to 200 feet deep, depending on soil conditions and size of the system. Approximately 250 to 450 feet of tube per ton of heat pump capacity is needed. Bore holes are backfilled with a grout in order to ensure contact with the surrounding ground, as air spaces would seriously diminish the loop's capacity to exchange heat with the ground. Exhibit 2.9 compares specifications for the two loop configurations.

Exhibit 2.9
Vertical versus Horizontal Installation Specifications

3-Ton System	Land Space Required: "Footprint"	Trench/Bore Hole Dimensions	Loop Length in feet	Loop Cost
HORIZONTAL	Up to 5,000 Sq. ft.	Trench: 3-6 ft. deep 4-24 in. wide 200-500 ft. long	1,200-1,800	$1,050 - $1,500
VERTICAL	Up to 500 Sq. ft.	Bore Hole: 60-200 ft. deep 3-6 in. diameter	750-1,350	$2,100 - $3,000

Horizontal and vertical ground loop systems have several variations that can be applied as site conditions warrant (see Appendix A for detailed descriptions).

Overall, 54% of **GROUND SOURCE HEAT PUMP** loop installations to date have been vertical, 43% horizontal, and 3% are pond installations (in which a closed loop is placed in a body of surface water, which replaces the ground as the heat exchange medium).[29]

GROUND LOOP COSTS

Working with utilities and with EPRI, ground loop installers have been successful in reducing installation costs significantly over the past several years. For instance, Public Service of Indiana (PSI), through a program run in cooperation with EPRI, reduced vertical loop costs for a 3-ton system from about $3000 to $2400, due to improving driller experience and economies of scale from more efficient job scheduling.[30] For an aggressive utility program installing many retrofit systems as well as new construction systems (particularly mass-installations), a cost reduction of an additional 10-15%, or about $2100 per 3-ton system, can be assumed.

Where there is sufficient land space, horizontal loops are preferred over vertical loops because they are cheaper to install. In addition, they are less intrusive of ground water reservoirs. In areas where contractors have gained experience and expertise in laying ground loops , such as in the PSI program, installation costs have come down to about $500 per ton, or $1500 for a three-ton

29 IGSHPA Newsletter, The Source (October 1990), p.4.

30 EPRI, memo describing PSI program, 1991. EPA notes that the PSI program was targeted at new construction, and that no costs for re-landscaping were included. Such costs would have to be considered for retrofit situations.

system. Further design innovations, such as the SLINKY™ loop, can further reduce costs by 30%, or to about $1050 for a 3-ton system.

A. Standard Ground Source Heat Pump

The Waterfurnace WX series represents **STANDARD GROUND SOURCE HEAT PUMP** technology. A three ton unit has a rated cooling EER of 10.9 at 70 degrees F inlet loop fluid temperature and a heating COP of 3.1 at an inlet temperature of 50 degrees. These ratings are based upon ARI Standard 325-85. Since this report analyzes systems with closed ground loops, ARI 330 would be a preferable standard to use, however, no current 330 ratings exist for the WX series.

On a practical level, operating inlet water temperatures will vary with climate, ground temperature, soil conditions (type of soil, degree of saturation with ground water, etc.) and time of year. Total costs for the WX system, including installation, range from $5,699 - $8,200. Higher costs in some regions are due to size differences of the unit or the loop needed to accommodate more extreme climates without the need for back-up electric resistance heating.

B. Advanced Ground Source Heat Pump

The WaterFurnace AT series represents the **ADVANCED GROUND SOURCE HEAT PUMP** in this analysis. It uses a single speed scroll compressor, variable speed blower and a water "desuperheater."

Desuperheating provides hot water by utilizing heat from the hot refrigerant gas as it leaves the compressor and transferring it to a hot water tank (Exhibit 2.10). This function increases the efficiency of the system during the cooling mode, as this heat would need to be rejected back to the ground; during peak cooling periods during summer months, a desuperheater can satisfy full water heating load. During the heating season, when a desuperheater system must sometimes compete with the living space for heat, it does not provide 100% of the water heating load, and requires back-up water heating (in this report, we assume electric resistance).[31]

The rated performance of this system for ARI 325 is a cooling EER of 13.7 at 70 degrees inlet temperature and a heating COP of 3.7 at 50 degrees inlet temperature. For ARI Standard 330, the AT series has a rated cooling EER of 14.4 (77° F entering water temperature) and heating COP of 3.3 (32° F entering water temperature). Total costs, including installation, range from $6,370 - $8,615.

C. Emerging Ground Source Heat Pump

Continuing technological improvements can occur in the very near future that could move ground source heat pumps into a much larger market. In 1992 WaterFurnace introduced a two-speed scroll compressor. Further likely improvements include variable speed drive (as is included in **ADVANCED AIR SOURCE HEAT PUMPS**) and a fully integrated, demand water heating function, which would nearly obviate the need for electric resistance back-up water heating.

For **EMERGING GROUND SOURCE HEAT PUMPS**, 2-speed technology and integrated water heating were assumed to increase both the average COP and EER by about 10% over the existing **ADVANCED GROUND SOURCE HEAT PUMP** described above. Modeling performed for various locations with the 2-speed compressor has shown increases in efficiency ranging from 8 percent to as high as 25 percent. An average increase in efficiency of 10 percent has been used, however, as a

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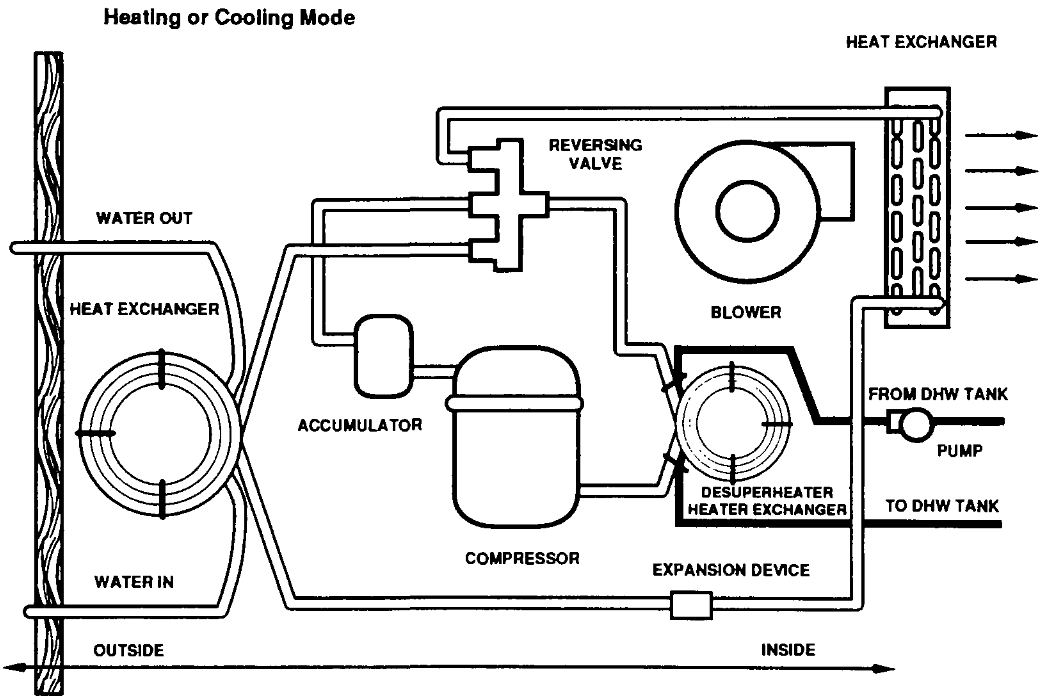
[31] Geothermal Heat Pump Options Manual. Edison Electric Institute. Washington, D.C.

Exhibit 2.10
Desuperheater Operation for a Ground Source Heat Pump



Source: "Geothermal Heat Pump Options Manual". Edison Electric Institute.

conservative national estimate of the improvement due to the introduction of this technology. Market conditions for the **EMERGING GROUND SOURCE HEAT PUMP** assume that it moves out of a niche towards a mass market; consequently, there would be no extra costs for producing these technologies, since added component costs would be offset by lower costs for existing fabrication and distribution.

EXISTING AND FUTURE IMPROVEMENTS IN GROUND SOURCE HEAT PUMPS

While not considered in this analysis, there are a number of technology improvements in ground source heat pumps that may be introduced to the mass market later in this decade. Exhibit 2.11 lists some of these possibilities.

EXHIBIT 2.11
GROUND SOURCE HEAT PUMP IMPROVEMENTS

Many of the improvements that could increase the performance of air source heat pumps can also be incorporated into ground source heat pumps. These include vapor extraction, improved compressors and efficiency- and capacity-enhancing R22 substitutes (See Exhibit 2.7)

Alternating Loops

Geotech of Troy, NY has developed a patented alternating loop system that switches parallel loops on and off. It is based on the principle that constant flow through geothermal loops causes soil heat resistivity to build up and ground loop performance to fall off. An alternating loop system, where loops are allowed to "rest" for periods of time, has the potential to maximize performance, leading to smaller loops and lower costs (See Appendix A).

Potential Super-Efficiency from Direct Expansion Heat Pumps (DXHP)

Instead of employing an antifreeze loop exchanging heat with the ground and then exchanging it again with the heat pump's R22 refrigerant, the direct expansion heat pump has a single heat exchange loop that passes the R22 itself through the ground in 1/4" copper tubes.

Advantages:

* elimination of antifreeze-to-refrigerant heat exchanger leads to higher efficiency
* heat exchange through 1/4" copper tubes more efficient than larger, plastic pipes
* loops require only about 1/2 land space as antifreeze loops
* lower installation costs

Barriers:

* technology is not currently rated by Air-Conditioning and Refrigeration Institute (ARI), so it is difficult to assess performance
* about 10 lbs. R22 is circulated in ground -- risk of leaking ozone-depleting substance higher than conventional ground source heat pumps

Steps Needed to Overcome Barriers:

* Receive ARI rating
* Work to introduce non-ozone depleting R22 substitutes

IV. OIL FURNACE WITH HIGH EFFICIENCY AIR CONDITIONING

The Thermopride oil furnace system with an efficiency rating of 85% was selected to represent this technology for comparative purposes in New England and the Mid-Atlantic. A two and a half ton, SEER 12 electric central air conditioner was assumed for cooling. The Thermopride furnace has a two-stage heat recovery furnace system with a power oil burner and a power vent controller for providing a hotter flame, and positive off-cycle damper. Total cost, including installation, was $6,515.

V. GAS FURNACES

A. Standard Gas Furnaces with A/C

A Lennox furnace with an efficiency rating of 80% was used to represent standard gas furnaces. A two and a half ton, 10 SEER central air conditioner was assumed for cooling. Total cost, including installation, was $3,575.

B. Advanced Gas Furnace with Efficient A/C

The Lennox Pulse furnace, which is a condensing furnace rated at 96% efficiency, was selected as the prototypical model to represent the high-efficiency gas system. A two and a half ton, 12 SEER central air conditioner was assumed for cooling. The Lennox Pulse requires no pilot burner, main burners or conventional flue. There is a primary and secondary heat exchanger (the condensing unit) that maximizes the extraction of energy from the exhaust products of combustion. Total capital cost, including installation, was $5,000.

C. Emerging Gas-Fired Air Source Heat Pump

The Gas Research Institute (GRI) and York International have developed a gas-engine driven air source heat pump. York International is currently conducting a field testing program with 100 units in 1992, and commercialization is planned for January, 1994.[34] The **GAS-FIRED HEAT PUMP** uses a gas-fired engine to convert the energy in the natural gas into the mechanical energy necessary for operating the heat pump. The combustion of gas at the end-use eliminates the losses in efficiency from electricity transmission and distribution and allows the waste heat from combustion to be used in space heating or water heating. The **GAS-FIRED HEAT PUMP** can also substantially reduce summer peak demand for electricity while simultaneously filling the summer "valley" for gas utilities.

The emerging **GAS-FIRED HEAT PUMP** employs a vapor compression refrigeration cycle like an air source heat pump, driven by a five horsepower, four-stroke, single-cylinder gas engine rather than an electric motor. The engine was designed and developed by Battelle Columbus Labs and Briggs and Stratton Company. It is engineered for long service life with maintenance intervals of once per year or every 4,000 hours of operation. Endurance tests have indicated an engine design life in excess of 40,000 hours, equivalent to 10 years of service.[35] The engine is linked to a high-efficiency, reciprocating compressor, as well as to a water/glycol engine heat-recovery system. The unit is controlled by a microprocessor that optimizes fan speed, engine speed and cycling rates. **GAS-FIRED HEAT PUMPS** have a lower thermal balance point than typical electric heat pumps, and

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[34] Richard Sweetser, Executive Director, American Gas Cooling Center, conversation, June 12, 1991.

[35] Gas Research Institute pamphlet, 'Research-Engine-Driven Gas Heat Pump', undated.

consistently deliver air to a house at 95°F. Test data of York gas-fired heat pumps have demonstrated seasonal gas cooling COPs in the range of 0.93 - 1.21 and gas heating COPs from 1.04 - 1.54.[36]

These seasonal gas COPs suggest that the **GAS-FIRED HEAT PUMP** does not have as high an end-use efficiency as advanced electric heat pumps, while this is true it should be noted that usually less than one-third of the energy that enters the electric generating plant reaches the end-use site in the form of electricity, while the natural gas distribution system delivers about 90 percent of its source energy to the end-use site. This differential between electric and gas generation and distribution systems is accounted for when comparing equipment performance in Chapter 3 and in Appendix C.

The **GAS-FIRED HEAT PUMP** has an inherent load-matching capability because engine speed can be varied over a broad range, allowing its output to be modulated in order to provide capacity to meet a load. It also produces added heating capacity through engine heat recovery independent of operating mode. This capability enhances overall heating system performance.

The currently developing stage of **GAS-FIRED HEAT PUMP** technology raises some unresolved issues as to product price, annual maintenance cost, product lifetime and emissions, especially NO_x. For instance, the only available published information on emissions noted that NO_x emissions were measured at 300 ppm in the field test.[37] Conversion of this datum yields NO_x emissions at 0.14 kg/million Btu input energy (MMBtu). This is approximately 75 % of the NO_x emission rate for electricity delivered from a typical modern gas combustion turbine utilizing steam injection for NO_x removal but is 50 % greater than for an advanced gas combined cycle plant utilizing stem/water injection.[38]

Research has shown that NO_x can be reduced by retarding the ignition timing; however. this reduces engine efficiency. A leaner air/fuel ratio can also reduce NO_x emissions, but this too lowers efficiency. GRI is planning a two year study which will attempt to reduce NO_x emissions by 50% without degrading the efficiency.[39] Product price is estimated to be consistent with recent industry publications on the **GAS-FIRED HEAT PUMP,** which estimate the installed cost for a 3-ton unit at $6,800.[40] Annual maintenance costs were set at $100, which is slightly higher than for electric heat pumps. Product lifetime is assumed to be the same as for all other systems (20 years).

Given the lack of data in the public domain regarding the performance characteristics of the **GAS-FIRED HEAT PUMP**, modeling of the gas-fired heat pump was performed by York, International, working with Oak Ridge National Laboratory on behalf of the Gas Research Institute and American Gas Cooling Center. This modeling exercise used the same inputs as were used for all other equipment analyzed in this report (Chapter Three). Total costs for the **GAS-FIRED HEAT PUMP** used for this analysis, including installation, range from $4,800 to $6,800, reflecting a range in heat pump sizes from 2 tons to 3 tons, as selected for each location by the York, International modelers. Of

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[36] York Gas Heat Pump Field Test Performance Summary, GRI-102991-0511.

[37] Air Conditioning, Heating and Refrigeration News, Oct. 21, 1991, p. 3

[38] Union of Concerned Scientists, et al, America's Energy Choices - Technical Appendices, Union of Concerned Scientists, Cambridge, MA, 1992, page I-4.

[39] Personal communication, Chuck French, GRI, March 8, 1993.

[40] American Gas Cooling Center, Cool Times, Vol.3, December 1992/January 1993, p. 3.

course, since the gas-fired heat pump has not yet appeared on the market, this price range has a higher degree of uncertainty than others used for this analysis.

FUTURE PERFORMANCE IMPROVEMENT OPTIONS FOR GAS-FIRED HEAT PUMPS

Manufacturers, GRI and other research bodies have been working for some time on product R&D on various advanced **GAS-FIRED HEAT PUMP** designs (Exhibit 2.12). These efforts represent an ongoing effort, like that in the electric appliance industry, to continuously improve products with regard to their primary market attributes -- energy efficiency and price. To the extent that they can be commercialized at a cost-effective price, some have the potential to have environmental performance that is comparable or superior to any current or emerging technology analyzed in this report. One such product is the GAX absorption heat pump due on the market in the mid-1990s (see Appendix F).

EXHIBIT 2.12
FUTURE IMPROVEMENTS FOR GAS-FIRED HEAT PUMPS

Technology	Description	Potential Effect
Heat Activated Heat Pump	- Free-piston Stirling engine drives compressor via magnetic coupling	Seasonal COPs of 1.7 (heating) and 1.2 (cooling)
	- Power system requires no shaft seals or lubricants	Lower emissions
		Long life and low maintenance costs
GAX Heat Pump	- Absorption cycle instead of compression/expansion cycle	Comparable efficiency and emissions, lower cost than engine-driven
Gas-fired Desiccant System	- Desiccant wheel absorbs 90% of moisture; air is then cooled first by metal disk and then by evaporating water	Very high efficiency: EER of 17.7
		No CFCs or HCFCs needed
	- cooling can be enhanced by adding a ground loop where ground water is less than 55° F	EERs of over 30 may be attainable

Sources:

Heat Activated Heat Pump: Mechanical Technology Incorporated, Power Systems Division, "Advanced Technology for High-Efficiency Power Systems," undated brochure. MTI, Power Systems Division, Latham, NY

GAX heat pump: Richard Sweetser, American Gas Cooling Center, June 12, 1992

Desiccant Systems: Matthew Wald, New York Times, "Staying Cool and Saving the Ozone," June 22, 1992, p. D1. Gas-fired, ground coupled desiccant system presented by D.H. McFadden, W.P. Teagan, D. Malloy, "Design of a HCFC Free Ground-Coupled Desiccant Air Conditioner (with Heating Function), Proceedings, 42nd International Appliance Technical Conference, Madison, WI, May 21-22, 1991.

Although not evaluated in this report, it should be noted that ground-coupling is a possible configuration for **GAS-FIRED HEAT PUMPS**. Although the price of a ground loop will increase the overall price of the system, the advantages are that ground-coupling would increase efficiency and greatly reduce natural gas pressure drops and storage requirements during peak periods when two-thirds of the heat would be supplied by the earth.

CHAPTER THREE

ANALYSIS OF SPACE CONDITIONING EQUIPMENT: ECONOMICS, ENVIRONMENTAL EFFECTS, AND THE POTENTIAL FOR UTILITY DSM PROGRAMS

The cost-effectiveness and environmental impact of the various space conditionin technologies are evaluated in this chapter on a location-by-location basis. The evaluation is done from the perspective of the potential cost-effectiveness of utility programs, leading to Chapter Four's assessment of the impact that aggressive utility programs would have on market demand for advanced space conditioning and emissions during the 1995-2005 period.

SCOPE OF ANALYSIS

A "typical" single family home that would require a three-ton heat pump system in a temperate climate was used for the basis of this analysis. Costs and performance characteristics for alternative equipment were applied to this hypothetical dwelling. The economic and environmental impacts were then estimated using regional climate, energy prices and utility fuel mixes.

Six locations representative of the major climate zones in the U.S. (Exhibit 3.1) were used. Since some of the advanced equipment considered in the report provide the additional service of heating water, this load is taken into consideration in each location as well. Exhibit 3.2 shows the relative space heating, cooling and water heating loads in each representative location:

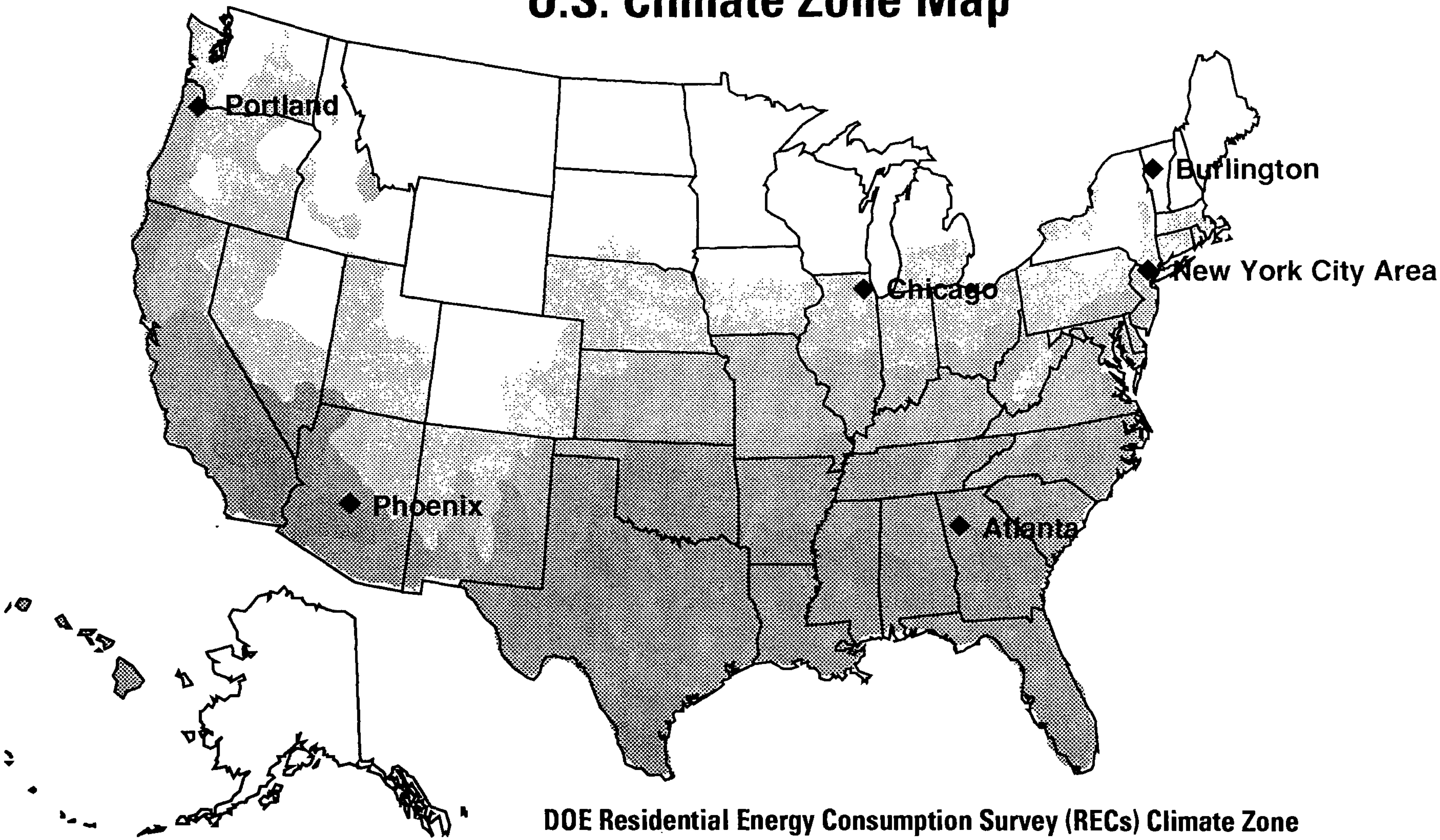
Exhibit 3.2

Energy Requirements (MMBtu) in Selected Locations
For Prototypical Residence Modeled in Report

Location	Space Heating	Space Cooling	Water Heating	Design Heat Load	Design Temp (° F)	Design Cool Load	Design Temp (° F)	Internal Gains (Btu/hr)
Burlington	84.1	6.2	10.8	44,536	-10	20,801	88	7,234
Chicago	63.5	13.3	10.5	39,879	-2	23,250	93	7,472
New York	62.3	11.5	10.6	36,413	4	21,776	90	6,729
Portland	42.9	5.1	10.0	24,482	23	21,776	90	5,601
Atlanta	29.8	23.0	8.8	25,020	22	23,745	94	4,207
Phoenix	17.2	54.4	7.1	18,602	34	30,107	109	4,079

Local energy prices and regional fuel mixes were used for both the consumer-based economic and environmental analyses in each representative location. In assessing the potential role for utility DSM programs, values for the avoided capital and fuel costs for representative electric and gas utilities from each of the locations were used.

Exhibit 3.1
U.S. Climate Zone Map



DOE Residential Energy Consumption Survey (RECs) Climate Zone

- Zone 1 is < 2,000 CDD and > 7,000 HDD
- Zone 2 is < 2,000 CDD and 5,500-7,000 HDD
- Zone 3 is < 2,000 CDD and 4,000-5,499 HDD
- Zone 4 is < 2,000 CDD and < 4,000 HDD
- Zone 5 is 2,000 CDD or more and < 4,000 HDD

SPACE CONDITIONING EQUIPMENT PERFORMANCE AND COST COMPARISON

For each location, the first cost of each technology was determined and its operating performance in the space heating, space cooling and water heating mode was calculated.[1] One significant factor affecting both first cost and performance was the sizing decision. In consultation with experts in the industry and in the field, EPA used the dominant seasonal demand in each location to drive the electric equipment sizing decision. For instance, in Burlington, it was assumed that the heat pumps installed in the prototypical house would be 3.5 tons, as dictated by the home's high heating load. In Chicago and New York, the systems were sized at 3 tons, while in the remaining locations, 2.5 ton systems were used.

However, given the lack of market experience with the **GAS-FIRED HEAT PUMP**, experts from the gas industry most familiar with the cost and operating characteristics of the **GAS-FIRED HEAT PUMP** provided the sizing recommendations for it in the six locations. They recommended sizing all systems according to their ability to handle the cooling load in each location. Thus, for the **GAS-FIRED HEAT PUMP**, this analysis assumes a 2 ton system in Burlington, a 2.5 ton system in Chicago and the New York area, and 3 ton systems in Portland, Atlanta and Phoenix.

Source Seasonal Performance Factors: End-use equipment efficiency (as measured by SPF, EER, SEER, COP or HSPF) is insufficient to compare the performance and environmental impacts of electric vs. fossil fuel equipment. Electric equipment receives approximately 27% of the energy that originally goes into electricity generation. Losses associated with extracting, processing and transporting fuel to the power plant and generating, transmitting and distributing electricity to end users account for the other 73%. Gas loses about 9% of the input energy during fuel extraction, processing, transportation and distribution.[2] In order to provide consistency and fairness, the report emphasizes source operating performance, which takes into account these losses.

Annualized Costs: Cost comparisons are on an annualized basis, and include energy costs, capital costs and maintenance costs. Annual energy costs are derived from current residential energy rates for the local utility. **GAS-FIRED HEAT PUMPS** are assumed to have a higher annual maintenance cost than the electric heating and cooling technologies because they utilize an internal combustion engine ($100 for the GFHP vs. $50 for ground source heat pumps and other equipment).[3] Capital equipment costs are annualized over a twenty year period at a 10% consumer discount rate.[4]

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[1] See Appendix E for description of the model used to estimate energy consumption and seasonal performance factors.

[2] Both electric and gas losses are taken from American Gas Association, "Home Heating Efficiencies for Natural Gas, Fuel Oil and Electricity," Issue Brief 1990-13, October 29, 1990.

[3] Before this report was to be published, new estimates on the maintenance costs for the **GAS-FIRED HEAT PUMP** were received. Experts in the gas industry now estimate that annual maintenance costs for the **GAS-FIRED HEAT PUMP** could be as high as $175, rather than $100 (though the first two years would be covered in the equipment's purchase price). Thus, the present value of the maintenance costs for the **GAS-FIRED HEAT PUMP** would change from approximately $850 to $1,200. This cost update is not included in any of the cost-effectiveness analyses which follow.

[4] Overall, this annualization is quite conservative with regard to ground source heat pumps which, because they operate indoors, may last longer than the other types of equipment. It also does not account for the full lifetime of ground loops, which carry warranties of up to 55 years.

ENVIRONMENTAL EFFECTS AND TOTAL SOCIETAL COST

In this part of the study the environmental impacts of the alternative space conditioning equipment are examined and their "social costs" estimated.[5] The emissions of primary concern are CO_2, SO_2, and NO_x, which are calculated for four electric generating scenarios: the **REGIONAL** electric generation mix forecast for the Year 2000; a modern coal plant (**ADVANCED FLUIDIZED BED COMBUSTION**); a modern advanced, baseload gas plant (**ADVANCED GAS COMBINED CYCLE**); and a modern gas combustion turbine (**NATURAL GAS COMBUSTION TURBINE**), which is a common option for meeting peak utility demand.

The estimates for social costs associated with the use of different types of equipment were based on a recent report published by the Union of Concerned Scientists[6]. For each major emission type the following values were used:

	$/kg
CO_2	0.013
SO_2	0.88
NO_x	6.42

Of course, a more detailed utility "dispatch" model, which reflects a marginal power plant as utilized on a utility's grid during various seasonal peak and off-peak hours, might give the most accurate estimation of the emission impacts of space conditioning equipment. However, the scenarios used in this report provide a good first cut at comparing advanced equipment with each other and with more standard equipment.

COST-EFFECTIVENESS SCREENING FOR UTILITY PROGRAMS

Utilities must be able to compare the cost of purchasing advanced heating technologies to other demand reduction and supply-side resources before they can decide whether to invest in such technologies as part of their demand-side management program portfolio. The value of the energy saved by the new technologies must be greater than the cost of providing the energy in some other way, such as with a new electric power plant or new gas pipeline capacity. This analysis -- a "cost-effectiveness test" for conservation -- can be performed using the "Total Resource Cost" (TRC) test.[7] (See Exhibit 3.3)

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[5] "Social costs" take into account costs that are not captured in the market price. These "external costs," or "externalities" will vary widely based on the particular product and how it is produced and brought to market. The most common externalities considered by utilities and their regulators are environmental externalities -- specifically, those costs associated with air pollution impacts. While it is extremely difficult to assign dollar values to these impacts -- which can include damage to human, animal and plant health, buildings, and aesthetic qualities such as visibility -- several state regulatory bodies have employed methodologies that calculate the cost of controlling or mitigating the emissions as a proxy. Other externalities not considered here can include the land impacts of fuel extraction and transportation, security costs (such as military defense of key energy sources) and the effect on local jobs and commerce.

[6] The figures used in the analysis are from Union of Concerned Scientists et al, America's Energy Choices - Technical Appendices, 1992.

[7] For a comprehensive description of the TRC and other tests for utility DSM measures, see California Public Utility Commission and California Energy Commission, Standard Practice Manual: Economic Analysis of Demand-Side Management Programs, P400-87-006, December, 1987.

Exhibit 3.3

SAMPLE TRC CALCULATION

The TRC ratio is defined as follows:

$$\frac{\text{Value of Utility Capacity and Energy Savings}}{\text{Incremental Cost + Administrative Cost + Cost of Replacement Fuel and Capacity}}$$

Whereas, the TRC Net Present Value is given by:

Present Value of Savings - (Incremental Cost + Administrative Cost + Total Utility Cost)

Consider an Emerging Ground Source Heat Pump with a Vertical ground loop replacing a Standard Air Source Heat Pump in the Upper New York Metropolitan area. This measure will reduce winter electricity consumption by 6,395 kWh and summer electricity consumption by 1,655 kWh. Furthermore, it will reduce peak summer demand by 5.7 kW and peak winter demand by 5.3 kW. The total net present value of electric utility capacity and energy savings in 1992 dollars is $8,388.

On the cost side, the incremental cost for replacing a Standard Air Source Heat Pump with an Emerging Ground Source Heat Pump with a Vertical Loop is $3,295. The administrative cost is the cost faced by the utility to administer the incentive program. For this measure the administrative cost is assumed to be $150. Since this is a case of simply replacing one electric technology with another, there is no cost for replacement fuel or capacity.

The TRC ratio is therefore:

$$\frac{\$8,388}{\$3,295 + \$150 + \$0} = \underline{\underline{2.43}}$$

And, the TRC Net Present Value = $8,388 - ($3,295 + $150 + $0) = <u>$4,943</u>

It is insightful to compare these two values to TRC ratios and net present values calculated by replacing the same standard air source heat pump with a Gas-Fired Heat Pump. Winter electricity consumption would be reduced by 10,838 kWh and summer electricity consumption by 2,888 kWh. Peak demand would be reduced by 15.4 kW in the winter and 6.9 kW in the summer. These reductions result in electric utility capacity and energy savings valued in 1992 dollars at $15,956.

The incremental cost of a Gas-Fired Heat Pump is $1,800. Combined with its somewhat higher maintenance cost results in a maintenance-adjusted incremental cost for this measure of $2,206. The administrative cost of this measure will again be assumed to be $150. This measure will increase natural gas consumption by 792.9 Therms, resulting in a cost of replacement fuel valued at $8,255.

The TRC ratio is therefore:

$$\frac{\$15,956}{\$2,206 + \$150 + \$8,255} = \underline{\underline{1.50}}$$

And, the TRC Net Present Value = $15,956 - ($2,206 + $150 + $8,255) = <u>$5,345</u>

The TRC <u>ratio</u> for the Gas-Fired Heat Pump is lower than for the Emerging Ground Source Heat Pump/Vertical Loop, while the TRC <u>net present value</u> is slightly higher. The difference is due to the presence of a replacement fuel utility cost in the denominator of the Gas-Fired Heat Pump's TRC ratio. Fuel switching will thus often result in lower ratios and higher net present values than same-fuel substitutions.

The TRC is the benefit/cost test used in many states with strong integrated resource planning (IRP) policies, since it is the most comprehensive from the standpoint of the entire service territory. It compares the avoided energy and capacity benefits of a conservation measure to its incremental equipment costs and the administrative costs the utility incurs in delivering the efficiency measure to the participating customer.

The TRC test evaluates whether total costs paid for energy in the utility service territory will increase or decrease as the result of a DSM measure, regardless of who pays for the measure -- the recipient of the measure or ratepayers as a whole. If the benefits exceed the costs, the "TRC ratio" is greater than 1 and the measure is "cost-effective." If the benefit/cost ratio is less than 1, the DSM measure "fails" because it would raise total energy costs in the territory relative to other options. Similarly, if the difference between the present value of the benefits and the present value of the costs (i.e., the Net Present Value, or NPV) is positive, then the measure passes the test, since it returns net value; if the NPV is negative, the measure fails.

Electric Utility Avoided Costs. For each representative climate zone location, the analysis used the avoided energy cost streams of a sample local electric utility. The utilities were:

Burlington:	Boston Edison
Chicago:	Commonwealth Edison
New York:	Long Island Lighting Co.(LILCO)
Portland:	Portland General Electric
Atlanta:	Georgia Power
Phoenix:	Arizona Public Service

Each region was assumed to need additional capacity during the period of analysis (program starting in 1995). The average annual levelized cost for the least-cost capacity option, a typical combustion turbine, including transmission and distribution costs, is $76/kW-yr. Factoring in transmission and distribution losses and the fact that a power plant will not be available all the time (an electric generation "capacity factor" of 80% was used), a kW of energy demand savings has a value of about $102/yr. Using a twenty year investment period at a utility discount rate of 10.8%, this figure yields a present value of about $910/kW.[8]

In calculating the benefits and costs of advanced space conditioning options, the additional electric generating capacity that is avoided by investing in efficiency appears on the "benefit" side of the equation. For the four locations with the greatest annual heating loads (Burlington, Chicago, upper New York metropolitan area, and Portland), the analysis splits the capacity benefits equally between winter and summer peaks, reflecting a "dual peak" utility. For the two Southern locations (Atlanta and Phoenix, the analysis assigns the capacity benefits to the summer peak, reflecting a "summer peaking" utility.

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[8] A review of utility avoided capacity costs shows a wide variance in assumptions about the technology that would have been used, cost methodologies and results. As a result, published avoided capacity costs can be higher or lower than the benchmark used here for the regional comparison. In addition, individual utilities may have higher capacity avoided costs during winter or summer peak periods, depending on whether they are "winter peaking" or "summer peaking" utilities (indeed, some are "dual peaking").

In arriving at the estimate used in this report, Barakat & Chamberlin reviewed some current examples that were available. For instance, "Utility A" (name withheld by request because of pending rate case) had a current avoided annual capacity cost of only $28.76, but it did not include T&D costs. Another, LILCO, had an annual cost of $77.97, which did include T&D. A third, Commonwealth Edison, had an annual cost of $138-188, broken down into $86/kW generation, $27/kW transmission and $25-75 distribution. A cost of $76/kW-yr represents a reasonable, conservative estimate for capital costs that account for T&D as well as generation. Since the TRC results for advanced space conditioning technologies are sensitive to capacity avoided costs, it is important that individual utilities accurately incorporate all avoided capacity cost components into their cost-effectiveness analysis. Barakat and Chamberlin, memo to EPA, June 10, 1992.

Gas Utility Avoided Costs. A different approach was required to obtain gas utility avoided costs. The theory and practice of estimating gas avoided costs is not yet well-advanced, and in fact many gas utilities do not even estimate avoided costs, since the utilities are not actively engaged in the analysis of DSM programs. Where gas avoided costs were available, they varied by a wide margin and did not have a comparable structure, making a consistent analysis across regions difficult.[9]

To ensure comparability, a proxy avoided cost was estimated using data available for the Boston region, where reasonably well-developed gas avoided costs existed. First, the ratio of the Boston Gas Company avoided cost to the regional residential price of gas[10] was calculated. This ratio was then multiplied by the regional prices corresponding to the other cities examined in the study, to obtain a proxy avoided cost for each of those regions, This method of estimating avoided costs provides a more consistent basis for comparison than was otherwise available, but the estimates are inherently inexact. Better estimates will be available as gas utilities develop rigorous avoided cost estimates. It may also be conservative, since it does not capture whatever winter peak day benefits an efficient gas system may provide.

On the cost side of the TRC analysis, a utility program administration cost of $150 per installation was also assumed in addition to incremental capital costs, which vary depending on the type of equipment replaced -- electric resistance, standard heat pump, or standard gas or oil furnace. In performing the analysis, a nominal utility discount rate of 10.8% was used.

For **EMERGING GROUND SOURCE HEAT PUMPS**, two TRC results were calculated; one for SLINKY™ loops and one for vertical loops. This is necessary because, although the two ground loops are modeled to yield the same performance characteristics, the SLINKY™ has lower capital costs, which affect the TRC test outcome. Any utility program can be expected to have a combination of horizontal and vertical installations, and therefore the overall TRC results for a program would fall somewhere in between the SLINKY™ and vertical test results.

The following section presents a summary of the comparative analyses performed at each location. A more detailed, location-by-location presentation is presented in Appendix C.

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9 Barakat and Chamberlin, memorandum, June 18, 1992.

10 DRI, Quarterly Energy Review, Winter 1991.

THE PERFORMANCE AND OPERATING COST SUPERIORITY OF ADVANCED SPACE CONDITIONING TECHNOLOGIES

Advanced space conditioning technologies have clear advantages over "baseline" technologies from the standpoint of performance, operating cost and environmental impact. Exhibits 3.4 through 3.9 provide an illustration of these advantages.

Exhibits 3.4 through 3.6 show the source space heating, space cooling and water heating efficiencies of equipment selected for the analysis. In Exhibit 3.4, the technologies with the lowest source space heating efficiencies in almost all locations are the **STANDARD GAS FURNACE** and the **STANDARD AIR-SOURCE HEAT PUMP**. The only exception to this is that the **ADVANCED AIR SOURCE HEAT PUMP** has a lower source heating efficiency than the gas furnace in the coldest location (Burlington). This is due to a combination of low air-source heat pump operating performance in extreme winter conditions, and the inherent performance advantage of using natural gas as a primary fuel at the end-use sight (as indicated above, electricity generation, transmission and distribution delivers only 27% of the original energy to the end user, while natural gas systems deliver 91%).

Exhibit 3.4

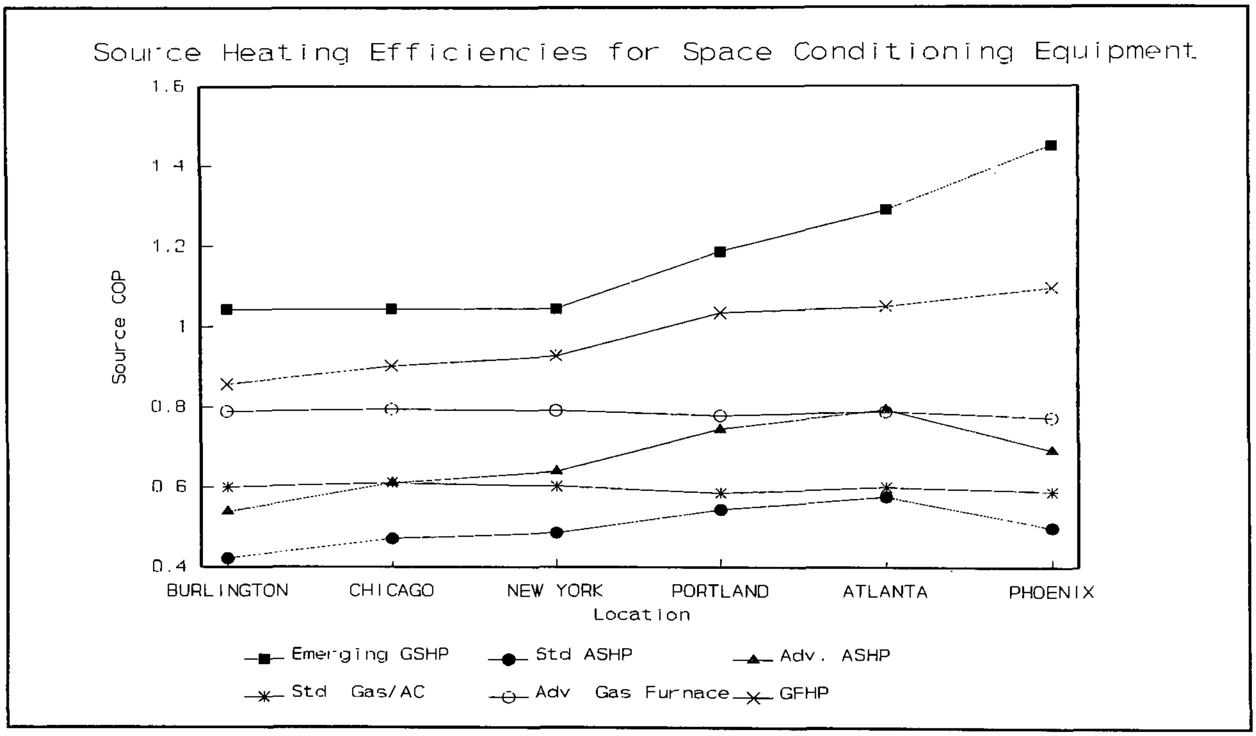


Exhibit 3.5

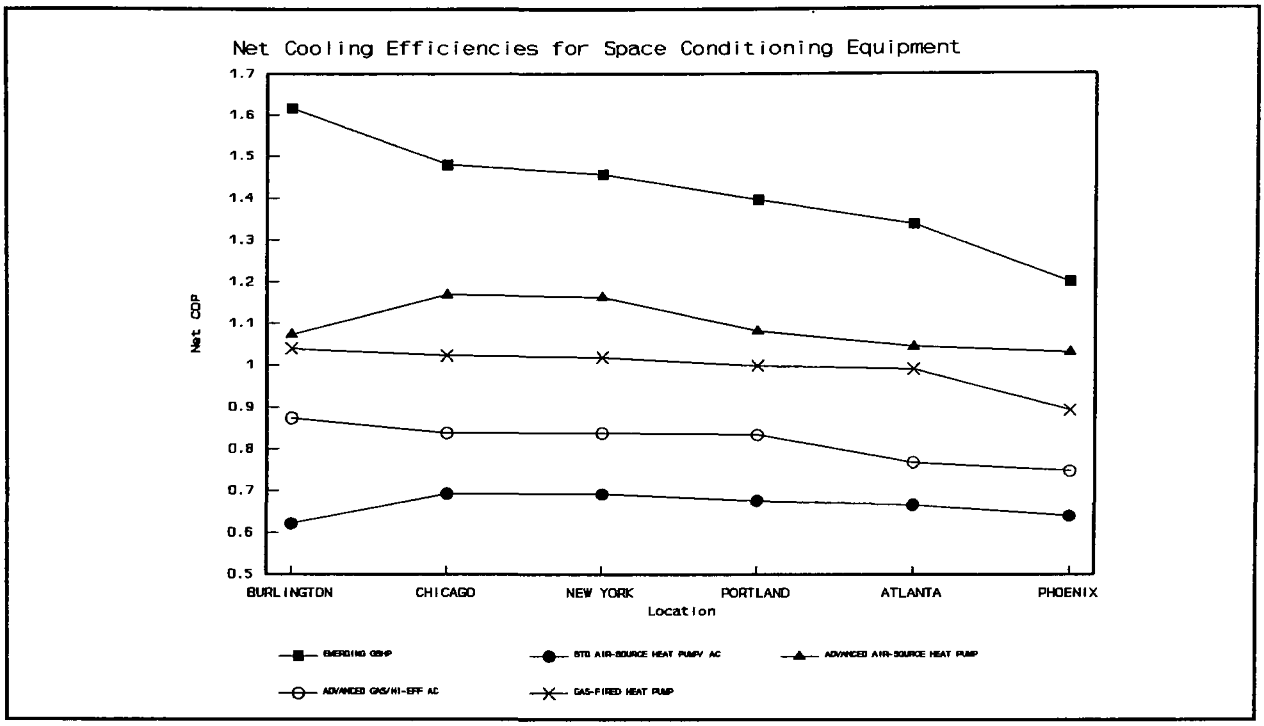
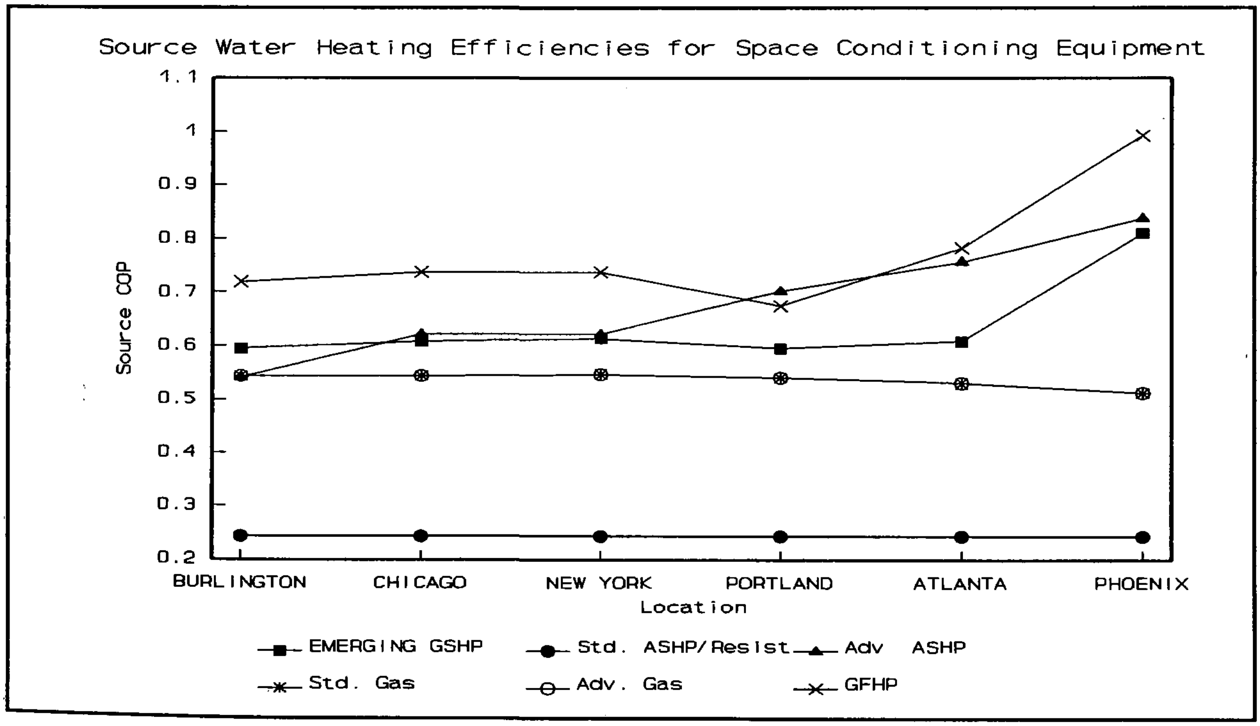


Exhibit 3.6



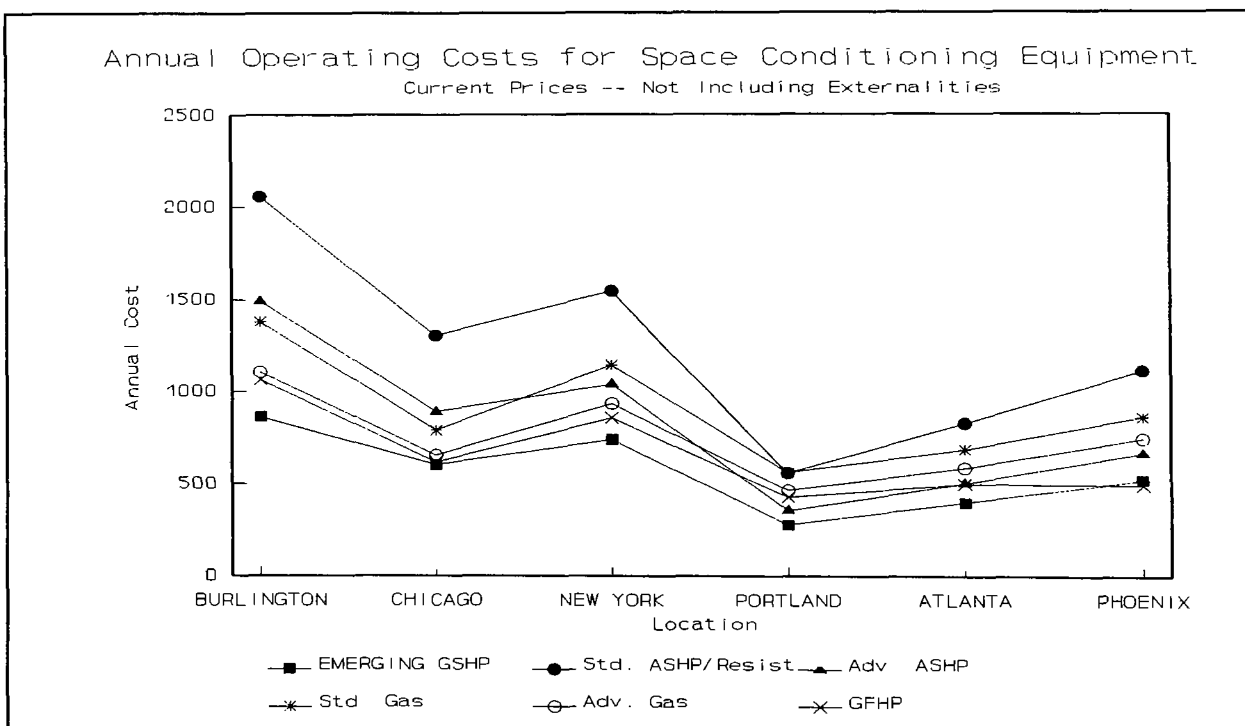
A comparison of the best performing electric and gas technologies, the **GAS-FIRED HEAT PUMP** and the **EMERGING GROUND SOURCE HEAT PUMP**, against the two standard technologies (the **STANDARD GAS FURNACE** and the **STANDARD AIR SOURCE HEAT PUMP**) in Exhibit 3.4 clearly shows the wide gap in source operating performance. This gap is also shown in Exhibits 3.5 and 3.6, where the standard air conditioning and water heating technologies lag well behind the leaders in performance.

Source operating performance correlates strongly with annual operating expense, as demonstrated by Exhibit 3.7. Again, the standard technologies are among the highest-operating cost technologies, with the only exception being the **ADVANCED AIR SOURCE HEAT PUMP** having a higher cost than the **STANDARD GAS FURNACE** in the coldest two locations, again a reflection of the performance factors mentioned above.

Exhibit 3.9 provides an indication of the relative air impacts of standard equipment relative to the most advanced technologies. Under the **REGIONAL** electricity generation mix scenario, either the **STANDARD AIR SOURCE HEAT PUMP** or the **STANDARD GAS FURNACE** has the highest carbon dioxide emissions of all the equipment shown -- here the only notable exception is in comparing the **STANDARD AIR SOURCE HEAT PUMP** to advanced gas technologies in Portland. In this location, the gas technologies furnace have higher CO_2 emissions because the regional electricity mix is forecasted to be overwhelmingly comprised of non-emitting renewables, due to the Northwest's large hydroelectric resource base.

These data suggest that significant economic and environmental benefits could accrue by shifting the market toward more advanced technologies. Just which advanced space conditioning technologies are the most superior, however, depends on how they compare in terms of performance, cost, and environmental impact.

Exhibit 3.7



COMPARISON OF THE MOST ADVANCED TECHNOLOGIES

The results from the location-by-location analyses demonstrate some key patterns on the operating performance, equipment cost, environmental impact and DSM cost-effectiveness of the various advanced equipment studied. In general, the analyses highlighted the **EMERGING GROUND SOURCE HEAT PUMP, GAS-FIRED HEAT PUMP, ADVANCED AIR SOURCE HEAT PUMP** and **ADVANCED GAS FURNACE** as the superior technologies. Exhibits 3.4 to 3.23 provide a summary comparison of these leading technologies from several different perspectives.

SOURCE OPERATING PERFORMANCE

In all locations, comparisons of source operating performance for a total system highlighted the dominance of the **EMERGING GROUND SOURCE HEAT PUMP** for electric equipment and the **GAS-FIRED HEAT PUMP** for gas equipment. Despite the inherent disadvantage faced by electric equipment in source operating performance, Exhibits 3.4 and 3.5 show a clear advantage by the **EMERGING GROUND SOURCE HEAT PUMP** in both heating and cooling performance in every location. Although not shown in Exhibit 3.4, the **ADVANCED GROUND SOURCE HEAT PUMP** consistently had the second-highest heating and cooling SPFs among all electric and gas equipment.

The **GAS-FIRED HEAT PUMP** consistently had the best heating and cooling SPFs among gas equipment, with source performance levels roughly comparable to the **STANDARD GROUND SOURCE HEAT PUMP** in heating mode and the **ADVANCED AIR SOURCE HEAT PUMP** in cooling mode. Its cooling SPF was significantly higher than that for the high-efficiency air conditioner that was modeled with the **ADVANCED GAS FURNACE.**

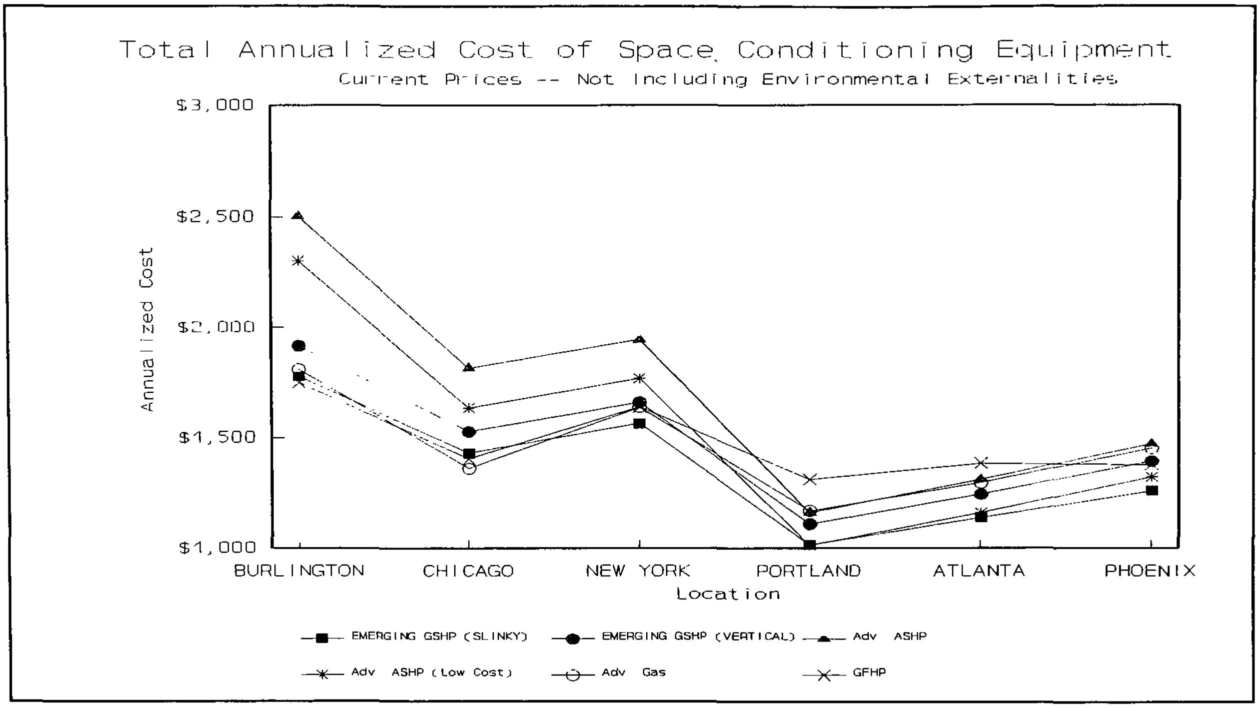
In water heating mode (Exhibit 3.6), the field was led by the **GAS-FIRED HEAT PUMP** in all locations except Portland. This is attributed not only to the inherent fuel type advantage described above, but also to an efficient use by the desuperheater of waste combustion heat, which is available during both space heating and cooling modes. Thus, despite the fact that the **GAS-FIRED HEAT PUMP** was not modeled to provide water heating on demand (as do the **EMERGING GROUND SOURCE HEAT PUMP** and the **ADVANCED AIR SOURCE HEAT PUMP**), it provided the prototypical household's water heating needs more efficiently than either of the two most advanced electric technologies.

TOTAL ANNUALIZED COST

As mentioned above, there is a strong correlation between operating performance and annual operating cost. Within a given fuel type at a given location, the lowest annual operating costs are associated with the most efficient equipment. Thus, the **EMERGING GROUND SOURCE HEAT PUMP** and the **GAS-FIRED HEAT PUMP** had the lowest overall operating costs in each location for their respective fuel types. However, annualized capital costs must also be factored in to get a complete picture of total system costs. In addition, local electricity or gas prices as well as local climate can affect both the relative importance of capital vs. operating costs, and comparisons between electric and gas equipment.

Exhibit 3.8 shows the total annual costs (capital, operating and maintenance) for the most advanced equipment studied. Generally, the **EMERGING GROUND SOURCE HEAT PUMP/SLINKY™ LOOP** system was found to be very competitive under current prices in most locations; the two locations in which the **GAS-FIRED HEAT PUMP** had lower total annualized costs were in Burlington and Chicago. As Exhibit 3.8 shows, there is no clearly dominating advanced technology in any location; rather, two or more systems are generally clustered within a relatively tight range.

Exhibit 3.8



What Exhibit 3.8 does not show is that, given their higher capital cost, advanced technologies don't have a clear advantage over standard technologies in locations in which consumer energy prices are low or where the climate is relatively moderate. For instance:

* Portland: the **HIGH-EFFICIENCY AIR SOURCE HEAT PUMP** and the **STANDARD AIR SOURCE HEAT PUMP** both have lower total annual costs than the **EMERGING GROUND SOURCE HEAT PUMP/VERTICAL LOOP**. Meanwhile, the **STANDARD GAS FURNACE** system is lower-cost than either of the advanced gas technologies.

* Chicago: the lowest-cost technology is the **STANDARD GAS FURNACE** system.

* Atlanta: the **STANDARD GAS FURNACE** system is the lowest-cost gas system, having a total annualized cost roughly equivalent to that of the **EMERGING GROUND SOURCE HEAT PUMP/VERTICAL LOOP**.

In the other three locations, advanced equipment has consistently lower costs than standard equipment. Still, results in Portland, Chicago and Atlanta illustrate show that, for a market to develop for advanced space conditioning equipment in many areas, either: a) environmental costs associated with equipment operation must be accounted for; or b) programs that reduce the incremental capital cost of advanced equipment must be developed by utilities and/or other organizations.

ENVIRONMENTAL IMPACTS OF SPACE CONDITIONING EQUIPMENT

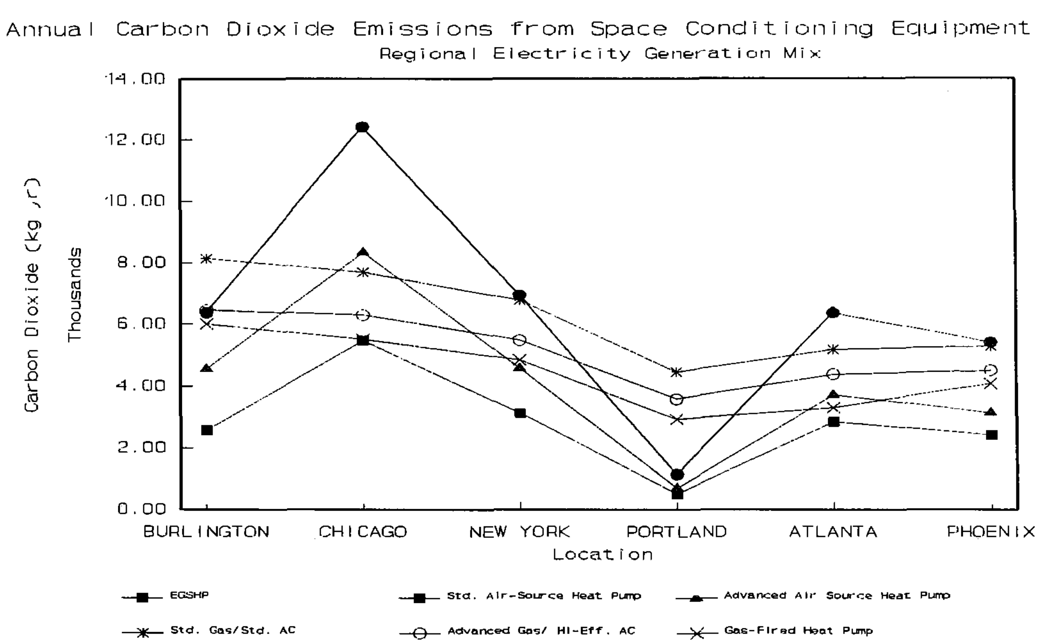
The relative air pollution impacts of the various space conditioning equipment are influenced not only by operating performance and regional climate, but also by assumptions made about the fuel used to generate electricity in the region. As described above, four alternative electricity generation scenarios were employed: the **REGIONAL** fuel mix in 2000, generation by an **ADVANCED FLUIDIZED BED COAL PLANT**, generation by an **ADVANCED NATURAL GAS COMBINED CYCLE** plant, and generation by a **NATURAL GAS COMBUSTION TURBINE**.

Carbon Dioxide Emissions. The location-by-location analyses led to striking results with regard to relative carbon dioxide emissions from the equipment analyzed. Given the inherent performance advantages of on-sight primary fuel use, as well as the low carbon content of natural gas, one might expect that CO_2 emissions for advanced gas equipment would be lower than for electric equipment.

Exhibit 3.9 demonstrates that this is not the case under the year 2000 **REGIONAL** scenario. In fact, in all locations, CO_2 emissions were lowest from the **EMERGING GROUND SOURCE HEAT PUMP**. In those locations in which there is relatively little coal in the forecasted regional fuel mix (Burlington, New york, Portland and Phoenix), the CO_2 advantage of the **EMERGING GROUND SOURCE HEAT PUMP** is substantial. In these locations, the **ADVANCED AIR SOURCE HEAT PUMP** emits less CO_2 than the **GAS-FIRED HEAT PUMP**. In the most coal-intensive location, Chicago, the **EMERGING GROUND SOURCE HEAT PUMP** has CO_2 emissions that are roughly equivalent to those of the **GAS-FIRED HEAT PUMP.**

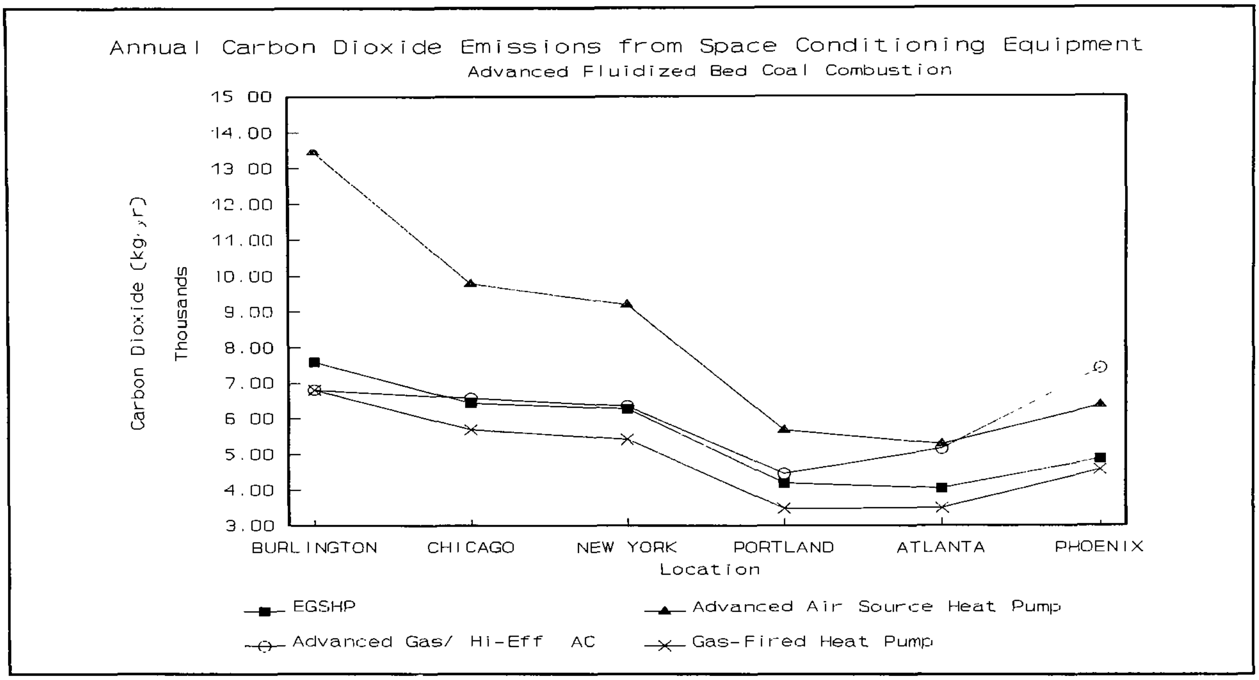
As seen in Exhibit 3.9, the **GAS-FIRED HEAT PUMP** has consistently lower CO_2 emissions than the **ADVANCED GAS FURNACE**. Analysis of the data in Appendix D indicates that, under the **REGIONAL** scenario, the **GAS-FIRED HEAT PUMP** reduces CO_2 by 23-36% over the **STANDARD GAS FURNACE** and by 7-25% over the **ADVANCED GAS FURNACE.**

Exhibit 3.9



The **ADVANCED FLUIDIZED BED COAL** generating scenario, as summarized in Exhibit 3.10, produces more expected results, with the **GAS-FIRED HEAT PUMP** as the lowest CO_2 emitter in all regions. It is notable that, even in this carbon-intensive scenario, the **EMERGING GROUND SOURCE HEAT PUMP** compares favorably with the **ADVANCED GAS FURNACE**, with lower emissions in all locations except the coldest (Burlington).

Exhibit 3.10



In the **ADVANCED NATURAL GAS COMBINED CYCLE** generating scenario (Exhibit 3.11), the **EMERGING GROUND SOURCE HEAT PUMP** is clearly the lowest emitter of CO_2 in all locations, with substantial advantages over natural gas equipment. Among the most advanced equipment, the **ADVANCED AIR SOURCE HEAT PUMP** has the second-lowest CO_2 emissions. This would suggest that, if considerations about CO_2 emissions were to drive decisions about the most advantageous use of natural gas, one might prefer that it be used in advanced natural gas combined cycle generating plants powering the most advanced electric space conditioning equipment, rather than used in advanced natural gas end-use equipment.

Likewise, in the **NATURAL GAS COMBUSTION TURBINE** generating scenario (Exhibit 3.12), the **EMERGING GROUND SOURCE HEAT PUMP** remains the lowest CO_2 emitting advanced technology, although its advantage is of a much smaller magnitude. The **ADVANCED AIR SOURCE HEAT PUMP**, on the other hand, becomes the highest CO_2 emitter in this scenario in the three coldest locations and has higher emissions than the **GAS-FIRED HEAT PUMP** in all locations except Phoenix.

Exhibit 3.11

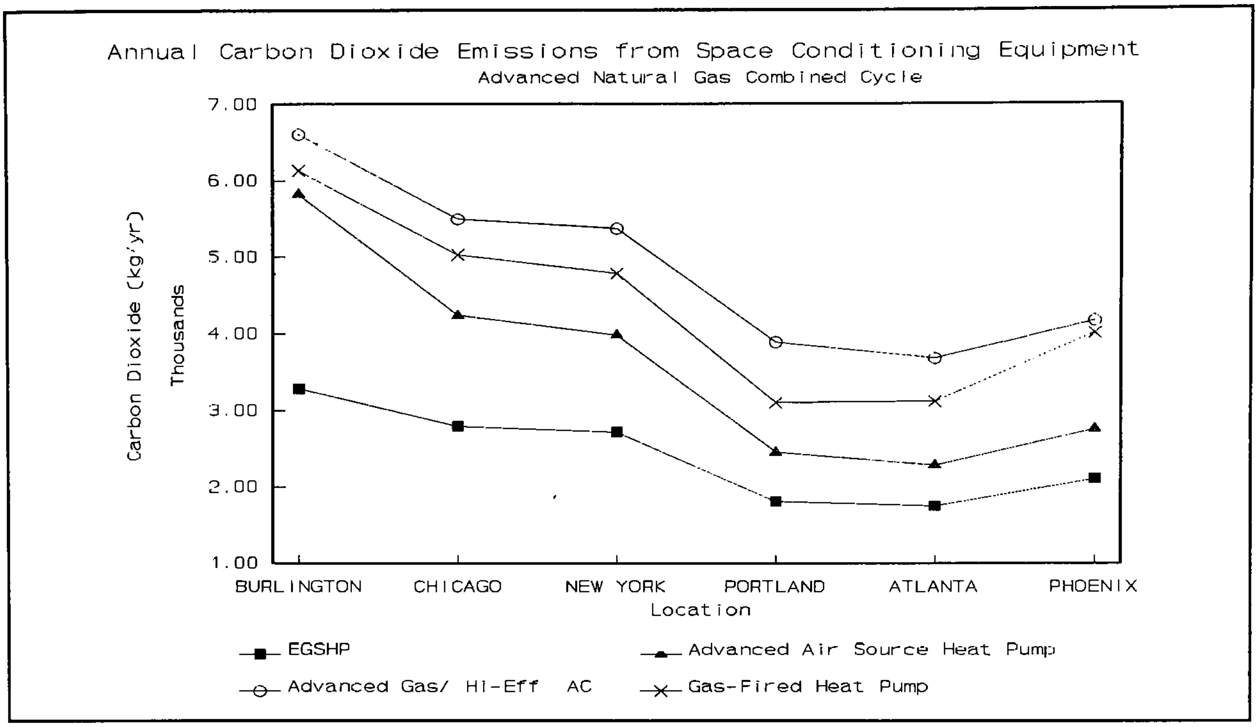
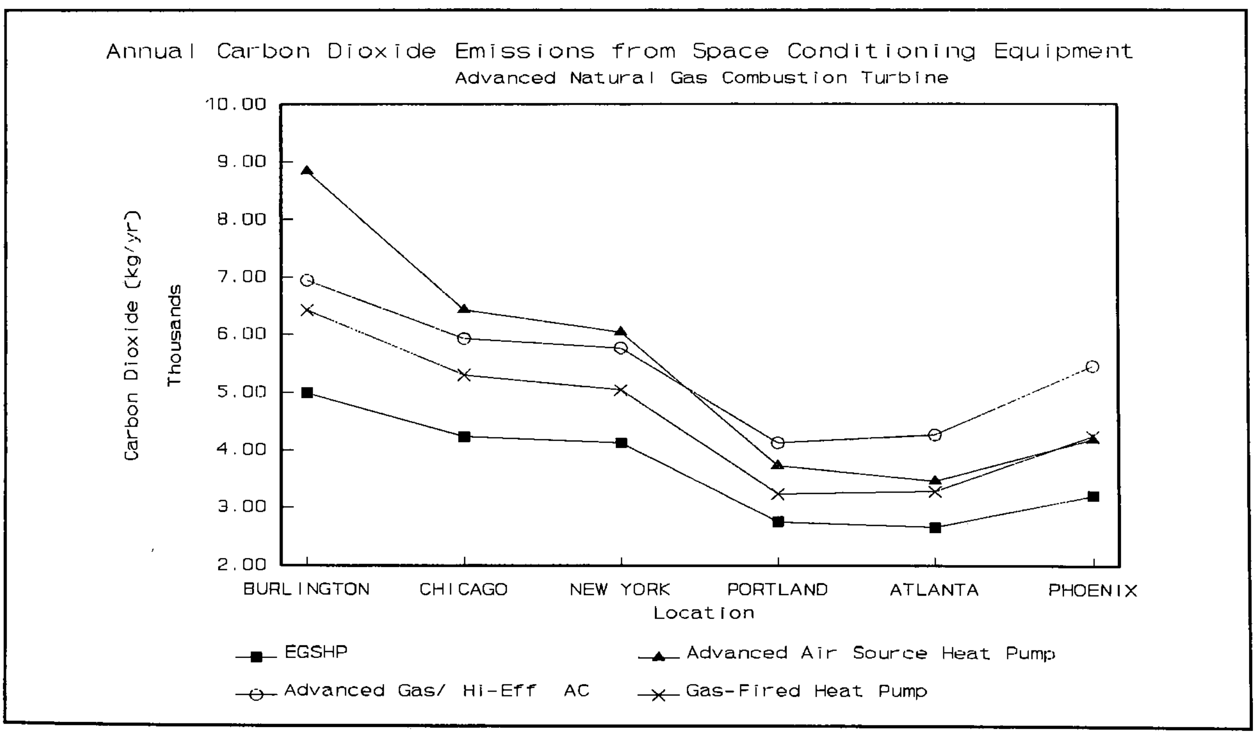


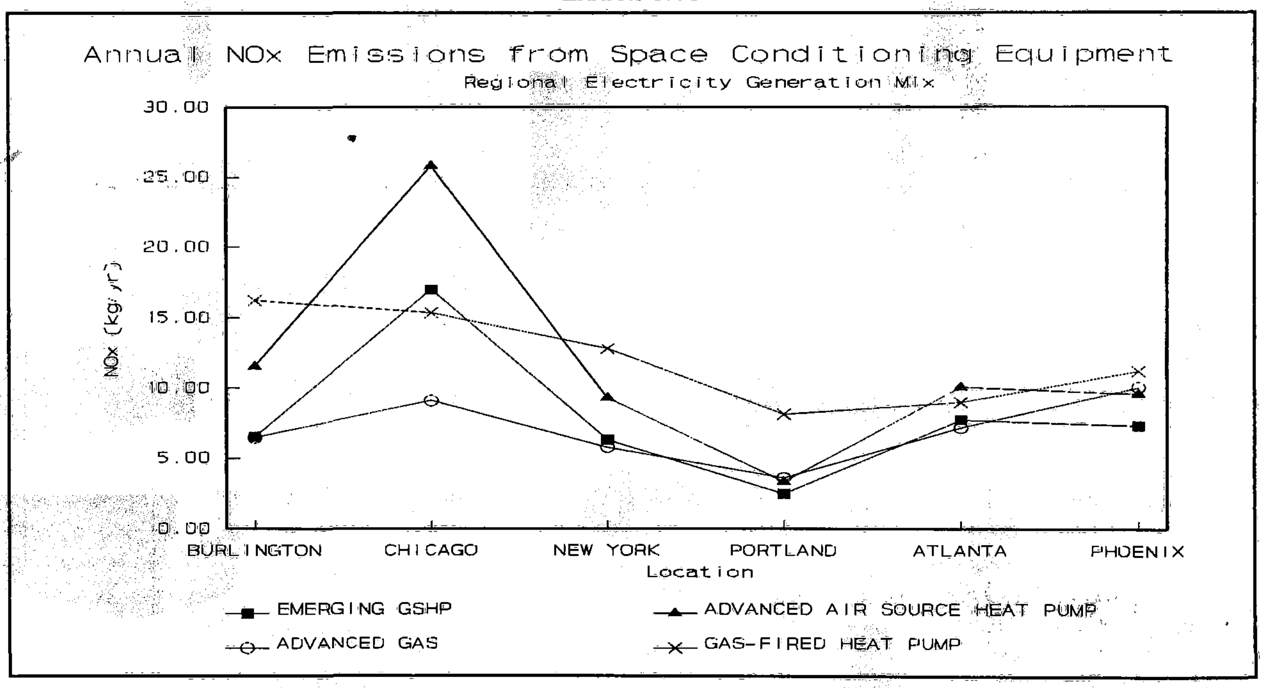
Exhibit 3.12



Nitrogen Oxide Emissions. Exhibit 3.13, which compares NO_x emissions from the most advanced space conditioning equipment under the **REGIONAL** electric generation scenario, shows results that vary significantly from location to location. As in the case of CO_2 emissions, NO_x emissions from the **GAS-FIRED HEAT PUMP** are a function of the total BTUs required in the location's climate; they are highest in the most extreme hot or cold regions. Emissions from the other equipment are influenced greatly by regional NO_x emission levels for electricity generation.

In the colder regions, the **ADVANCED GAS FURNACE** has lower NO_x emissions than the **GAS-FIRED HEAT PUMP**. This result highlights the fact that the **GAS-FIRED HEAT PUMP** has significantly higher NO_x emission rates than the **ADVANCED GAS FURNACE** does. In the two warmest locations, NO_x emissions for the **ADVANCED GAS FURNACE** system rise relative to the **GAS-FIRED HEAT PUMP**, due to its meeting the dominant cooling load with an electric central air conditioner. Where the regional electric generation mix has moderate to low NO_x emission levels (Burlington, New York, Portland and Phoenix), the **EMERGING GROUND SOURCE HEAT PUMP** also has lower NO_x emissions than the **GAS-FIRED HEAT PUMP**.

Exhibit 3.13



The NO_x emission results become much more consistent under the **ADVANCED FLUIDIZED BED COAL, ADVANCED NATURAL GAS COMBINED CYCLE**, and **NATURAL GAS COMBUSTION TURBINE** generating scenarios (Exhibits 3.14, 3.15, and 3.16). Here the **GAS-FIRED HEAT PUMP** is at a distinct disadvantage relative to the other advanced space conditioning equipment, while the **EMERGING GROUND SOURCE HEAT PUMP** emerges clearly as the lowest emitter in all locations under all three scenarios. Again, the **ADVANCED NATURAL GAS COMBINED CYCLE** scenario shows lower emissions associated with use of natural gas in an advanced generating plant powering electric end use equipment, than with advanced natural gas end-use equipment.

Exhibit 3.14

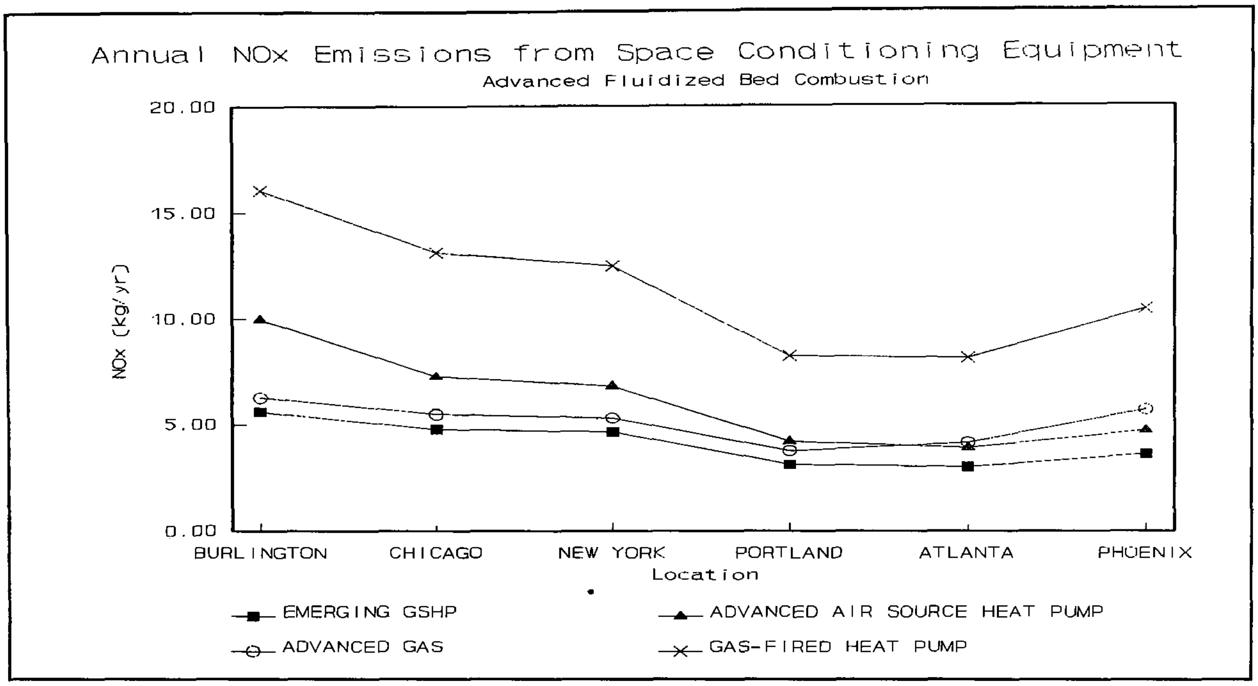


Exhibit 3.15

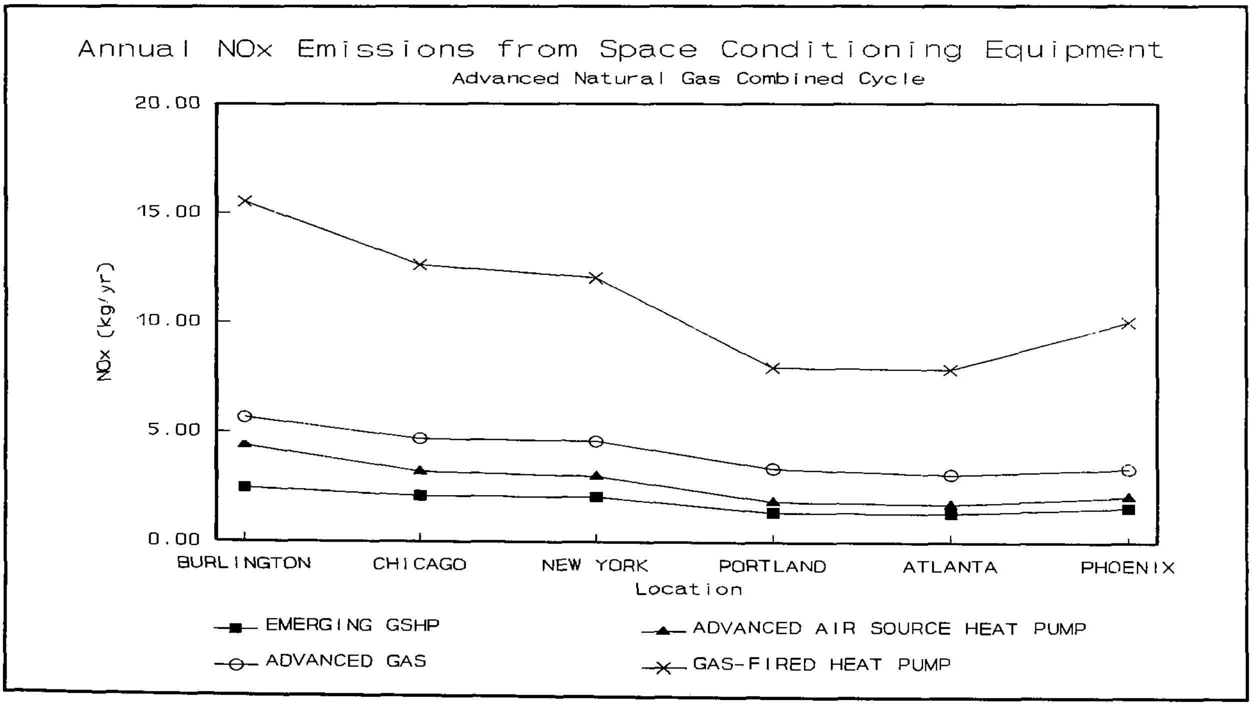
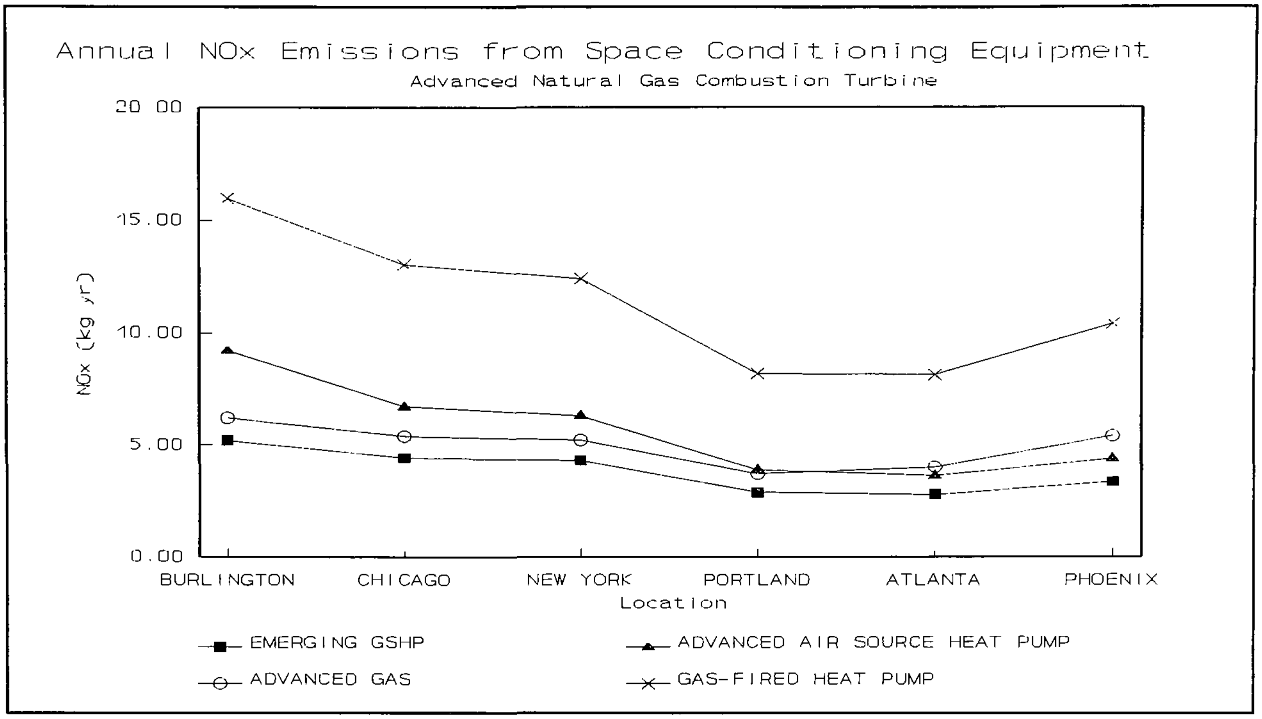


Exhibit 3.16



Sulfur Dioxide Emissions. Since the **GAS-FIRED HEAT PUMP** uses relatively little electricity (to power fans and controls), and since the SO_2 content of natural gas is very low, it generally has the lowest SO_2 emissions of any advanced equipment in the **REGIONAL** electricity generation scenario (Exhibit 3.17). Where regional SO_2 emissions associated with the generation of electricity are relatively high (Burlington, Chicago, Atlanta and, to a lesser extent, New York), this advantage is significant. As Exhibits 3.18, 3.19 and 3.20 indicate, the total SO_2 emissions associated for all advanced equipment in the **ADVANCED FLUIDIZED BED COAL**, **ADVANCED NATURAL GAS COMBINED CYCLE**, and **NATURAL GAS COMBUSTION TURBINE** scenarios are all negligible.

Exhibit 3.17

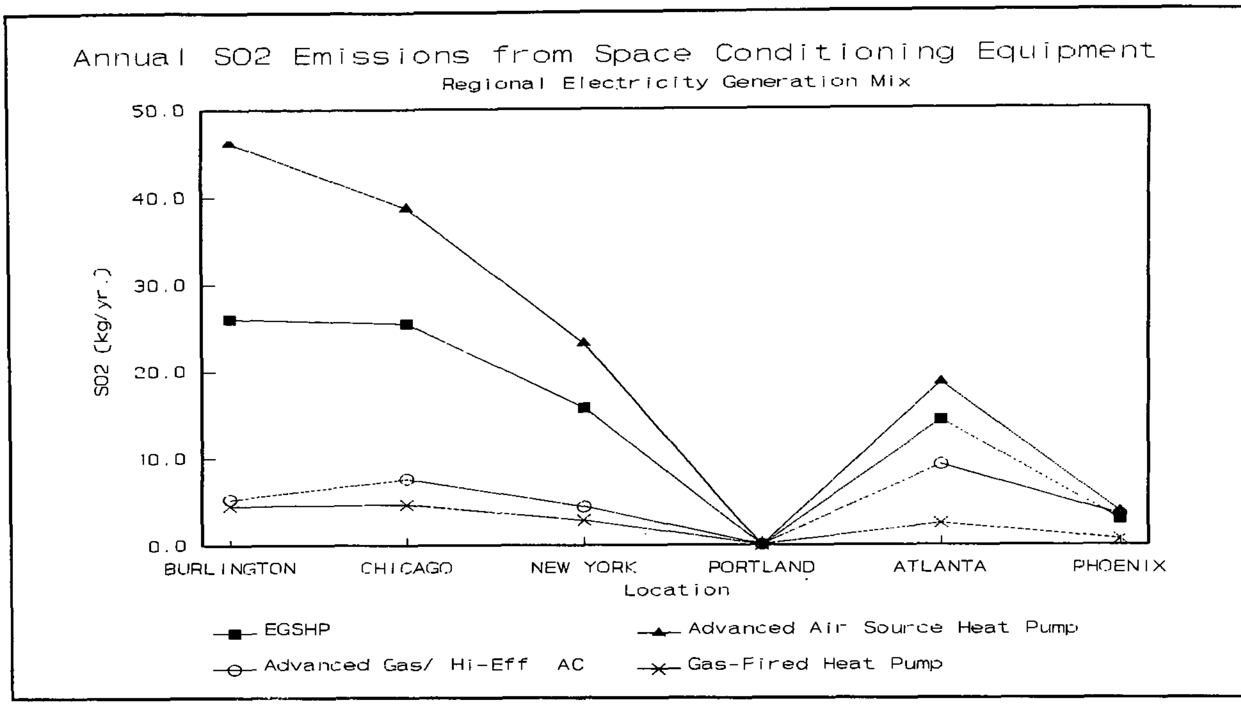


Exhibit 3.18

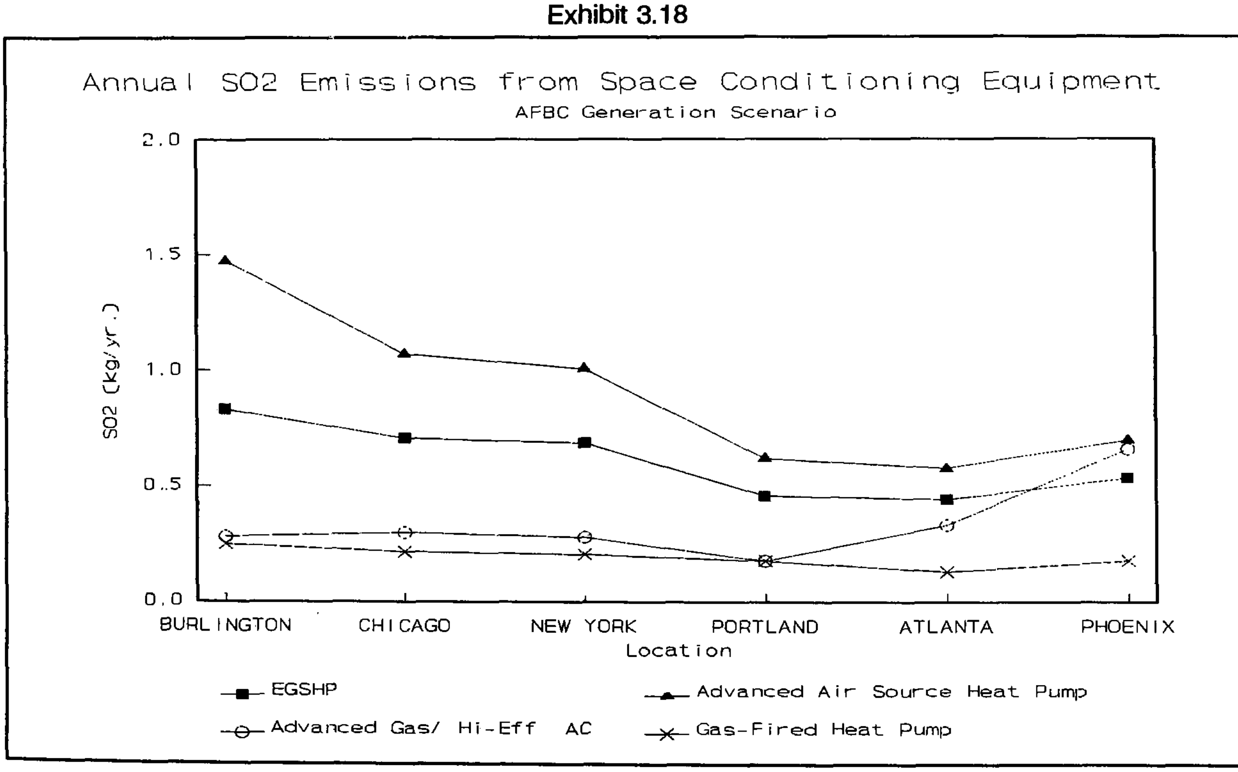


Exhibit 3.19

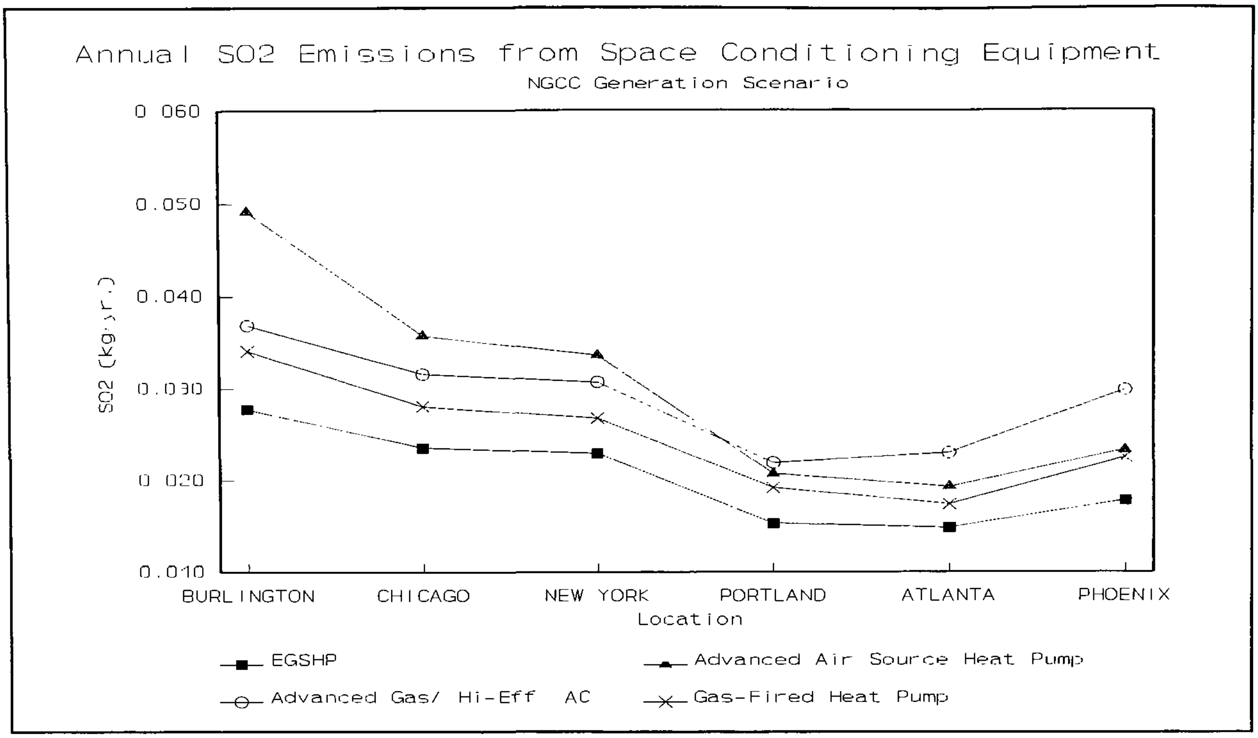
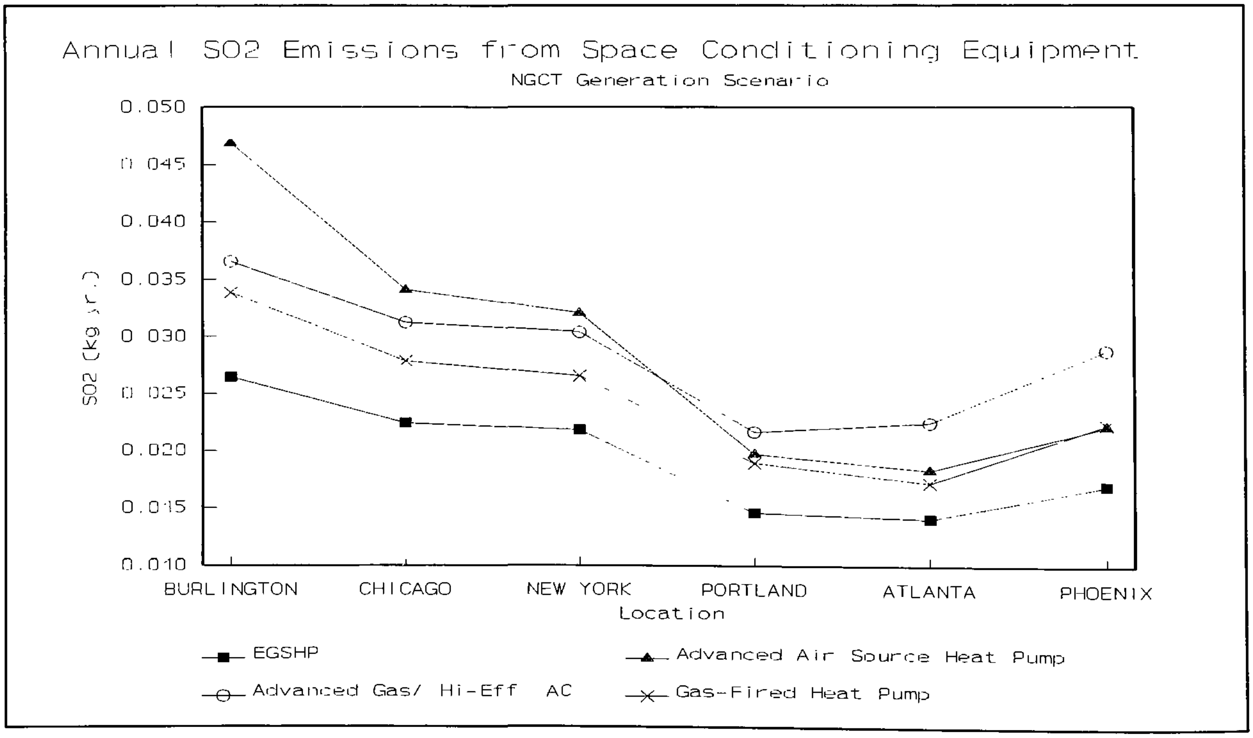
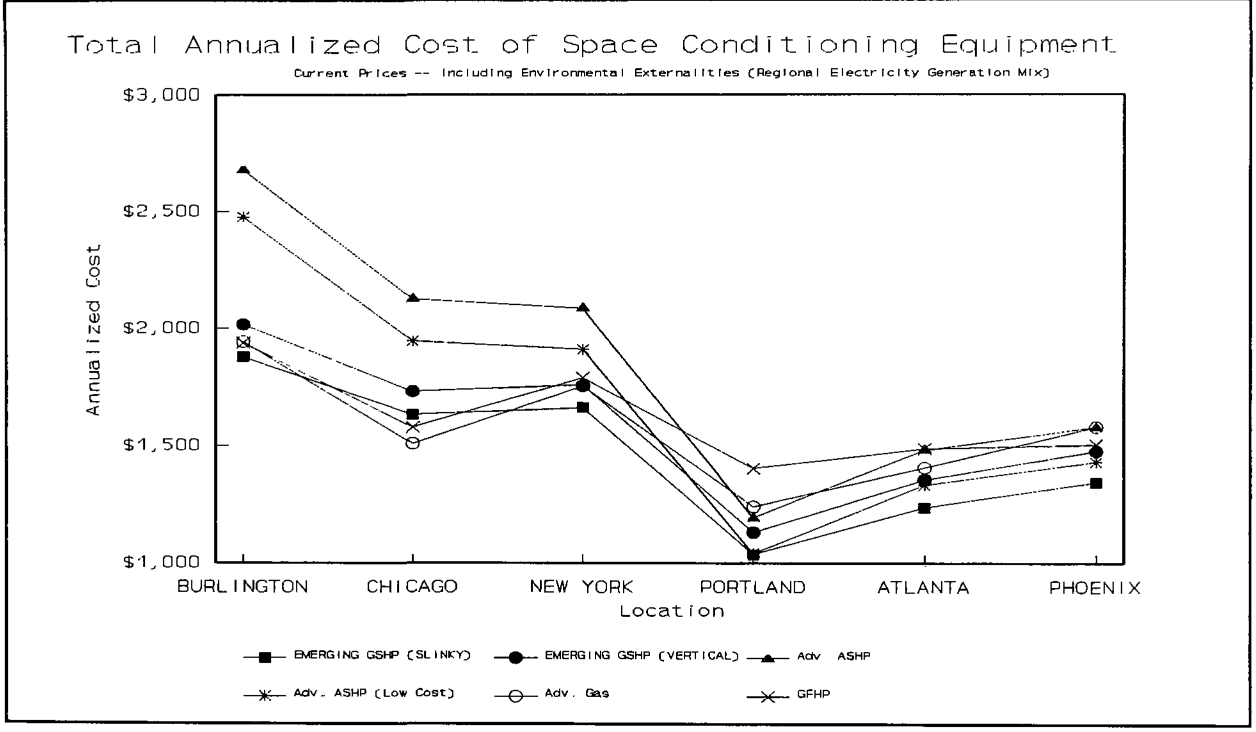


Exhibit 3.20



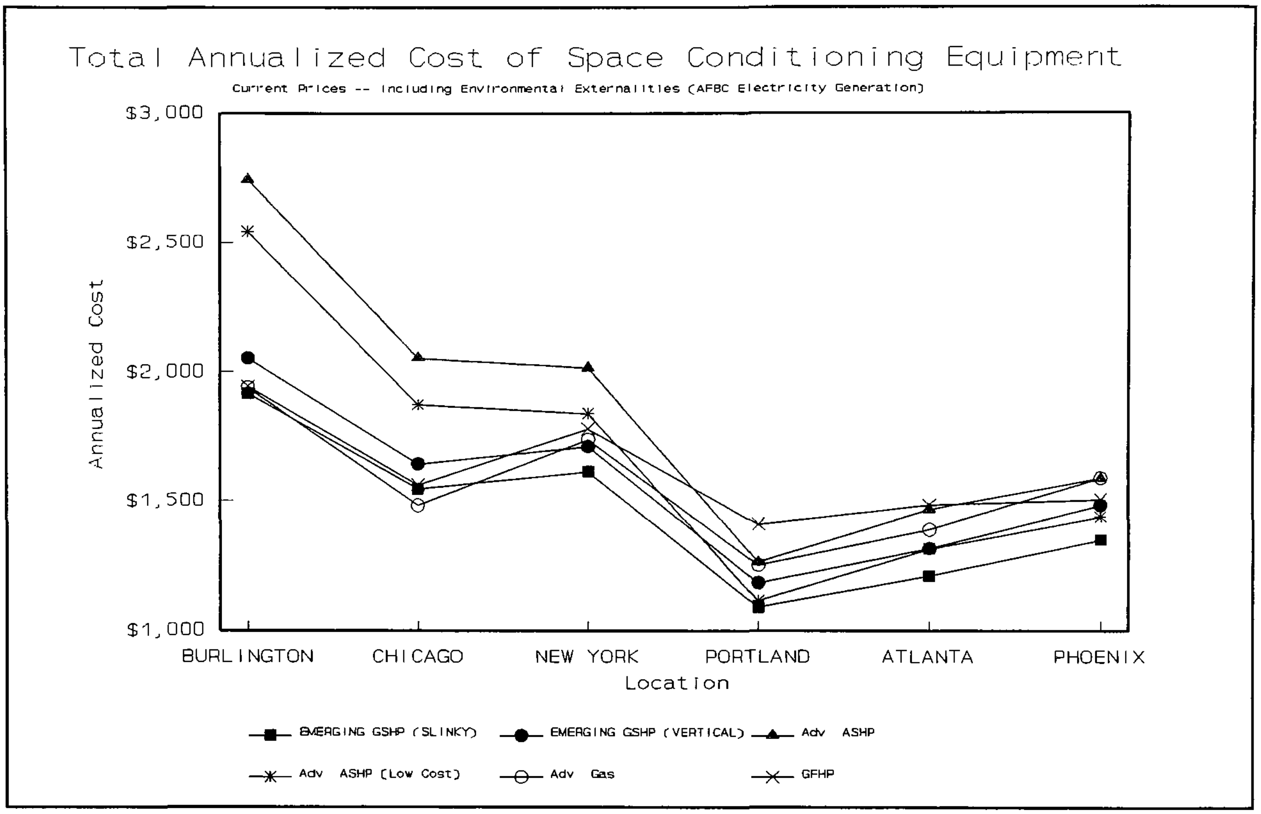
<u>Effect of Externality Costs on Total Annualized Equipment Costs.</u> In a few of the locations and electricity generation scenarios, the total externality costs associated with the air emissions from advanced space conditioning equipment effected their relative annual costs. However, the relative shifts were quite small as a percentage of total costs. For the Chicago area in the **REGIONAL** electricity fuel mix scenario, high emissions slightly increased the cost advantage enjoyed by the advanced gas equipment over **EMERGING GROUND SOURCE HEAT PUMPS** (comparison of Exhibit 3.21 with Exhibit 3.8). Conversely, the **REGIONAL** scenario creates a very slight cost advantage for the **EMERGING GROUND SOURCE HEAT PUMP/SLINKY LOOP** system in Burlington. Similarly, consideration of externalities slightly increased the cost advantage of the **EMERGING GROUND SOURCE HEAT PUMP/SLINKY™ LOOP** system over other systems in Atlanta and Phoenix.

Exhibit 3.21



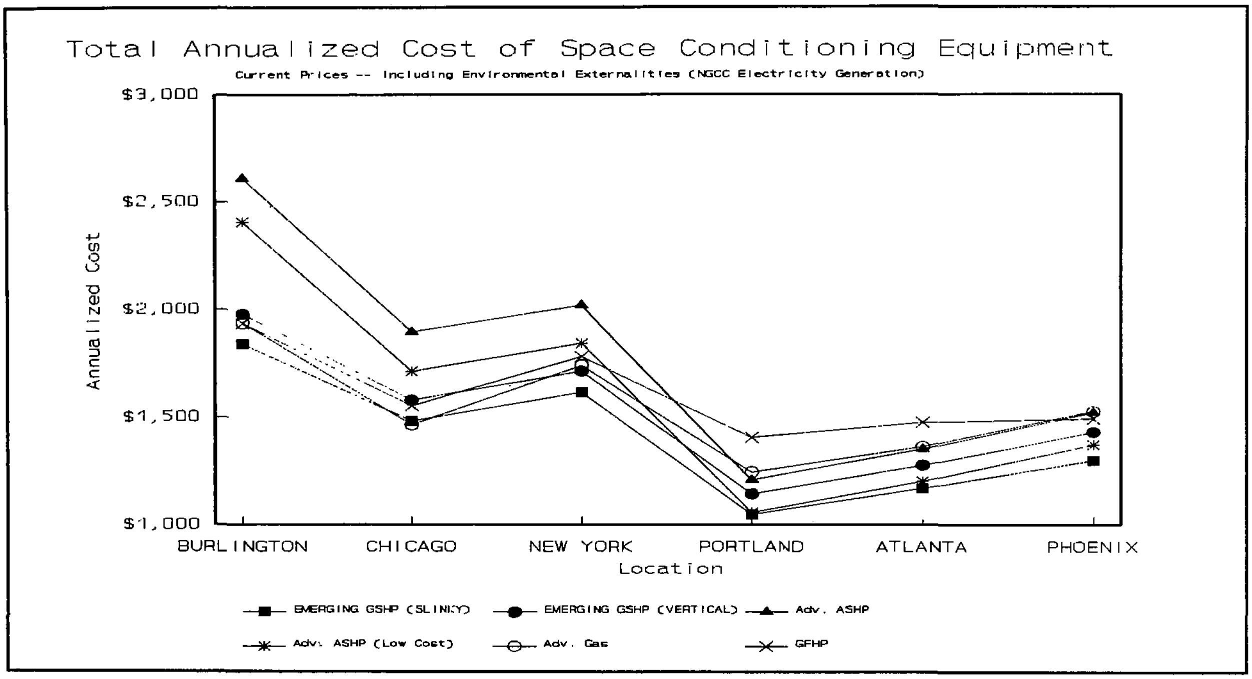
Consideration of externalities in the **ADVANCED FLUIDIZED BED COAL** generating scenario (Exhibit 3.22) similarly did not significantly shift the relative cost competitiveness of the most advanced equipment, relative to the non-externality case (Exhibit 3.7). Exhibit 3.22 does indicate a slight shift upward of the **ADVANCED AIR SOURCE HEAT PUMPS** relative to the other advanced technologies.

Exhibit 3.22



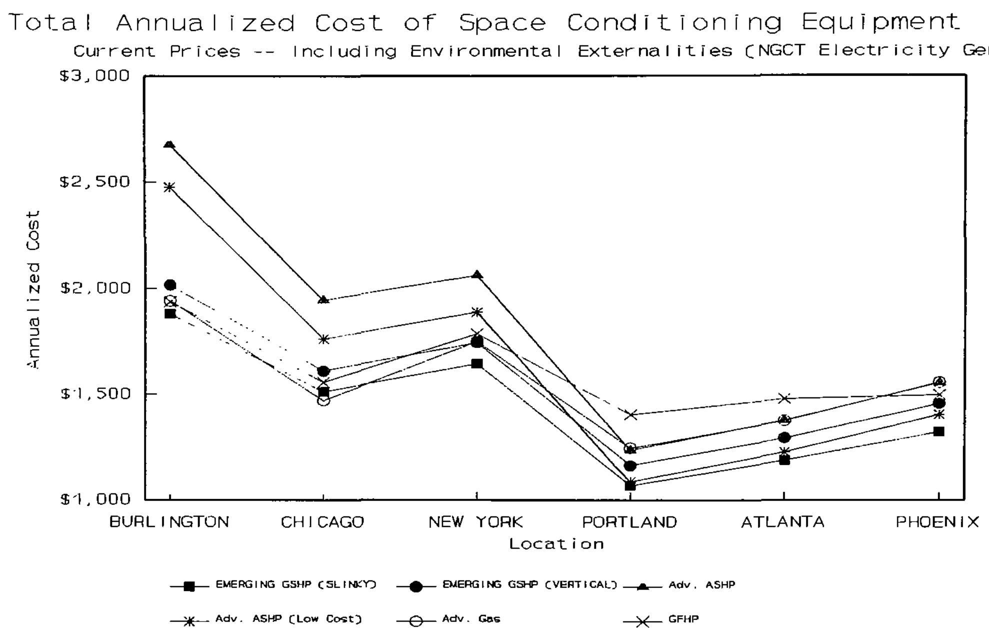
Given its low emissions, the **ADVANCED NATURAL GAS COMBINED CYCLE** generating scenario (Exhibit 3.23) slightly lowered the total cost of the **EMERGING GROUND SOURCE HEAT PUMPS** relative to other equipment, particularly the gas technologies. For instance, under this scenario the **EMERGING GROUND SOURCE HEAT PUMP/SLINKY$_{TM}$** system now had a slight cost advantage over the **GAS-FIRED HEAT PUMP** in Chicago, and was just slightly higher in cost than the **ADVANCED GAS FURNACE**. It was also the lowest cost in Burlington. In other locations, such as Atlanta and Phoenix, an existing slight cost advantage over gas equipment was increased.

Exhibit 3.23



As might be expected, the **NATURAL GAS COMBUSTION TURBINE** generating scenario (Exhibit 3.24), because it has higher emissions than the **ADVANCED NATURAL GAS COMBINED CYCLE** scenario, produces a smaller shift in favor of the **EMERGING GROUND SOURCE HEAT PUMPS**.

Exhibit 3.24



Again, however, under all emission scenarios, the shifts in relative costs between advanced technologies were a small percentage of the overall annual cost of the equipment. They did have a slightly larger effect on the relative costs of advanced equipment and standard equipment, overcoming some of the disadvantages that advanced equipment experienced in Portland, Chicago and Atlanta (as discussed above on page 3-12). For instance, in Portland, the **HIGH EFFICIENCY** and **STANDARD AIR SOURCE HEAT PUMPS** were no longer less expensive than the **EMERGING GROUND SOURCE HEAT PUMP/VERTICAL LOOP** system. In Chicago, the emission scenarios caused the total societal cost of the **STANDARD GAS FURNACE** to become larger than the **ADVANCED GAS FURNACE** (although it was still lower than the **GAS-FIRED HEAT PUMP**). In Atlanta, the **STANDARD GAS FURNACE** was still the lowest-cost gas system to the consumer, but its cost disadvantage relative to the **EMERGING GROUND SOURCE HEAT PUMP/VERTICAL LOOP** had about doubled (although it was still only about $60/year higher).

Thus, one of the two conditions that could possibly ameliorate the capital cost barrier to advanced equipment -- inclusion of environmental externality values at the level employed in the report -- would not likely be sufficient to do enough to change consumer behavior. Other mechanisms to reduce capital costs, such as utility conservation incentives, would likely be much more effective.

UTILITY COST-EFFECTIVENESS TESTS

Utility cost-effectiveness, as measured by the Total Resource Cost (TRC) test described above, were performed. Total Resource Cost (TRC) ratios for the most advanced equipment, evaluated as substitutes for standard efficiency systems, are presented in Exhibits 3.25, 3.27 and 3.29. TRC net present value (NPV) summaries for corresponding replacement scenarios are presented in Exhibits 3.26, 3.28 and 3.30.

Replacing **ELECTRIC RESISTANCE**: For this replacement scenario, the TRC ratio results (Exhibit 3.25) suggest that the **EMERGING GROUND SOURCE HEAT PUMPS** and the **LOW-COST ADVANCED AIR SOURCE HEAT PUMP** are the most cost-effective replacements in all locations. The **GAS-FIRED HEAT PUMP** and the **ADVANCED GAS FURNACE** generally have strong ratios (except for the latter in Atlanta), but they are not as high.

The TRC NPV figure (Exhibit 3.26), however, suggests a different order of cost-effectiveness in the three coldest locations (Burlington, Chicago and New York). In Burlington and Chicago, the **GAS-FIRED HEAT PUMP** had the highest NPV, while in New York it also compared well with the **EMERGING GROUND SOURCE HEAT PUMPS.** In Portland, both advanced gas technologies had an NPV comparable to the **LOW-COST ADVANCED AIR SOURCE HEAT PUMP**, which had a much higher ratio. In the warmest locations (Atlanta and Phoenix), the ordering of NPV results between advanced electric and gas options in Exhibit 3.26 are roughly comparable to the ratios in Exhibit 3.25.

Another striking change from the TRC ratio results to the NPV results is that the **LOW-COST AIR SOURCE HEAT PUMP** drops toward the bottom of the pack in the four coldest locations (Burlington, Chicago, New York and Portland), even though its TRC ratio in those locations is quite high. It retains its strong showing in the warmest locations, however.

Exhibit 3.25

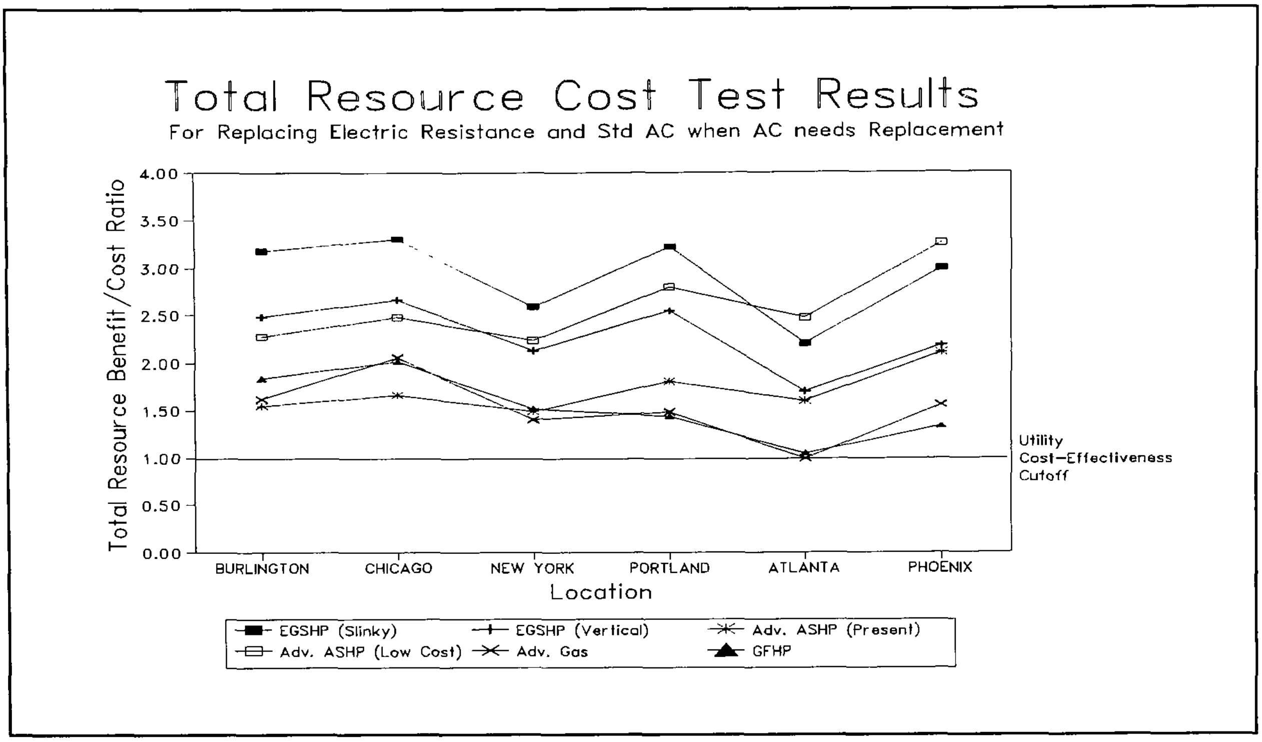
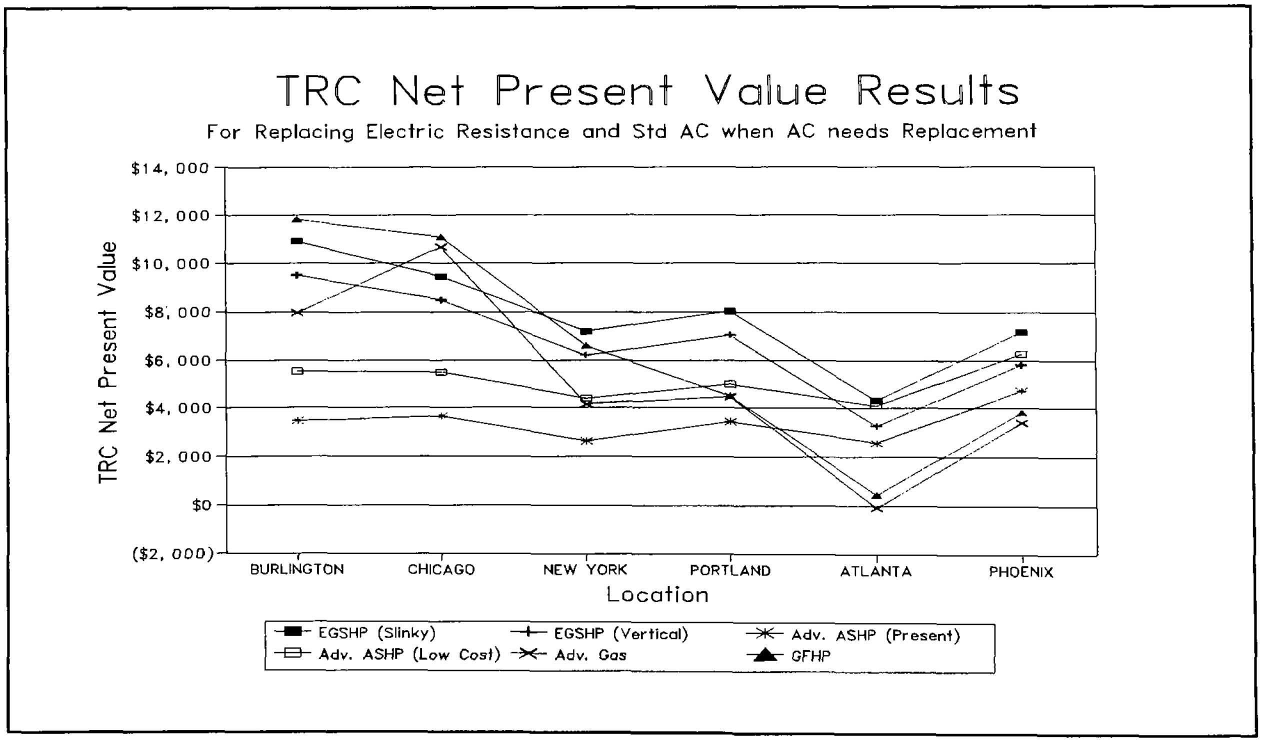


Exhibit 3.26



<u>Replacing STANDARD AIR SOURCE HEAT PUMPS</u>: For this replacement scenario, the relative ordering of TRC ratios and TRC NPVs is very similar to the "replacing **ELECTRIC RESISTANCE**" scenario. Again, the ratios (Exhibit 3.27) suggest that the **EMERGING GROUND SOURCE HEAT PUMPS** and the **LOW-COST ADVANCED AIR SOURCE HEAT PUMP** are the best replacements. Again, however, the ordering shifts when one views the NPVs in Exhibit 3.28, with the advanced gas technologies looking very strong in the colder climates and dropping off to the same relative position in Atlanta and Phoenix. Also, Exhibit 3.28 shows that, from an NPV standpoint, the **LOW-COST ADVANCED AIR SOURCE HEAT PUMP** once again drops off in all locations but Atlanta and Phoenix.

Exhibit 3.27

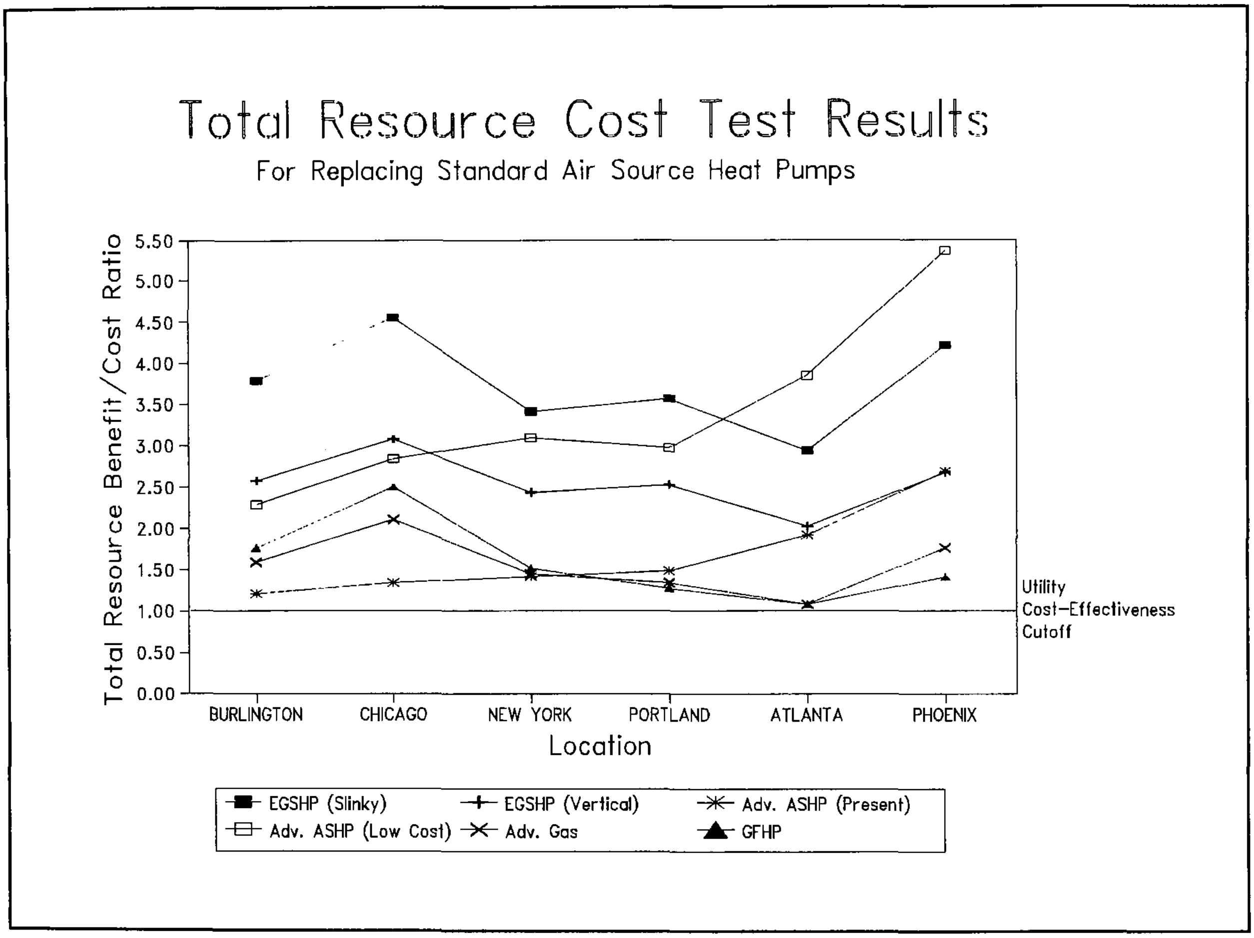
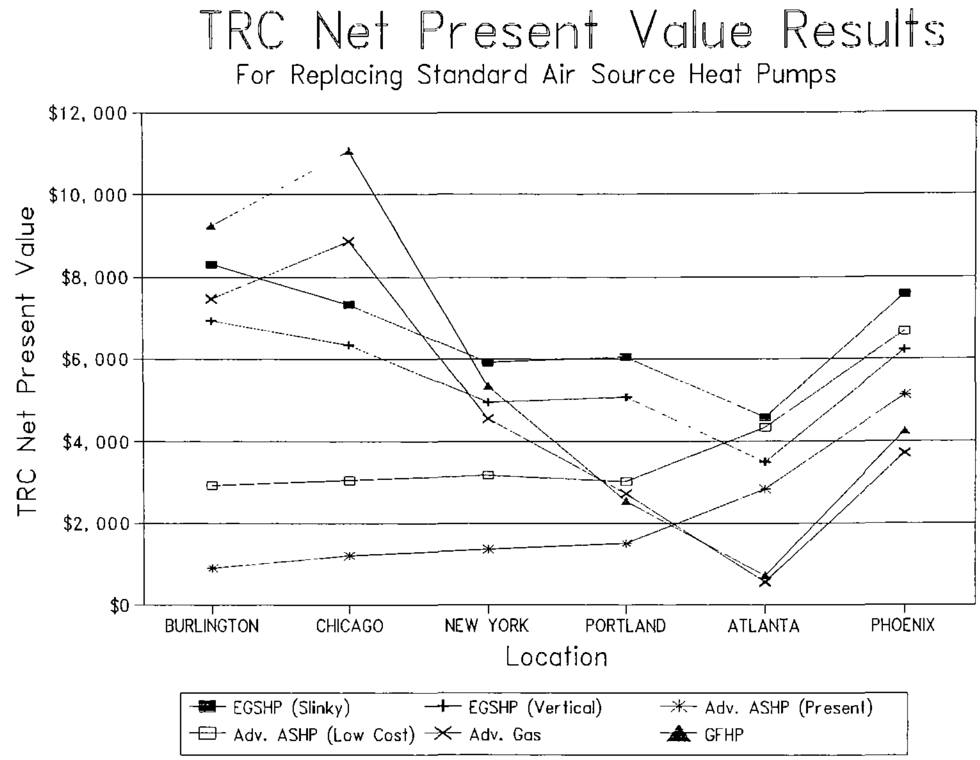


Exhibit 3.28



<u>Replacing STANDARD GAS FURNACES/STANDARD AC</u>: In this replacement scenario, the TRC ratios in Exhibit 3.29 clearly show an advantage for the advanced gas equipment in the three coldest locations (Burlington, Chicago and New York), with **EMERGING GROUND SOURCE HEAT PUMPS** actually failing the test in Chicago. Interestingly, in Burlington and New York, the NPV results in Exhibit 3.30 show the **EMERGING GROUND SOURCE HEAT PUMPS** comparing very favorably with the advanced gas systems. Again, as in the first two scenarios, the advanced electric equipment begins to get both higher TRC ratios <u>and</u> TRC NPVs as one goes to the warmer climates.

Exhibit 3.29

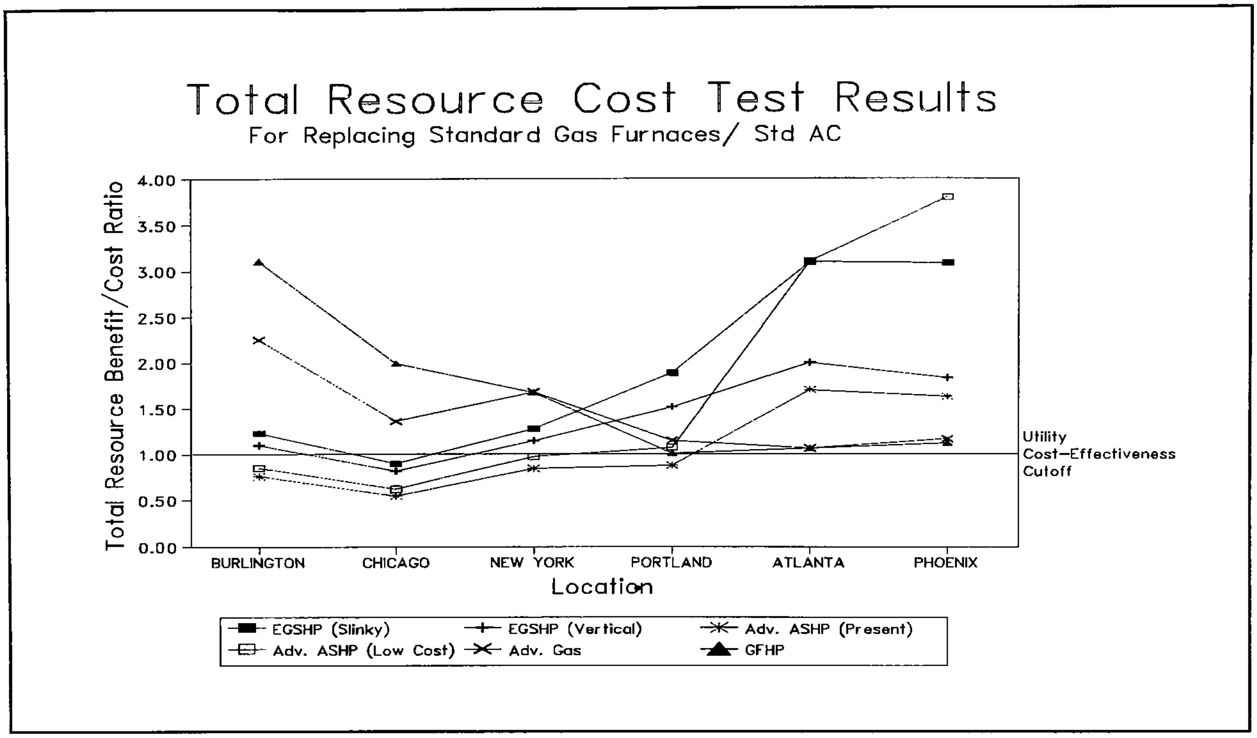
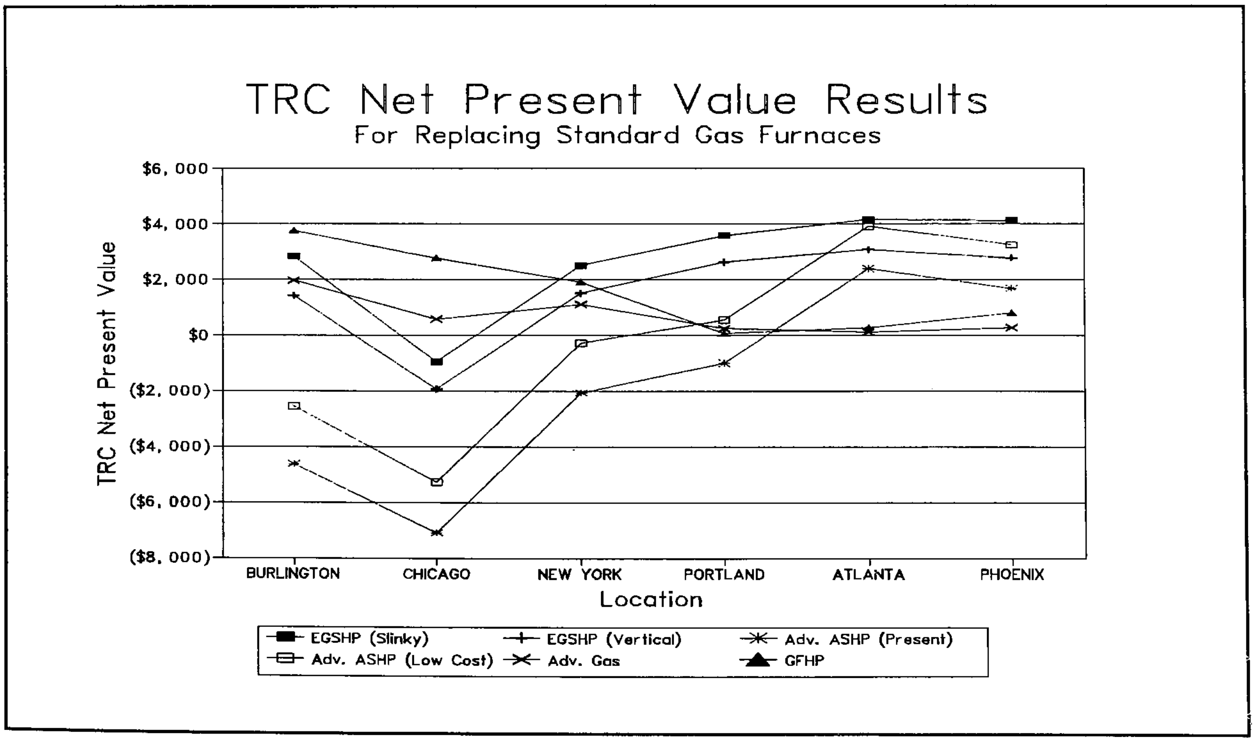


Exhibit 3.30



CONCLUSIONS

The above analysis highlights the **EMERGING GROUND SOURCE HEAT PUMP**, particularly the system utilizing the new, lower-cost **SLINKY**™ loop, as a leading space conditioning technology in all locations and from most perspectives -- operating performance, annualized cost, environmental impact and attractiveness to utilities as a DSM measure. Combining these with its attractive maintenance and consumer satisfaction attributes, the **EMERGING GROUND SOURCE HEAT PUMP** appears to provide very significant opportunities for cost-effective pollution prevention in the space conditioning market. On the other hand, a strong infrastructure for marketing and installing this technology must be developed in most areas before it can enjoy the kind of market penetration breakthroughs that seem possible.

The **GAS-FIRED HEAT PUMP** also promises relatively good operating performance and CO_2 reduction, and may become a superior space conditioning alternative in colder climates, where it is highly cost-effective from a utility DSM standpoint. While it did not yield the best results in the Southern locations, the **GAS-FIRED HEAT PUMP** is still cost-effective as a substitute for standard equipment. However, this technology has not as yet been commercialized, and therefore has many uncertainties associated with it. First, capital cost is not yet determined, although the industry expects the 3 ton unit introduced in 1994 to sell for around $6800 installed. Second, since it utilizes an internal combustion technology that will be installed out-of-doors, it may require relatively high maintenance over the unit's life. Third, its relatively high NO_x emission rate may slow its acceptance in many areas, especially those out of compliance with ground-level air quality standards. Given these uncertainties for the **GAS-FIRED HEAT PUMP**, the **ADVANCED GAS FURNACE** may yet achieve significant market penetration, especially in colder regions.

The **LOW-COST ADVANCED AIR SOURCE HEAT PUMP** also appears to be an attractive technology, if in fact the cost breakthroughs modeled in this analysis can be achieved. In particular, this technology appears very attractive for utility DSM promotion in Southern climates, where the greatest penetration of existing heat pump stock already exists. The **ADVANCED AIR SOURCE HEAT PUMP** enjoys some important market advantages over the **GROUND SOURCE HEAT PUMP** -- namely, its installation is simpler, and it has a much larger dealer/installer infrastructure, as well as higher recognition among consumers, than does the **GROUND SOURCE HEAT PUMP**. On the other hand, its installation is by no means as simple as that of a **STANDARD AIR SOURCE HEAT PUMP,** given its advanced controls and its water heating function, which necessitates plumbing. Furthermore, not all consumers have been satisfied with the heat pumps that they have bought in the past, which might hamper the sales of even a clearly superior technology.

CHAPTER FOUR

THE POTENTIAL MARKET FOR ADVANCED SPACE CONDITIONING EQUIPMENT

INTRODUCTION

This chapter explores the total market potential for advanced electric and gas space conditioning equipment, both with and without utility-based incentives. The first major section focuses on the market for the advanced electric technologies that showed promising results in Chapter Three, **ADVANCED AIR SOURCE HEAT PUMPS** and **EMERGING GROUND SOURCE HEAT PUMPS**. It estimates the potential demand -- both with and without aggressive utility DSM incentive payments -- for these equipment in each of the five major climate zones identified in Chapter Three, as well as for the United States as a whole. It also correlates the demand estimates to reductions in energy demand, avoidance of generating capacity, and effects on CO_2, NO_x, and SO_2 emissions.

The second major section presents a similar climate zone-based analysis for advanced gas equipment -- both **ADVANCED GAS FURNACES** and **GAS-FIRED HEAT PUMPS**.

The emission reduction estimates are then integrated for both electric and gas equipment, to show the overall pollution prevention potential for each climate zone and the nation at large. The analysis then estimates the value of the reduction in the risk involved with the key greenhouse gas, CO_2, that advanced space conditioning can bring about.

BACKGROUND ON MARKET POTENTIAL ANALYSIS

Aggressive utility programs to overcome the market barriers to advanced space conditioning equipment can reduce customer bills, improve the environment and increase national and local competitiveness.

The market potential analysis in this report uses housing and energy usage data for each climate zone from the Energy Information Administration's most recent Residential Energy Consumption Survey.[1]

A "base case" is formulated for each climate zone based on an optimistic estimate of market penetration of the most advanced technologies with no utility involvement. The estimate assumes that a local infrastructure to sell and service advanced space conditioning technologies can be created without utility programs. The estimate is then based on equipment price and performance, average energy prices within the climate zone, and the paybacks associated with advanced equipment.

Exhibit 4.1 shows the penetration curve used, in which market demand is a function of economic payback and consumer acceptance. Because the report deals with emerging technologies that have not achieved a very high degree of consumer awareness and acceptance, the market penetration model employs a factor that moderates penetration of the advanced equipment. This market "stickiness" against the new technologies decreases over time to reflect increased marketing, consumer awareness and acceptance.[2]

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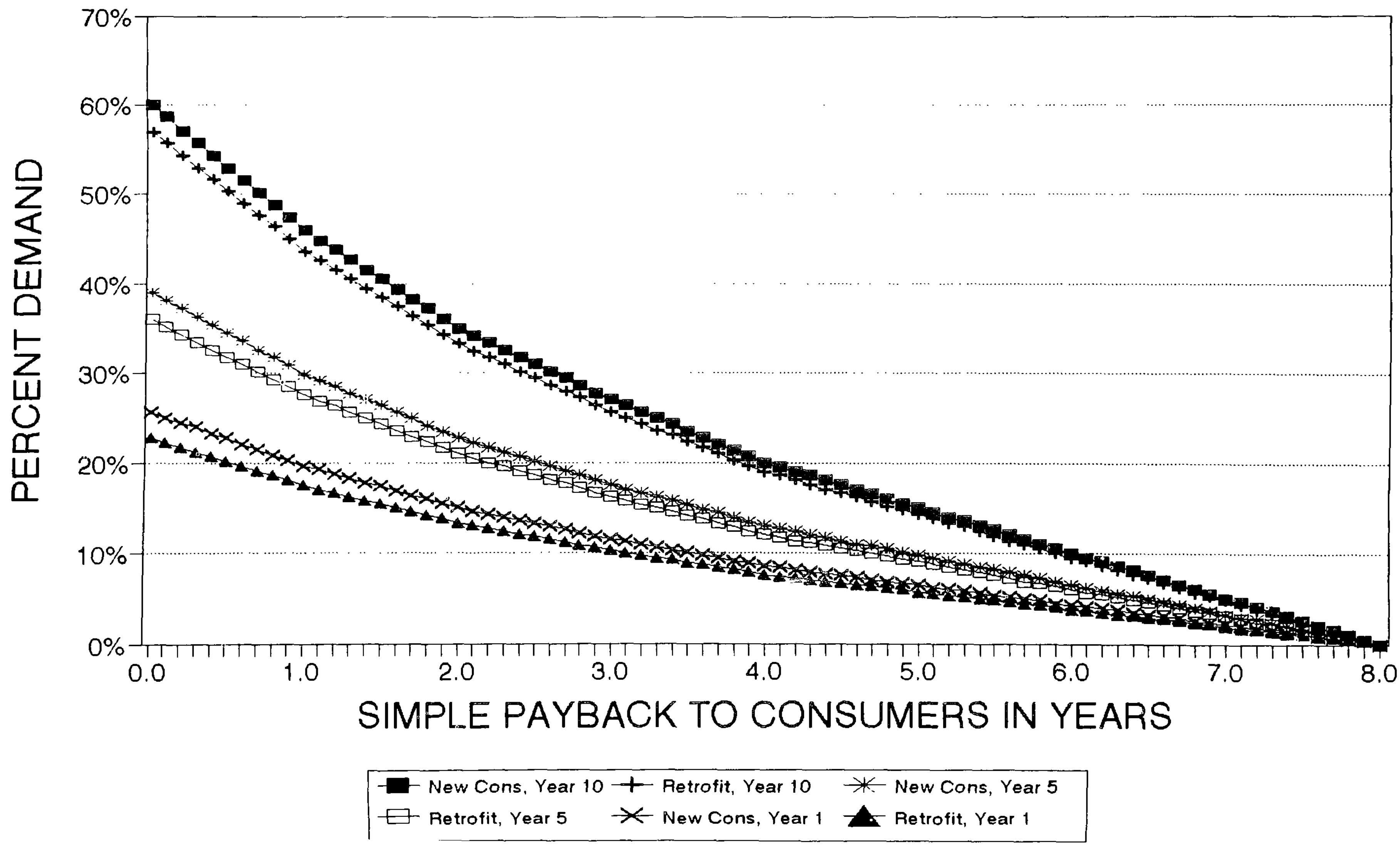
[1] EIA, Housing Characteristics 1990, DOE/EIA-0314(90), May 1992.

[2] Curve was derived by Barakat & Chamberlin in work done for an electric utility in the Southwest.

Exhibit 4.1

MARKET DEMAND ESTIMATION CURVE

Same-Fuel Substitutions



Since the analysis in Chapter Three was based on the performance and price of a heating and cooling system that was modeled on a "typical" single-family house, the market potential analysis in this chapter is restricted to single-family homes with central air conditioning.[3] Thus, the analysis is incomplete as advanced systems could have significantly higher penetrations if townhouses and apartments were to be included.

The market penetration model assumes no fuel switching between gas and electric heating systems. Gas-heated homes remain gas-heated, and electrically-heated homes remain electric. In the real world, some fuel switching will be justified and some will occur. Of course, on the cooling side, the substitutions of **GAS-FIRED HEAT PUMPS** for **STANDARD GAS FURNACES** does involve substitution of gas cooling for electric air conditioners.

Climate Zones 1 through 4 include some penetration of the residential oil heating market.[4] For these regions, oil-heated homes are "allowed" to switch to advanced electric heat pumps.[5]

In the case of **GROUND SOURCE HEAT PUMPS**, the analysis assumes that horizontal loops can be installed in half the homes and that vertical loops are necessary in the other half.

In the case of **ADVANCED AIR SOURCE HEAT PUMPS**, the analysis assumes the **PRESENT COST** case in the baseline. The utility program approach, however, assumes the **LOW-COST** scenario. This is because the absence of more aggressive utility programs can be expected to preserve the current barriers to market penetration and cost reduction for the **ADVANCED AIR SOURCE HEAT PUMP**. A concerted, strategic utility effort to increase its penetration, on the other hand, would have the likely benefit of ensuring price reductions due to higher volume. Since **AIR SOURCE HEAT PUMPS** have been around for decades, the "stickiness" factor reflecting consumer awareness and acceptance was not used for them.

To assess the impact of advanced space conditioning equipment on air emissions, it was necessary to use national emission factors for CO_2, NO_x and SO_2.[6] This was due to the fact that the five major climate zones stretch across various power generating regions in such a way as to render climate zone-specific emission factor estimates nearly impossible.

After generating a base case, a vigorous utility program scenario is assumed. Beginning in 1995, all utilities offer incentives for the full incremental cost of the advanced space conditioning equipment whenever the TRC ratio is greater than 1. The effect of the utility incentives is to drastically reduce the consumer payback period, and thereby increase the penetration of the new technologies. For **ADVANCED GAS FURNACE** system, the TRC of the furnace itself was considered without including the high efficiency air conditioner. It would be unrealistic to assume that, because the system as a whole passes the TRC, the gas utility would promote the **ADVANCED GAS FURNACE** in

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[3] EIA, Housing Characteristics 1990, DOE/EIA-0314(90), May 1992, Table 11, p. 38.

[4] Ibid., Table 29, p. 82.

[5] In actuality, some switching to advanced gas equipment can be expected to occur; this however, would hardly affect the overall results of the market penetration analysis.

[6] The national emission factors were derived from the Year 2000 reference case developed by EIA, "Annual Outlook for U.S. Electric Power 1991," July 1991, DOE/EIA-0474(91), Table B11. Using the same T&D loss estimate as used elsewhere in the report (8%), the factors are: for CO_2, 191.8 kg/MMBtu; for NO_x, 0.522 kg/MMBtu; and for SO_2, 0.803 kg/MMBtu.

its DSM programs if it failed in isolation. This actually occurred in Atlanta and Phoenix -- in both locations, the full system passed the TRC test, but only by merit of the efficient air conditioner. Since the **ADVANCED GAS FURNACE** failed the TRC by itself, no utility program was assumed for the furnace in those climate zones.

In estimating the market potential, no environmental externalities are considered, only the market costs of energy.

Based on the model results, this chapter describes the market potential first for the advanced electric technologies, **GROUND SOURCE HEAT PUMPS** and **ADVANCED AIR SOURCE HEAT PUMPS**; and then for advanced gas technologies ,**GAS-FIRED HEAT PUMPS** and **ADVANCED GAS FURNACES/HIGH-EFFICIENCY AIR CONDITIONERS**, within each climate zone. The overall effect of an aggressive utility program on market penetration is assessed for the years 2000 and 2005, and presented, along with energy savings, in summary tables. Total avoided emissions from the advanced equipment are presented for each climate zone at the end of the chapter.

POTENTIAL FOR EMERGING GROUND SOURCE AND ADVANCED AIR SOURCE HEAT PUMPS

CLIMATE ZONE 1

For Climate Zone 1, **EMERGING GROUND SOURCE HEAT PUMPS** and **ADVANCED AIR SOURCE HEAT PUMPS** are assumed to replace **ELECTRIC RESISTANCE/CENTRAL AIR CONDITIONING**, either in new construction or in the replacement market. Substitution for oil furnaces is modeled to occur as well. Overall, for this climate zone about 33,000 electric resistance systems and 20,500 oil systems are installed each year (new and replacement markets combined).

The results for advanced heat pumps are probably underestimated, since the EIA survey data for Climate Zone 1 did not reflect a statistically valid number of air source heat pumps on which to base a potential market for more advanced heat pumps. As a result, the market for air source heat pumps against which the advanced electric technologies could compete was taken as zero. Although it is logical to assume that little penetration of **AIR SOURCE HEAT PUMPS** has occurred in the northernmost regions of the U.S., one can expect there to be greater than zero penetration.

As Exhibit 4.2 indicates, the market for advanced heat pumps without the presence of utility incentives is around 7,800 units per year in 2000. This is based on the optimistic assumption that a marketing and delivery infrastructure is in place without the assistance of utility programs. In reality, the development of delivery infrastructures, especially for **GROUND SOURCE HEAT PUMPS**, has not been especially robust without utility programs. Still, even with this conservative assessment of the net effect of utility programs, Exhibit 4.2 indicates more than a tripling of the market for advanced heat pumps in the year 2000 relative to the baseline.

Exhibit 4.2 shows a net increase in winter demand in both the baseline and utility program scenarios. This is due to the relatively high number of oil furnaces being switched to advanced electric systems. As noted above, in the real world, some of these oil systems would be switching to gas (where gas service is available).

Exhibit 4.2
Advanced Electric Heat Pump Market Potential

Climate Zone 1 -- Year 2000 (1995-2000 Program Delivery)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total GSHP Market	4,121	10,746	6,625
Total ASHP Market	3,654	15,668	12,015
KWH Avoided	715,127,377	1,820,923,135	1,105,795,758
Winter MW Avoided	113	(80)	(193)
Summer MW Avoided	287	951	664
Gal. Oil Avoided	3,296,702	27,283,051	23,986,349
CO2 Avoided (MT)	499,977	1,463,830	963,853
NOx Avoided (MT)	1,292	3,423	2,131
SO2 Avoided (MT)	2,019	5,512	3,493

Climate Zone 1 -- Year 2005 (Program Delivery 1995-2005)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total GSHP Market	7,222	14,841	7,619
Total ASHP Market	4,146	15,288	11,142
KWH Avoided	1,482,287,742	3,303,679,337	1,821,391,595
Winter MW Avoided	260	(287)	(547)
Summer MW Avoided	592	1,851	1,259
Gal. Oil Avoided	7,918,614	65,533,361	57,614,747
CO2 Avoided (MT)	1,047,286	2,817,704	1,770,418
NOx Avoided (MT)	2,686	6,324	3,638
SO2 Avoided (MT)	4,207	10,315	6,108

CLIMATE ZONE 2

The Climate Zone 2 market potential analysis indicates a huge opportunity for growth in advanced space conditioning equipment that could result from utility programs. Zone 2 is much more heavily populated than Zone 1; for instance, the total market for which advanced electric heat pumps can compete in 2000 is about 190,000 new and existing households, almost four times as many in Zone 1 (about 30,000 of these are estimated to be oil).

Correspondingly, the savings figures listed in Exhibit 4.3 are quite large compared to the Zone 1 results. With the help of utility programs, the potential market for advanced electric heat pumps more than triples from 35,000 units to over 100,000 units per year in 2000. This higher level of penetration compared to Climate Zone 1 leads to correspondingly higher energy savings, capacity savings, and avoided emissions.

Exhibit 4.3
Advanced Electric Heat Pump Market Potential

Climate Zone 2 -- Year 2000 (1995-2000 Program Delivery)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total GSHP Market	22,711	43,045	20,334
Total ASHP Market	13,838	63,678	49,840
KWH Avoided	1,857,048,097	5,180,904,835	3,323,856,738
Winter MW Avoided	788	1,664	876
Summer MW Avoided	1,268	3,832	2,564
Gal. Oil Avoided	5,144,567	29,397,527	24,252,960
CO2 Avoided (MT)	1,604,488	4,241,580	2,637,092
NOx Avoided (MT)	4,259	10,937	6,678
SO2 Avoided (MT)	6,605	17,103	10,498

Climate Zone 2 -- Year 2005 (Program Delivery 1995-2005)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total GSHP Market	40,380	59,283	18,903
Total ASHP Market	16,180	58,937	42,757
KWH Avoided	3,939,435,030	9,599,600,661	5,660,165,631
Winter MW Avoided	1,799	3,070	1,272
Summer MW Avoided	2,844	7,540	4,696
Gal. Oil Avoided	12,357,163	70,612,360	58,255,197
CO2 Avoided (MT)	3,484,376	8,198,431	4,714,055
NOx Avoided (MT)	9,224	20,859	11,635
SO2 Avoided (MT)	14,316	32,746	18,430

CLIMATE ZONE 3

Climate Zone 3 has a market with a much higher penetration of electric resistance heating and heat pumps than Zones 1 and 2. This reflects the historically high penetration of electric technologies in warmer regions in the U.S. Thus, the market for which advanced electric heat pumps can compete increases to just over 300,000 households per year (both new construction and replacements) in 2000, as opposed to about 190,000 in Zone 2. This market increases to over 330,000 units in 2005. About 25,000 households are estimated to have oil heat in the baseline.

Correspondingly, the results of the market potential analysis, presented in Exhibit 4.4, reflect substantially larger market opportunities for advanced electric heat pumps in Zone 3. Utility incentives could increase their penetration by more than a factor of seven in 2000, from 23,000 units to over 175,000. This increased demand could increase to over 200,000 units in 2005.

Although the magnitude of the potential market for advanced electric heat pumps is larger in Climate Zone 3 than in Climate Zone 2, the amounts of potential electricity and oil savings and emissions reductions are not quite as high, due to the fact that the overall climate is more moderate. The results for Climate Zone 3 are conservative in this respect, since they are based on the modeled results in Portland, OR, where summer cooling loads are low. It is likely that the potential energy savings and emissions reduction for this climate zone are larger than reflected in Exhibit 4.4.

Exhibit 4.4
Advanced Electric Heat Pump Market Potential

Climate Zone 3 -- Year 2000 (1995-2000 Program Delivery)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total GSHP Market	18,306	72,826	54,521
Total ASHP Market	4,836	103,847	99,012
KWH Avoided	709,659,681	5,210,309,047	4,500,649,366
Winter MW Avoided	669	4,186	3,517
Summer MW Avoided	577	6,192	5,615
Gal. Oil Avoided	786,593	16,865,571	16,078,978
CO2 Avoided (MT)	623,929	3,798,493	3,174,564
NOx Avoided (MT)	1,681	9,985	8,304
SO2 Avoided (MT)	2,596	15,528	12,933

Climate Zone 3 -- Year 2005 (Program Delivery 1995-2005)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total GSHP Market	27,030	102,425	75,395
Total ASHP Market	4,505	98,139	93,635
KWH Avoided	1,537,780,338	10,266,407,504	8,728,627,166
Winter MW Avoided	1,615	9,151	7,535
Summer MW Avoided	1,295	12,468	11,173
Gal. Oil Avoided	1,310,989	40,510,786	39,199,798
CO2 Avoided (MT)	1,296,171	7,572,324	6,276,153
NOx Avoided (MT)	3,498	19,764	16,266
SO2 Avoided (MT)	5,400	30,799	25,400

CLIMATE ZONE 4

Climate Zone 4 continues the trend toward increasing market opportunities for high efficiency heat pumps as one moves further South, since the historical penetration of electric heating continues to increase relative to other climate zones. Advanced electric heat pumps would compete in a market installing about 360,000 new and replacement systems in 2000, increasing to about 400,000 units in 2005 (only about 7,500 of these are oil systems).

As shown in Exhibit 4.5, the presence of utility programs would have a profound impact over the baseline scenario, especially with regard to **ADVANCED AIR SOURCE HEAT PUMPS**. Together with **EMERGING GROUND SOURCE HEAT PUMPS**, they would experience an exploding market, with potential demand increasing by a more than a factor of fifteen, from 15,000 units to over 217,000 in 2000. This potential would grow to nearly 250,000 units in 2005, with **EMERGING GROUND SOURCE HEAT PUMPS** picking up ground due to increased consumer awareness and acceptance.

Due to increasingly milder climate, the energy savings and emission reduction results for Climate Zone 4 are not much higher than those for Zone 2 and Zone 3, despite higher potential market penetration in terms of numbers of units.

Exhibit 4.5
Advanced Electric Heat Pump Market Potential

Climate Zone 4 -- Year 2000 (1995-2000 Program Delivery)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total GSHP Market	14,494	89,407	74,914
Total ASHP Market	520	127,686	127,166
KWH Avoided	183,265,559	5,817,549,475	5,634,283,916
Winter MW Avoided	296	5,750	5,454
Summer MW Avoided	194	7,308	7,113
Gal. Oil Avoided	894,211	3,518,206	2,623,996
CO2 Avoided (MT)	323,074	4,027,029	3,703,955
NOx Avoided (MT)	860	10,879	10,019
SO2 Avoided (MT)	1,333	16,789	15,456

Climate Zone 4 -- Year 2005 (Program Delivery 1995-2005)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total GSHP Market	18,322	125,772	107,451
Total ASHP Market	669	119,483	118,815
KWH Avoided	442,526,156	11,708,814,454	11,266,288,298
Winter MW Avoided	748	12,955	12,207
Summer MW Avoided	481	14,854	14,373
Gal. Oil Avoided	2,147,880	8,450,677	6,302,796
CO2 Avoided (MT)	666,995	8,084,277	7,417,283
NOx Avoided (MT)	1,770	21,811	20,041
SO2 Avoided (MT)	2,745	33,672	30,926

CLIMATE ZONE 5

Climate Zone 5 is the warmest of the major climate zones characterized in the EIA residential survey. As is the case with Zone 4, there is substantial opportunity for advanced electric heat pumps to compete in a market growing to about 310,000 units per year in 2000 and 350,000 by 2005. Most of this opportunity comes from competition with existing air source heat pumps (the analysis, based on housing census data, assumes no oil heating in the market, and only about 11,000 electric resistance system installations or replacements).

Exhibit 4.6 continues to demonstrate the strong effect of utility programs, especially on the market for **ADVANCED AIR SOURCE HEAT PUMPS**. Overall, advanced heat pump demand goes from 35,000 in the 2000 baseline scenario to 190,000 in the utility program scenario -- a factor of five.

Exhibit 4.6
Advanced Electric Heat Pump Market Potential

Climate Zone 5 -- Year 2000 (1995-2000 Program Delivery)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total GSHP Market	25,639	78,986	53,347
Total ASHP Market	9,624	111,249	101,624
KWH Avoided	698,056,668	5,316,621,697	4,618,565,029
Winter MW Avoided	787	6,415	5,628
Summer MW Avoided	862	6,803	5,941
Gal. Oil Avoided	0	0	0
CO2 Avoided (MT)	693,294	3,708,070	3,014,776
NOx Avoided (MT)	1,885	10,083	8,198
SO2 Avoided (MT)	2,904	15,532	12,628

Climate Zone 5 -- Year 2005 (Program Delivery 1995-2005)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total GSHP Market	43,022	111,941	68,919
Total ASHP Market	12,711	105,106	92,395
KWH Avoided	1,862,622,897	10,991,713,161	9,129,090,265
Winter MW Avoided	2,063	13,051	10,988
Summer MW Avoided	2,287	13,979	11,692
Gal. Oil Avoided	0	0	0
CO2 Avoided (MT)	1,651,620	7,610,833	5,959,213
NOx Avoided (MT)	4,491	20,696	16,205
SO2 Avoided (MT)	6,918	31,880	24,962

TOTAL OPPORTUNITIES IN THE U.S. FOR EMERGING GROUND SOURCE HEAT PUMPS AND ADVANCED AIR SOURCE HEAT PUMPS

Exhibit 4.7 compiles the demand estimates in all five climate zones for advanced electric heat pumps. Together, **EMERGING GROUND SOURCE HEAT PUMPS** and **ADVANCED AIR SOURCE HEAT PUMPS** could save over 23 billion kWh of electricity per year by 2000, 19 billion of which would be attributable to utility programs. These programs could reduce winter demand capacity by 18,000 MW and summer demand by 25,000 MW -- the equivalent of 60 and 83 typical (300 MW) electric generation plants, respectively. National CO_2 savings would total over 17 million metric tons (MMT). Almost 80% of these energy, demand and emission reductions would be attributable to utility efforts.

The potential market for **EMERGING GROUND SOURCE HEAT PUMPS** would increase by a factor of 3.5 over the baseline by 2000 as a result of aggressive utility investments, to almost 300,000 units per year. Utility programs could have an even more striking effect on **ADVANCED AIR SOURCE HEAT PUMPS**, whose market potential would increase by a factor of thirteen, to almost 420,000 units per year.

Due to increasing consumer awareness and acceptance, **GROUND SOURCE HEAT PUMPS** would continue to enjoy increasing market share up through 2005 relative to **ADVANCED AIR SOURCE HEAT PUMPS**, with demand growing steadily to over 40,000 units per year, while **ADVANCED AIR SOURCE HEAT PUMPS** level off to around 400,000 units per year.

Exhibit 4.7 illustrates that by 2005, with a market demand of over 800,000 units per year, advanced electric heat pumps could double the amount of total annual energy savings, capacity avoidance, and emission reductions achieved in 2000. This shows the striking accumulating effects of ever-increasing penetration of the nation's housing stock with energy-saving, pollution preventing space conditioning technologies.

Exhibit 4.7
Advanced Electric Heat Pump Market Potential

U.S. Total -- Year 2000 (1995-2000 Program Delivery)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total GSHP Market	85,270	295,011	209,741
Total ASHP Market	32,472	422,128	389,656
KWH Avoided	4,163,157,382	23,346,308,188	19,183,150,806
Winter MW Avoided	2,653	17,935	15,281
Summer MW Avoided	3,187	25,085	21,897
Gal. Oil Avoided	10,122,073	77,064,356	66,942,282
CO2 Avoided (MT)	3,744,761	17,239,001	13,494,240
NOx Avoided (MT)	9,977	45,307	35,330
SO2 Avoided (MT)	15,457	70,464	55,007

U.S. Total -- Year 2005 (Program Delivery 1995-2005)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total GSHP Market	135,976	414,263	278,287
Total ASHP Market	38,211	396,954	358,743
KWH Avoided	9,264,652,163	45,870,215,118	36,605,562,955
Winter MW Avoided	6,485	37,939	31,454
Summer MW Avoided	7,497	50,692	43,194
Gal. Oil Avoided	23,734,646	185,107,184	161,372,538
CO2 Avoided (MT)	8,146,447	34,283,569	26,137,121
NOx Avoided (MT)	21,669	89,454	67,785
SO2 Avoided (MT)	33,586	139,412	105,826

POTENTIAL FOR GAS-FIRED HEAT PUMPS AND ADVANCED GAS FURNACE SYSTEMS

CLIMATE ZONE 1

In Climate Zone 1, the new construction and replacement market for gas furnaces is estimated to be around 145,000 units per year. The effect of utility efforts to promote **GAS-FIRED HEAT PUMPS** and **ADVANCED GAS FURNACES** would increase penetration four-fold over the baseline estimate (Exhibit 4.8).[7] Once established by utility programs, the penetration of **GAS-FIRED HEAT PUMPS** increases a little relative to advanced gas furnaces by the year 2005, due to increasing consumer awareness and acceptance.

Exhibit 4.8 illustrates the energy savings, summer capacity avoidance, and effect on emissions of the higher penetrations of advanced gas equipment. The exhibit shows a net increase in NO_x emissions in Climate Zone 1. The **GAS-FIRED HEAT PUMPS** would increase NO_x emissions by 1,348 MT/year by 2000 relative to the **STANDARD GAS FURNACE** systems they would replace. **ADVANCED GAS FURNACES**, on the other hand would reduce NO_x emissions by 714 MT, leading to the net increase shown in the exhibit. The relative increase in **GAS-FIRED HEAT PUMP** NO_x emissions lead to larger net increase in the region by 2005 relative to the baseline scenario. Concern over high NO_x emissions could seriously hamper the acceptance of utility programs promoting **GAS-FIRED HEAT PUMPS** in areas in which they are otherwise competitive as DSM measures.

Exhibit 4.8
Advanced Gas Equipment Market Potential

Climate Zone 1 -- Year 2000 (1995-2000 Program Delivery)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total Adv Gas Market	13,042	57,907	44,865
Total GFHP Market	9,250	33,901	24,651
Therms Avoided	43,779,685	177,919,452	134,139,767
KWH Avoided	55,318,570	221,722,346	166,403,777
Summer MW Avoided	230	873	643
CO2 Avoided (MT)	262,088	1,064,445	802,358
NOx Avoided (MT)	(212)	(635)	(422)
SO2 Avoided (MT)	156	624	468

[7] Baseline estimate only includes customers using standard gas furnaces.

Climate Zone 1 -- Year 2005 (Program Delivery 1995-2005)

EQUIPMENT	BASELINE	W/ PROGRAM	PROGRAM EFFECT
Total Adv Gas Market	14,790	49,496	34,706
Total GFHP Market	17,039	44,955	27,916
Therms Avoided	89,999,332	335,098,690	245,099,358
KWH Avoided	115,706,602	423,842,931	308,136,328
Summer MW Avoided	511	1,766	1,255
CO2 Avoided (MT)	539,214	2,006,164	1,466,950
NOx Avoided (MT)	(584)	(1,658)	(1,074)
SO2 Avoided (MT)	325	1,192	867

CLIMATE ZONE 2

Utility programs would have a profound effect on the potential market for advanced gas equipment in Climate Zone 2, allowing them to achieve high penetration in a market that grows to just over 500,000 units per year by 2000. As in Zone 1, low baseline demand changes drastically with utility programs, which would cause an estimated demand of about 116,600 **GAS-FIRED HEAT PUMPS** and almost 200,000 **ADVANCED GAS FURNACES** in 2000 (Exhibit 4.9). In 2005, some demand would shift to the **GAS-FIRED HEAT PUMPS**, as in Climate Zone 1, due to increasing consumer awareness and acceptance.

The large gas market leads to the largest opportunities for advanced gas penetration and for CO_2 reduction among any of the five climate zones. In fact, Climate Zone 2 comprises nearly half of all the CO_2 emissions achieved nationally by advanced gas equipment.

However, as in Climate Zone 1, **GAS-FIRED HEAT PUMPS** would again cause an increase in NO_x emissions of 3,305 MT/year by 2000, relative to **STANDARD GAS FURNACE** systems. **ADVANCED GAS FURNACES,** on the other hand, would reduce NO_x emissions by 1,984 MT/year, reducing the overall increase. Again, unless increased NO_x emissions from **GAS-FIRED HEAT PUMPS** are addressed in the next few years, this equipment may cause concern for policymakers and utilities.

Exhibit 4.9
Advanced Gas Equipment Market Potential

Climate Zone 2 -- Year 2000 (1995-2000 Program Delivery)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total Adv Gas Market	10,540	199,265	188,725
Total GFHP Market	17,314	116,659	99,345
Therms Avoided	46,658,421	511,293,884	464,635,463
KWH Avoided	107,938,677	1,014,033,621	906,094,943
Summer MW Avoided	336	2,938	2,602
CO2 Avoided (MT)	260,156	2,936,069	2,675,913
NOx Avoided (MT)	(365)	(1,322)	(957)
SO2 Avoided (MT)	293	2,777	2,484

Climate Zone 2 -- Year 2005 (Program Delivery 1995-2005)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total Adv Gas Market	10,540	170,320	159,780
Total GFHP Market	27,919	154,700	126,781
Therms Avoided	103,202,444	977,778,915	874,576,471
KWH Avoided	245,905,509	2,010,046,723	1,764,141,214
Summer MW Avoided	775	5,932	5,156
CO2 Avoided (MT)	571,816	5,579,053	5,007,237
NOx Avoided (MT)	(920)	(3,650)	(2,730)
SO2 Avoided (MT)	667	5,493	4,826

CLIMATE ZONE 3

The estimated total market on the gas side in Climate Zone 3 is about 285,000 units per year by 2000, rising modestly to just over 290,000 by 2005. As in Climate Zone 2, demand for advanced gas equipment would be almost entirely dependent on utility programs; in this climate zone, even longer paybacks would prevent any appreciable consumer demand absent aggressive utility incentive programs. By 2000, utilities could take an essentially non-existent market and turn it into about 175,000 annual sales of advanced gas equipment. This would remain relatively stable into 2005, although there would be some shift toward demand for **GAS-FIRED HEAT PUMPS.**

As in Climate Zones 1 and 2, **GAS-FIRED HEAT PUMPS** would increase NO_x emissions, this time by a total of 1,024 MT in 2000, against a reduction of 679 MT caused by **ADVANCED GAS FURNACES.**

Exhibit 4.10

Advanced Gas Equipment Market Potential

Climate Zone 3 -- Year 2000 (1995-2000 Program Delivery)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total Adv Gas Market	5,766	109,000	103,234
Total GFHP Market	0	63,814	63,814
Therms Avoided	5,673,744	208,031,228	202,357,484
KWH Avoided	4,843,440	275,823,766	270,980,326
Summer MW Avoided	23	1,553	1,529
CO2 Avoided (MT)	32,642	1,253,898	1,221,256
NOx Avoided (MT)	34	(344)	(379)
SO2 Avoided (MT)	14	775	761

Climate Zone 3 -- Year 2005 (Program Delivery 1995-2005)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total Adv Gas Market	5,766	93,167	87,401
Total GFHP Market	0	84,622	84,622
Therms Avoided	10,401,864	397,920,282	387,518,418
KWH Avoided	8,879,640	549,241,305	540,361,665
Summer MW Avoided	43	3,123	3,081
CO2 Avoided (MT)	59,844	2,411,020	2,351,177
NOx Avoided (MT)	63	(1,012)	(1,074)
SO2 Avoided (MT)	25	1,541	1,516

CLIMATE ZONE 4

The estimated total market for gas equipment in Climate Zone 4 is 283,000 in 2000, rising to 306,000 in 2005. As reported in Chapter Three, **ADVANCED GAS FURNACE** systems fail the utility TRC test in Climate Zone 4, while **GAS-FIRED HEAT PUMPS** pass. Thus, Exhibit 4.11 shows no utility-induced demand gains for **ADVANCED GAS FURNACES** in this region. On the other hand, utility programs support the entire **GAS-FIRED HEAT PUMP** market, which grows to over 100,000 units in 2000 and almost 175,000 units in 2005.

As in Climate Zones 1 through 3 , **GAS-FIRED HEAT PUMPS** would increase NO_x emissions in Climate Zone 4, in this case by 345 MT/year in 2000, relative to **STANDARD GAS FURNACES/STANDARD AIR CONDITIONERS.**

Exhibit 4.11
Advanced Gas Equipment Market Potential

Climate Zone 4 -- Year 2000 (1995-2000 Program Delivery)

			NET PROGRAM
EQUIPMENT	BASELINE	W/ PROGRAM	EFFECT
Total Adv Gas Market	6,036	6,036	0
Total GFHP Market	0	108,162	108,162
Therms Avoided	3,875,112	41,011,299	37,136,187
KWH Avoided	13,834,512	1,310,730,923	1,296,896,411
Summer MW Avoided	24	1,793	1,768
CO2 Avoided (MT)	29,173	1,035,492	1,006,319
NOx Avoided (MT)	42	(303)	(345)
SO2 Avoided (MT)	38	3,587	3,549

Climate Zone 4 -- Year 2005 (Program Delivery 1995-2005)

			NET PROGRAM
EQUIPMENT	BASELINE	W/ PROGRAM	EFFECT
Total Adv Gas Market	6,036	6,036	0
Total GFHP Market	0	174,414	174,414
Therms Avoided	7,104,372	95,295,158	88,190,786
KWH Avoided	25,363,272	3,105,224,808	3,079,861,536
Summer MW Avoided	45	4,245	4,200
CO2 Avoided (MT)	53,484	2,443,284	2,389,800
NOx Avoided (MT)	77	(742)	(819)
SO2 Avoided (MT)	70	8,497	8,427

CLIMATE ZONE 5

Again, as in Zone 4, the **ADVANCED GAS FURNACE** system fails the TRC tests, and therefore experiences no change in market demand over the baseline. The **GAS-FIRED HEAT PUMP**, on the other hand, fares much better, with potential demand growing to over 80,000 units by 2000 (all of which are attributable to utility efforts). This continues to grow to over 130,000 units by 2005. As can be seen in Exhibit 4.12, NO_x emissions are reduced in this climate zone, not increased as in the other four climate zones.

Note that the penetration of **GAS-FIRED HEAT PUMPS** under the utility program scenario leads to a large net increase in overall annual gas usage. This is due to the domination of the annual cooling load over heating in this climate zone, and the fact that electric cooling is being replaced by gas cooling. Correspondingly, the annual electricity savings are also relatively high.

Exhibit 4.12
Advanced Gas Equipment Market Potential

Climate Zone 5 -- Year 2000 (1995-2000 Program Delivery)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total Adv Gas Market	4,594	4,594	0
Total GFHP Market	0	82,332	82,332
Therms Avoided	1,736,532	(111,349,073)	(113,085,605)
KWH Avoided	27,122,976	2,492,411,407	2,465,288,431
Summer MW Avoided	22	1,733	1,710
CO2 Avoided (MT)	26,752	999,540	972,787
NOx Avoided (MT)	56	1,183	1,127
SO2 Avoided (MT)	74	6,802	6,727

Climate Zone 5 -- Year 2005 (Program Delivery 1995-2005)

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total Adv Gas Market	4,594	4,594	0
Total GFHP Market	0	132,763	132,763
Therms Avoided	3,183,642	(265,371,415)	(268,555,057)
KWH Avoided	49,725,456	5,904,278,530	5,854,553,074
Summer MW Avoided	41	4,103	4,062
CO2 Avoided (MT)	49,046	2,359,216	2,310,170
NOx Avoided (MT)	103	2,780	2,677
SO2 Avoided (MT)	136	16,112	15,976

TOTAL OPPORTUNITIES IN THE U.S. FOR ADVANCED GAS TECHNOLOGIES

Exhibit 4.13 totals the results for all five climate zones for gas equipment, summarizing the overall effect of a utility program on the introduction of the advanced gas technologies. The presence of aggressive utility programs could lead to a total annual demand for **ADVANCED GAS FURNACES** of just about 375,000 units by 2000, up from a baseline demand that is about one-ninth that figure. **GAS-FIRED HEAT PUMPS** would rely even more on utility incentive programs, increasing from about 25,000 sales to about 400,500 in 2000.

Together, **ADVANCED GAS FURNACES** and **GAS-FIRED HEAT PUMPS** would reduce gas consumption by over 3 billion therms by 2000, a figure that almost doubles, to almost 6.5 billion therms in 2005. Almost 9,000 MW of capacity in summer would be avoided by 2000, or the equivalent of 30 three hundred megawatt power plants. This would increase to 19,000 MW (about 63 power plants) in 2005. Carbon dioxide emission reductions would total over 7 MMT in 2000, doubling to almost 15 MMT by 2005.

Over 90% of these energy, demand and emission reductions would be attributable to utility programs. Climate Zone 2 accounts for the largest share of the national opportunities, due to the relative size of its market and the fact that advanced gas systems perform very well in colder climates.

As mentioned in the summaries above, the increase in NO_x emissions in four of the climate zones by the **GAS-FIRED HEAT PUMP** may be cause for concern, dampening the obvious CO_2 reductions that they accrue.

Exhibit 4.13
Advanced Gas Equipment Market Potential

U.S. Total for Gas Technologies -- Year 2000 (1995-2000 Program Delivery)

			NET PROGRAM
EQUIPMENT	BASELINE	W/ PROGRAM	EFFECT
Total Adv Gas Market	39,978	376,802	336,825
Total GFHP Market	26,564	404,868	378,303
Therms Avoided	101,723,494	826,906,791	725,183,297
KWH Avoided	209,058,175	5,314,722,062	5,105,663,888
Summer MW Avoided	636	8,889	8,253
CO2 Avoided (MT)	610,810	7,289,444	6,678,633
NOx Avoided (MT)	(445)	(1,420)	(975)
SO2 Avoided (MT)	575	14,564	13,989

U.S. Total – 2005

EQUIPMENT	BASELINE	W/ PROGRAM	NET PROGRAM EFFECT
Total Adv Gas Market	41,726	323,613	281,887
Total GFHP Market	44,958	591,454	546,495
Therms Avoided	213,891,654	1,540,721,630	1,326,829,976
KWH Avoided	445,580,479	11,992,634,297	11,547,053,818
Summer MW Avoided	1,415	19,168	17,753
CO2 Avoided (MT)	1,273,403	14,798,737	13,525,334
NOx Avoided (MT)	(1,261)	(4,281)	(3,019)
SO2 Avoided (MT)	1,224	32,836	31,612

TOTAL POTENTIAL FOR EMISSION REDUCTIONS FROM ADVANCED SPACE CONDITIONING TECHNOLOGIES

Exhibits 4.14 and 4.15 give the total combined emission reductions by climate zone and for the U.S. in the Years 2000 and 2005. Together, electric and gas utilities can contribute to substantial reductions in CO_2, NO_x and SO_2 emissions.

Exhibit 4.14
Emission Reductions
From Advanced Electric & Gas Technologies

Year 2000 (1995-2000 Program Delivery)

EMISSIONS	BASELINE	W/ PROGRAM	EFFECT
Climate Zone 1			
CO2 Avoided (MT)	762,064	2,528,275	1,766,211
NOx Avoided (MT)	1,080	2,789	1,709
SO2 Avoided (MT)	2,175	6,136	3,961
Climate Zone 2			
CO2 Avoided (MT)	1,864,644	7,177,649	5,313,005
NOx Avoided (MT)	3,894	9,615	5,721
SO2 Avoided (MT)	6,898	19,880	12,982
Climate Zone 3			
CO2 Avoided (MT)	656,571	5,052,391	4,395,821
NOx Avoided (MT)	1,715	9,641	7,926
SO2 Avoided (MT)	2,609	16,303	13,694
Climate Zone 4			
CO2 Avoided (MT)	352,247	5,062,520	4,710,274
NOx Avoided (MT)	902	10,576	9,674
SO2 Avoided (MT)	1,371	20,375	19,004
Climate Zone 5			
CO2 Avoided (MT)	720,046	4,707,609	3,987,563
NOx Avoided (MT)	1,941	11,267	9,326
SO2 Avoided (MT)	2,978	22,334	19,356
Total U.S.			
CO2 Avoided (MT)	4,355,571	24,528,445	20,172,874
NOx Avoided (MT)	9,532	43,888	34,355
SO2 Avoided (MT)	16,032	85,028	68,997

Exhibit 4.15
Emission Reductions
From Advanced Electric & Gas Technologies

Year 2005 (Program Delivery 1995-2005)

EMISSIONS	BASELINE	W/ PROGRAM	EFFECT
Climate Zone 1			
CO2 Avoided (MT)	1,586,499	4,823,868	3,237,369
NOx Avoided (MT)	2,102	4,666	2,564
SO2 Avoided (MT)	4,532	11,507	6,975
Climate Zone 2			
CO2 Avoided (MT)	4,056,192	13,777,484	9,721,292
NOx Avoided (MT)	8,304	17,209	8,905
SO2 Avoided (MT)	14,983	38,239	23,256
Climate Zone 3			
CO2 Avoided (MT)	1,356,015	9,983,344	8,627,329
NOx Avoided (MT)	3,561	18,753	15,192
SO2 Avoided (MT)	5,425	32,340	26,916
Climate Zone 4			
CO2 Avoided (MT)	720,478	10,527,561	9,807,082
NOx Avoided (MT)	1,847	21,070	19,223
SO2 Avoided (MT)	2,815	42,169	39,354
Climate Zone 5			
CO2 Avoided (MT)	1,700,666	9,970,049	8,269,383
NOx Avoided (MT)	4,594	23,477	18,883
SO2 Avoided (MT)	7,055	47,993	40,938
Total U.S.			
CO2 Avoided (MT)	9,419,850	49,082,305	39,662,455
NOx Avoided (MT)	20,408	85,174	64,766
SO2 Avoided (MT)	34,810	172,248	137,438

AVOIDED ENVIRONMENTAL RISK

The market demand analysis above did not incorporate externality "adders" in formulating its estimate. As aforementioned, the U.N. Convention on Climate that was signed in Rio de Janeiro committed the U.S. to a set of actions to reduce its carbon dioxide emissions. Several different approaches to meeting this commitment have been proposed.

One way of focusing on the risk associated with higher CO_2 emissions by not implementing strong utility programs is that CO_2 emissions expose a utility to the financial risks of future mitigation requirements. Public utility commissions have already become aware of this issue, as evidenced by the California Commission's opinion summarized in Chapter 1. Exhibit 4.16 provides estimates of the total value of CO_2 risk avoidance (based on externality adders currently being used in New York, Massachusetts and the Union of Concern Scientists) that could be achieved by utilities if the net aggregate market penetrations presented in Exhibits 4.7 and 4.13 were realized. It shows that the value of CO_2 risk avoidance grows to as much as a half billion dollars in 2000, and to over a billion dollars by 2005.

Exhibit 4.16
Carbon Dioxide Risk Avoidance Achieved
by Advanced Space Conditioning Technologies

Year 2000 (1995-2000 Program Delivery)

Carbon Dioxide Shadow Price	Value from Advanced Electric Heat Pumps	Value from Advanced Gas Furnaces and Heat Pumps	Total Value
$1.32/Metric Ton New York Public Service Commission	$22,755,482	$9,622,066	$32,377,547
$13/Metric Ton Union of Concerned Scientists (used in this report)	$224,107,016	$94,762,766	$318,869,783
$24/Metric Ton Massachusetts Dept. of Public Utilities	$413,736,030	$174,946,646	$588,682,675

Year 2005 (Program Delivery 1995-2005)

Carbon Dioxide Shadow Price	Value from Advanced Electric Heat Pumps	Value from Advanced Gas Furnaces and Heat Pumps	Total Value
$1.32/Metric Ton New York Public Service Commission	$45,254,311	$19,534,333	$64,788,643
$13/Metric Ton Union of Concerned Scientists (used in this report)	$445,686,392	$192,383,578	$638,069,971
$24/Metric Ton Massachusetts Dept. of Public Utilities	$822,805,647	$355,169,683	$1,177,975,330

ADDITIONAL OPPORTUNITIES FROM EARLY RETIREMENTS

Except for the case of electric resistance heating (in which homeowners replace electric furnaces with heat pumps when their air conditioners are ready to be replaced), the market analysis presented above focuses only on the new construction and purchases of new equipment when existing equipment is at the end of its service "life." It does not account for potential market interventions to induce homeowners to *early-retire* other types of very inefficient space conditioning systems. Early retirement presents another potentially cost-effective option for utilities and other market intervenors.

Large advances in appliance and equipment efficiency have been made by manufacturers since the early to mid-1970's, when energy efficiency first came into large-scale focus in the U.S. This means that there is still a significant amount of working stock that is outdated, inefficient and costly to operate. Not only is the rated energy performance of such stock very low by today's standards, but data collected to date shows that, with age, its efficiency is generally even worse than its rating indicates. Consequently, its owners are experiencing a hemorrhage of dollars that would be better invested in new equipment that would save energy and money.

Utilities have for some time recognized the value of early retirement programs. A variety of electric utilities have successfully implemented programs to take old, inefficient refrigerators and air conditioners off their grid. "Second refrigerator turn-in programs" often pay customers a small incentive -- a cash award or a savings bond -- to allow the utility to remove working second refrigerators. This captures a large reduction in both electricity demand and energy consumption. Furthermore, by capturing chemicals, recycling materials, and disposing of the balance of the appliance in an more environmentally sound manner, the utilities also capture a measure of good will.

Some utilities, such as the Sacramento Municipal Utility District (SMUD) have taken steps to link early retirement incentives with incentives for new, efficient refrigerators. Such linkages can be used to induce a homeowner to retire an inefficient primary refrigerator before he or she otherwise would have and replace it with an efficient new refrigerator.

This approach could be applied to old, outdated and deteriorated space conditioning equipment as well. Utilities could analyze the benefits that they would receive by inducing early retirement, and pay the homeowner an additional incentive based on that value. Applied to new, advanced technologies like those studied in this report, such a program would not only benefit homeowners, utilities and the environment, but they would also benefit industry and employment by increasing the size of the space conditioning market and accelerating the growth of the advanced technology niche.

OTHER TECHNOLOGIES

EMERGING GROUND SOURCE HEAT PUMPS, ADVANCED AIR SOURCE HEAT PUMPS, GAS-FIRED HEAT PUMPS and **ADVANCED GAS FURNACES** were highlighted in the market penetration because of their superior performance and cost potential across most geographic regions. However, other technologies may improve faster or at lower cost. So it is impossible to state with certainty that these technologies are the only ones to pursue. As the special low-cost scenario suggests, **ADVANCED AIR SOURCE HEAT PUMPS** in particular could gain in performance and/or price to tip the scales in their favor in many areas. Double or triple effect absorption heat pumps or desiccant wheel heat pumps (either air or ground source) might also compete strongly in the near term. Opportunities also exist for advanced central air conditioners.

The point is simple: in the race to win the market, the technological target is always moving!

CHAPTER FIVE

OPPORTUNITIES FOR ENHANCING THE MARKET FOR ADVANCED SPACE CONDITIONING EQUIPMENT

INTRODUCTION

This chapter discusses the challenges that must be met before the advanced space conditioning technologies identified as promising in Chapters Three and Four can achieve significant market penetration. Specific challenges are listed for each advanced technology -- **EMERGING GROUND SOURCE HEAT PUMPS, ADVANCED AIR SOURCE HEAT PUMPS, GAS-FIRED HEAT PUMPS, AND ADVANCED GAS FURNACE SYSTEMS.**

The discussion then turns to various strategies that utilities could adopt to meet these challenges, working in partnership with other utilities, government and non-governmental organizations, and the industry. Finally, some examples of partnerships that EPA has been involved with to accelerate advanced technologies in other end-use areas are reviewed as illustrations of the effect of concerted market action.

EMERGING GROUND SOURCE HEAT PUMPS

With a volume of roughly 20,000 units per year, produced mainly by four companies, the **GROUND SOURCE HEAT PUMP** industry occupies a relatively small niche in the national market. However, as the analyses in Chapters Three and Four suggest, **GROUND SOURCE HEAT PUMPS** can play a large role in transforming the space conditioning market toward "greener" technologies that prevent pollution cost-effectively. Key challenges exist in expanding the market penetration of **GROUND SOURCE HEAT PUMPS**:

Continuing Equipment Performance and Installation Improvements

The **GROUND SOURCE HEAT PUMP** industry has kept a strong focus on energy efficiency, since it is one of the strongest marketing attributes of this technology. However, in order to maximize this attribute, the industry needs to continue introducing high-efficiency components across its products. These include dual- or variable-speed compressor technologies, microprocessor controls, optimized heat exchangers and integrated domestic water heating.

Similarly, the industry needs to continue working with research bodies, government agencies, universities, dealers and installers to continue reducing the first costs of ground loop installations. Of course, this will mean using different solutions in different regions, in response to regional climate, soil, housing characteristics, and labor and equipment costs.

EPA, DOE, EPRI, EEI and other organizations can play a role in this effort to continuously improve new electric **GROUND SOURCE HEAT PUMP** technologies and installation procedures. For instance, work to reduce the environmental impact of direct exchange ground source heat pumps (DXHPs) by working with the industry on safe, non-chlorine R22 substitutes, could go a long way to achieve introduction of a technology that is lower in first cost, has better performance, and results in less environmental impact, than anything else analyzed in this report.

Development of Marketing and Delivery Infrastructure

In most areas of the nation, particularly urban and suburban areas, there is neither a marketing infrastructure to sell **GROUND SOURCE HEAT PUMPS** nor a dependable contracting capability to install them reliably and cost-effectively. Thus, any utility program in such an area will likely involve a ramp-up period in which residential (and for that matter, commercial) HVAC dealers are made aware of the promotion and given an opportunity to receive training and experience.

In the joint EPRI/Public Service Indiana (PSI) program, installers (and the utility DSM staff) gained experience while working on a few large, whole-development installations in new construction. EPRI has continued to work on similar types of developmental efforts with other utilities as well.

Developmental efforts with newly participating utilities can include communicating with dealers and contractors about the program. Contractors must be carefully qualified, in order to ensure high installation quality. Such organizations as the International Ground Source Heat Pump Association (IGSHPA) in Stillwater, OK provide direct contractor training and provide contractors with materials that assist in sizing and installing equipment and ground heat exchangers (for instance, EPRI is currently working with IGSHPA on integrating a soil characteristics database into an installation manual). Conversely, contractors can find out about training centers closer to their home region.

Training and experience-building in proper equipment sizing, cost-effective drilling and trenching technologies and techniques are all essential components to development of a successful implementation effort. Field experience for both contractors and utilities can be gained by following the PSI model of attracting the participation of tract developers who order multiple installations in new developments as they are constructed. As experience is gained, quality will increase and costs will come down. Once a suitable installation infrastructure is built up, the utility and participating dealers and contractors would be ready to go into an expanded program that includes both new construction and retrofits.

This leads to the next essential component of a successful, sustained commercialization initiative: organizing a steady, dependable market that will provide enough demand to optimally sequence jobs in both new construction and retrofits. Utilities, dealers and other interested organizations can form marketing and public education partnerships to develop such a market. However, this must be properly sequenced with the development of solid installation expertise, in order to assure an-ever growing network of the best kind of marketing: word-of-mouth endorsements by satisfied consumers and businesses.

ADVANCED AIR SOURCE HEAT PUMPS

Reducing First Cost

The regional performance and utility-based cost-effectiveness analyses in Chapter 3 indicate that the **ADVANCED AIR SOURCE HEAT PUMP** will be much more attractive from the standpoint of utility conservation programs once its sales volume increases enough to allow for substantial cost reductions.

Concerted action by utilities and other organizations could vastly improve the demand for **ADVANCED AIR SOURCE HEAT PUMPS** and lead to economies of scale in production. In order to overcome the "Catch-22" that exists, however, such actions will likely come about only if expectations are high that they will have the intended price effect. Utilities and other organizations must work together and with the industry to explore ways to accomplish this goal within the constraint of antitrust laws.

Performance Improvements

Furthermore, if the **ADVANCED AIR SOURCE HEAT PUMP** is to compete strongly in colder climates, additional technical work may be required to increase its cold-weather heating capacity and operating performance. From the utility's standpoint, it is particularly important that the **ADVANCED AIR SOURCE HEAT PUMP** require as little back-up electric resistance heat during winter peaks as possible.

It may be possible that the air-source industry, faced with competition by newer technologies such as **GROUND SOURCE HEAT PUMPS** and **GAS-FIRED HEAT PUMPS**, could respond with further improvements in performance in order to gain market share. It may be possible for manufacturers to work on performance improvements at the same time that they join in partnerships with utilities and other organizations to achieve the increased penetration and economies of scale mentioned above. In such a scenario, a portion of the price reductions resulting from higher market volume would be offset by including additional, performance-improving technologies that would further increase the **ADVANCED AIR SOURCE HEAT PUMP's** cost-effectiveness and attractiveness to utilities.

Some measures have been taken to boost the performance of **AIR SOURCE HEAT PUMPS** through off-peak thermal storage (Chapter 2) so that they can provide more comfort during winter peak load periods without requiring daytime electric resistance backup. These measures may be especially appropriate for utility promotion in cases where **GROUND SOURCE HEAT PUMPS** are not feasible (such as where it is not possible to install ground loops). However, although a limited number of such installations may improve overall utility load factors, thermal storage systems that rely heavily on electric resistance would do nothing to reduce overall utility emissions (unless utility marginal off-peak, baseload capacity is dominated by non-emitting resources, such as hydroelectric or nuclear, or low-emitting resources such as advanced natural gas combined cycle).

GAS-FIRED HEAT PUMPS

In many regions, particularly those dominated by winter heating loads, the **GAS-FIRED HEAT PUMP** appears to be quite competitive with other gas and electric end uses. However, these analyses were performed without the benefit of commercial introduction. Several factors, explicit or implied in the analysis, could impede the penetration of **GAS-FIRED HEAT PUMPS**.

Product Reliability

There is limited documentation on the lifetime of the **GAS-FIRED HEAT PUMPS** or on the actual frequency of maintenance during that lifetime. The constant, all-season cycling of the **GAS-FIRED HEAT PUMP** will involve thousands of hours of engine operation time over the service life of the unit. The gas engine may require frequent maintenance and early replacement, leading to substantially higher maintenance cost differentials over other equipment than were modeled for this report. Obviously, this would negatively effect the cost-effectiveness of this technology.

Preliminary observations, however, are encouraging. The variable speed operation of the GAS-FIRED HEAT PUMP will provide more even temperature and humidity control than single speed equipment. Although the load-following capability of variable speed equipment will increase the total operating hours in a year, these greater operating hours will be offset by a substantial reduction in equipment on-off cycles. The gas engine has undergone extensive durability testing in the laboratory and in field testing. To date, accumulated engine test hours are approaching 500,000 test hours. Field test experience of 45,000 demonstrated gas heat pump reliability in excess of 99 %. Cumulative experience provides evidence that engine life will exceed 60,000 hours (15 to 20 years of normal operation). Currently an annual maintenance interval is required to change the oil, oil filter, air filter and spark plug. A rigorous maintenance program coupled with good application experience may, increase this interval to two years.[1]

Product Cost

Second, the first cost of the equipment across various nominal sizes is not known with certainty. While a large market and competition might reduce capital costs and make **GAS-FIRED HEAT PUMPS** more competitive in all regions, it is not known yet how quickly or to what degree this will happen.

Environmental Impact

Finally, based on GRI data, the analysis indicates that the internal combustion engine-driven **GAS-FIRED HEAT PUMP** currently has relatively high NO_x emissions. This led to net increases in most of the climate zones where **GAS-FIRED HEAT PUMPS** were modeled for promotion by utility DSM programs. If not successfully addressed by GRI efforts, NO_x emissions could be a serious detractor to widespread penetration in many areas because of air quality concerns, and could affect policy decisions regarding the use of **GAS-FIRED HEAT PUMPS**. Natural gas in fully-controlled advanced combined cycle generating plants and the promotion of the most efficient electric technologies would result in higher net efficiencies for the electric equipment (based on high generating plant efficiencies) and less emissions of CO_2 and NO_x.

NO_x emissions may necessitate the inclusion of control technologies in order to ensure acceptance of **GAS-FIRED HEAT PUMPS** in many areas. Of course, this may affect the product's first cost, performance and maintenance needs. Continuing efforts to commercialize the technologies such as the GAX, dessicants, and the Stirling external combustion engine could lead to reduced emissions, lower capital costs, and increased system performance.

ADVANCED GAS FURNACE SYSTEMS

As Chapter Four suggested, **ADVANCED GAS FURNACES/HIGH EFFICIENCY AIR CONDITIONERS** can also play a significant role in reducing air emissions in the residential space conditioning market, particularly in heating-dominated climates. They can achieve penetration especially among consumers who for various reasons cannot or will not move to **GAS-FIRED HEAT PUMPS**. For instance, since furnaces and air conditioners represent two separate systems, many homeowners could be expected to desire replacing only one or the other as they are individually retired from service.

Although they were modeled together to provide some consistency to the analysis in this report, **ADVANCED GAS FURNACES** and **CENTRAL ELECTRIC AIR CONDITIONERS** require promotional actions that must come from separate utilities, except in cases where the local utility is an integrated gas and electric utility. However, given strong DSM initiatives, both gas and electric utilities offering strong rebates for both furnaces and air conditioners can play an extremely important role in reaching consumers whom the **GAS-FIRED HEAT PUMP** will not be an attractive or feasible option.

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[1] Memorandum, Chuck French, Gas Research Institute, March 9, 1993.

OPTIONS FOR UTILITY ACTION TO ENHANCE THE ADVANCED SPACE CONDITIONING EQUIPMENT MARKET

Based on the report's analysis and on its involvement with voluntary industry efforts to develop new technologies, EPA has identified several steps that utilities could take to help advanced space conditioning technologies achieve their full market potential, after determining, based on their own individual analysis, that they are cost-effective DSM technologies. These options for utility action follow:

Exhibit 5.1
Options for Utility Actions to Promote Advanced Space Conditioning Equipment

1. Join in Partnerships with other Utilities
2. Sustain Effort over Time
3. Provide Clear Efficiency Improvement Goals
4. Provide a Program "Ramp-up" Period
5. Pay Rebates Directly to Manufacturer or Dealer
6. Provide Incentives for Continuous Efficiency Improvements
7. Expand Market through Early Retirement of Older, Inefficient Equipment
8. Attract Landlord and Builder Participation in Program
9. Support Continuing Product Research and Development
10. Support Non-DSM, Market-Based Incentives
11. Use Innovative Mechanisms other than Rebates

1. Join in Partnerships with Other Utilities

Manufacturers face significant risks in considering major investments in new technologies (e.g., retooling a factory to scale-up production). This is especially true for residential technologies that trade off higher first costs for life cycle energy savings. If many consumers are not willing to pay the extra capital costs, the manufacturer sees no reason to make the investment and bring the technology to market.

Of course, this barrier can be overcome with utility conservation programs. However, any individual utility in the United States, no matter how large, is not likely to be able to develop a rebate program that will inspire a manufacturer to invest in that new technology. It could not likely account for enough sales of a particular product to justify the manufacturer's investment in an entire production line.

On the other hand, if enough utilities come together to coordinate their DSM programs and pool their demand for an advanced technology, they can create a large enough market to justify investments by one or more manufacturers to commercialize the technology on a mass production level.

2. Sustained Effort

Utilities can further reduce the risk to product manufacturers if they commit to a relatively long-term advanced space conditioning technology procurement program -- for instance, five years or more, with some time allowed for program "ramp-up" (see below). This provides manufacturers with an unprecedented degree of certainty about the market for the new product. The longer the utility commitment, the more clearly the manufacturer is able to see that the investment it must make to introduce new technologies or scale up production of existing technology will earn healthy profits over its amortization period.

3. Clear Efficiency Improvement Objectives

Utilities participating in a sustained effort to promote advanced space conditioning technologies can offer informal "guidance" to manufacturers by indicating the specific efficiency of the equipment for which they will provide rebates. These efficiency levels may go beyond existing technologies for future program years. The efficiency targets could reflect improvements in existing equipment or prototypes. For **GROUND SOURCE HEAT PUMPS**, utilities may wish to specify future subsidy eligibility standards that require the adoption of such technologies as variable speed drives and integrated water heating functions.

4. Utility Program "Ramp-Up" Period

Utilities should give programs a year or two of development and set-up before reaching full implementation. This time can be used to communicate the program, particularly to HVAC vendors in their service territory, and to develop a capable dealership, installation and servicing infrastructure. For **GROUND SOURCE HEAT PUMPS**, efforts could focus on expertise in installing both vertical and horizontal ground loops, and optimizing the system design and operations in various local soil conditions. In this area, utilities can avail themselves of existing contractor training and "train-the-trainer" programs, such as that provided by the International Ground Source Heat Pump Association (IGSHPA).

EPRI's Utility Program Development Efforts. As mentioned above, electric utilities promoting **GROUND SOURCE HEAT PUMPS** could develop hands-on contractor installation experience by following the approach used by EPRI in its programs with Public Service of Indiana (PSI) and several other utilities. In the PSI project, early efforts centered on multiple installations in new developments. This provided PSI and its contractors with a means of building up installation capabilities, increasing reliability and reducing costs. Once this expertise has been nurtured, the utility can work with vendors to expand into the much larger replacement/retrofit market.

Since working with PSI, EPRI has continued to refine and apply its practical, implementation-oriented approach to several other utilities. It remains committed to educating utilities to the point at which they are able to manage successful, cost-effective programs independently.

Similarly, for **ADVANCED AIR SOURCE HEAT PUMPS** and **GAS-FIRED HEAT PUMPS**, dealers will have to be made aware of the utility's efforts, and training in installation and maintenance will need to be carried out.

If well-coordinated, the utility ramp-up period could be used by manufacturers to implement investments in new production, whether that be in developing entirely new product lines or continually improving on existing technologies. Thus, when the utilities are ready to fully implement their incentive programs, the manufacturer(s) will be able to respond with a sufficient number of eligible units.

5. Direct Manufacturer or Dealer Incentives.

Several utilities have become interested in offering incentives, such as rebates or sales support payments, to dealers or manufacturers instead of to purchasing consumers. There are two main reasons why such design can be beneficial for a program to accelerate technology: a) the more directly utilities "communicate" with the manufacturer or dealerships, both verbally and through incentives, the more likely the manufacturer will respond with a positive production decision; and b) the further up the distribution chain the incentive is placed, the greater will be its likely price effect. This is because the incentive "arrests" a portion (or all) of the incremental cost of an improved technology before the distributor or retailer pays that extra cost and takes an additional mark-up on it.

Exhibit 5.2 illustrates the advantage of a direct manufacturer incentive by comparing it to a "no incentive" and a "customer rebate" scenario. Column A (No Incentive) shows a hypothetical, unsubsidized transaction. Suppose a heat pump costs $3,500 to build, and the manufacturer takes a 30% markup on it, selling it directly to a dealer for $4,550. The dealer in turn takes another 30% markup, selling it to the consumer for $5,915.

Column B shows the price effect of a $1,500 consumer rebate on this transaction. The effect is straightforward, since the manufacturer and the dealer have been unaffected by the subsidy, and therefore take the same markup, leading to the same selling price as in Column A -- $5,915. The rebate after the sale leads to a net cost to the consumer of $4,415.

Column C shows how the manufacturer incentive works to the consumer's advantage. The same $1,500 utility incentive payment is paid directly to the manufacturer, reducing the manufacturer's price by $1,500. Since the dealer pays less, the 30% dealer markup is of a smaller magnitude than in Columns A and B. Because it occurs "upstream" from the dealer markup, the $1,500 utility incentive payment is 30% more effective in lowering the consumer price than the consumer rebate -- it would have taken a consumer rebate of $1,950 to reduce the price of the heat pump as much as the $1,500 manufacturer rebate does.

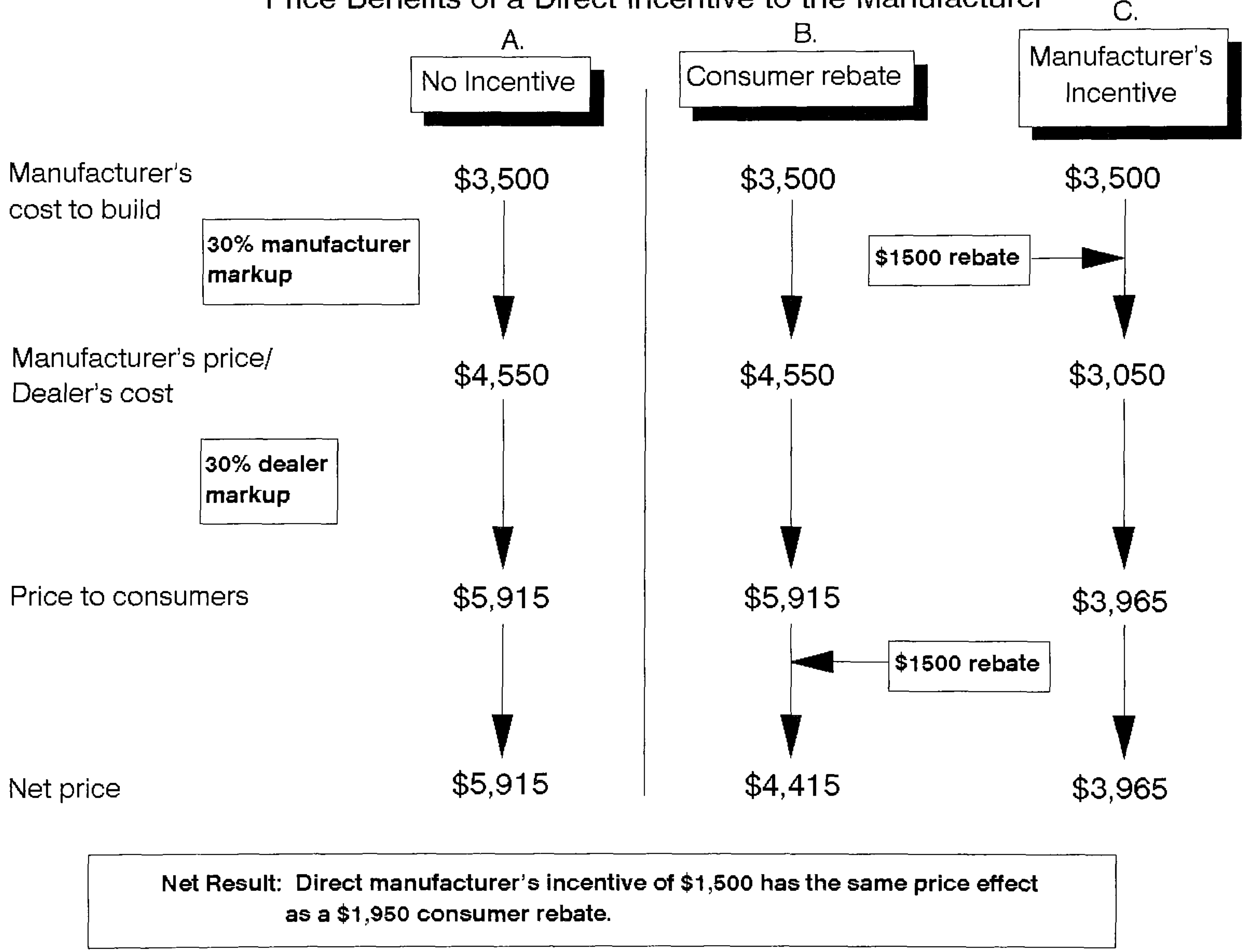
Of course, the payment directly to the manufacturer affects the utility's control over verifying that the consumer is its customer before the incentive is paid. Utilities participating in a common program initiative could carry out a dialogue with the industry in order to understand how distribution is carried out before deciding how incentives can best be designed -- to the manufacturer, to distributors, to dealers, or to consumers. This dialogue not only provides valuable insights to utilities interested in optimizing DSM program design, but also educates manufacturers as to where utility DSM is headed and underscores the level of commitment that utilities are bringing to their programs.

6. Incentives for Continuous Improvement.

In designing long-term programs to affect manufacturer production decisions, participating utilities must select a threshold efficiency standard for program eligibility. That minimum level may or may not be based on currently best available technologies. However, not knowing how far manufacturers might eventually be able to go in improving unit efficiency, participating utilities could develop an open-ended incentive schedule. In other words, for additional kWh saved or peak kW avoided beyond the minimum level, utilities would be willing to pay an extra amount of incentive.

This would provide a strong incentive for manufacturers to continuously improve their equipment, especially if the incremental cost for the improvement is less than the incremental utility incentive offer. Also, it would provide flexibility by allowing manufacturers to produce cost-effective savings through any technological pathways that they choose. Manufacturers could then openly compete through continuous improvements for the utility-subsidized energy efficiency market.

Exhibit 5.2
Price Benefits of a Direct Incentive to the Manufacturer



7. Market Expansion through Early Retirement

As discussed at the end of Chapter Four, utilities could expand the market and provide an additional niche for advance space conditioning equipment by promoting the early retirement of old, inefficient and poorly performing equipment.

8. Work to Attract Landlords and Builders as Participants.

Utilities that are willing to pay close to or all of the incremental cost of advanced technologies for space conditioning will stand a good chance of attracting the participation of landlords and builders. This is because first cost drives their market decisions even more than it does homeowners, since they generally do not receive the economic benefits of the energy savings. Incentive program structures can follow the example of PSI's pilot program, in which the utility picked up responsibility for installing the ground loop through its own competitively-selected contractor, and also awarded a rebate on the high-efficiency heat pump equipment as well.[2] Public housing authorities can also be encouraged to participate in the program, in order to bring the benefits of advanced space conditioning equipment to lower-income consumers.

9. Continuing Product Research and Development.

The commercialization efforts of utilities, including incentives for continuous product improvement as discussed above, are well complemented by continuous, near- and long-term product R&D. In addition to its program development work, EPRI has been engaged over the years in such research. Much of this has focused on bringing down the costs of ground loops, which EPRI identified as a top priority for ground source heat pumps a few years ago. In the area of heat pump equipment, EPRI has played a central role with selected manufacturers to produce such products as the Carrier Hydrotech 2000, and, more recently, a dual-fuel air-source heat pump (which was not included in the scope of this report).

Similarly, the Department of Energy (DOE) has long played a role in carrying out the kind of long-term product R&D that domestic manufacturers often find too risky. Through various national research laboratories, and by funding manufacturers directly, DOE continues to support R&D in the areas of advanced technologies and alternative refrigerants and insulating agents.

On the gas side, the Gas Research Institute has worked, much like EPRI, with manufacturers interested in developing and commercializing high efficiency gas end use technologies. GRI and the American Gas Cooling Center (AGCC) worked directly with York, International to develop the **GAS-FIRED HEAT PUMP** that is analyzed above; it is also engaged with manufacturers in developing gas-powered absorption, desiccant and Stirling technologies.

Any forward-looking, long-term utility procurement of advanced technologies should maintain a focus on product R&D as supported by EPRI, DOE and GRI. It provides a mechanism for broadening the technological response to a market demand for energy efficiency, thereby increasing both competition and the odds that the efficiency goal will be obtained. It provides a valuable alternative to "end state" approaches that rely too heavily on the success of a single technology to the expense of other viable alternatives.

Continuing Substitute Refrigerant Work. The presence of sustained utility incentives, coupled with a recognition by the industry that it is necessary to consider R22 alternatives, can also

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[2] EPRI, Waldon Pond

result in an accelerated transition in the industry to alternative refrigerants that are both suitable from a toxicity and safety standpoint and save money and energy through increased performance.

As discussed in Chapter Two, EPA is particularly interested in R32's promise as a capacity- and efficiency-improving substitute for R22 in heat pumps. EPA will continue to work with involved organizations to develop safe and effective substitutes for use in advanced equipment in order to pursue its strong commitment to stratospheric ozone protection and climate stabilization.

10. Alternatives to DSM: Market-Based Incentives.

As an alternative or a complement to building efficiency regulations and utility DSM investments, state regulators or legislators can devise methods to provide financial incentives that induce developers to increase the efficiency of new buildings. Electric demand hook-up fees have long been discussed as such a mechanism. The hook-up fee could be set at a $/kW level that is greater than or equal to the cost of an investment in energy efficiency that is cost-effective on a lifecycle basis. It allows developers flexibility in responding with measures that they find suitable.

11. Innovative Program Design -- Alternatives to Rebates

Utilities have often explored innovative alternatives to rebates to overcome the high first cost barriers to efficient equipment. Equipment leasing programs, in which the utility or a third party energy service firm owns the energy-efficient equipment and leases it to the user for a monthly charge, is one such approach. The user is not required to pay the high first cost for the equipment or take responsibility for maintaining it; the monthly charge schedule can be structured so that any extra capital costs associated with the efficient technology are offset by reduced energy bills.

A properly structured "shared savings" arrangement that pegs a monthly payment for equipment use to the energy savings achieved provides the customer with a net positive cash flow, while giving the lessor an incentive to maximize energy savings through equipment performance and maintenance. Such programs are usually reserved for commercial utility customers, but some utilities have lately begun to seriously consider variations of this approach in their **GROUND SOURCE HEAT PUMP** programs (Exhibit 5.3).

Exhibit 5.3
Utility Ownership of Ground Loops

The key element in the high capital cost for a **GROUND SOURCE HEAT PUMP** is the ground loop. If the customer did not face this cost, the system would be extremely cost-competitive with other technologies. Innovative thinkers in the DSM field have identified the ground loop as a variation of a renewable "power plant" that produces both heating and cooling. Instead of the homeowner bearing the cost of the loop installation, the utility could build and own the loop itself. In this approach, the utility would treat the loop much as it would a generating facility and charge the customer for the heating and cooling that it provides. The loop thus earns revenues and a rate of return on investment comparable to any other generating facility. This approach has several positive attributes:

- the first cost of the system to the homeowner is drastically reduced, as in the case of a DSM incentive;
- a utility could install one large loop to service multiple customers, such as in a townhouse development, thereby reducing costs;
- the utility enjoys a relatively low cost of capital relative to a ratepayer, thereby improving the economics of the measure;
- the loop is a depreciable asset that provides a tax benefit to the utility, which could pass part of the benefit along to the consumer;
- the utility could institute a leasing arrangement that recovers the loop costs from the individual homeowner purchasing the ground source heat pump; and
- other ratepayers are not asked to subsidize the participant through their rates, as is often the case with DSM measures.

Example: A utility lease arrangement induces a homeowner to buy an **ADVANCED GROUND SOURCE HEAT PUMP** instead of a **STANDARD AIR SOURCE HEAT PUMP** in the upper New York metropolitan area. The utility rebate covers the extra cost of the heat pump unit but the utility installs and owns the loop and leases it to the homeowner:

Incremental Cost of Heat Pump Unit	$960
Loop Cost	$2,335
Present Value of Depreciation Tax Benefit	$607
Net Cost to Recover through Loop Lease	$1,728
Duration of Lease	20 years
Utility Pre-Tax Return Rate (35% tax rate)	16.6%
Monthly Lease Payment	$25
Average Monthly Bill Savings	$55
Net Monthly Consumer Savings	$30
Pre-Tax Income Effect for Consumer (28% marginal income tax rate)	$461

Under this arrangement, the homeowner gets a steady stream of savings that actually increases with inflation, and in 20 years even takes over ownership of the loop -- without laying out any extra money up front. Meanwhile, the expense of the rebate faced by utility ratepayers is only about 30% of what it would have been if the rebate had covered the cost of both the heat pump and the loop ($960 vs. $3,295).

Of course, there are institutional and ownership issues that would have to be addressed, much as in the case of utility pipelines and distribution poles. However, the potential benefits are substantial enough to warrant serious consideration as an alternative to a rebate program approach.

Source: Discussion paper by John R. Nelson, President, Geotech, Inc., 8033 Main Street, Troy, NY 12180. Data for the example is taken from Appendix C.

THE CONSORTIUM FOR ENERGY EFFICIENCY

Of the above options for utility action, the first is likely to have the greatest impact, since no matter what the scheme, no individual utility working on its own can hope to have the impact that it could have working in conjunction with other utilities, regardless of its program approach.

One institutional framework is currently emerging as a channel for utilities to communicate and coordinate their efforts to accelerate the market penetration of emerging, advanced technologies. The Consortium for Energy Efficiency (CEE) is a unique, public/private partnership of utilities, power authorities, public agencies (including EPA) and conservation groups. Its prime mission is to identify where technological opportunities for energy efficiency and pollution prevention exist and to overcome market barriers to those technologies through common utility efforts.

Such utility initiatives to accelerate new technologies have been dubbed "Golden Carrots"SM. The first Golden CarrotSM program was initiated in 1991; 25 utilities and power authorities from around the nation designed the Super Efficient Refrigerator Program (SERP) to offer over $28 million in utility incentives to promote the early introduction of super-efficient, chlorofluorocarbon (CFC) free refrigerators by a manufacturer winning a bid competition.

SERP has utilized some of the elements listed above in its program design. It represents a coordinated, long-term DSM procurement program; utilities committed as early as 1991 to paying incentives for super-efficient refrigerators that will be delivered between 1994 and the Fall of 1997. The time provided for program set-up will be used by the manufacturer awarded the contract for the design, testing and production of complying units; utilities will use that period to field test pre-production models, implement systems for refrigerator tracking and payment, and developing marketing materials (such as a logo identifying the award winning refrigerators). Where the refrigerators are shipped to market, price reductions will be assured by direct manufacture incentive payments.

Since SERP utilities were unsure of just how much efficiency manufacturers could achieve with new refrigerator configurations, they also designed their competitive bid to encourage as much cost-effective energy conservation as possible. This was done by offering incentives that could increase with each extra kWh/yr. saved and giving extra points in the bid scoring for the extra efficiency.

Golden CarrotSM-type approaches can be applied broadly in the area of space conditioning equipment. For example, in order to promote the work of GRI and York International, the American Gas Cooling Center has initiated a consortium with gas utilities to help commercialize **GAS-FIRED HEAT PUMPS** in 1994. The discussions have involved producing a guaranteed pool of incentive money to be paid directly by gas utilities to the manufacturer during the first few years of sales. The utilities then would recoup their investment through a royalty. This initiative has the potential to evolve into a strong, sustained and comprehensive effort to accelerate the market penetration of gas-fired heat pumps. So far, about $14 million in sales subsidy support, targeted at reducing the sales price of 25,000 units in the first few years, is envisioned.[3]

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[3] Personal Communication, Richard Sweetser, Executive Director, American Gas Cooling Center, Arlington, VA, June 12, 1992.

ENERGY STAR HVAC SYSTEMS

Utilities and manufacturers can complement initiatives supporting advanced space conditioning equipment with participation in EPA's Energy Star approach. The Energy Star program is a voluntary partnership between manufacturers and EPA in which the manufacturer agrees to produce energy efficient products, in return for the market benefits of using EPA's "stamp of approval," the Energy Star Logo. Coupled with cooperative publicity efforts, the Energy Star Logo will let consumers know that the product is among the very best on the market from an energy efficiency (and, therefore, operating cost) standpoint.

The Energy Star HVAC system designation could work directly with a variety of utility program designs, providing a valuable marketing tool to help consumers become better informed about the presence of an advanced technology on the space conditioning market.

OPPORTUNITIES IN EXPORT MARKETS

As part of its mission on global climate stabilization and ozone protection, EPA works with major international players to promote energy efficiency and pollution prevention goals. In doing so, EPA provides American manufacturers with key opportunities to expand into new markets overseas. This simultaneously achieves the goals of protecting the global environment and promoting the competitiveness of American industry.

For instance, through its international technology transfer programs EPA has complemented its domestic work promoting super efficient, CFC-free refrigerators with programs in major developing countries, such as India and China. EPA is involved in numerous such projects in Asia, Eastern Europe, and Central and South America.

FUTURE EPA PLANS FOR SPACE CONDITIONING EQUIPMENT

EPA plans to continue its dialogues with HVAC manufacturers, utilities, utility commissions, DOE, GRI, AGCC, AGA, EPRI and EEI to develop markets for highly efficient residential space conditioning systems, and to translate those dialogues into timely, tangible and effective actions on the market. We are evaluating programs to support development of:

1. Aggregate purchases
2. Coordinated Utility Rebate Programs
3. Filings with public utility commissions on IRP policies that promote strategic, cost-effective DSM leading to rapid market transformation
4. Energy Star™ Logos for superior products
5. Ongoing R-22 replacement work
6. Advanced R&D on better compressors, non-azeotropic refrigerants, capacity control through fluid regulation, and variable capacity/speed systems

We encourage readers to begin working with us immediately. Contact Michael L'Ecuyer, Global Change Division, U.S. Environmental Protection Agency, Mail Code 6202J, 401 M Street SW, Washington, DC 20460.

APPENDIX A

APPROACHES TO GROUND HEAT EXCHANGE LOOPS

An essential component to the operating efficiency and cost-effectiveness of a **GROUND SOURCE HEAT PUMP** is a properly sized, properly functioning ground heat exchange loop. This Appendix describes some of the approaches to ground loops, both "traditional" and new.

VERTICAL LOOPS

Configuration: A vertical ground loop requires the insertion of a U-shaped section of plastic pipe into a drilled borehole. Borehole size requirements are 5-6" for loops using 1 1/2-2" pipe and 3-4" for loops using 3/4-1" pipe. Depending on the total length of pipe required (which depends on climate and soil type), multiple borehole loop sections may be required. These are connected either in series or in parallel configurations. Series configurations typically use 1-1 1/2" pipes connected so that the returning fluid from one vertical loop feeds the inlet to the next (Exhibit A-1). Parallel loops typically use 3/4" pipes off of a common feed header. The fluid flows simultaneously through each of the vertical loops and is returned to the heat pump via a common return header. The return header has a reverse-return flow to ensure balanced flow through each vertical loop (Exhibit A-2).

Laying a Vertical Loop: Drilling equipment, similar to that used in the oil industry or for drilling water wells, is frequently used for installing a vertical loop. For this reason, vertical loops are generally more expensive than horizontal loops because of the high costs associated with the purchase and use of installation equipment. Costs vary across regions, due to differing soil conditions, driller experience and capacity, labor costs, and whether or not the region has an already-existing infrastructure for oil-drilling or well-drilling. Technological improvements that would drastically reduce the cost of vertical installations are not expected. Reductions in cost are expected to occur, however, as a result of economies of scale from job scheduling and equipment utilization.

Exhibit A-1
Ground Source Heat Pump Ground Loop Configuration: Vertical, Series Installation

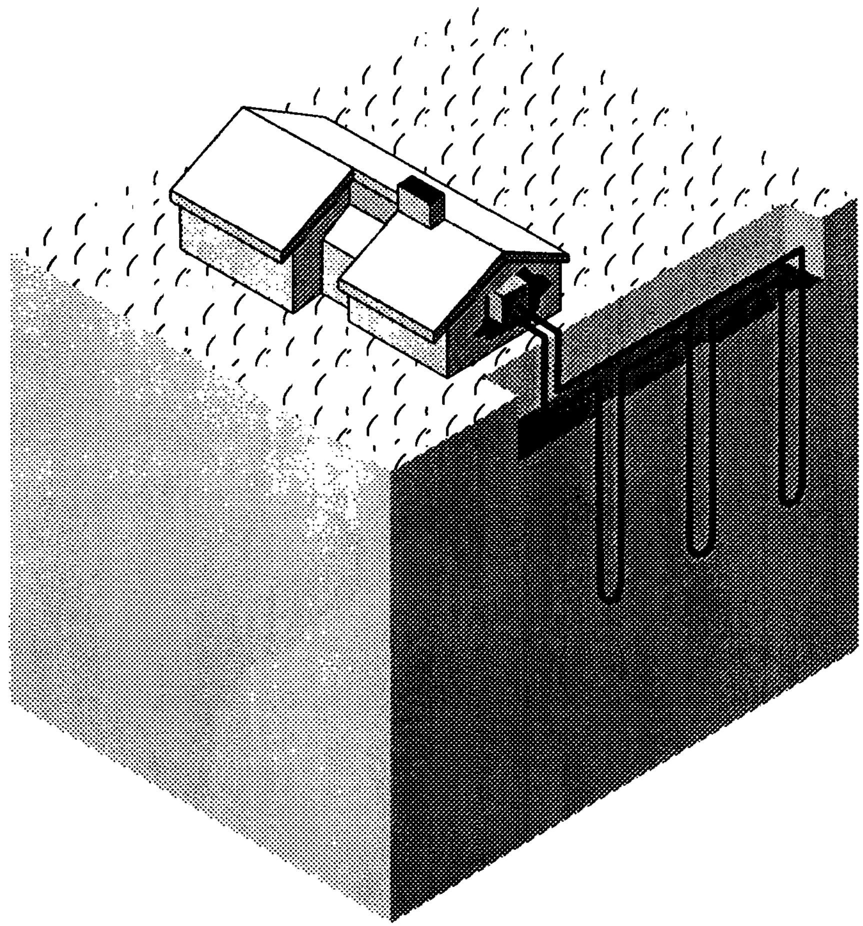
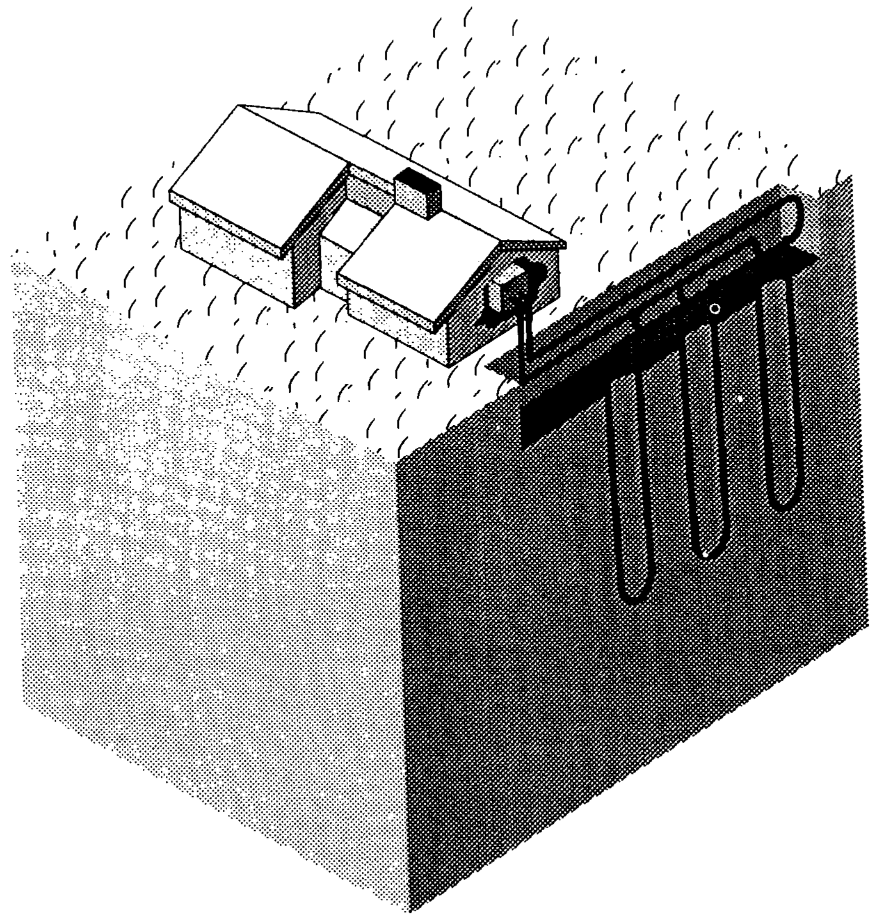


Exhibit A-2
Ground Source Heat Pump Ground Loop Configuration: Vertical, Parallel Installation



HORIZONTAL LOOPS

Configuration: Horizontal loops are placed in trenches 3-6' deep and 4-24" in width; in colder climates, they may be put in deeper than 6', at an increased cost. Alternatively, the length of the loop can be increased to accommodate large winter ground heat exchange loads.

Laying a horizontal loop: Horizontal loops can be placed in single-pipe trenches excavated by a trenching machine (Exhibit A-3) or in multiple-pipe trenches excavated by a backhoe. In either case, this is standard equipment used for excavation of any commercial or residential construction. Multiple-pipe trenches can have pipes that are laid on top of each other (for instance, at four- and six-foot depths with backfill in between), or side-by-side in the wider trenches. Multiple-pipe trenches require approximately 20% more pipe, but can reduce total trench lengths by about 40%. As in the case of vertical loops, horizontal loops can be placed in series or in parallel (See Exhibit A-4 for an example).

The "SLINKY™" Horizontal Ground Loop

Installation experts in the Midwest, working with Oklahoma State University, have developed a new, low-cost horizontal configuration that requires less trenching than traditional horizontal loops. In the "SLINKY™" system, the polyethylene pipe is wrapped into a coiled configuration and dropped into a trench that is only about 6" wide (Exhibit A-5). This configuration uses up to twice the pipe, but reduces trench lengths by up to 73%. Where a regular horizontal installation would require a trench 400 - 600 feet long per ton, a slinky installation can be put in using trenches 80 - 125 feet long per ton. Since trenching represents the majority of the ground loop installation cost, the SLINKY™ system represents a major cost reduction -- about 30% over the low end of horizontal systems, or about $1,050 - $1,500 for a three-ton system, as opposed to $1,500 - $2,000.

Exhibit A-3
Ground Source Heat Pump Ground Loop Configuration: Horizontal, Single Pipe Installation

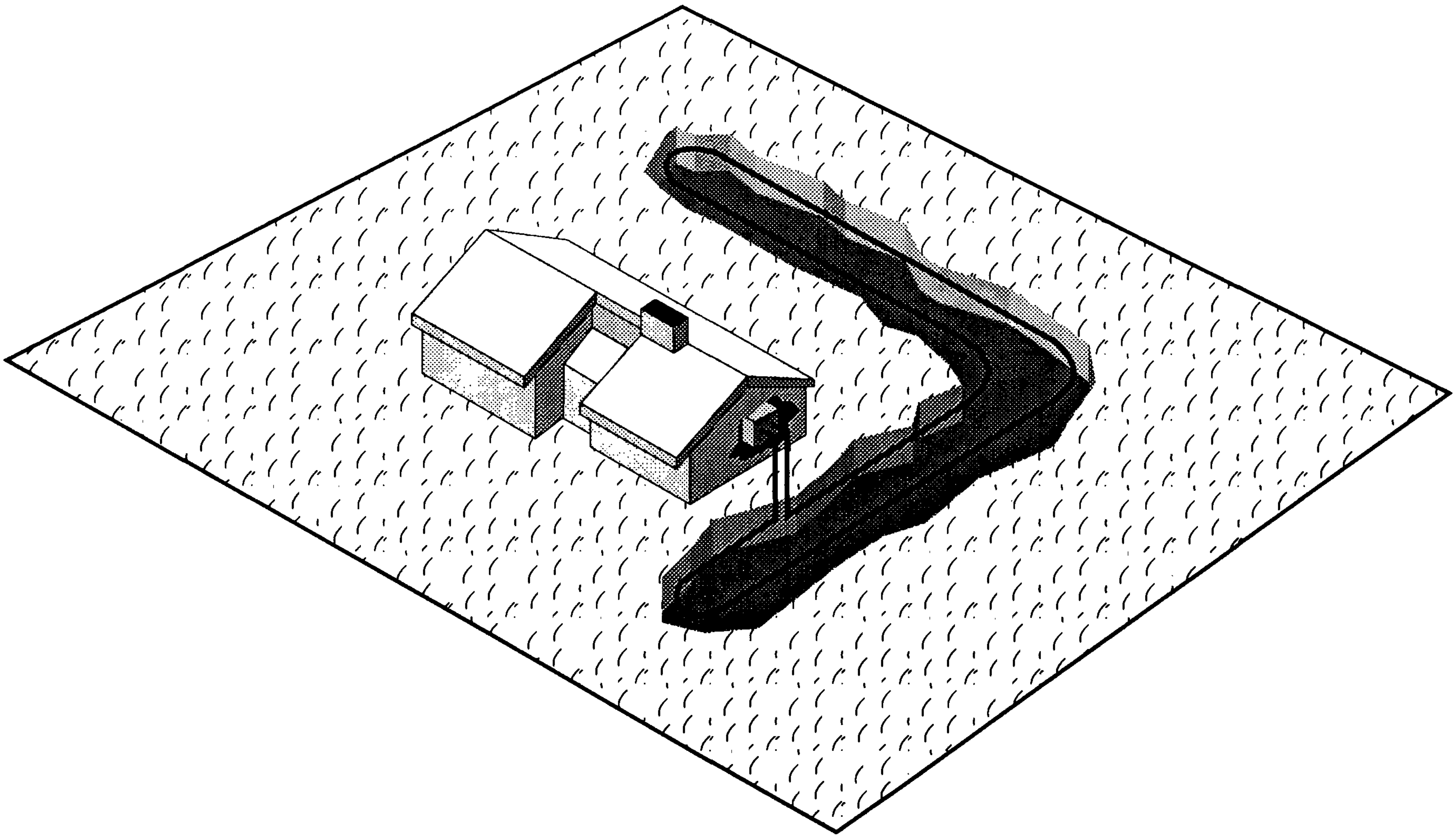


Exhibit A-4
Ground Source Heat Pump Ground Loop Configuration: Horizontal, Parallel Installation

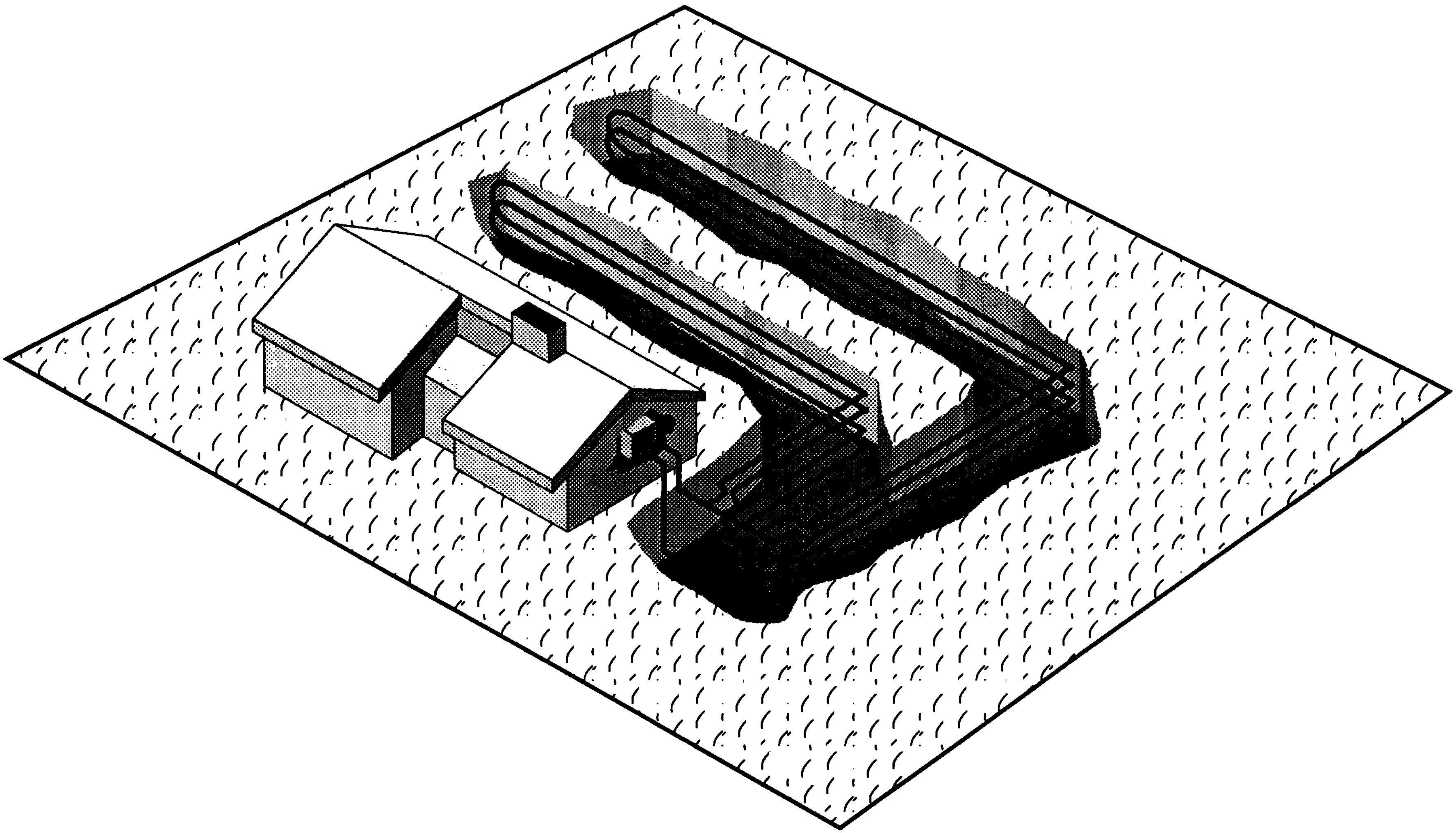
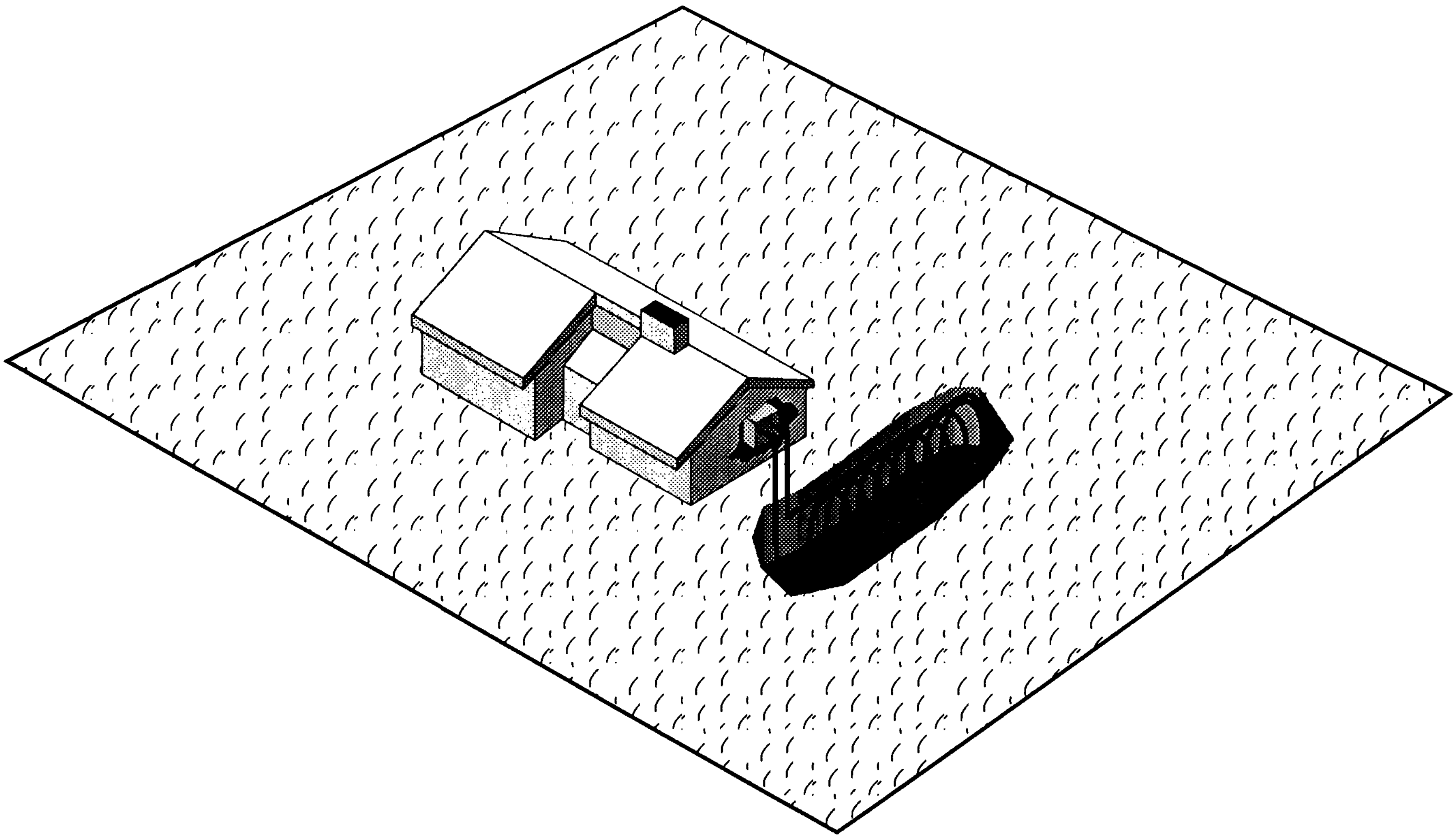


Exhibit A-5
Ground Source Heat Pump Ground Loop Configuration: Slinky™ Installation



Alternative to Trenching: Horizontal Bores

In many situations, especially retrofits, existing structures or other obstacles make it impossible to dig enough trench to install a horizontal ground loop. In response, Ditch Witch International developed the Jet Track™ Guided Boring System. This system is an adaptation of technology used to run electric cables under existing structures such as roads without necessitating tearing up the road. The one drawback is that they may not be able to operate well in very rocky or boulder-laden soil.

The Jet Track™ system consists of a boring rig designed to fit through garden fences that feeds sections of boring bits into the earth at an angle. A specially designed head on the lead bit allows its direction to be controlled and sends radio signals to a monitoring unit that gives its location and depth. A field worker reading this information communicates by radio with the worker at the boring rig and instructs him to control the direction of the bit -- to turn left, go deeper, come up higher, etc. Once the bit has re-emerged at a predetermined location, the bit head is changed to one that holds the ground loop pipe, which is then dragged through the hole as the bit is retracted back to the rig. The Ditch Witch system simultaneously injects grout as this process is carried out (Exhibit A-6).

Alternating Loops

Another method of installation has been developed by Geotech of Troy, NY. It uses a system of multiple independent ground loops between which the circulating fluid can be switched intermittently during operation. As the geothermal system cycles through one loop the efficiency of the heat exchange is reduced as the soil temperature changes and the temperature difference between the incoming refrigerant and the soil is reduced.[1] When resistance builds up, the Geotech system simply switches to a different loop so that the heat can be replenished or dispersed in the first loop, as the case may warrant. As a result, the system's overall capacity to reject heat to or extract it from the surrounding soil remains fairly stable, even during peak usage periods. Switching of independent loops also allows for better balance in the system and better turbulence, which further increases the efficiency of the heat exchange and allows for systems to be designed with shorter total loop runs. The modular nature and dynamic balancing feature of the system also increases flexibility allowing installation of combinations of different loop lengths and configurations.[2]

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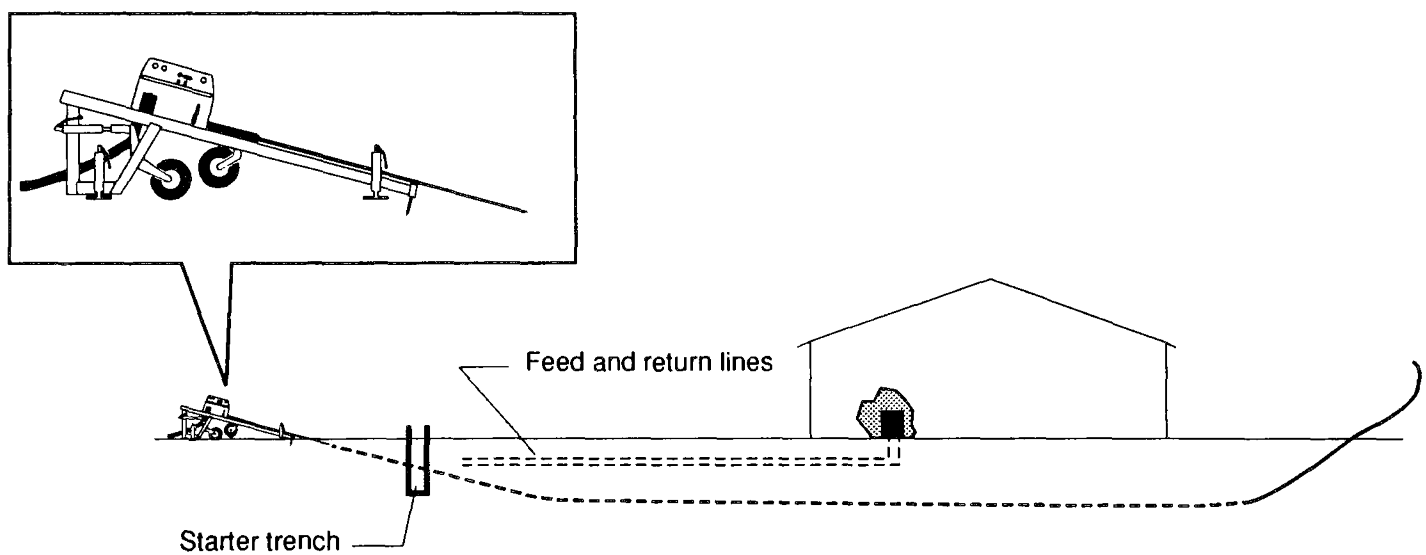
[1] In summer, heat would be deposited in the soil and soil temperature would rise. In winter, heat would be extracted from the soil and soil temperature would fall.

[2] "A Review of Geotech Heat Pump System (Heat Exchanger Loops)" Shiao-Hung Chiang, Ph.D. Energy Research Center, University of Pittsburgh. 4 Jan. 1991. Submitted to Atlantic Energy, Inc.

Exhibit A-6
Guided Boring System



APPENDIX B

EMISSION FACTORS USED IN REPORT

Regional Generation Mixes and Emissions[1]

NEW ENGLAND

Fuel	Utility Generation	Non-Utility Generation	Total	Percent of Total
Coal	16.2	1.1	17.3	14.04%
Gas	6.8	2.8	9.6	7.79%
Oil	32.9	0.8	33.7	27.35%
Nuclear	39.1	0.0	39.1	31.74%
Renewable	5.1	18.4	23.5	19.07%
Total	**100.1**	**23.1**	**123.2**	**100.00%**

Pollutant	Million Tons	Million kg	Generation kg/mmBtu	Delivered kg/mmBtu
SO_2	0.4	363.6	0.865	0.940
NO_x	0.1	90.9	0.216	0.235
CO_2	39.6	36,000	85.616	93.061

NEW YORK/NEW JERSEY

Fuel	Utility Generation	Non-Utility Generation	Total	Percent of Total
Coal	26.9	3.7	30.6	14.56%
Gas	37.0	5.4	42.4	20.17%
Oil	52.0	0.2	52.2	24.83%
Nuclear	46.1	0.0	56.8	27.02%
Renewable	28.2	10.7	28.2	13.42%
Total	**190.2**	**20.0**	**210.2**	**100.00%**

Pollutant	Million Tons	Million kg	Generation kg/mmBtu	Delivered kg/mmBtu
SO_2	0.5	454.5	0.634	0.689
NO_x	0.2	181.8	0.253	0.275
CO_2	99.1	90,090.9	125.578	136.497

[1] Source for Regional and National Utility Generation Emission Factors: Energy Information Agency, Annual Outlook for U.S. Electric Power, DOE/EIA-0474(91). July 1991, Appendix B.

MID-WEST

Fuel	Utility Generation	Non-Utility Generation	Total	Percent of Total
Coal	435.5	9.3	444.8	69.31%
Gas	38.0	14.1	52.1	8.12%
Oil	4.2	0.4	4.6	0.72%
Nuclear	122.0	0.0	122.0	19.01%
Renewable	6.0	12.3	18.3	2.85%
Total	**605.7**	**36.1**	**641.8**	**100.00%**

Pollutant	Million Tons	Million kg	Generation kg/mmBtu	Delivered kg/mmBtu
SO_2	2.4	2,181.8	0.996	1.083
NO_x	1.6	1,454.5	0.664	0.722
CO_2	516.7	469,727.3	214.442	233.089

SOUTH ATLANTIC

Fuel	Utility Generation	Non-Utility Generation	Total	Percent of Total
Coal	420.0	9.6	429.6	55.31%
Gas	57.1	4.4	61.5	7.92%
Oil	50.9	0.4	51.3	6.60%
Nuclear	170.0	0.0	170.0	21.89%
Renewable	34.5	29.8	64.3	8.28%
Total	**732.5**	**44.2**	**776.7**	**100.00%**

Pollutant	Million Tons	Million kg	Generation kg/mmBtu	Delivered kg/mmBtu
SO_2	2.6	2,363.6	0.892	0.969
NO_x	1.4	1,272.7	0.480	0.522
CO_2	516.2	469,272.7	177.025	192.419

WEST

Fuel	Utility Generation	Non-Utility Generation	Total	Percent of Total
Coal	67.6	1.5	69.1	14.04%
Gas	75.7	26.9	102.6	7.79%
Oil	17.8	0.2	18.0	27.35%
Nuclear	50.8	0.0	50.8	31.74%
Renewable	71.4	40.8	112.2	19.07%
Total	**283.3**	**69.4**	**352.7**	**100.00%**

Pollutant	Million Tons	Million kg	Generation kg/mmBtu	Delivered kg/mmBtu
SO_2	0.2	181.8	0.865	0.940
NO_x	0.5	454.5	0.216	0.235
CO_2	164.3	149,363.6	85.616	93.061

NORTHWEST

Fuel	Utility Generation	Non-Utility Generation	Total	Percent of Total
Coal	7.3	0.4	7.7	4.25%
Gas	8.7	2.3	11.0	6.07%
Oil	2.8	0.2	3.0	1.66%
Nuclear	14.8	0.0	14.8	8.17%
Renewable	138.0	6.7	144.7	79.86%
Total	**171.6**	**9.6**	**181.0**	**100.00%**

Pollutant	Million Tons	Million kg	Generation kg/mmBtu	Delivered kg/mmBtu
SO_2	0.0	0.0	0.000	0.000
NO_x	0.1	90.9	0.147	0.160
CO_2	20.6	18,727.3	30.282	32.915

NATIONAL

Pollutant	Million Tons	Million kg	Generation kg/mmBtu	Delivered kg/mmBtu
SO_2	10.0	9,090.9	0.740	0.803
NO_x	6.5	5,909.1	0.480	0.522
CO_2	2,388.1	2,171,000	176.44	191.8

EMISSION FACTORS (kg/MMBTU)

GAS FURNACE EMISSION FACTORS

SO2	0.001
NOx	0.045
CO2	51.670

OIL FURNACE EMISSION FACTORS

SO2	0.142
NOx	0.051
CO2	73.175

GAS-FIRED HEAT PUMP EMISSION FACTORS

SO2	0.001
NOx	0.140
CO2	51.670

ADVANCED GAS COMBINED CYCLE

SO2	0.001
NOx	0.089
CO2	109.056

ADVANCED FLUIDIZED BED COAL

SO2	0.030
NOx	0.203
CO2	251.866

GAS-FIRED COMBUSTION TURBINE

SO2	0.001
NOx	0.188
CO2	179.721

APPENDIX C

LOCATION-BY-LOCATION COMPARISON OF SPACE CONDITIONING EQUIPMENT

CLIMATE ZONE 1: BURLINGTON, VERMONT

This climate zone represents the coldest regions in the U.S. (Exhibit 3.1), covering Northern New England, Upper New York State, the Northern Midwest and West, and various mountainous regions. For the representative location, Burlington VT, the house used for the analysis was modeled to require 84.10 MMBtu for heating, 6.20 MMBtu for cooling, and 10.80 MMBtu for water heating annually, for a total energy demand of 101.10 MMBtu. Because of a significant presence of oil-heated homes on this regional market, OIL FURNACES are modeled as one of the competing technologies.

PERFORMANCE AND COST

Exhibit C.1 compares the operating performance of all of the representative space conditioning technologies described in Chapter 2. The three columns on the left indicate each equipment's modeled end-use seasonal performance factor (SPF, calculated by dividing the number of Btu's demanded in the location for heating, cooling or water heating by the number of Btu's of energy input the equipment required to meet that demand). The higher the SPF, the higher the technology's end-use efficiency.

The three right-hand columns of Exhibit C.1 show source SPF, accounting for the losses in the generation, transmission and distribution system for each fuel type. The two best net energy performers in each category are highlighted:

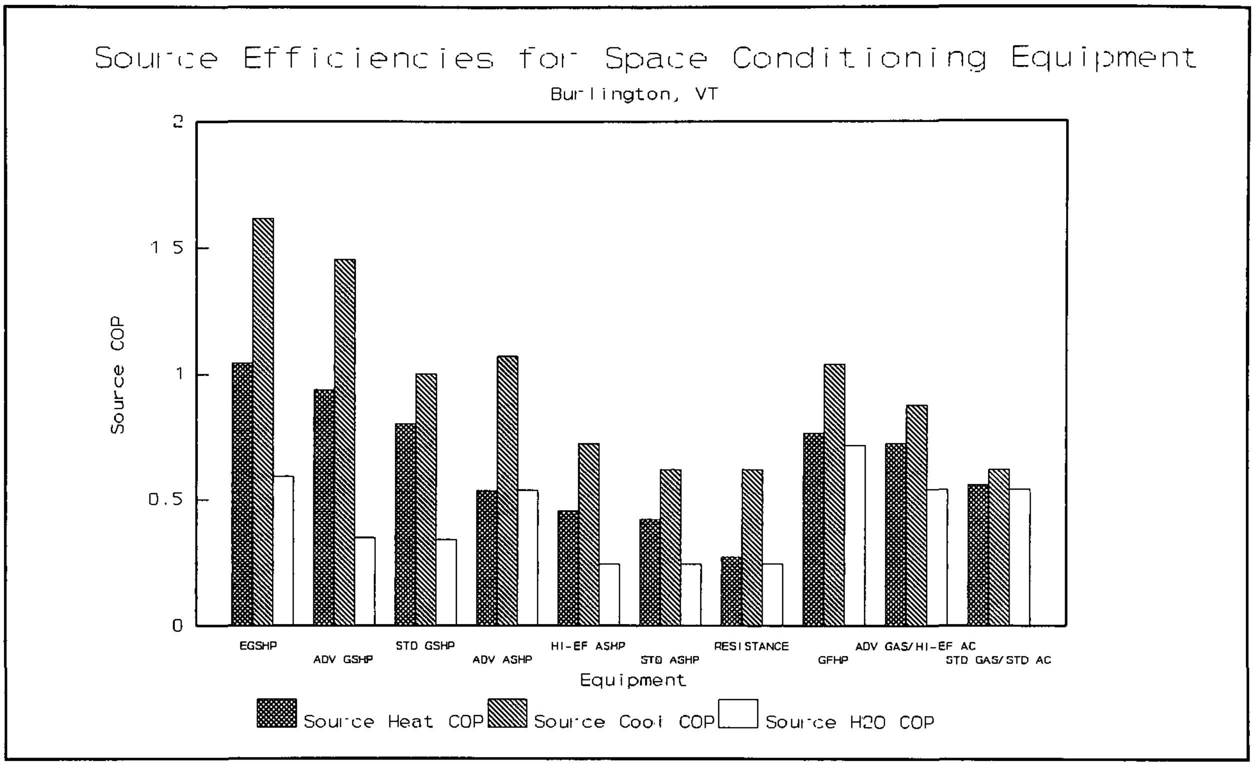
Exhibit C.1
Performance of Space Conditioning Equipment
Burlington, VT (including water heating)

	END USE EFFICIENCY			SOURCE EFFICIENCY		
	HEAT	COOL	H20	HEAT	COOL	H20
EQUIPMENT TYPE	SPF	SPF	SPF	SPF	SPF	SPF
Emerging Ground Source Heat Pump	3.86	5.99	2.20	1.04	1.62	0.59
Advanced Ground Source Heat Pump	3.48	5.39	1.29	0.94	1.46	0.35
Standard Ground Source Heat Pump	2.97	3.71	1.26	0.80	1.00	0.34
Advanced Air Source Heat Pump	1.99	3.98	2.00	0.54	1.07	0.54
High Efficiency Air Source Heat Pump	1.69	2.69	0.90	0.46	0.73	0.24
Standard Air Source Heat Pump	1.56	2.30	0.90	0.42	0.62	0.24
Electric Resistance/ Standard AC	1.00	2.30	0.90	0.27	0.62	0.24
Gas-Fired Heat Pump	0.94	1.30	0.79	0.77	1.04	0.72
Advanced Gas Furnace/ High Efficiency AC	0.87	3.24	0.60	0.72	0.87	0.54
Standard Gas Furnace/ Standard AC	0.66	2.30	0.60	0.56	0.62	0.54
Advanced Oil Furnace/ High Efficiency AC	0.73	3.24	0.90	0.59	0.87	0.24

* The emerging GSHP listed in this table reflects the operating performance of the SLINKY™ or the vertical system.

As Exhibits C.1 and C.2 show, the EMERGING GROUND SOURCE HEAT PUMP clearly has the highest source operating efficiency in both heating and cooling mode, followed by the ADVANCED GROUND SOURCE HEAT PUMP. The GAS-FIRED HEAT PUMP outperforms all other technologies in water heating mode and is similar to the ADVANCED AIR SOURCE HEAT PUMP in cooling mode.

Exhibit C.2



As one would expect, the electric technologies improve uniformly in performance as they increase in sophistication from ELECTRIC RESISTANCE to the EMERGING GROUND SOURCE HEAT PUMP, with the exception that the ADVANCED AIR SOURCE HEAT PUMP outperforms the STANDARD GROUND SOURCE HEAT PUMP in cooling and water heating modes and performs better than the ADVANCED GROUND SOURCE HEAT PUMP and similar to the EMERGING GROUND SOURCE HEAT PUMP in water heating mode. The latter is due to the fact that, like the EMERGING GROUND SOURCE HEAT PUMP, it has a fully-integrated water heating function that meets the home's water heating demand without the need for substantial electric resistance water heating backup.

Based on a combination of superior performance and capital costs, the GAS-FIRED HEAT PUMP (which, based on its operating performance, can be expected to compete best in heating-dominated areas) has the lowest total annualized cost of all space conditioning equipment in this location, followed closely by the EMERGING GROUND SOURCE HEAT PUMP and the ADVANCED GAS FURNACE. Exhibits C.3 and C.4 summarize the overall technology cost comparison. Exhibit C.3 highlights the two least expensive technologies in terms of annual capital, annual operating and total costs.

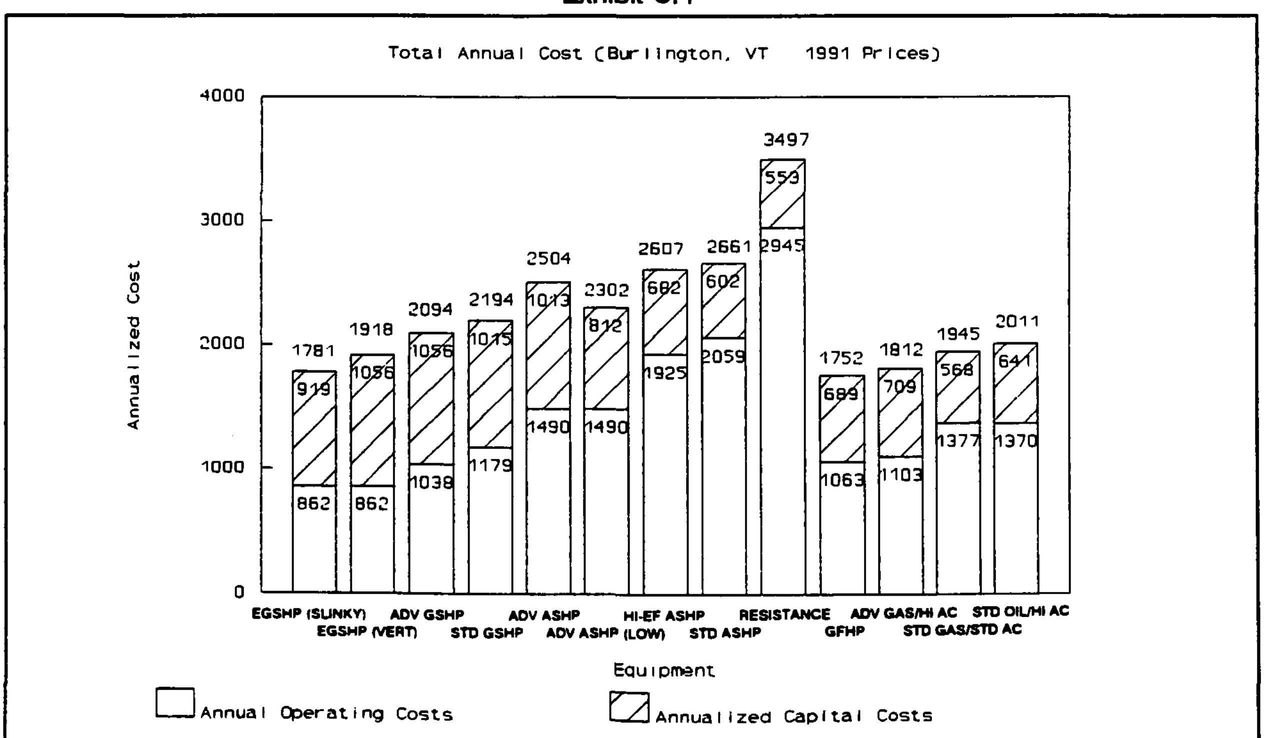
Exhibit C.3
Annual Cost Of Space Conditioning Equipment
Burlington, VT

EQUIPMENT TYPE	INSTALLED COST*	ANNUAL CAPITAL	ANNUAL OPERATING	TOTAL COST
Emerging Ground Source Heat Pump (SLINKY)	$9,335	$919	$862	$1,781
Emerging Ground Source Heat Pump (Vertical)	$10,730	$1,056	$862	$1,918
Advanced Ground Source Heat Pump	$10,730	$1,056	$1,038	$2,094
Standard Ground Source Heat Pump	$10,315	$1,015	$1,179	$2,194
Advanced Air Source Heat Pump (Present Cost)	$10,295	$1,013	$1,490	$2,504
Advanced Air Source Heat Pump (Low Cost)	$8,250	$812	$1,490	$2,302
High Efficiency Air Source Heat Pump	$6,925	$682	$1,925	$2,607
Standard Air Source Heat Pump	$6,115	$602	$2,059	$2,661
Electric Resistance/ Standard AC	$5,615	$553	$2,945	$3,497
Gas-Fired Heat Pump	$7,000	$689	$1,063	$1,752
Advanced Gas Furnace/ High Efficiency AC	$7,200	$709	$1,103	$1,812
Standard Gas Furnace/ Standard AC	$5,775	$568	$1,377	$1,945
Advanced Oil Furnace/ High Efficiency AC	$6,515	$641	$1,370	$2,011

* Includes duct work ($1800) and water heater ($315 for electric and $400 for gas)

** Based on average 1991 residential prices: $.10/kWh electric and $.80/therm, as estimated by Barakat and Chamberlin

Exhibit C.4



ENVIRONMENTAL EFFECTS AND TOTAL SOCIETAL COST

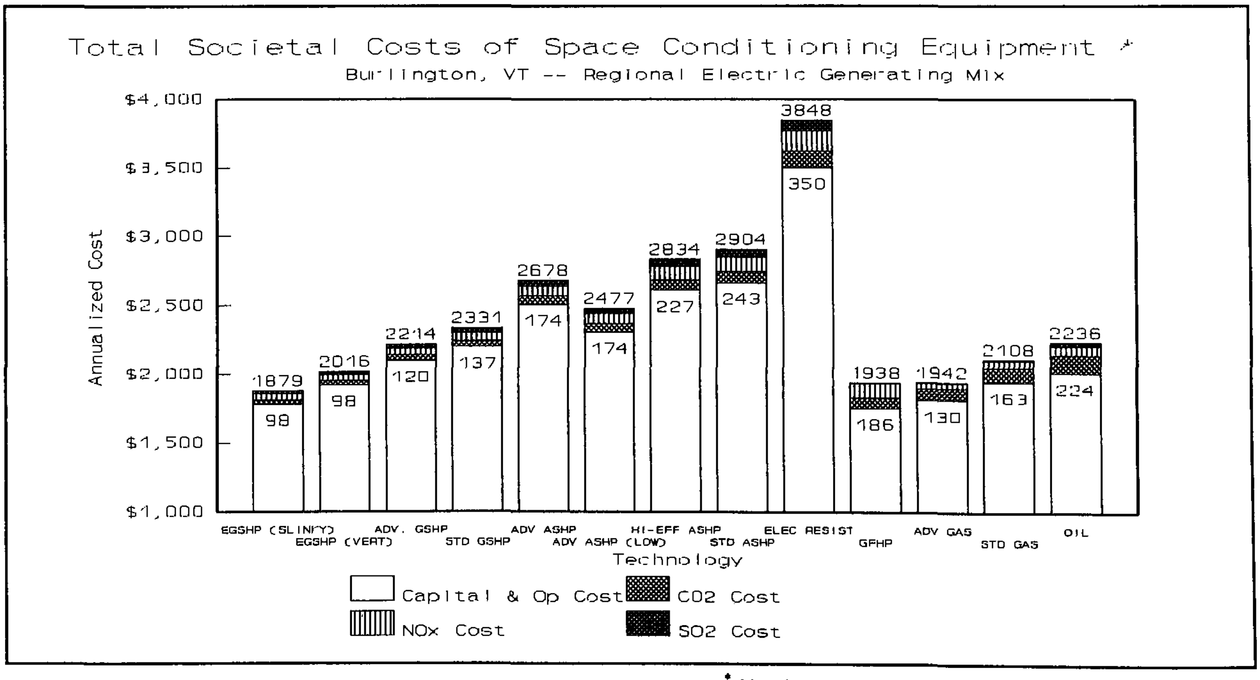
Regional Electric Generation Fuel Mix Scenario: The forecasted 2000 New England generating fuel mix includes about one-third nuclear and one-quarter oil (Appendix B). Thus, using the externality values discussed in Chapter Three, the GAS-FIRED HEAT PUMP has higher externality costs associated with it than the EMERGING and ADVANCED GROUND SOURCE HEAT PUMPS and the ADVANCED GAS FURNACE. (Exhibit C.5 and Appendix D). The EMERGING GROUND SOURCE HEAT PUMP emits 57% less CO_2 than the GAS-FIRED HEAT PUMP and 60% less NO_x. Thus, despite SO_2 emissions that are about 6 times higher (26 kg/yr. vs. 4.5 kg/yr), the advantage that the EMERGING GROUND SOURCE HEAT PUMP has in total annualized cost in this location increases somewhat when externality costs are factored in.

The environmental superiority of EMERGING GROUND SOURCE HEAT PUMPS over advanced AIR SOURCE HEAT PUMPS, STANDARD AIR SOURCE HEAT PUMPS, and ELECTRIC RESISTANCE are clearly evident from Exhibit C.5 and Appendix D. The EMERGING GROUND SOURCE HEAT PUMP has CO_2, NO_X and SO_2 emissions that are 45% lower than those for the ADVANCED AIR SOURCE HEAT PUMP, 60% lower than the STANDARD AIR SOURCE HEAT PUMP, and 72% lower than ELECTRIC RESISTANCE. These relative emissions between EMERGING GROUND SOURCE HEAT PUMPS and the other electric technologies hold true for all the generation scenarios.

The EMERGING GROUND SOURCE HEAT PUMP, which is modeled to replace oil in the market analysis in Chapter 4, results in a 74% (7,500 kg/yr.) CO_2 reduction over the ADVANCED OIL FURNACE. It also reduces NO_x by 35% and SO_2 by 21% over the ADVANCED OIL FURNACE.

Compared to the STANDARD GAS FURNACE, the GAS-FIRED HEAT PUMP produces 26% less CO_2 and only two-thirds the SO_2. On the other hand, it produces twice the NO_x emissions. A similar compromise between CO_2 and NO_x emissions for the GAS-FIRED HEAT PUMP and the ADVANCED GAS FURNACE results in higher overall externality costs for the GAS-FIRED HEAT PUMP.

Exhibit C.5



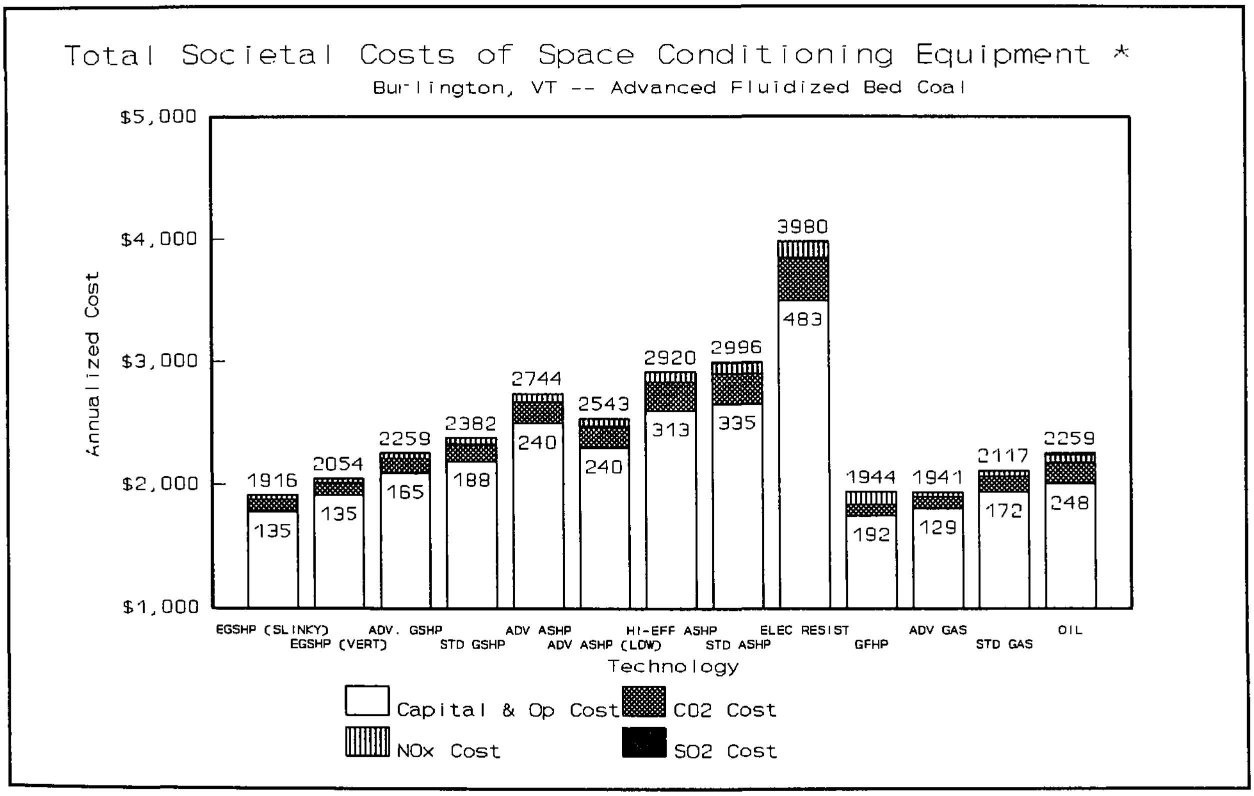
* Number inside column refers to total externality cost.

Advanced Fluidized Bed Coal (AFBC) Scenario: This scenario assumes that the marginal plant in the region is an advanced, pressurized fluidized bed combustion coal (AFBC) plant. This technology represents an advanced technology to reduce emissions of SO_2. It also tends to result in relatively low NO_x emissions. However, CO_2 emissions for electric technologies under this scenario are high, due to coal's high carbon content (see Appendix B for emission rates used in the AFBC scenario).

Exhibit C.6 and Appendix D show that the total externality costs for the EMERGING GROUND SOURCE HEAT PUMP, driven by much higher CO_2 emissions, are now similar to the externality costs of the ADVANCED GAS FURNACE. In this scenario, the ADVANCED GAS FURNACE's and the GAS-FIRED HEAT PUMP'S CO_2 emissions are 10% lower than those of the EMERGING GROUND SOURCE HEAT PUMP. However, the GAS-FIRED HEAT PUMP's NO_x emissions are more than twice as high as either the EMERGING GROUND SOURCE HEAT PUMP or ADVANCED GAS FURNACE.

Relative to the STANDARD GAS FURNACE, the GAS-FIRED HEAT PUMP has a similar tradeoff, reducing CO_2 emissions by 27% while doubling NO_x emissions. On the other hand, the GAS-FIRED HEAT PUMP is clearly superior to baseline electric technologies, reducing CO_2 emissions by 63% and 75% over the STANDARD AIR SOURCE HEAT PUMP and ELECTRIC RESISTANCE, respectively, while simultaneousLY lowering NO_x and SO_2 emissions.

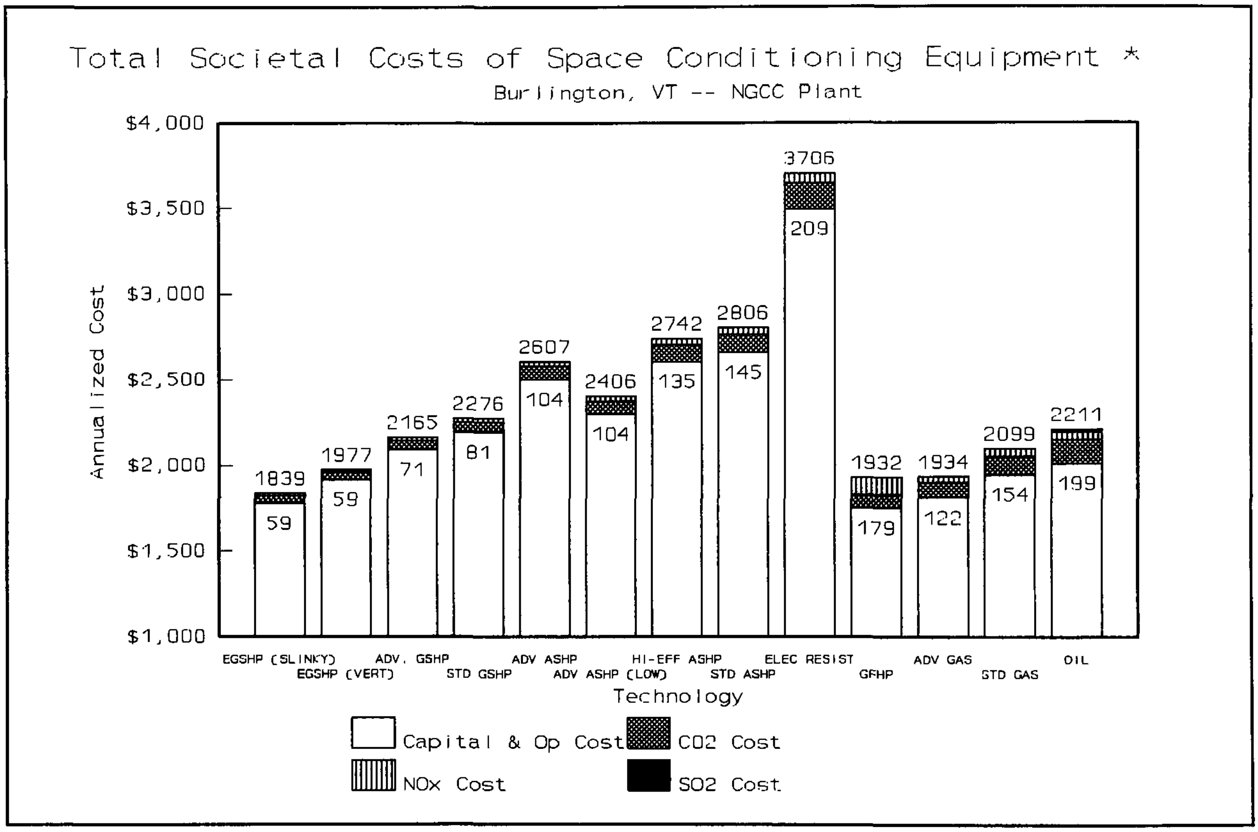
Exhibit C.6



* Number inside column refers to total externality cost.

Advanced Natural Gas Combined Cycle (NGCC) Scenario: This scenario assumes that the marginal plant on the regional grid is an advanced, natural gas, combined-cycle plant. Because of its high generating efficiency and clean fuel source, **NGCC** substantially reduces the CO_2, NO_x and SO_2 associated with electricity end uses relative to other fossil fuel plants. In the **NGCC** scenario (Exhibit C.7 and Appendix D), the ADVANCED AIR SOURCE HEAT PUMP and all of the GROUND SOURCE HEAT PUMP technologies have lower externality costs than all other technologies. However, the externality cost advantage causes only the EMERGING GROUND SOURCE HEAT PUMP/SLINKY system to have lower total societal costs than GAS-FIRED HEAT PUMPS and ADVANCED GAS FURNACES.

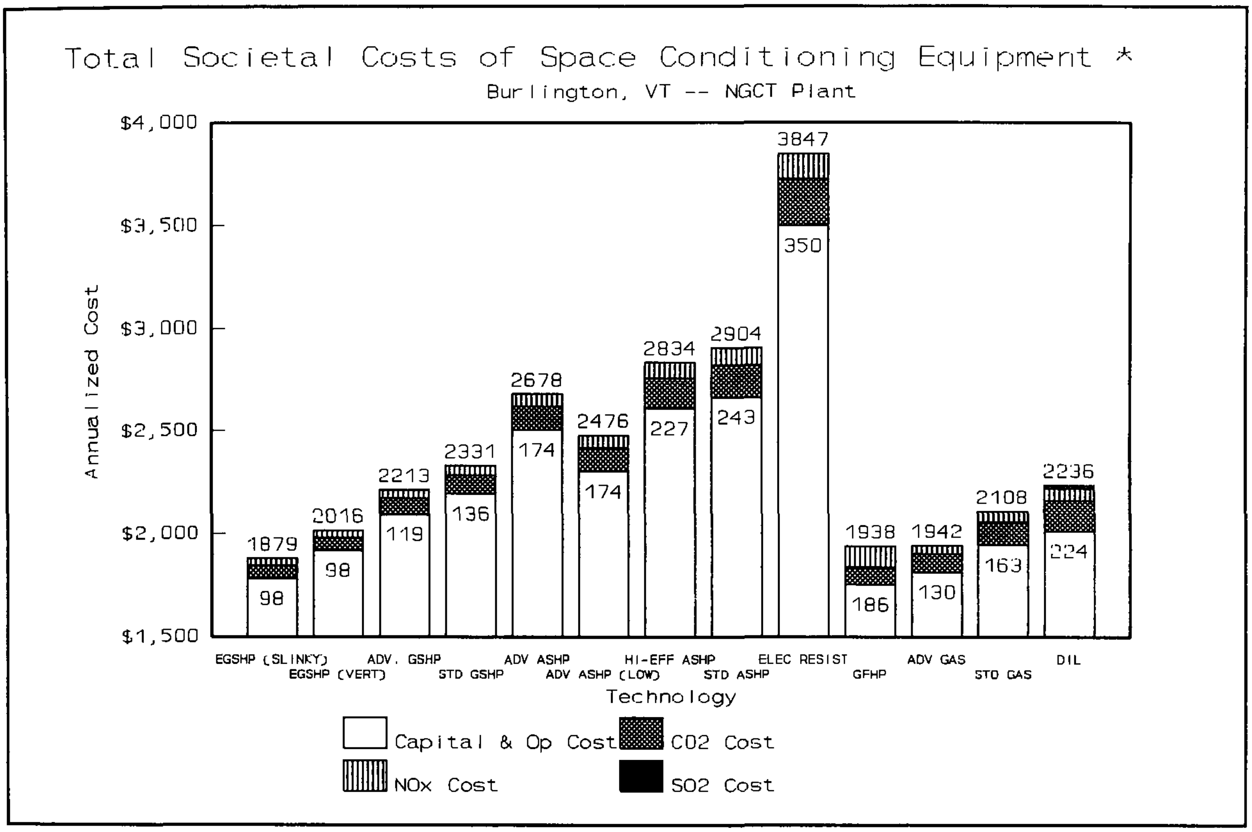
Exhibit C.7



* Number inside column refers to total externality cost.

Natural Gas Combustion Turbine (NGCT) Scenario: This scenario assumes that a typical modern gas combustion turbine is the marginal power plant. This scenario results in a much smaller advantage in total externality costs for ADVANCED GROUND SOURCE HEAT PUMPS than the previous scenario (Exhibit C.8 and Appendix D). Again, only the EMERGING GROUND SOURCE HEAT PUMP/SLINKY system has a lower total societal cost than advanced gas equipment.

Exhibit C.8



* Number inside column refers to total externality cost.

CHOICES FOR UTILITIES: COST-EFFECTIVENESS SCREENING

The cost-effectiveness of various utility programs will depend on a realistic assessment of which technologies compete in a particular residence, and at what costs.

The utility cost-effectiveness analysis and estimate of utility program effect on payback, as described in Chapter 3, was performed for various equipment substitutions and is presented in Exhibit C.9. ELECTRIC RESISTANCE, STANDARD AIR SOURCE HEAT PUMPS, STANDARD GAS FURNACES, and STANDARD OIL FURNACEs were selected as the base technologies for which substitutions would be evaluated.

For houses with electric or oil heating, there may not be easy access to gas service; in such cases, the cost of adding gas service will likely be prohibitive. The results of utility cost-effectiveness screening presented in this Appendix assume that gas service is available to the household.

As discussed in Chapter Three, the results for Burlington are driven by the avoided energy costs for a typical utility in the New England region (Boston Edison). Externality costs are not included in these marginal energy costs. The analysis factors in an avoided capacity value of about $102/kW/yr, which accounts for generating capacity factor and transmission and distribution costs and losses.

Administrative costs are assumed to be $150 per household. The utility incentive is assumed to cover the entire incremental cost of the equipment whenever the Total Resource Cost Test ratio is 1 or greater. In those cases in which the TRC ratio is below 1, no utility incentive is assumed.

The test results indicate that, given the very high space heating requirements in New England, ELECTRIC RESISTANCE is a prime candidate for replacement. Based on a combination of results -- highest TRC ratios and net present values, as well as high emission reductions -- the EMERGING and ADVANCED GROUND SOURCE HEAT PUMP technologies and the GAS-FIRED HEAT PUMP appear to be the superior replacement technologies. While it has a fairly high TRC ratio, the LOW-COST ADVANCED AIR SOURCE HEAT PUMP does not yield the same magnitude of net present value or emission reductions.

EMERGING GROUND SOURCE HEAT PUMPS and GAS-FIRED HEAT PUMPS also appear to have the best overall results for replacing STANDARD AIR SOURCE HEAT PUMPS and STANDARD OIL FURNACES.

In replacing STANDARD GAS FURNACES, the GAS-FIRED HEAT PUMP and the ADVANCED GAS FURNACE both have strong results. The GAS-FIRED HEAT PUMP yields a higher TRC ratio, per-unit net present value and higher CO_2 and SO_2 reductions. On the other hand, the GAS-FIRED HEAT PUMP increases NO_x emissions. While their TRC ratios are not as high, GROUND SOURCE HEAT PUMPS yield the highest CO_2 reductions when replacing STANDARD GAS FURNACES.

Exhibit C.9
Utility Program Cost-Effectiveness
Burlington, Vermont

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Oil Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)	(gal.)			Without Incent.	With Incent.	CO2	NOx	SO2
Replace Electric Resistant Heating/AC with:**														
Emerging Ground Source Heat Pump (SLINKY)	$4,870	$4,870	20,827	6.0	4.6	0.0	0.0	3.17	$10,902	2.68	0.00	6,614	16.70	66.81
Emerging Ground Source Heat Pump (Vertical)	$6,265	$6,265	20,827	6.0	4.6	0.0	0.0	2.48	$9,507	3.45	0.00	6,614	16.70	66.81
Advanced Ground Source Heat Pump	$6,265	$6,265	19,068	6.0	4.6	0.0	0.0	2.34	$8,571	3.78	0.00	6,056	15.29	61.17
Advanced Air Source Heat Pump (Present Cost)	$6,230	$6,230	14,545	0.0	4.7	0.0	0.0	1.55	$3,481	4.90	0.00	4,620	11.67	46.66
Advanced Air Source Heat Pump (Low Cost)	$4,185	$4,185	14,545	0.0	4.7	0.0	0.0	2.27	$5,526	3.29	0.00	4,620	11.67	46.66
Advanced Gas Furnace/ High Efficiency AC***	$3,050	$3,050	23,818	17.4	0.5	-935.0	0.0	1.61	$7,939	2.27	0.00	2,731	16.74	87.58
Gas Air-to-Air Heat Pump	$2,850	$2,850	27,564	17.4	7.1	-1031.1	0.0	1.84	$11,834	1.82	0.00	3,183	7.01	88.32
Advanced Oil Furnace/ High Efficiency AC	$2,450	$2,450	24,278	12.9	0.5	0.0	-812.5	1.41	$5,522	2.06	0.00	(903)	13.20	59.98

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Oil Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)	(gal.)			Without Incent.	With Incent.	CO2	NOx	SO2
Replace Standard Air Source Heat Pump with:														
Emerging Ground Source Heat Pump (SLINKY)	$2,820	$2,820	11,973	6.0	4.6	0.0	0.0	3.80	$8,309	2.68	0.00	3,802	9.60	38.41
Emerging Ground Source Heat Pump (Vertical)	$4,215	$4,215	11,973	6.0	4.6	0.0	0.0	2.58	$6,914	4.01	0.00	3,802	9.60	38.41
Advanced Ground Source Heat Pump	$4,215	$4,215	10,214	6.0	4.6	0.0	0.0	2.37	$5,978	4.72	0.00	3,244	8.19	32.77
Advanced Air Source Heat Pump (Present Cost)	$4,180	$4,180	5,691	0.0	4.7	0.0	0.0	1.21	$888	8.24	0.00	1,807	4.56	18.26
Advanced Air Source Heat Pump (Low Cost)	$2,135	$2,135	5,691	0.0	4.7	0.0	0.0	2.28	$2,933	4.21	0.00	1,807	4.56	18.26
Advanced Gas Furnace/ High Efficiency AC	$1,000	$1,000	18,481	17.4	5.0	-1115.0	0.0	1.59	$7,468	1.31	0.00	(82)	9.64	59.17
Gas Air-to-Air Heat Pump	$800	$800	18,710	17.4	7.1	-1031.1	0.0	1.76	$9,241	0.99	0.00	370	(0.09)	59.91
Advanced Oil Furnace/ High Efficiency AC	$400	$400	15,424	12.9	0.5	0.0	-812.5	1.26	$2,929	0.94	0.00	(3,715)	6.10	31.58

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Oil Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)	(gal.)			Without Incent.	With Incent.	CO2	NOx	SO2
Replace Standard Gas Furnace/AC with:														
Emerging Ground Source Heat Pump (SLINKY)	$3,245	$3,245	(6,175)	-11.4	0.1	1415.0	0.0	1.24	$2,804	5.92	0.00	5,558	1.60	(19.67)
Emerging Ground Source Heat Pump (Vertical)	$4,640	$4,640	(6,175)	-11.4	0.1	1415.0	0.0	1.11	$1,409	8.47	0.00	5,558	1.60	(19.67)
Advanced Ground Source Heat Pump	$4,640	$4,640	(7,934)	-11.4	0.1	1415.0	0.0	1.03	$472	11.91	0.00	5,000	0.19	(25.31)
Advanced Air Source Heat Pump (Present Cost)	$4,605	$0	(12,457)	-17.4	0.2	1415.0	0.0	0.76	($4,617)	>20	>20	3,564	(3.44)	(39.82)
Advanced Air Source Heat Pump (Low Cost)	$2,560	$0	(12,457)	-17.4	0.2	1415.0	0.0	0.85	($2,572)	>20	>20	3,564	(3.44)	(39.82)
Advanced Gas Furnace/ High Efficiency AC***	$1,425	$1,425	333	0.0	0.5	300.0	0.0	2.25	$1,963	5.45	0.00	1,674	1.63	1.10
Gas-Fired Heat Pump	$1,225	$1,225	562	0.0	2.6	383.9	0.0	3.10	$3,736	4.06	0.00	2,126	(8.10)	1.84
Advanced Oil Furnace/ High Efficiency AC	$825	$0	(2,724)	-4.5	-4.0	1415.0	-812.5	0.85	($2,577)	>20	>20	(1,959)	(1.91)	(26.50)

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Oil Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)	(gal.)			Without Incent.	With Incent.	CO2	NOx	SO2
Replace Standard Oil Furnace/AC with:														
Emerging Ground Source Heat Pump (SLINKY)	$3,720	$3,720	(2,975)	-6.9	4.6	0.0	894.9	1.85	$5,528	4.87	0.00	8,092	3.91	7.99
Emerging Ground Source Heat Pump (Vertical)	$5,115	$5,115	(2,975)	-6.9	4.6	0.0	894.9	1.53	$4,133	6.70	0.00	8,092	3.91	7.99
Advanced Ground Source Heat Pump	$5,115	$5,115	(4,734)	-6.9	4.6	0.0	894.9	1.36	$3,197	8.45	0.00	7,534	2.50	2.35
Advanced Air Source Heat Pump (Present Cost)	$5,080	$0	(9,257)	-12.9	4.7	0.0	894.9	0.86	($1,893)	>20	>20	6,097	(1.13)	(12.16)
Advanced Air Source Heat Pump (Low Cost)	$3,035	$3,035	(9,257)	-12.9	4.7	0.0	894.9	1.01	$152	13.88	0.00	6,097	(1.13)	(12.16)
Advanced Gas Furnace/ High Efficiency AC	$1,900	$1,900	3,533	4.5	5.0	-1115.0	894.9	1.34	$4,687	3.98	0.00	4,208	3.95	28.76
Gas Air-to-Air Heat Pump	$1,700	$1,700	3,762	4.5	7.1	-1031.1	894.9	1.50	$6,460	3.29	0.00	4,660	(5.78)	29.50
Advanced Oil Furnace/ High Efficiency AC	$1,300	$1,300	476	0.0	0.5	0.0	82.4	1.10	$148	9.42	0.00	575	0.41	1.16

If TRC <1, no incentive program is assumed. Where TRC test is greater than 1, entire incremental cost is covered by the incentive.

Results reflect replacement of existing ELECTRIC RESISTANCE at the end of the central AC's service life. We assume in this scenario that the ELECTRIC RESISTANCE does not need replacement. Thus, we compare the capital cost of the entire advanced system against only the replacement AC. In the case of new construction, a much higher TRC is obtained, since in this case the cost of the ELECTRIC RESISTANCE system would have to be factored in.

* Measured by itself, the HIGH-EFFICIENCY AIR CONDITIONER has a TRC of 1.24 when replacing a STANDARD AIR CONDITIONER. Likewise, the ADVANCED GAS FURNACE has a TRC of 2.47 when replacing a STANDARD GAS FURNACE.

A FOCUS ON CARBON DIOXIDE REDUCTIONS

Exhibits C.10 to C.13 order the space conditioning equipment analyzed for this location by the magnitude of their CO_2 emissions under each electric generation scenario. Each exhibit also indicates the standard equipment for which each advanced technology is cost-effective by having a TRC ratio higher than 1.

From the perspective of CO_2 emissions, EMERGING and ADVANCED GROUND SOURCE HEAT PUMPS are clearly preferable under the REGIONAL, ADVANCED NATURAL GAS COMBINED CYCLE, and NATURAL GAS COMBUSTION TURBINES generating scenarios. If, however, the marginal generation plant is ADVANCED FLUIDIZED BED COAL, the gas technologies have an advantage by cost-effectively reducing the most CO_2.

Exhibit C.10

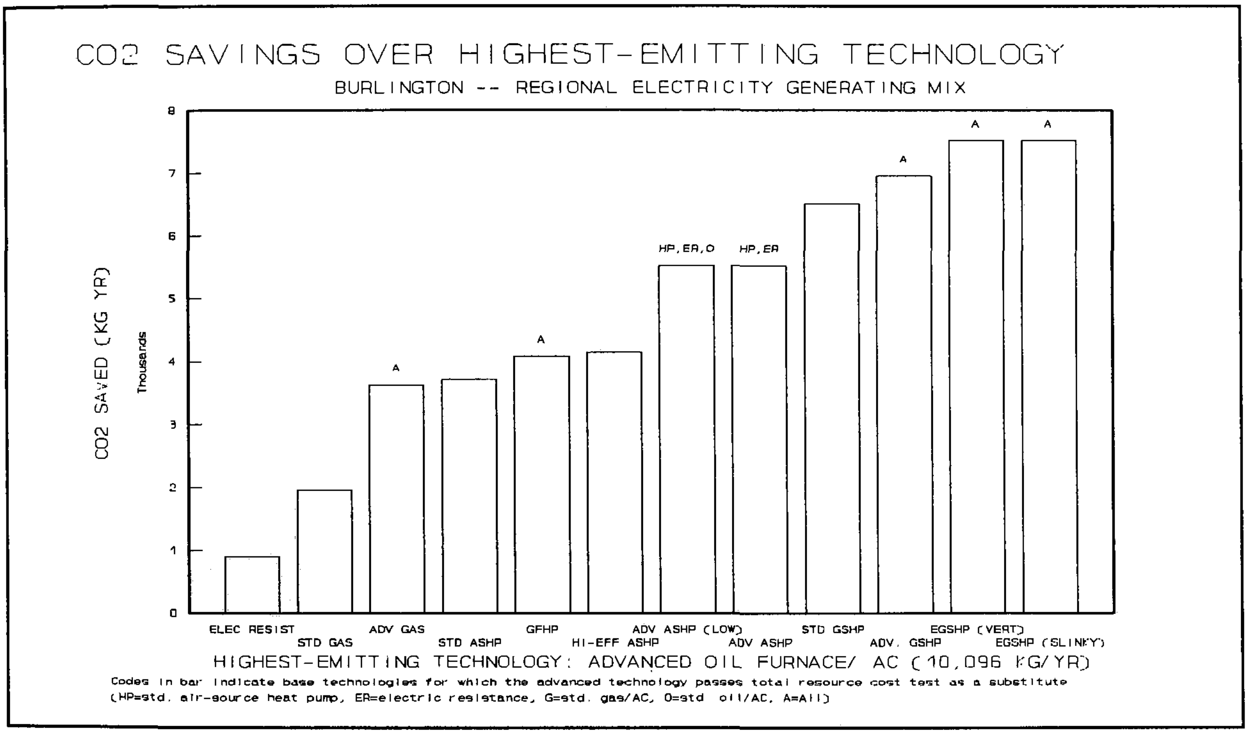


Exhibit C.11

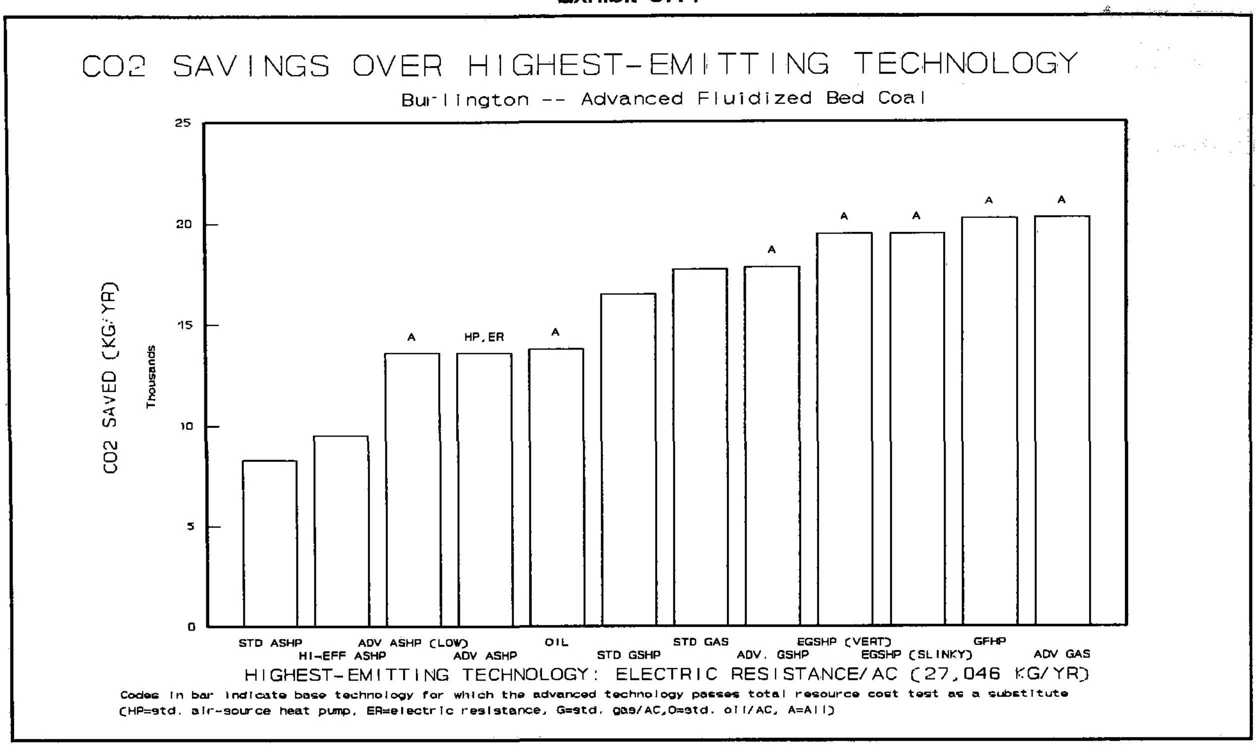


Exhibit C.12

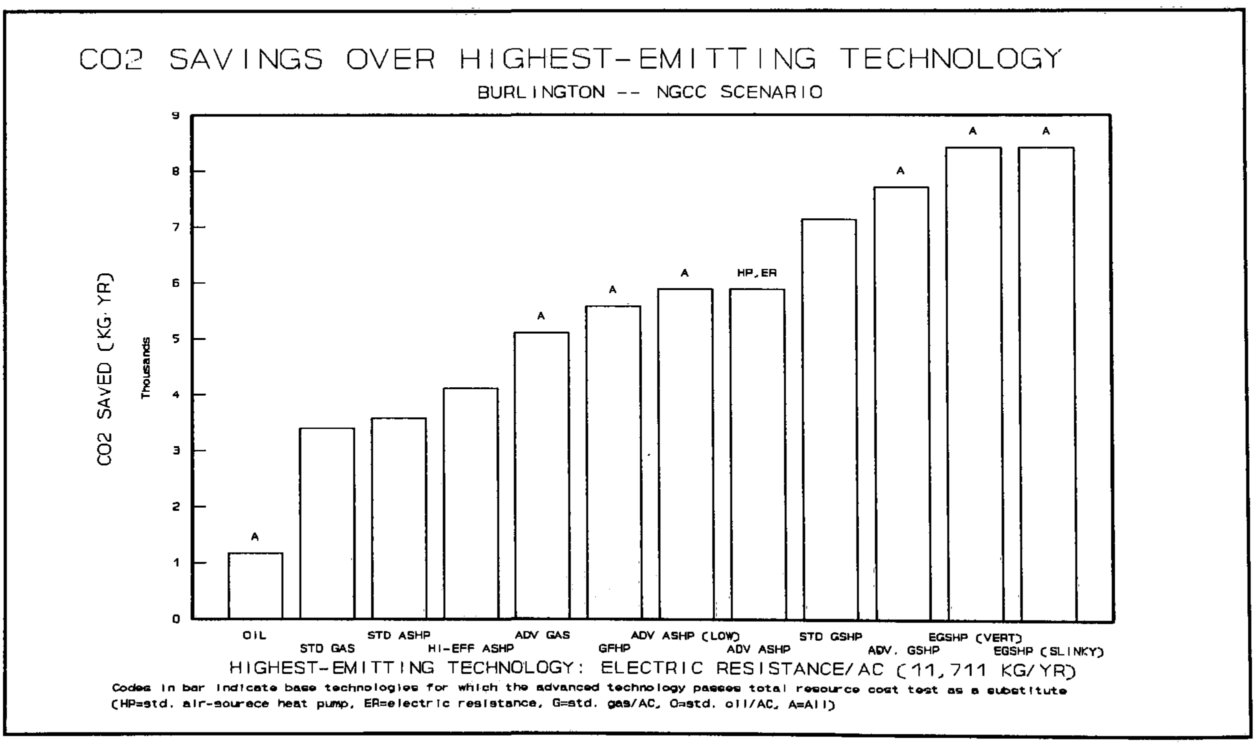
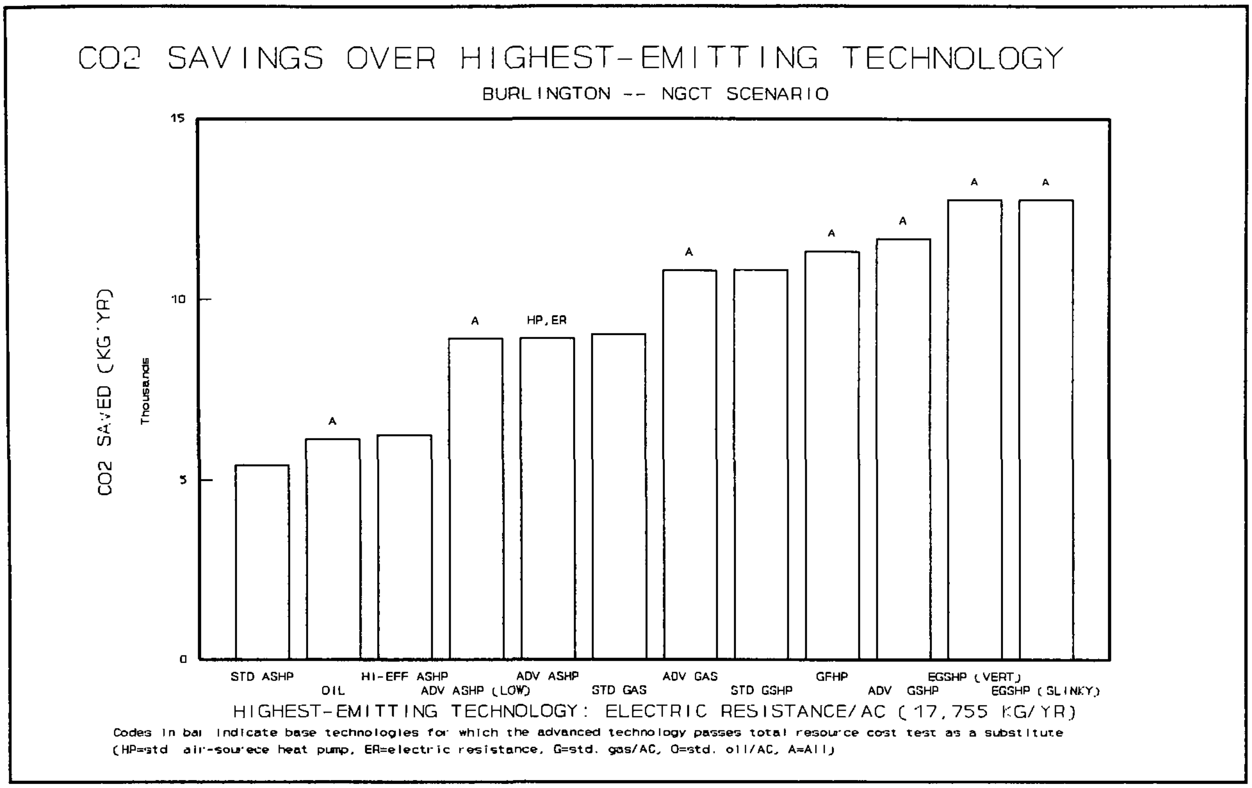


Exhibit C.13


CO2 SAVINGS OVER HIGHEST-EMITTING TECHNOLOGY
BURLINGTON -- NGCT SCENARIO
CO2 SAVED (KG/YR)
Thousands
15
10
5
0
A
A
HP,ER
A
A
A
A
A
STD ASHP
OIL
HI-EFF ASHP
ADV ASHP (LOW)
ADV ASHP
STD GAS
ADV GAS
STD GSHP
GFHP
ADV GSHP
EGSHP (VERT)
EGSHP (SLINKY)
HIGHEST-EMITTING TECHNOLOGY: ELECTRIC RESISTANCE/AC (17,755 KG/YR)
Codes in bar indicate base technologies for which the advanced technology passes total resource cost test as a substitute
(HP=std air-sourece heat pump, ER=electric resistance, G=std. gas/AC, O=std. oil/AC, A=All)

CLIMATE ZONE 2: CHICAGO, ILLINOIS

Climate Zone 2 cuts a broad swath across the industrialized East and Midwest, and continues into portions of the West and Northwest (Exhibit 3.1). Due to relatively dense populations, large differences in the relative cost of electricity and gas, and variations in electricity generation fuel mixes across this zone, two representative areas were selected for this chapter's analyses. For the Midwest (Chicago area), the prototypical home was modeled to consume 63.50 MMBtu for heating, 13.30 MMBtu for cooling, and 10.50 MMBtu for water heating annually, for a total demand of 87.30 MMBtu. This constitutes a high heating demand and a moderate cooling demand relative to the rest of the locations sampled in this chapter.

PERFORMANCE AND COST

Exhibit C.14 compares the operating performance of all of the representative space conditioning technologies described in Chapter 2. The three columns on the left indicate each equipment's modeled end-use seasonal performance factor (SPF, calculated by dividing the number of Btu's demanded in the location for heating, cooling or water heating by the number of Btu's of energy input the equipment required to meet that demand). The higher the SPF, the higher the technology's end-use efficiency.

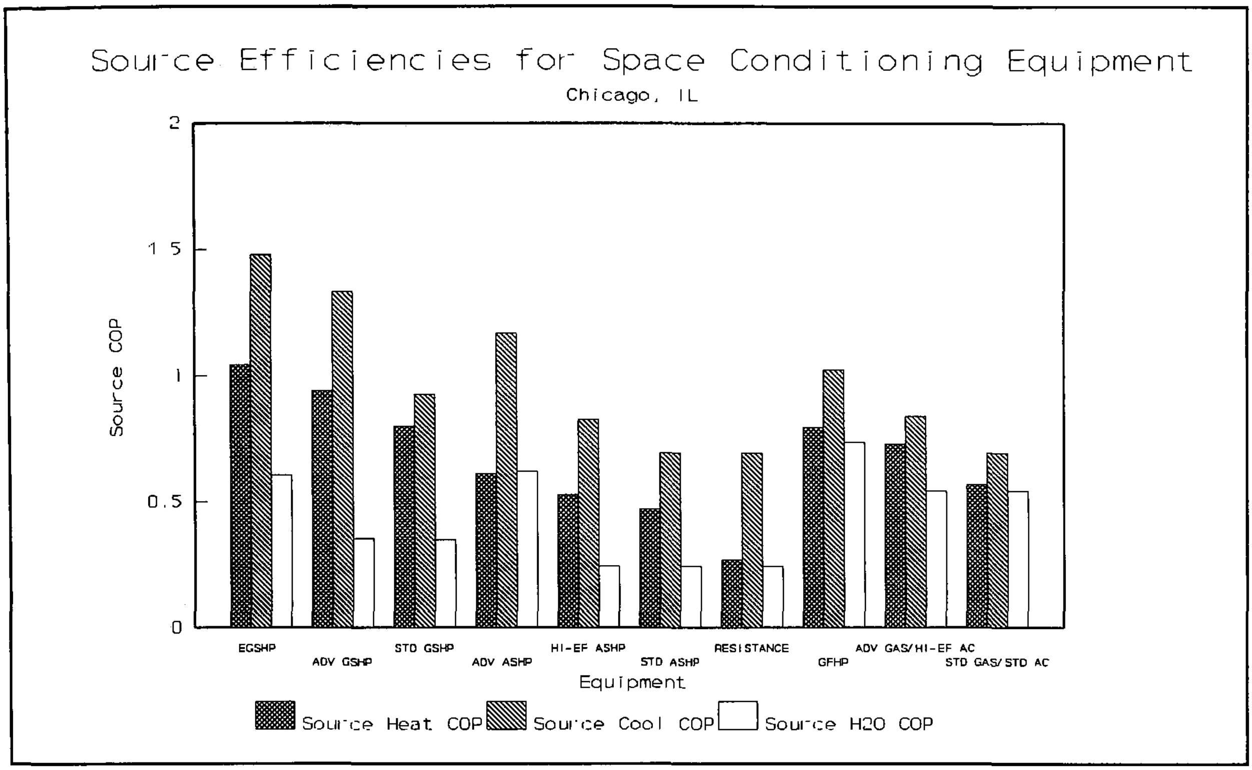
The three right-hand columns of Exhibit C.14, and Exhibit C.15, show source SPF, accounting for the losses in the generation, transmission and distribution system for each fuel type. The two best net energy performers in each category are highlighted:

Exhibit C.14
Performance of Space Conditioning Equipment
Chicago, IL (including water heating)

	END USE EFFICIENCY			SOURCE EFFICIENCY		
	HEAT	COOL	H20	HEAT	COOL	H20
EQUIPMENT TYPE	SPF	SPF	SPF	SPF	SPF	SPF
Emerging Ground Source Heat Pump	3.86	5.48	2.25	1.04	1.48	0.61
Advanced Ground Source Heat Pump	3.48	4.93	1.31	0.94	1.33	0.35
Standard Ground Source Heat Pump	2.96	3.43	1.29	0.80	0.93	0.35
Advanced Air Source Heat Pump	2.26	4.33	2.30	0.61	1.17	0.62
High Efficiency Air Source Heat Pump	1.96	3.06	0.90	0.53	0.83	0.24
Standard Air Source Heat Pump	1.74	2.57	0.90	0.47	0.69	0.24
Electric Resistance/ Standard AC	1.00	2.57	0.90	0.27	0.69	0.24
Gas-Fired Heat Pump	0.99	1.28	0.81	0.79	1.02	0.74
Advanced Gas Furnace/ High Efficiency AC	0.87	3.11	0.60	0.73	0.84	0.54
Standard Gas Furnace/ Standard AC	0.67	2.57	0.60	0.57	0.69	0.54

* The emerging GSHP listed in this table reflects the operating performance of the Slinky or the vertical system.

Exhibit C.15



As in Burlington, the EMERGING GROUND SOURCE HEAT PUMP has the best source efficiency for space heating and space cooling, but does not fare as well in the water heating mode as the GAS-FIRED HEAT PUMP. Since Chicago's climate is dominated by heating load, the advanced gas technologies and the EMERGING GROUND SOURCE HEAT PUMPs have the lowest total annual costs.

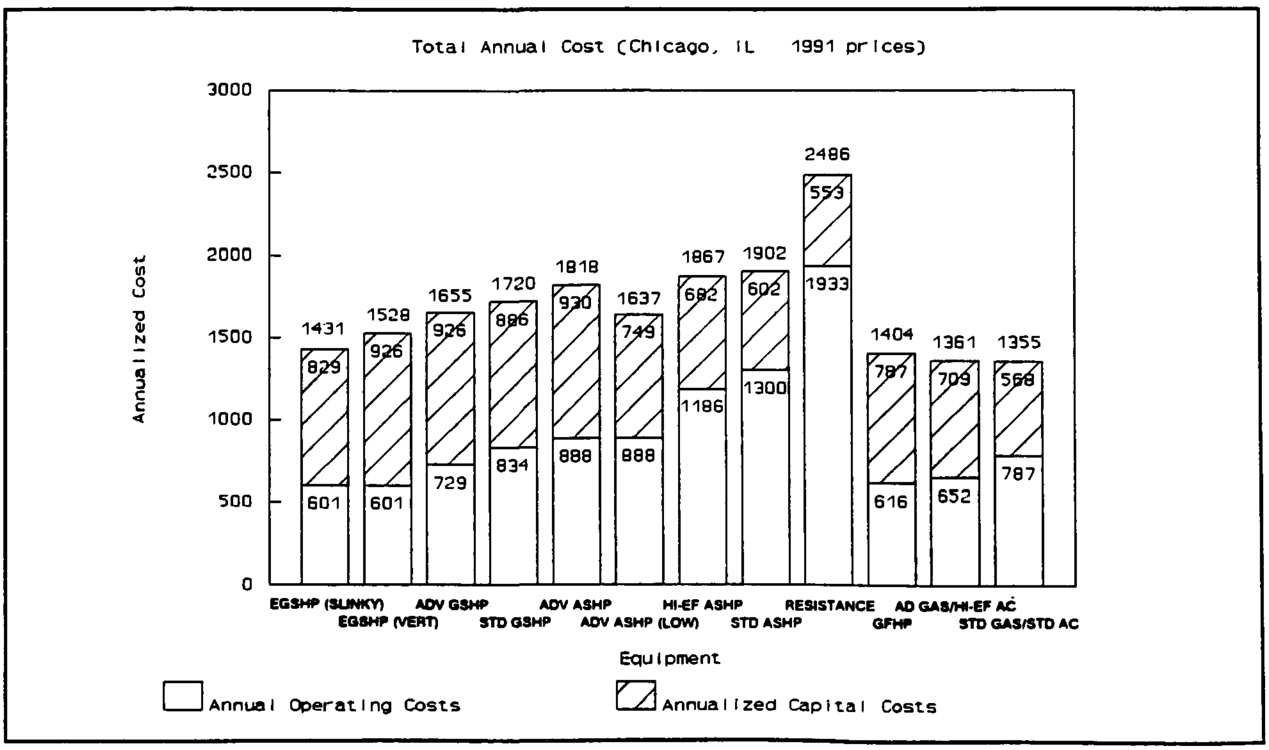
Chicago also has current residential gas rates that are low enough that the higher capital costs of both the GAS-FIRED HEAT PUMP and the ADVANCED GAS FURNACE result in total annual costs that are slightly higher than that of the STANDARD GAS FURNACE, as shown by Exhibits C.16 and C.17. Exhibit C.16 highlights the two least expensive technologies with respect to annual capital, annual operating and total costs.

Exhibit C.16
Annual Costs Of Space Conditioning Equipment
Chicago, IL

EQUIPMENT TYPE	INSTALLED COST*	ANNUAL CAPITAL	ANNUAL OPERATING	TOTAL COST
Emerging Ground Source Heat Pump (SLINKY)	$8,425	$829	$601	$1,431
Emerging Ground Source Heat Pump (Vertical)	$9,410	$926	$601	$1,528
Advanced Ground Source Heat Pump	$9,410	$926	$729	$1,655
Standard Ground Source Heat Pump	$9,005	$886	$834	$1,720
Advanced Air Source Heat Pump (Present Cost)	$9,445	$930	$888	$1,818
Advanced Air Source Heat Pump (Low Cost)	$7,613	$749	$888	$1,637
High Efficiency Air Source Heat Pump	$6,925	$682	$1,186	$1,867
Standard Air Source Heat Pump	$6,115	$602	$1,300	$1,902
Electric Resistance/ Standard AC	$5,615	$553	$1,933	$2,486
Gas-Fired Heat Pump	$8,000	$787	$616	$1,404
Advanced Gas Furnace/ High Efficiency AC	$7,200	$709	$652	$1,361
Standard Gas Furnace/ Standard AC	$5,775	$568	$787	$1,355

* Includes duct work ($1800) and water heater ($315 for electric and $400 for gas)
** Based on average 1991 residential rates: $.08/kWh electric and $.50/therm gas (Barakat & Chamberlin).

Exhibit C.17



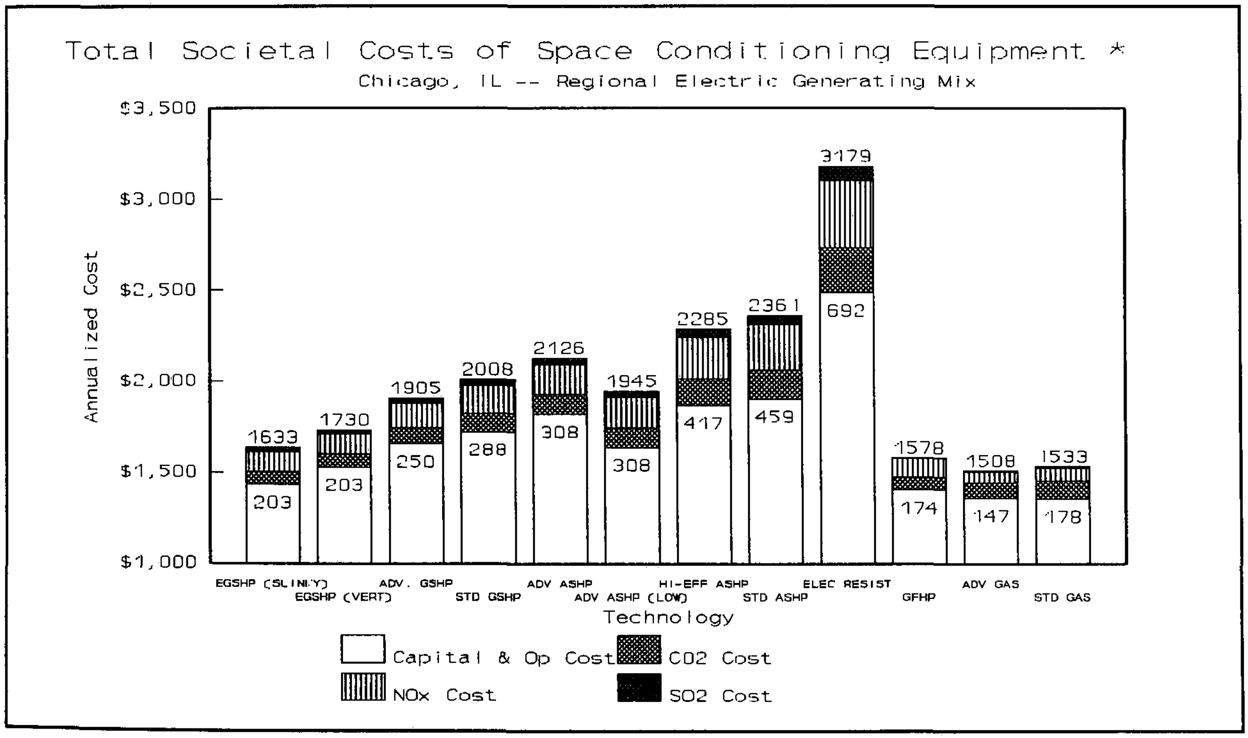
ENVIRONMENTAL EFFECTS AND TOTAL SOCIETAL COST

Regional Electric Generation Fuel Mix Scenario: Due to substantial regional reliance on coal-fired power plants, the Year 2000 regional fuel mix in the Midwest has high emission rates for CO_2, NO_X and SO_2. Therefore, the externality costs associated with electric space conditioning technologies are much higher than in other regions. They are also significantly higher than for any of the gas technologies, including STANDARD GAS FURNACE (Exhibit C.18 and Appendix D). For instance, the GAS-FIRED HEAT PUMP has only 85% of the overall externality costs of the EMERGING GROUND SOURCE HEAT PUMP, which is the best electric technology from an environmental standpoint. Similarly, the externality costs for the ADVANCED and STANDARD GAS FURNACES are also significantly lower. Subsequently, the cost-competitiveness enjoyed by gas equipment based on climate and residential energy rates is bolstered by much lower externality costs under this scenario.

Among gas technologies, the ADVANCED GAS FURNACE has the lowest overall externality costs due largely to it's 40% lower NO_x emissions than the GAS-FIRED HEAT PUMP. The GAS-FIRED HEAT PUMP does, however, produce 780 kg/year (14%) less CO_2 than the ADVANCED GAS FURNACE, and 2,168 kg/year (28%) less CO_2 than the STANDARD GAS FURNACE. Because the regional NO_x and SO_2 rates associated with electricity generation are high, the ADVANCED GAS FURNACE compares well against the other gas technologies in these areas as well, based on its lower NO_x emissions.

On the electric side, EMERGING GROUND SOURCE HEAT PUMPs emit 34% fewer CO_2, NO_x and SO_2 emissions than ADVANCED AIR SOURCE HEAT PUMPS, 56% fewer emissions than

Exhibit C.18

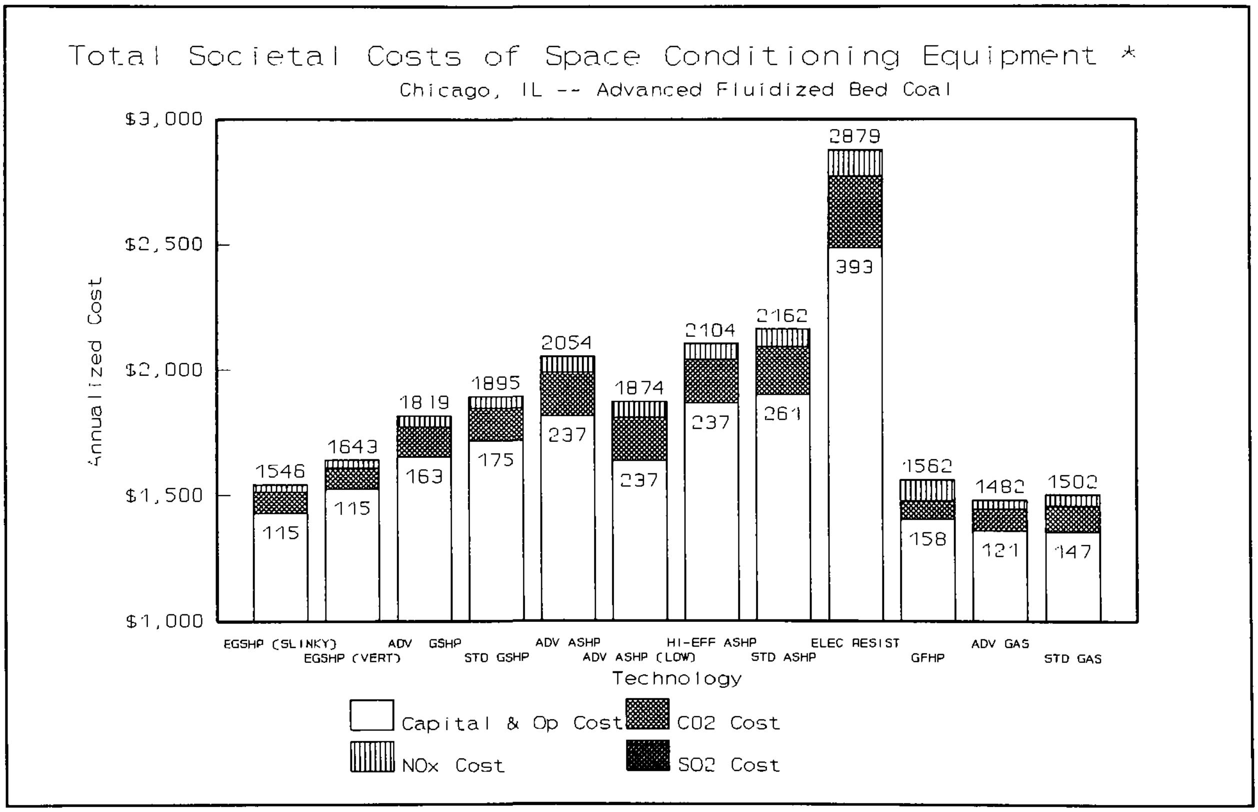


* Number inside column refers to total externality cost.

STANDARD AIR SOURCE HEAT PUMPS, and 71% less emissions than ELECTRIC RESISTANCE. These proportions hold true under any electricity generating scenario, given the proportion of relative electricity consumption between the technologies, which remains constant.

Advanced Fluidized Bed Coal Scenario: The AFBC scenario brings the total externality cost of the EMERGING GROUND SOURCE HEAT PUMP down to a lower level than all other technologies; however, the GAS-FIRED HEAT PUMP emits about 750 kg/year (13%) less CO_2 under this scenario than does the EMERGING GROUND SOURCE HEAT PUMP. This advantage is offset by the GAS-FIRED HEAT PUMP's higher NOx emissions, so that on balance the externality costs for the GAS-FIRED HEAT PUMP are somewhat higher.(Exhibit C.19 and Appendix D). The ADVANCED GAS FURNACE's lower NO_x emissions yield an externality cost comparable to that of the EMERGING GROUND SOURCE HEAT PUMPs. The gas technologies (including the STANDARD GAS FURNACE) generally still enjoy slightly lower total annual costs under this scenario than the EMERGING GROUND SOURCE HEAT PUMP although the EMERGING GROUND SOURCE HEAT PUMP with the lower cost SLINKY™ loop has slightly lower total societal costs than the GAS-FIRED HEAT PUMP.

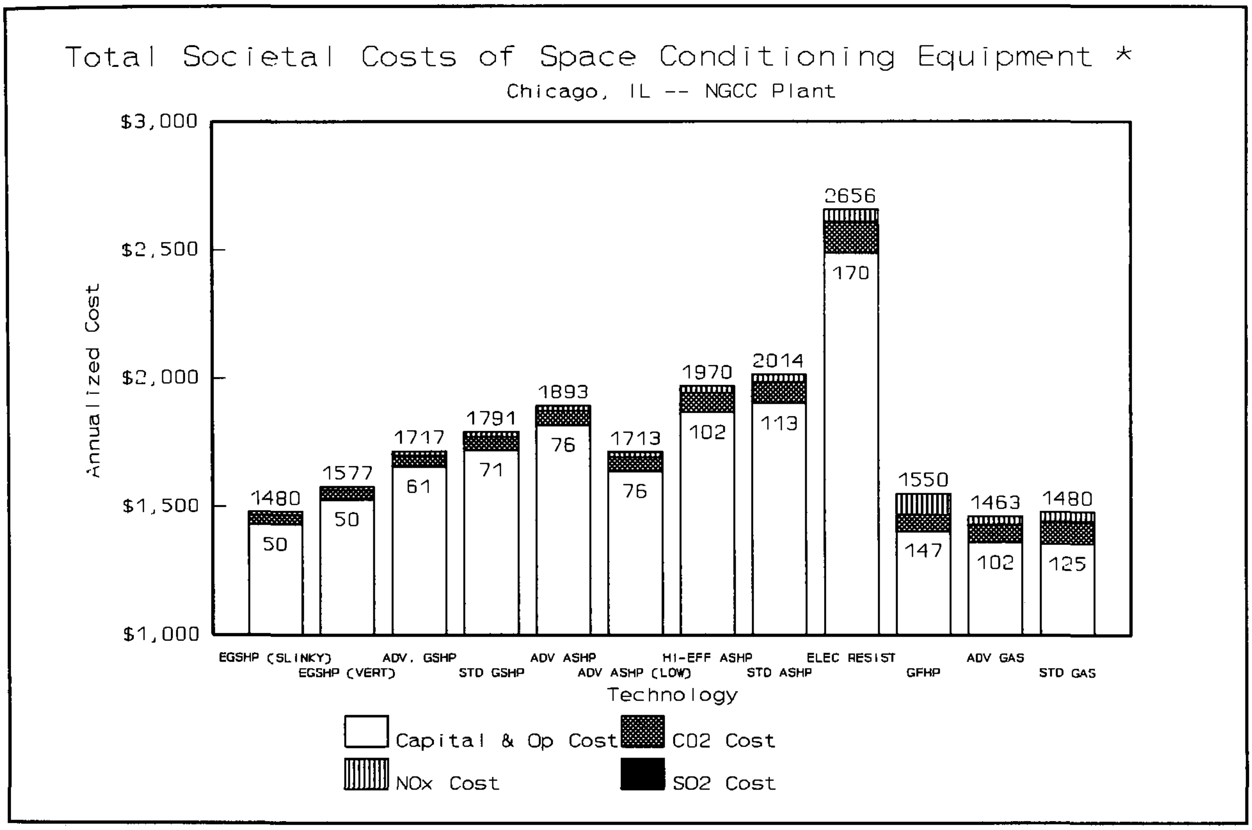
Exhibit C.19



* Number inside column refers to total externality cost.

Advanced Natural Gas Combined Cycle Scenario: Under this scenario (Exhibit C.20 and Appendix D), total emissions for all of the GSHPs are below those for all of the gas technologies. The ADVANCED GAS FURNACE, STANDARD GAS FURNACE, and EMERGING GROUND SOURCE HEAT PUMP (SLINKY™ loop) have the lowest annual societal costs of all options. The GAS-FIRED HEAT PUMP is slightly higher, and is comparable to the EMERGING GROUND SOURCE HEAT PUMP with a vertical loop.

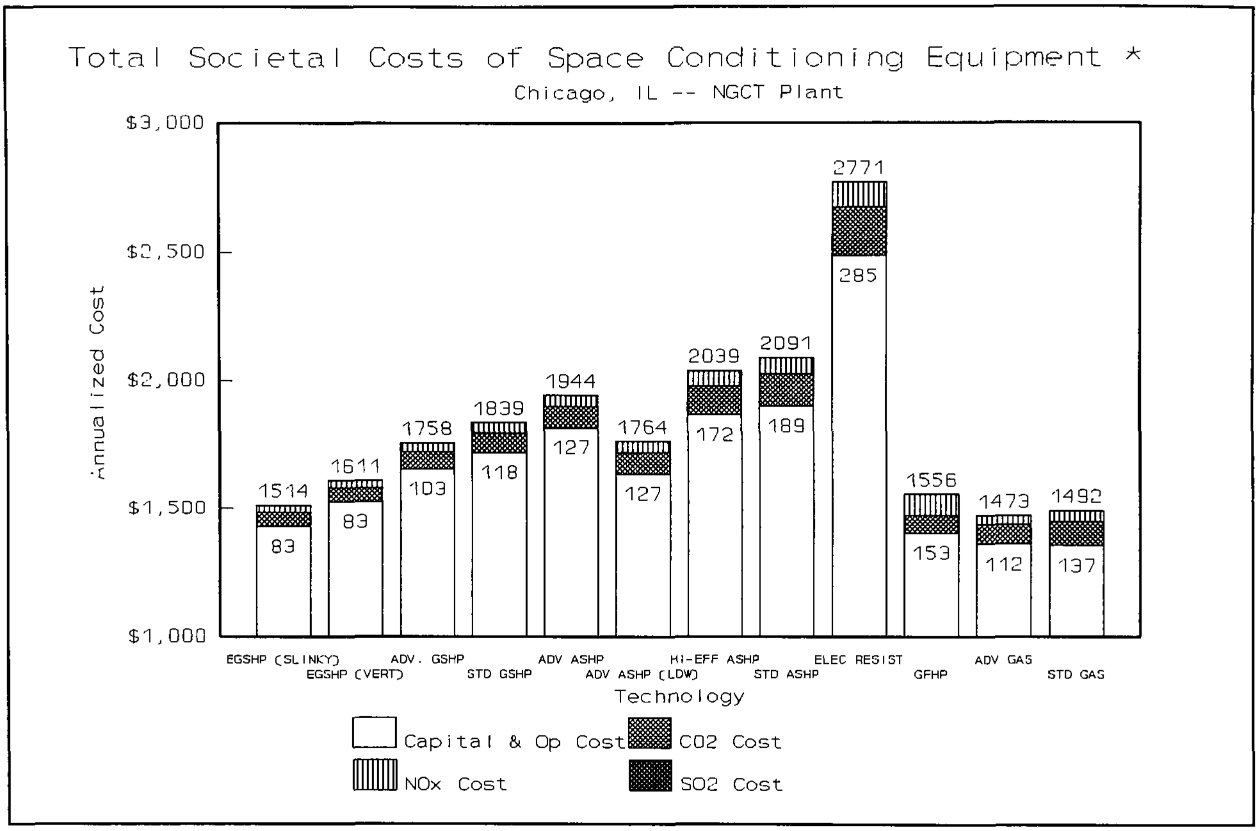
Exhibit C.20



* Number inside column refers to total externality cost.

Natural Gas Combustion Turbine (NGCT) Scenario: This scenario (Exhibit C.21) results in about the same ordering of total equipment societal costs as the previous scenario, with the cost of the **EMERGING GROUND SOURCE HEAT PUMPS** increasing slightly relative to the gas equipment.

Exhibit C.21



* Number inside column refers to total externality cost.

CHOICES FOR UTILITIES: COST-EFFECTIVENESS SCREENING

The cost-effectiveness of various utility programs will depend on a realistic assessment of which technologies compete in a particular residence, and at what costs.

The utility cost-effectiveness analysis and estimate of utility program effect on customer payback, as described in Chapter 3, was performed for various equipment substitutions and is presented in Exhibit C.22. ELECTRIC RESISTANCE, STANDARD AIR SOURCE HEAT PUMPS and STANDARD GAS FURNACES were selected as the base technologies for which substitutions would be evaluated.

For houses with electric or oil heating, there may not be easy access to gas service; in such cases, the cost of adding gas service will likely be prohibitive. The results of utility cost-effectiveness screening presented in this Appendix assume that gas service is available to the household.

As discussed in Chapter Three, the results for Chicago are driven by the avoided energy costs for a typical utility in the Midwest region (Commonwealth Edison). Externality costs are not included in these marginal energy costs. The analysis factors in an avoided capacity value of about $102/kW/yr, which accounts for generating capacity factor and transmission and distribution costs and losses.

Administrative costs are assumed to be $150 per household. The utility incentive is assumed to cover the entire incremental cost whenever the Total Resource Cost Test ratio is 1 or greater. In those cases in which the TRC ratio is below 1, no utility incentive is assumed.

As in Burlington, the TRC ratios are higher if ELECTRIC RESISTANCE or STANDARD AIR SOURCE HEAT PUMPS are replaced by advanced electric technologies (GSHPs) than they would be if the programs were for switching to natural gas. However, assuming that service is available, the GAS-FIRED HEAT PUMP and ADVANCED GAS FURNACE have the highest net present value when replacing ELECTRIC RESISTANCE and STANDARD AIR SOURCE HEAT PUMPS. The gas equipment also produces greater emissions reductions under the Regional Generating Mix.

A combination of relatively low gas avoided costs and a heating-dominated climate also drive the comparative cost-effectiveness results for equipment replacing STANDARD GAS FURNACES in the Midwest. Although they reduce CO_2 emissions significantly, EMERGING GROUND SOURCE HEAT PUMPS are not cost-effective when replacing STANDARD GAS FURNACES. They also increase NO_x and SO_2 emissions. The other electric technologies fail the TRC test as well.

The superior replacement for STANDARD GAS FURNACES in this location from the standpoint of TRC ratio, net present value, and emission reductions, is the GAS-FIRED HEAT PUMP; although the ADVANCED GAS FURNACE reduces NO_x emissions more, it does not compare nearly as well in terms of TRC ratio, net present value, CO_2 emissions, or SO_2 emissions.

Exhibit C.22
Utility Program Cost Effectiveness
Chicago, Illinois

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)			Without Incentive	With Incentive	CO2	NOx	SO2
Replace Electric Resistant Heating/AC with:**													
Emerging Ground Source Heat Pump (SLINKY)	$3,960	$3,960	16,651	5.6	4.8	0.0	3.30	$9,452	4.35	0.00	13,245	41.01	61.52
Emerging Ground Source Heat Pump (Vertical)	$4,945	$4,945	16,651	5.6	4.8	0.0	2.66	$8,467	5.43	0.00	13,245	41.01	61.52
Advanced Ground Source Heat Pump	$4,945	$4,945	15,054	5.6	4.8	0.0	2.51	$7,673	6.23	0.00	11,976	37.08	55.63
Advanced Air Source Heat Pump (Present Cost)	$5,380	$5,380	13,070	0.4	4.7	0.0	1.66	$3,660	7.35	0.00	10,397	32.20	48.29
Advanced Air Source Heat Pump (Low Cost)	$3,548	$3,548	13,070	0.4	4.7	0.0	2.49	$5,492	4.85	0.00	10,397	32.20	48.29
Advanced Gas Furnace/ High Efficiency AC***	$3,050	$3,050	21,503	15.3	5.0	-878.0	2.06	$10,684	4.34	0.00	12,431	48.90	79.36
Gas Air-to-Air Heat Pump	$3,850	$3,850	22,290	15.3	7.1	-832.2	2.02	$11,097	4.84	0.00	13,211	42.66	82.27

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)			Without Incentive	With Incentive	CO2	NOx	SO2
Replace Standard Air Source Heat Pump with:													
Emerging Ground Source Heat Pump (SLINKY)	$1,910	$1,910	8,607	5.6	5.0	0.0	4.55	$7,317	3.61	0.00	6,944	21.50	32.25
Emerging Ground Source Heat Pump (Vertical)	$2,895	$2,895	8,607	5.6	5.0	0.0	3.08	$6,332	5.47	0.00	6,944	21.50	32.25
Advanced Ground Source Heat Pump	$2,895	$2,895	7,420	5.6	5.0	0.0	2.88	$5,731	6.43	0.00	5,675	17.57	26.36
Advanced Air Source Heat Pump (Present Cost)	$3,330	$3,330	4,354	0.4	4.9	0.0	1.34	$1,195	11.20	0.00	4,097	12.69	19.03
Advanced Air Source Heat Pump (Low Cost)	$1,498	$1,498	4,354	0.4	4.9	0.0	2.84	$3,027	5.04	0.00	4,097	12.69	19.03
Advanced Gas Furnace/ High Efficiency AC	$1,000	$1,000	14,025	15.3	5.2	-878.0	2.10	$8,856	2.91	0.00	6,131	29.39	50.10
Gas Air-to-Air Heat Pump	$1,800	$1,800	15,279	15.3	7.3	-635.0	2.51	$11,047	3.16	0.00	6,910	23.15	53.01

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)			Without Incentive	With Incentive	CO2	NOx	SO2
Replace Standard Gas Furnace/AC with:													
Emerging Ground Source Heat Pump (SLINKY)	$2,335	$0	(4,945)	-9.7	0.3	1095.0	0.90	($974)	6.62	6.62	2,202	(6.10)	(16.63)
Emerging Ground Source Heat Pump (Vertical)	$3,320	$0	(4,945)	-9.7	0.3	1095.0	0.81	($1,959)	9.42	9.42	2,202	(6.10)	(16.63)
Advanced Ground Source Heat Pump	$3,320	$0	(6,132)	-9.7	0.3	1095.0	0.77	($2,561)	12.13	12.13	933	(10.03)	(22.52)
Advanced Air Source Heat Pump (Present Cost)	$3,755	$0	(9,198)	-14.9	0.2	1095.0	0.55	($7,096)	>20	>20	(645)	(14.92)	(29.85)
Advanced Air Source Heat Pump (Low Cost)	$1,923	$0	(9,198)	-14.9	0.2	1095.0	0.62	($5,264)	15.93	15.93	(645)	(14.92)	(29.85)
Advanced Gas Furnace/ High Efficiency AC***	$1,425	$1,425	473	0.0	0.5	217.0	1.36	$565	8.52	0.00	1,388	1.78	1.22
Gas Air-to-Air Heat Pump	$2,225	$2,225	1,727	0.0	2.6	460.0	1.99	$2,756	5.66	0.00	2,168	(4.46)	4.13

If TRC <1, no incentive program is assumed. Where TRC test is greater than 1, entire incremental cost is covered by the incentive.

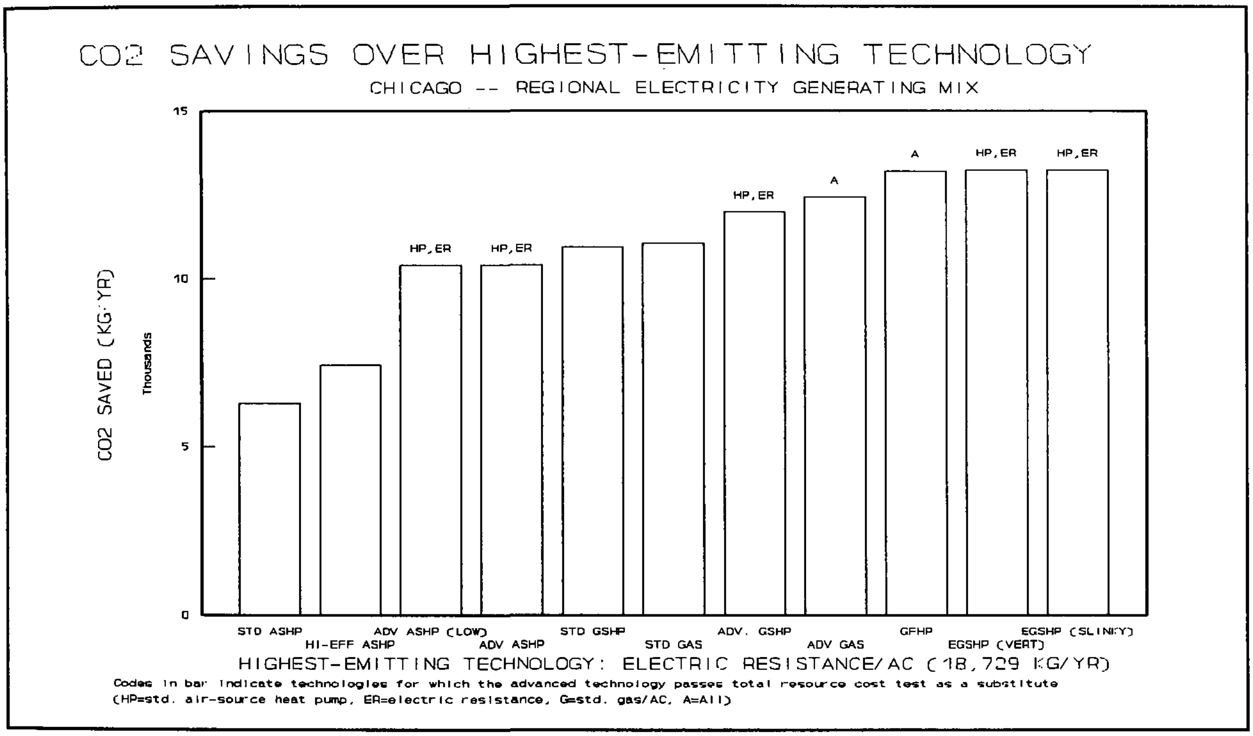
Results reflect replacement of existing ELECTRIC RESISTANCE at the end of the central AC's service life. We assume in this scenario that the ELECTRIC RESISTANCE does not need replacement. Thus, we compare the capital cost of the entire advanced system against only the replacement AC. In the case of new construction, a much higher TRC is obtained, since in this case the cost of the ELECTRIC RESISTANCE system would have to be factored in.

* Measured by itself, the HIGH-EFFICIENCY AIR CONDITIONER has a TRC of 1.20 when replacing a STANDARD AIR CONDITIONER. Likewise, the ADVANCED GAS FURNACE has a TRC of 1.05 when replacing a STANDARD GAS FURNACE.

A FOCUS ON CARBON DIOXIDE REDUCTIONS

Exhibits C.23 to C.26 rank all of the technologies studied in the report according to their CO_2 reductions under the three electric generation scenarios. From this perspective, it is clear that the more advanced technologies reduce CO_2 the most, and generally do so cost-effectively with the notable exception that the GROUND SOURCE HEAT PUMPS are not cost-effective replacements for STANDARD GAS FURNACES. Thus, while they reduce CO_2 the most in the REGIONAL, ADVANCED NATURAL GAS COMBINED CYCLE, and NATURAL GAS COMBINED TURBINE scenarios, the EMERGING GROUND SOURCE HEAT PUMPS were only appropriate replacements for standard electric equipment according to the utility market cost-effectiveness test. Only inclusion of environmental externalities into the Total Resource Cost Test would likely make them suitable replacements for the STANDARD GAS FURNACE as well.

Exhibit C.23



As can be seen in Exhibit C.24, under the ADVANCED FLUIDIZED BED COAL scenario, the GAS-FIRED HEAT PUMP combines general cost-effectiveness with the highest level of CO_2 reduction.

Exhibit C.24

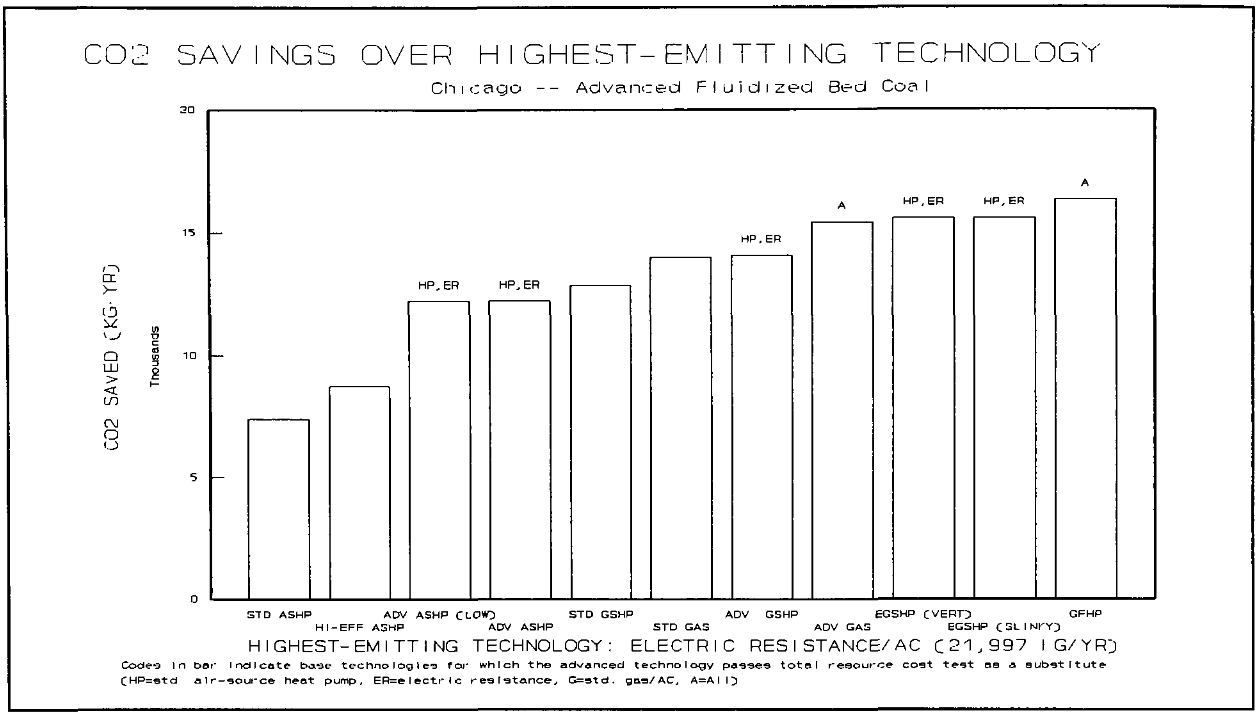


Exhibit C.25

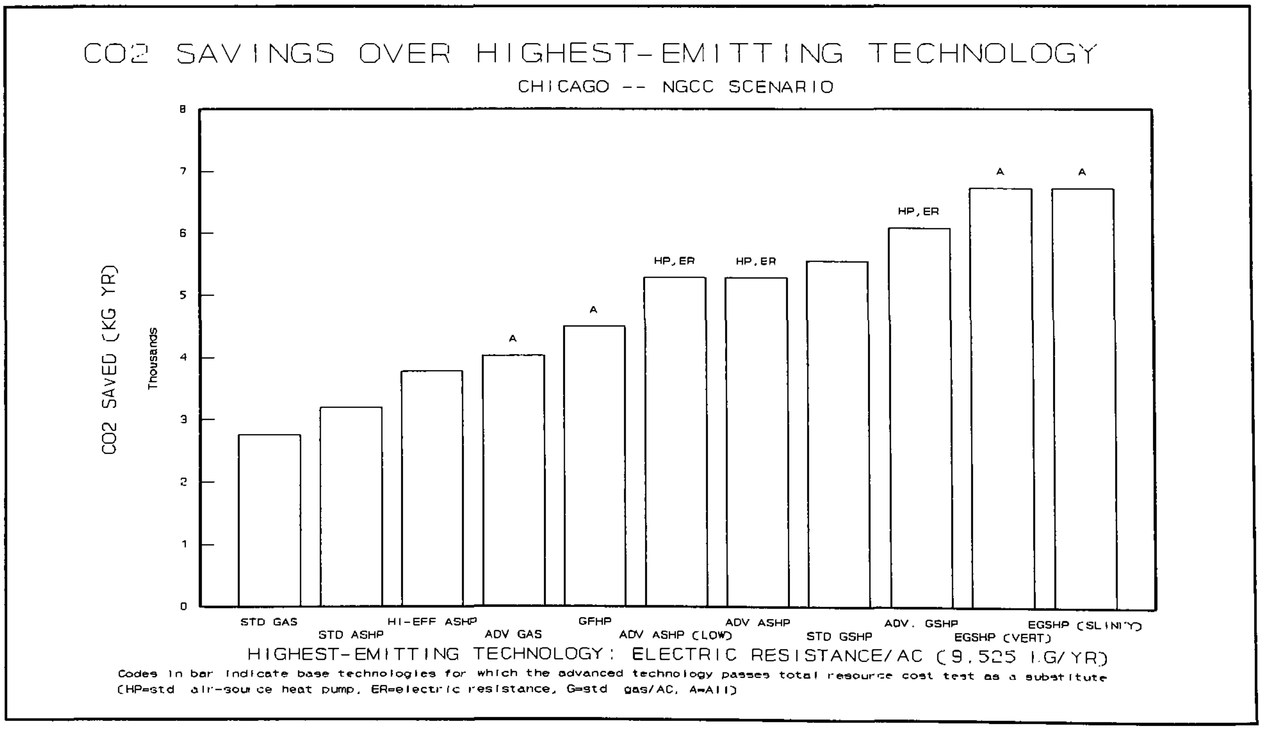
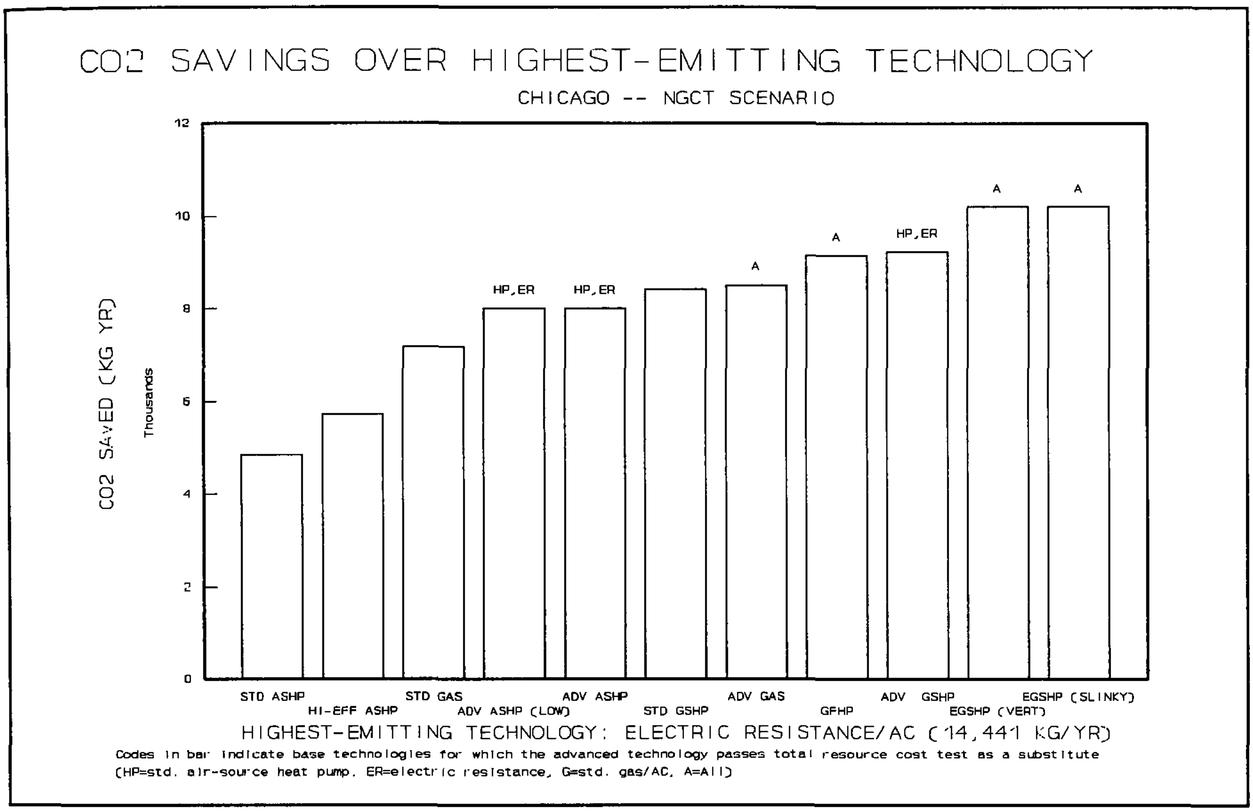


Exhibit C.26


CO2 SAVINGS OVER HIGHEST-EMITTING TECHNOLOGY
CHICAGO -- NGCT SCENARIO
CO2 SAVED (KG YR)
Thousands
0
2
4
6
8
10
12
HP,ER
HP,ER
A
A
HP,ER
A
A
STD ASHP
HI-EFF ASHP
STD GAS
ADV ASHP (LOW)
ADV ASHP
STD GSHP
ADV GAS
GFHP
ADV GSHP
EGSHP (VERT)
EGSHP (SLINKY)
HIGHEST-EMITTING TECHNOLOGY: ELECTRIC RESISTANCE/AC (14,441 KG/YR)
Codes in bar indicate base technologies for which the advanced technology passes total resource cost test as a substitute
(HP=std. air-source heat pump, ER=electric resistance, G=std. gas/AC, A=All)

CLIMATE ZONE 2: UPPER NEW YORK METROPOLITAN AREA

This location has more moderate heating and cooling seasons than the Chicago area. The prototypical house was estimated to require 62.30 MMBtu for heating, 11.50 MMBtu for cooling, and 10.60 MMBtu for water heating annually, for a total annual demand of 84.40 MMBtu. As in New England, the presence of a significant share of oil heating led to its inclusion in the utility cost-effectiveness screening.

PERFORMANCE AND COST

Exhibit C.27 compares the operating performance of all of the representative space conditioning technologies described in Chapter 2. The three columns on the left indicate each equipment's modeled end-use seasonal performance factor (SPF, calculated by dividing the number of Btu's demanded in the location for heating, cooling or water heating by the number of Btu's of energy input the equipment required to meet that demand). The higher the SPF, the higher the technology's end-use efficiency.

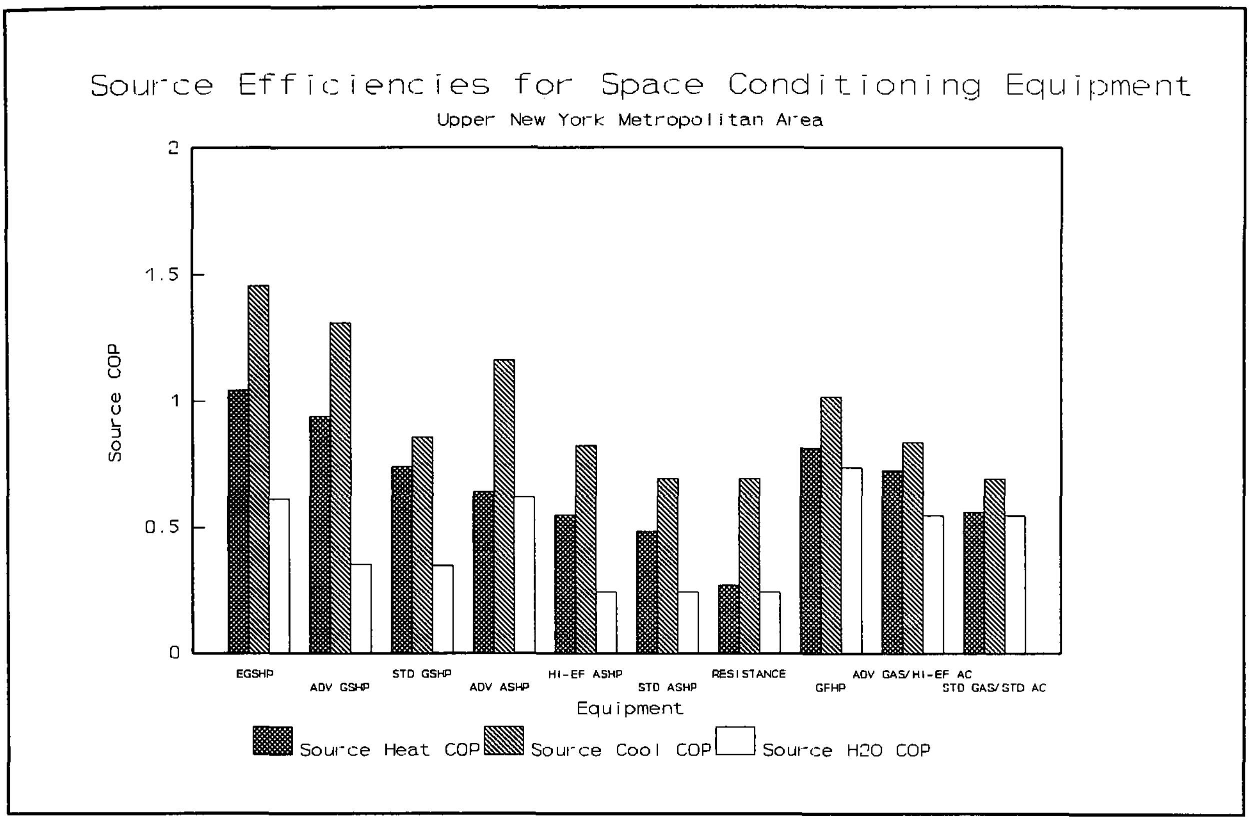
The three right-hand columns of Exhibit C.27, and Exhibit C.28, show source SPF, accounting for the losses in the generation, transmission and distribution system for each fuel type. The two best net energy performers in each category are highlighted:

Exhibit C.27
Performance of Space Conditioning Equipment
New York Area (including water heating)

	END USE EFFICIENCY			SOURCE EFFICIENCY		
	HEAT	COOL	H20	HEAT	COOL	H20
EQUIPMENT TYPE	SPF	SPF	SPF	SPF	SPF	SPF
Emerging Ground Source Heat Pump	3.87	5.39	2.27	1.04	1.46	0.61
Advanced Ground Source Heat Pump	3.48	4.86	1.31	0.94	1.31	0.35
Standard Ground Source Heat Pump	2.74	3.18	1.29	0.74	0.86	0.35
Advanced Air Source Heat Pump	2.37	4.31	2.30	0.64	1.16	0.62
High Efficiency Air Source Heat Pump	2.04	3.06	0.90	0.55	0.83	0.24
Standard Air Source Heat Pump	1.80	2.56	0.90	0.49	0.69	0.24
Electric Resistance/ Standard AC	1.00	2.56	0.90	0.27	0.69	0.24
Gas-Fired Heat Pump	1.02	1.27	0.81	0.81	1.02	0.74
Advanced Gas Furnace/ High Efficiency AC	0.87	3.11	0.60	0.73	0.84	0.55
Standard Gas Furnace/ Standard AC	0.66	2.56	0.60	0.56	0.69	0.55
Advanced Oil Furnace/ High Efficiency AC	0.73	3.11	0.90	0.59	0.84	0.24

* The emerging GSHP listed in this table reflects the operating performance of the SLINKY™ or the vertical system.

Exhibit C.28



Exhibits C.27 and C.28 follow the pattern established in previous locations for the space conditioning equipment analyzed here: once again, the EMERGING GROUND SOURCE HEAT PUMP trades off superior space heating and cooling efficiencies with a lower source water heating efficiency than the GAS-FIRED HEAT PUMP. The ADVANCED AIR SOURCE HEAT PUMP is modelled to have about the same source seasonal performance factor in water heating mode as the EMERGING GROUND SOURCE HEAT PUMP.

Exhibits C.29 and C.30 examine the cost of the various equipment for the upper New York Metropolitan Area. Exhibit C.29 highlights the two least expensive technologies with respect to annual capital, annual operating and total costs. As both exhibits show, the lowest annual costs, based on current fuel prices, are associated with EMERGING GROUND SOURCE HEAT PUMPS. However, the gas technologies are quite competitive (all of them beat the ADVANCED GROUND SOURCE HEAT PUMP).

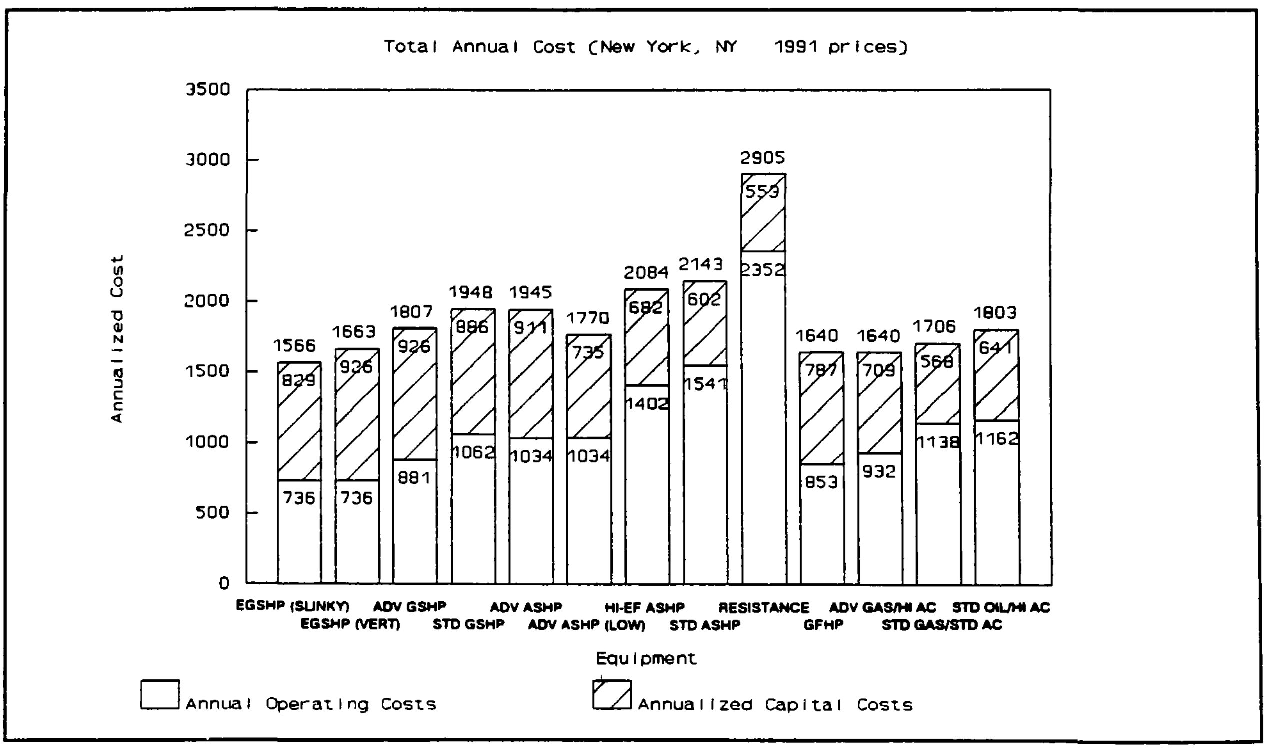
Exhibit C.29
Annual Costs Of Space Conditioning Equipment
Upper New York Metropolitan Area

EQUIPMENT TYPE	INSTALLED COST	ANNUAL CAPITAL	ANNUAL OPERATING	TOTAL COST
Emerging Ground Source Heat Pump (SLINKY)	$8,425	$829	$736	$1,566
Emerging Ground Source Heat Pump (Vertical)	$9,410	$926	$736	$1,663
Advanced Ground Source Heat Pump	$9,410	$926	$881	$1,807
Standard Ground Source Heat Pump	$9,005	$886	$1,062	$1,948
Advanced Air Source Heat Pump (Present Cost)	$9,255	$911	$1,034	$1,945
Advanced Air Source Heat Pump (Low Cost)	$7,470	$735	$1,034	$1,770
High Efficiency Air Source Heat Pump	$6,925	$682	$1,402	$2,084
Standard Air Source Heat Pump	$6,115	$602	$1,541	$2,143
Electric Resistance/ Standard AC	$5,615	$553	$2,352	$2,905
Gas-Fired Heat Pump	$8,000	$787	$853	$1,640
Advanced Gas Furnace/ High Efficiency AC	$7,200	$709	$932	$1,640
Standard Gas Furnace/ Standard AC	$5,775	$568	$1,138	$1,706
Advanced Oil Furnace/ High Efficiency AC	$6,515	$641	$1,162	$1,803

* Includes duct work ($1800) and water heater ($315 for electric and $400 for gas)

** Based on average 1991 residential rates: $.10/kWh electric and $.80/therm gas (Barakat and Chamberlin).

Exhibit C.30

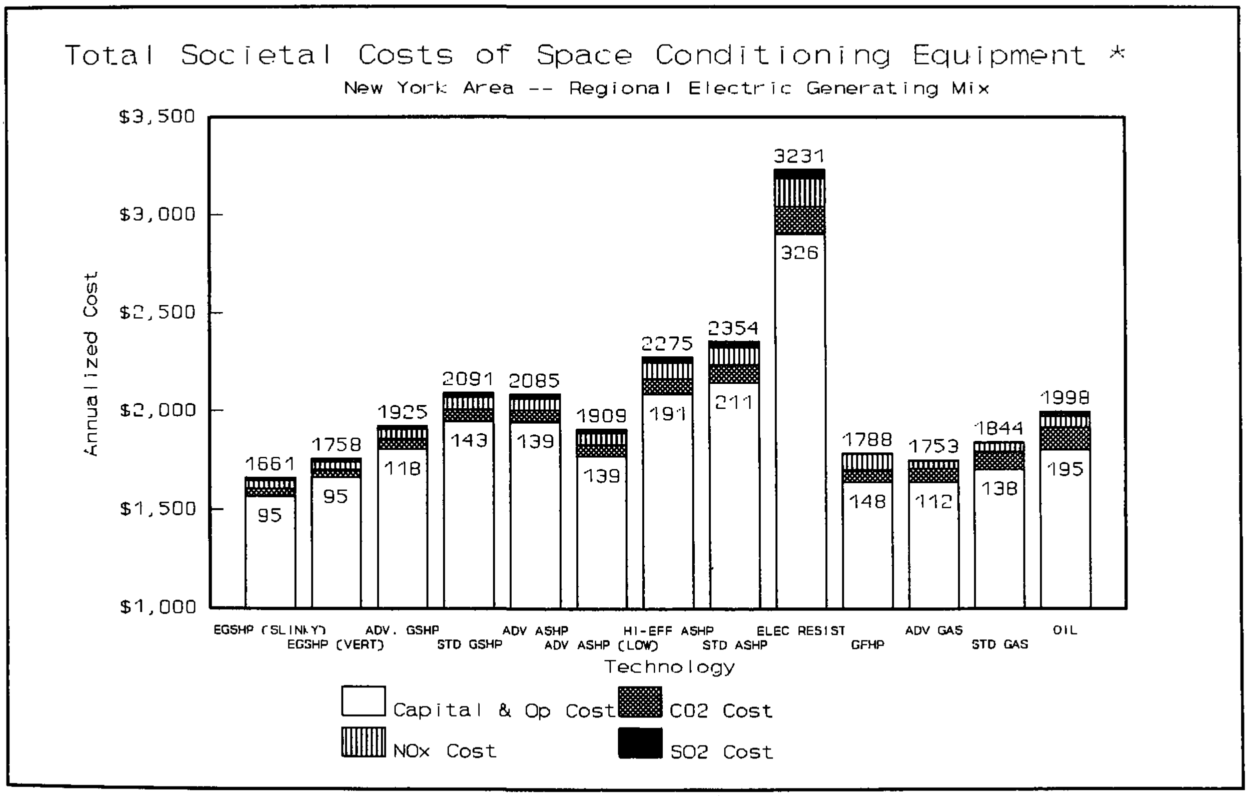


ENVIRONMENTAL EFFECTS AND TOTAL SOCIETAL COST

Regional Electric Generation Fuel Mix Scenario: As in other regions, the lowest-emission technologies are the GAS-FIRED HEAT PUMP, the EMERGING and ADVANCED GROUND SOURCE HEAT PUMPS and the ADVANCED GAS FURNACE. The best electric technology from an emissions standpoint, the EMERGING GROUND SOURCE HEAT PUMP, emits about 1730 kg/year (36%) less CO_2 than the GAS-FIRED HEAT PUMP, as well as about 50% less NO_x. However, it results in about five times the SO_2 emissions. Compared to the ADVANCED GAS FURNACE, the EMERGING GROUND SOURCE HEAT PUMP reduces CO_2 by 43%, while producing slightly higher NO_x and over three times the SO_2. Overall, the externality costs for the EMERGING GROUND SOURCE HEAT PUMP are lower than the two most advanced gas technologies (Exhibit C.31 and Appendix D), slightly improving their overall cost comparisons with the advanced gas technologies.

In comparing electric technologies, the EMERGING GROUND SOURCE HEAT PUMP has emissions of CO_2, NO_x and SO_2 that are 32% less than those for ADVANCED AIR SOURCE HEAT PUMPS, 56% less than STANDARD AIR SOURCE HEAT PUMPS, and 72% less than ELECTRIC RESISTANCE. Since these are proportional to overall electricity consumption, they are the same for all generating scenarios.

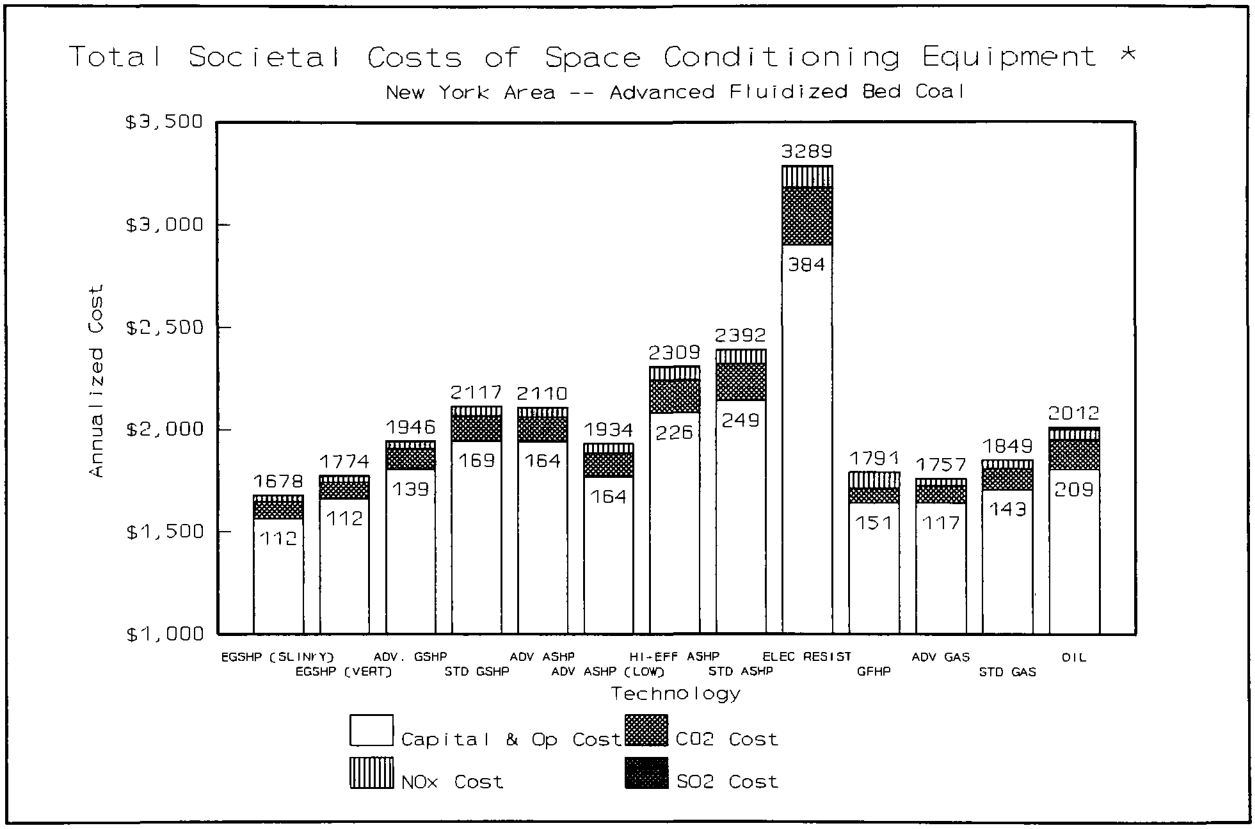
Exhibit C.31



* Number inside column refers to total externality cost.

Advanced Fluidized Bed Coal Scenario: As in Burlington, this generation scenario raises the relative CO_2 emissions for electric technologies. The lowest CO_2-emitting technology is now the GAS-FIRED HEAT PUMP, which yields a 14% improvement over the EMERGING GROUND SOURCE HEAT PUMP (Exhibit C.32 and Appendix D). However, its NO_x emissions are almost three times as high. Consequently, the total externality costs comparison under ADVANCED FLUIDIZED BED COAL shows about the same results as under the REGIONAL scenario, with the EMERGING GROUND SOURCE HEAT PUMP coming in with the lowest total externality costs.

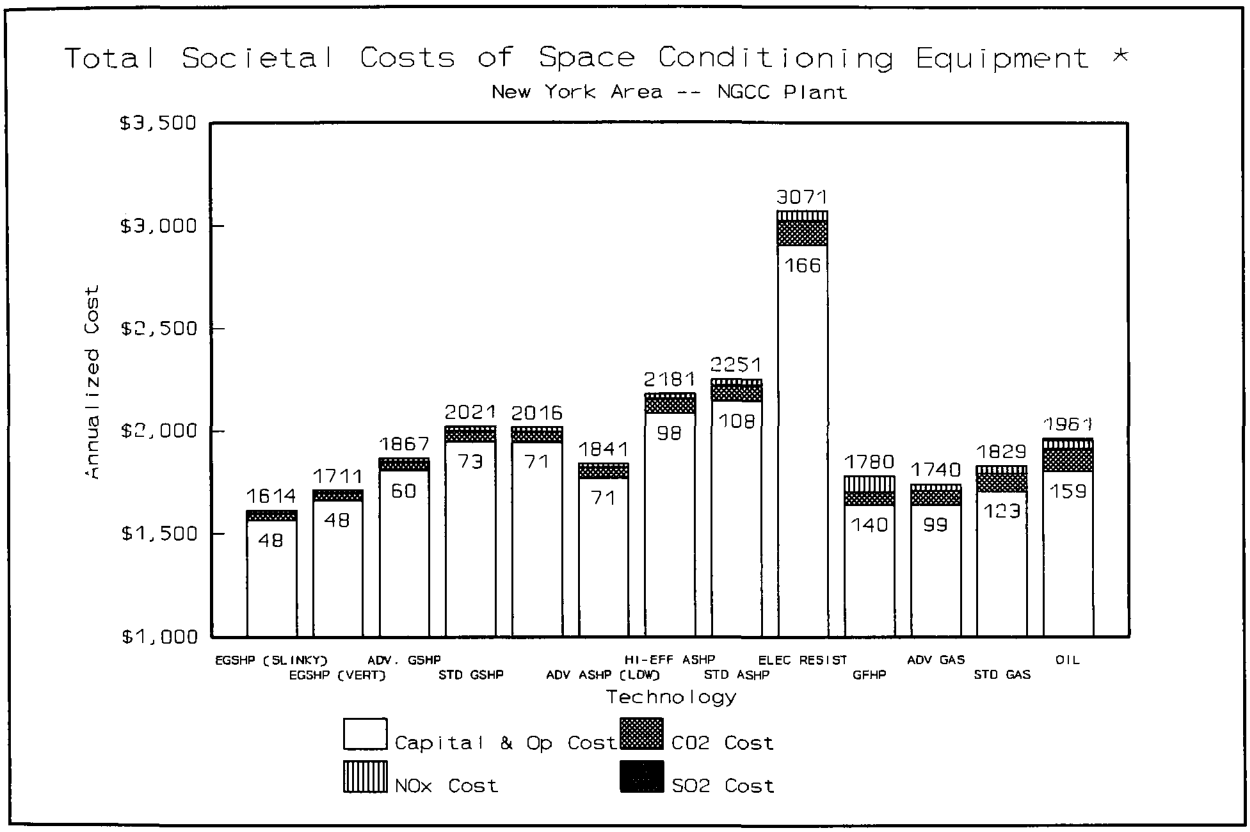
Exhibit C.32



* Number inside column refers to total externality cost.

Advanced Natural Gas Combined Cycle Scenario: Once again, this scenario significantly favors electric technologies over natural gas and oil technologies. Emerging GROUND SOURCE HEAT PUMPS would emit about 2,070 kg/yr (43%) less CO_2 than the GAS-FIRED HEAT PUMP, and less than one-sixth the NO_x emissions. Thus, their overall cost advantages are increased more under this scenario than for the two scenarios discussed above (Exhibit C.33 and Appendix D).

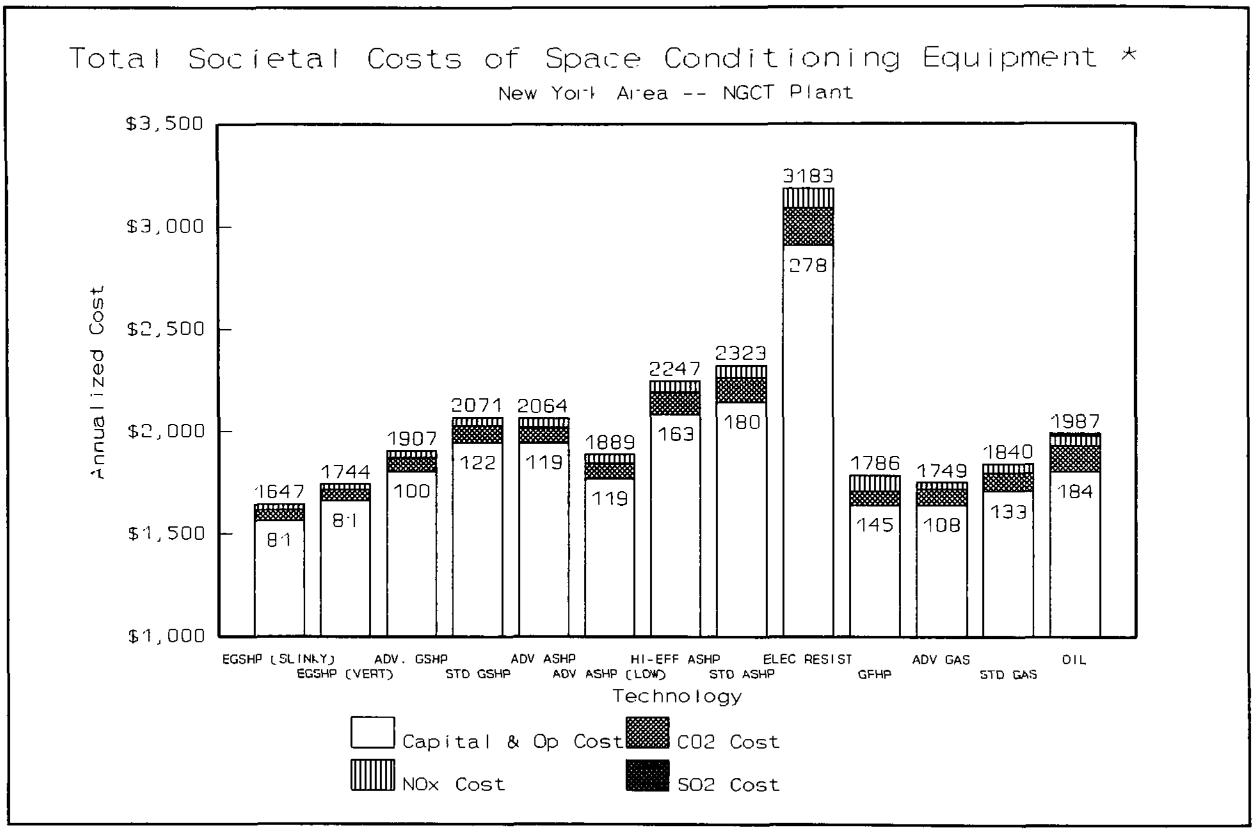
Exhibit C.33



* Number inside column refers to total externality cost.

Natural Gas Combustion Turbine Scenario: While this scenario (Exhibit C.34 and Appendix D) results in higher relative emissions for electric equipment than the previous scenario, the ADVANCED GROUND SOURCE HEAT PUMPS still have the lowest externality costs. EMERGING GROUND SOURCE HEAT PUMPS have CO_2 emissions that are 18% lower than the next lowest CO_2 emitter, the GAS-FIRED HEAT PUMP, and have the lowest overall societal cost, followed by the ADVANCED GAS FURNACE and GAS-FIRED HEAT PUMP.

Exhibit C.34



* Number inside column refers to total externality cost.

CHOICES FOR UTILITIES: COST-EFFECTIVENESS SCREENING

The cost-effectiveness of various utility programs will depend on a realistic assessment of which technologies compete in a particular residence, and at what costs.

The utility cost-effectiveness analysis and estimate of utility program effect on payback, as described in Chapter 3, was performed for various equipment substitutions and is presented in Exhibit C.35. ELECTRIC RESISTANCE, STANDARD AIR SOURCE HEAT PUMPS, STANDARD GAS FURNACES, and STANDARD OIL FURNACEs were selected as the base technologies for which substitutions could be promoted.

For houses with electric or oil heating, there may not be easy access to gas service; in such cases, the cost of adding gas service will likely be prohibitive. The results of utility cost-effectiveness screening presented in this Appendix assume that gas service is available to the household.

As discussed in Chapter Three, the results for the New York area are driven by the avoided energy costs for a typical utilities in the region (Long Island Lighting Company). Externality costs are not included in these marginal energy costs. The analysis factors in an avoided capacity value of about $102/kW/yr, which accounts for generating capacity factor and transmission and distribution costs and losses.

Administrative costs are assumed to be $150 per household. The utility incentive is assumed to cover the entire incremental cost of the equipment whenever the Total Resource Cost Test ratio is 1 or greater. In those cases in which the TRC ratio is below 1, no utility incentive is assumed.

The results of the utility TRC ratio tests and emissions reduction screening for the upper New York Metropolitan area suggest that the most advanced electric technologies are overall, superior substitutes for baseline electric technologies, gas service availability notwithstanding. Of the advanced electric technologies, the EMERGING GROUND SOURCE HEAT PUMP has the highest TRC ratios for replacing ELECTRIC RESISTANCE, STANDARD AIR SOURCE HEAT PUMPS and STANDARD OIL FURNACES. Although the LOW-COST ADVANCED AIR SOURCE HEAT PUMP has comparable TRC ratios it does not yield as high a net present value or emission reductions as do the EMERGING GROUND SOURCE HEAT PUMPS. The ADVANCED GROUND SOURCE HEAT PUMP also competes favorably with the LOW-COST ADVANCED AIR SOURCE HEAT PUMP in terms of emission reductions when replacing STANDARD OIL, although its TRC ratios and net present value yields are lower.

Among advanced gas technologies, the GAS-FIRED HEAT PUMP has a very high net present value for all four replacement scenarios and also significantly reduces CO_2 emissions when replacing ELECTRIC RESISTANCE, STANDARD AIR SOURCE HEAT PUMPS and STANDARD GAS FURNACES. Although somewhat lower than the GAS-FIRED HEAT PUMP, the ADVANCED GAS FURNACE nevertheless has high TRC net present values and emission reductions.

This location produced somewhat surprising results in comparing advanced equipment when replacing STANDARD GAS FURNACES. Neither the ADVANCED GAS FURNACE nor the GAS-FIRED HEAT PUMP have a clear advantage over the EMERGING GROUND SOURCE HEAT PUMPS. The EMERGING GROUND SOURCE HEAT PUMPS had the best results in terms of net present value and CO_2 reductions, but the advanced gas technologies had somewhat higher TRC ratios. GROUND SOURCE HEAT PUMPS would increase SO_2 emissions relative to high efficiency gas equipment, but the GAS-FIRED HEAT PUMP had higher NO_x emissions.

Exhibit C.35
Utility Program Cost-Effectiveness and Paybacks
New York Metropolitan Area

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Oil Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)	(gal.)			Without Incent.	With Incent.	CO2	NOx	SO2
Replace Electric Resistant Heating/AC with:**														
Emerging Ground Source Heat Pump (SLINKY)	$4,360	$4,360	16,157	5.7	5.4	0.0	0.0	2.59	$7,178	2.34	0.00	7,597	15.33	38.33
Emerging Ground Source Heat Pump (Vertical)	$5,345	$5,345	16,157	5.7	5.4	0.0	0.0	2.13	$6,193	2.87	0.00	7,597	15.33	38.33
Advanced Ground Source Heat Pump	$5,345	$5,345	14,712	5.7	5.4	0.0	0.0	2.02	$5,610	3.16	0.00	6,854	13.83	34.58
Advanced Air Source Heat Pump (Present Cost)	$5,190	$5,190	13,175	1.1	4.6	0.0	0.0	1.49	$2,624	3.42	0.00	6,138	12.39	30.97
Advanced Air Source Heat Pump (Low Cost)	$3,405	$3,405	13,175	1.1	4.6	0.0	0.0	2.24	$4,409	2.24	0.00	6,138	12.39	30.97
Advanced Gas Furnace/ High Efficiency AC***	$3,050	$3,050	17,713	15.4	0.5	-692.0	0.0	1.40	$4,146	2.04	0.00	5,235	15.87	49.66
Gas Air-to-Air Heat Pump	$3,850	$3,850	21,833	15.4	7.0	-792.9	0.0	1.52	$6,596	2.07	0.00	5,864	8.86	51.23
Advanced Oil Furnace/ High Efficiency AC	$2,450	$2,450	18,225	10.9	0.5	0.0	-602.0	1.19	$1,981	1.73	0.00	1,980	12.28	29.46

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Oil Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)	(gal.)			Without Incent.	With Incent.	CO2	NOx	SO2
Replace Standard Air Source Heat Pump with:														
Emerging Ground Source Heat Pump (SLINKY)	$2,310	$2,310	8,050	5.7	5.3	0.0	0.0	3.41	$5,928	2.47	0.00	3,821	7.71	19.28
Emerging Ground Source Heat Pump (Vertical)	$3,295	$3,295	8,050	5.7	5.3	0.0	0.0	2.43	$4,943	3.53	0.00	3,821	7.71	19.28
Advanced Ground Source Heat Pump	$3,295	$3,295	6,605	5.7	5.3	0.0	0.0	2.27	$4,360	4.31	0.00	3,077	6.21	15.53
Advanced Air Source Heat Pump (Present Cost)	$3,140	$3,140	5,068	1.1	4.5	0.0	0.0	1.42	$1,374	5.30	0.00	2,361	4.76	11.91
Advanced Air Source Heat Pump (Low Cost)	$1,355	$1,355	5,068	1.1	4.5	0.0	0.0	3.10	$3,159	2.29	0.00	2,361	4.76	11.91
Advanced Gas Furnace/ High Efficiency AC	$1,000	$1,000	13,058	15.4	4.9	-870.0	0.0	1.45	$4,544	1.19	0.00	1,459	8.25	30.60
Gas Air-to-Air Heat Pump	$1,800	$1,800	13,726	15.4	6.9	-792.9	0.0	1.50	$5,345	1.93	0.00	2,088	1.24	32.18
Advanced Oil Furnace/ High Efficiency AC	$400	$400	10,118	10.9	0.4	0.0	-602.0	1.08	$731	0.82	0.00	(1,796)	4.66	10.41

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Oil Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)	(gal.)			Without Incent.	With Incent.	CO2	NOx	SO2
Replace Standard Gas Furnace/AC with:														
Emerging Ground Source Heat Pump (SLINKY)	$2,735	$2,735	(4,722)	-9.7	0.9	1092.0	0.0	1.28	$2,470	9.23	0.00	3,652	0.74	(10.63)
Emerging Ground Source Heat Pump (Vertical)	$3,720	$3,720	(4,722)	-9.7	0.9	1092.0	0.0	1.15	$1,485	12.56	0.00	3,652	0.74	(10.63)
Advanced Ground Source Heat Pump	$3,720	$3,720	(6,167)	-9.7	0.9	1092.0	0.0	1.09	$902	>20	0.00	2,909	(0.76)	(14.38)
Advanced Air Source Heat Pump (Present Cost)	$3,565	$0	(7,704)	-14.3	0.1	1092.0	0.0	0.85	($2,084)	>20	>20	2,193	(2.21)	(17.99)
Advanced Air Source Heat Pump (Low Cost)	$1,780	$0	(7,704)	-14.3	0.1	1092.0	0.0	0.97	($299)	>20	>20	2,193	(2.21)	(17.99)
Advanced Gas Furnace/ High Efficiency AC***	$1,425	$1,425	286	0.0	0.5	222.0	0.0	1.69	$1,086	6.96	0.00	1,290	1.28	0.69
Gas Air-to-Air Heat Pump	$2,225	$2,225	954	0.0	2.5	299.1	0.0	1.68	$1,888	7.48	0.00	1,919	(5.74)	2.27
Advanced Oil Furnace/ High Efficiency AC	$825	$0	(2,654)	-4.5	-4.0	1092.0	-602.0	0.81	($2,727)	>20	>20	(1,965)	(2.31)	(19.50)

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Oil Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)	(gal.)			Without Incent.	With Incent.	CO2	NOx	SO2
Replace Standard Oil Furnace/AC with:														
Emerging Ground Source Heat Pump (SLINKY)	$3,210	$3,210	(1,270)	-5.2	5.4	0.0	660.0	2.35	$5,081	5.28	0.00	6,144	3.59	10.31
Emerging Ground Source Heat Pump (Vertical)	$4,195	$4,195	(1,270)	-5.2	5.4	0.0	660.0	1.86	$4,096	6.91	0.00	6,144	3.59	10.31
Advanced Ground Source Heat Pump	$4,195	$4,195	(2,715)	-5.2	5.4	0.0	660.0	1.66	$3,514	9.57	0.00	5,400	2.09	6.55
Advanced Air Source Heat Pump (Present Cost)	$4,040	$4,040	(4,252)	-9.8	4.6	0.0	660.0	1.06	$527	15.19	0.00	4,684	0.65	2.94
Advanced Air Source Heat Pump (Low Cost)	$2,255	$2,255	(4,252)	-9.8	4.6	0.0	660.0	1.35	$2,312	8.48	0.00	4,684	0.65	2.94
Advanced Gas Furnace/ High Efficiency AC	$1,900	$1,900	3,738	4.5	5.0	-870.0	660.0	1.33	$3,698	3.68	0.00	3,782	4.13	21.63
Gas Air-to-Air Heat Pump	$2,700	$2,700	4,406	4.5	7.0	-792.9	660.0	1.39	$4,499	4.43	0.00	4,411	(2.88)	23.21
Advanced Oil Furnace/ High Efficiency AC	$1,300	$0	798	0.0	0.5	0.0	58.0	0.92	($115)	8.12	8.12	527	0.54	1.44

* If TRC <1, no incentive program is assumed. Where TRC test is greater than 1, the entire incremental cost is covered by the incentive.

** Results reflect replacement of existing ELECTRIC RESISTANCE at the end of the central AC's service life. It is assumed in this scenario that the ELECTRIC RESISTANCE does not need replacement. Thus, we compare the capital cost of the entire advanced system against only the replacement AC. In the case of new construction, a much higher TRC is obtained, since in this case the cost of the ELECTRIC RESISTANCE system would have to be factored in.

*** Measured by itself, the HIGH-EFFICIENCY AIR CONDITIONER has a TRC of 1.13 when replacing a STANDARD AIR CONDITIONER. Likewise, the ADVANCED GAS FURNACE has a TRC of 1.82 when replacing a STANDARD GAS FURNACE.

A FOCUS ON CARBON DIOXIDE REDUCTIONS

Exhibits C.36 through C.39 look at the various technologies from the perspective of carbon dioxide reductions. As in Burlington and Chicago, the technologies clustered to the right of the graphs show a consistent correlation between superior equipment performance, reduced CO_2 emissions, and utility cost-effectiveness. Once again, the relative ordering of the most advanced gas and electric technologies depends on the electricity generation fuel scenario; in the Mid-Atlantic area, the REGIONAL, ADVANCED NATURAL GAS COMBINED CYCLE, and NATURAL GAS COMBUSTION TURBINE scenarios favor EMERGING GROUND SOURCE HEAT PUMPS, while in the ADVANCED COAL scenario the GAS-FIRED HEAT PUMP combines general cost-effectiveness with the lowest CO_2 emissions.

Exhibit C.36

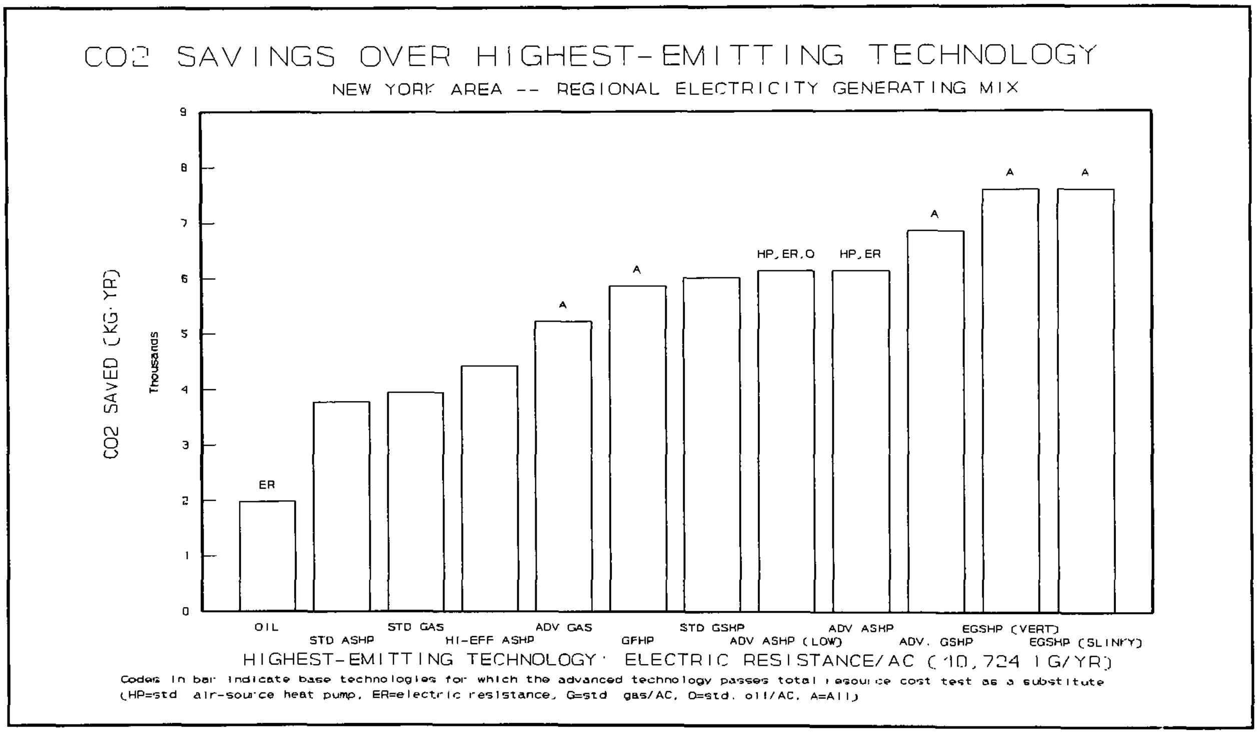


Exhibit C.37

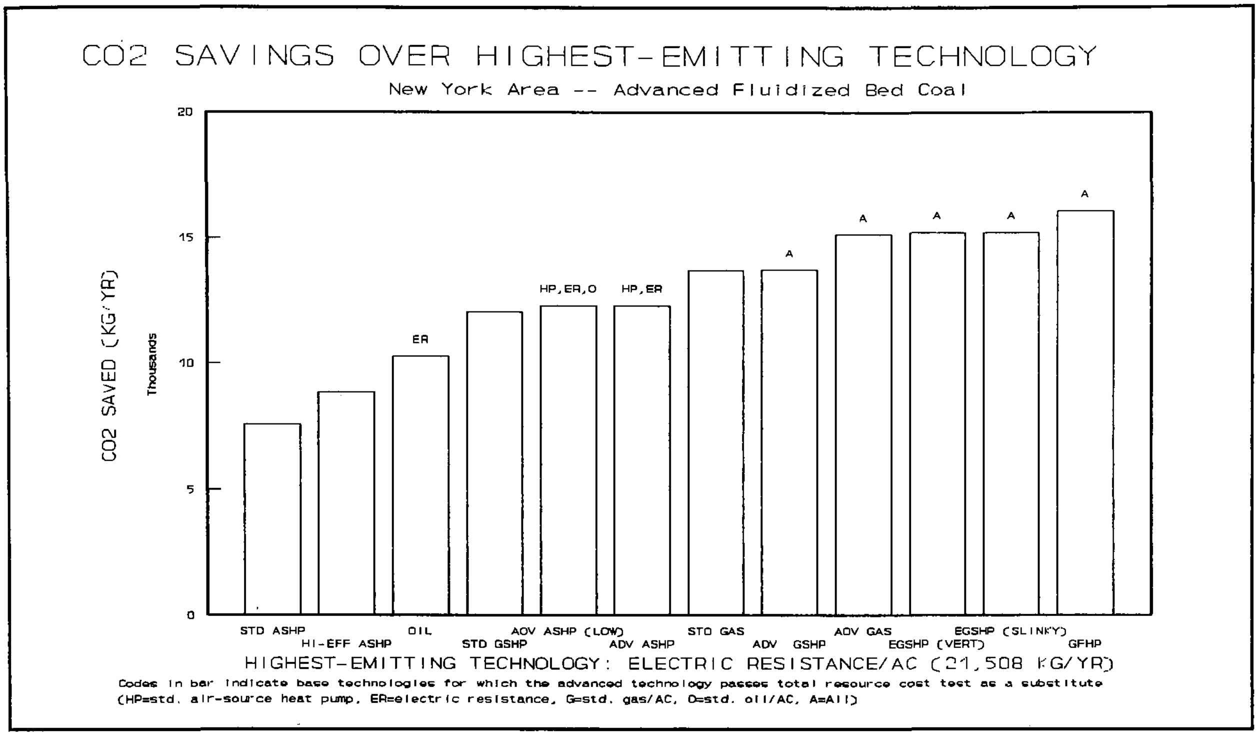


Exhibit C.38

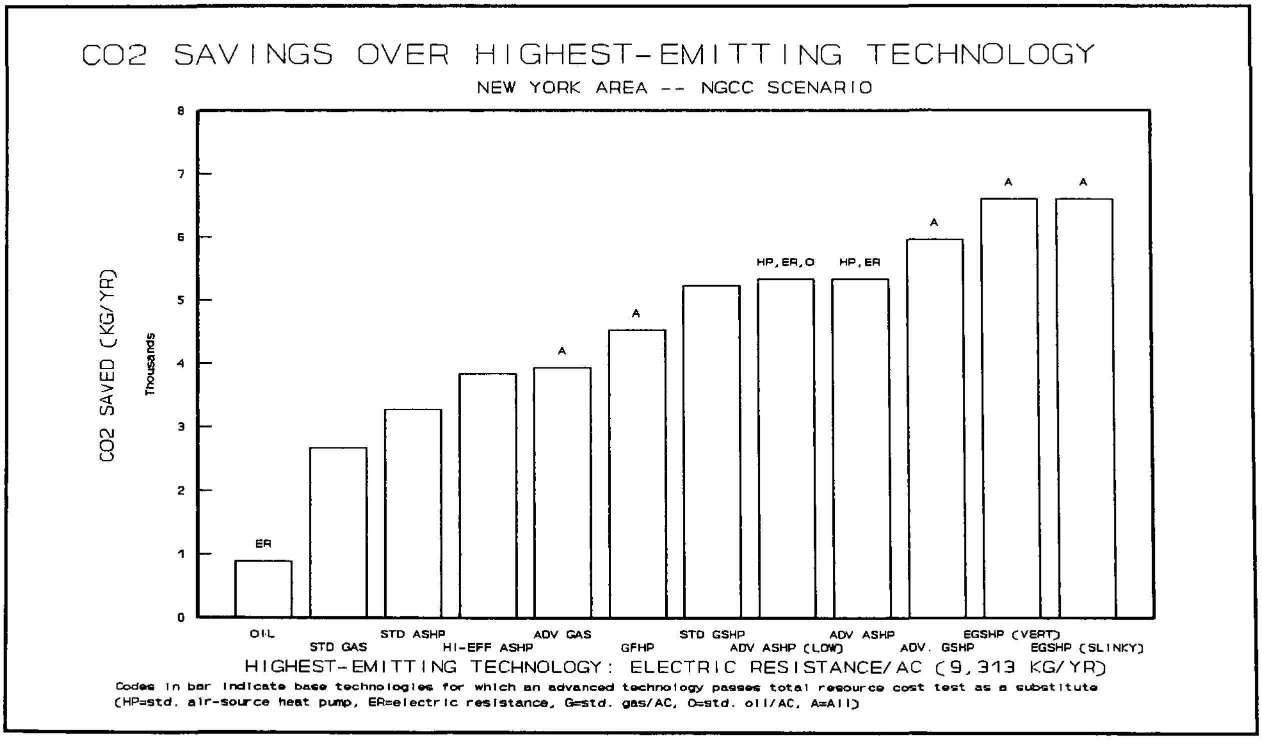
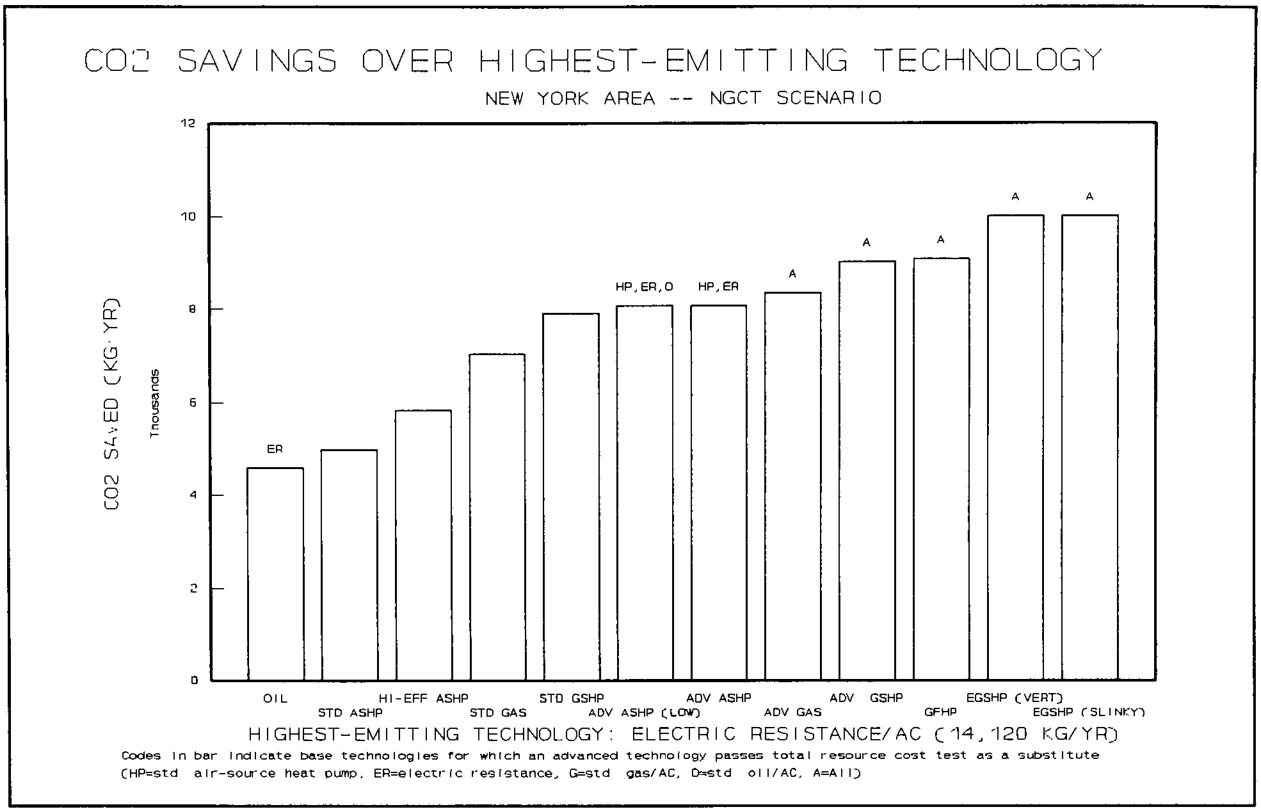


Exhibit C.39


CO2 SAVINGS OVER HIGHEST-EMITTING TECHNOLOGY
NEW YORK AREA -- NGCT SCENARIO
CO2 SAVED (KG/YR)
Thousands
0
2
4
6
8
10
12
ER
HP, ER, O
HP, ER
A
A
A
A
A
OIL
STD ASHP
HI-EFF ASHP
STD GAS
STD GSHP
ADV ASHP (LOW)
ADV ASHP
ADV GAS
ADV GSHP
GFHP
EGSHP (VERT)
EGSHP (SLINKY)
HIGHEST-EMITTING TECHNOLOGY: ELECTRIC RESISTANCE/AC (14,120 KG/YR)
Codes in bar indicate base technologies for which an advanced technology passes total resource cost test as a substitute
(HP=std air-source heat pump, ER=electric resistance, G=std gas/AC, O=std oil/AC, A=All)

CLIMATE ZONE 3: PORTLAND, OREGON

Climate Zone 3 cuts across the East and Midwest just to the South of Zone 2; it also includes a few sections of Arizona, Northern California, the Coastal Northwest, and parts of Idaho (Exhibit 3.1). For the representative location, Portland OR, the annual space heating demand is 42.9 MMBtu; the space cooling demand is 5.1 MMBtu; and the water heating demand is 10 MMBtu. Overall, Portland is the most "moderate" location analyzed.

PERFORMANCE AND COST

Exhibit C.40 compares the operating performance of all of the representative space conditioning technologies described in Chapter 2. The three columns on the left indicate each equipment's modeled end-use seasonal performance factor (SPF, calculated by dividing the number of Btu's demanded in the location for heating, cooling or water heating by the number of Btu's of energy input the equipment required to meet that demand). The higher the SPF, the higher the technology's end-use efficiency.

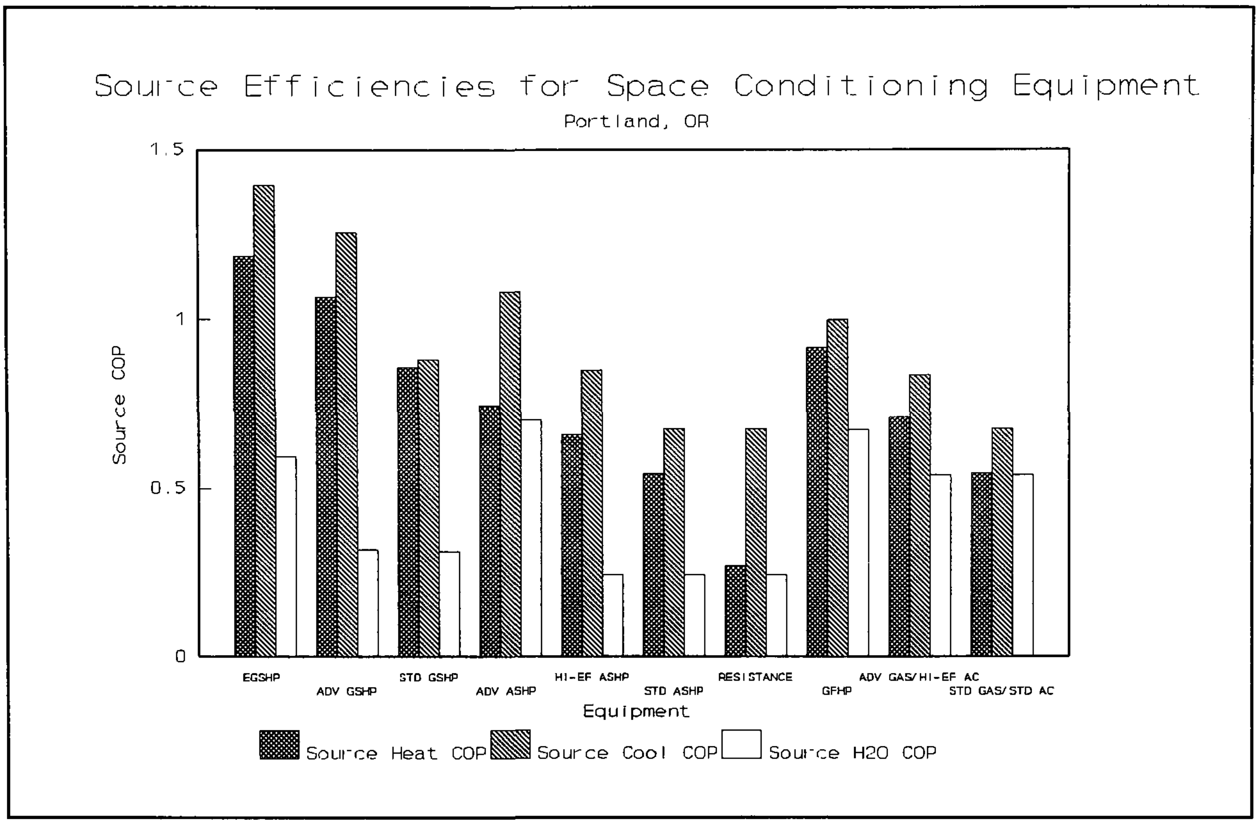
The three right-hand columns of Exhibit C.40, and Exhibit C.41, show source SPF, accounting for the losses in the generation, transmission and distribution system for each fuel type. The two best net energy performers in each category are highlighted:

Exhibit C.40
Performance of Space Conditioning Equipment
Portland, OR (including water heating)

	END USE EFFICIENCY			SOURCE EFFICIENCY		
	HEAT	COOL	H20	HEAT	COOL	H20
EQUIPMENT TYPE	SPF	SPF	SPF	SPF	SPF	SPF
Emerging Ground Source Heat Pump	4.39	5.17	2.20	1.19	1.40	0.59
Advanced Ground Source Heat Pump	3.95	4.66	1.18	1.07	1.26	0.32
Standard Ground Source Heat Pump	3.18	3.26	1.16	0.86	0.88	0.31
Advanced Air Source Heat Pump	2.75	4.01	2.60	0.74	1.08	0.70
High Efficiency Air Source Heat Pump	2.44	3.15	0.90	0.66	0.85	0.24
Standard Air Source Heat Pump	2.01	2.51	0.90	0.54	0.68	0.24
Electric Resistance/ Standard AC	1.00	2.51	0.90	0.27	0.68	0.24
Gas-Fired Heat Pump	1.14	1.25	0.74	0.92	1.00	0.67
Advanced Gas Furnace/ High Efficiency AC	0.85	3.09	0.59	0.71	0.84	0.54
Standard Gas Furnace/ Standard AC	0.64	2.51	0.59	0.55	0.68	0.54

* The emerging GSHP listed in this table reflects the operating performance of the SLINKY™ or the vertical system.

Exhibit C.41



As in the locations analyzed above, Exhibits C.40 and C.41 show the EMERGING GROUND SOURCE HEAT PUMP and the ADVANCED GROUND SOURCE HEAT PUMP as the best performers in the space heating and space cooling modes. The GAS-FIRED HEAT PUMP and the ADVANCED AIR SOURCE HEAT PUMP are the best performers in water heating mode.

Exhibits C.42 and C.43 provide the annual costs for each of the equipment analyzed. Exhibit C.42 highlights the two least expensive technologies with respect to annual capital, annual operating and total costs. Due to a winter season that is moderate compared to Climate Zones 1 and 2, and to relatively low regional electricity rates, the LOW-COST ADVANCED AIR SOURCE HEAT PUMP emerges as the lowest-cost technology under current energy prices, followed very closely by the EMERGING GROUND SOURCE HEAT PUMP/SLINKY^{TM} system (the higher annualized capital costs of the latter roughly cancel out its lower annual operating cost):

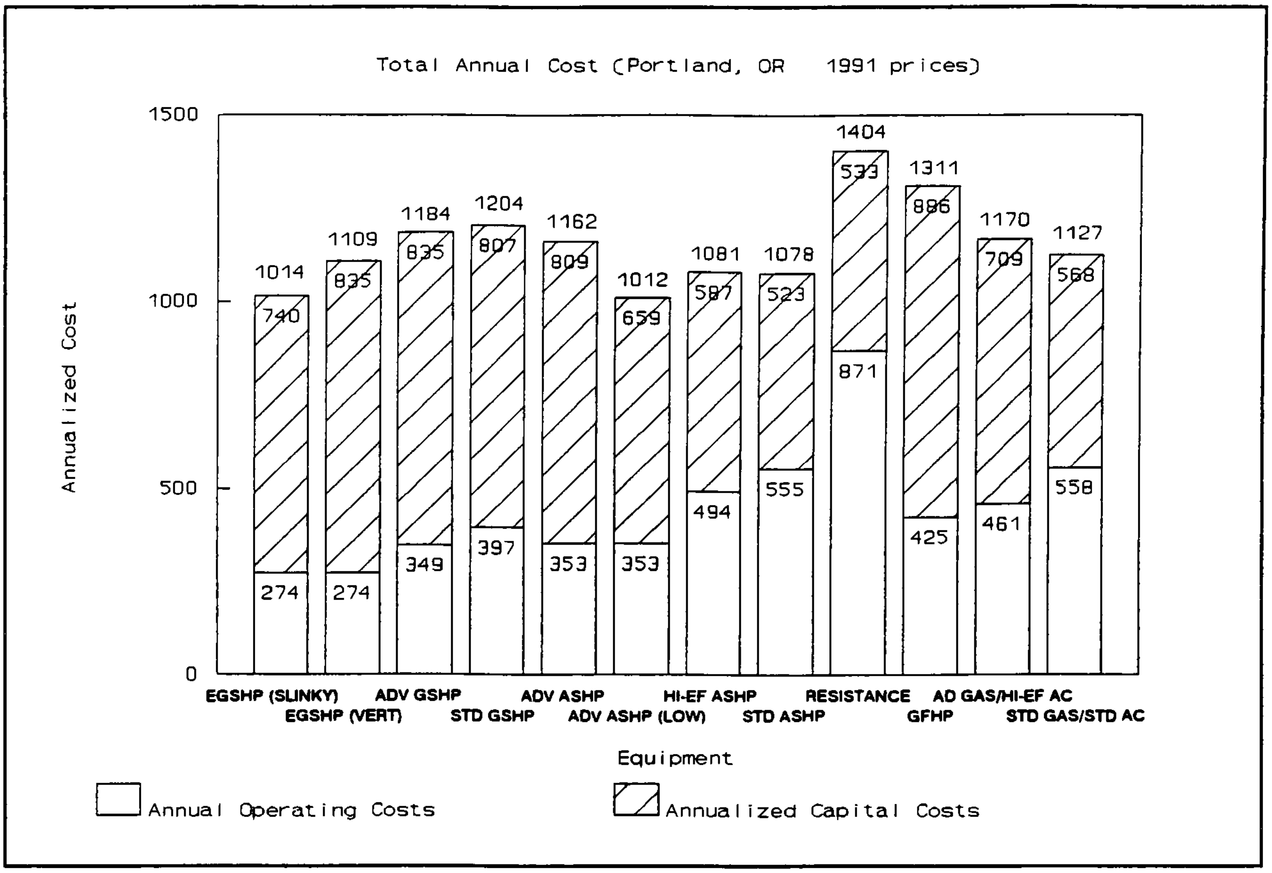
Exhibit C.42
Annual Costs Of Space Conditioning Equipment
Portland, OR

EQUIPMENT TYPE	INSTALLED COST*	ANNUAL CAPITAL	ANNUAL OPERATING	TOTAL COST
Emerging Ground Source Heat Pump (SLINKY)	$7,520	$740	$274	$1,014
Emerging Ground Source Heat Pump (Vertical)	$8,485	$835	$274	$1,109
Advanced Ground Source Heat Pump	$8,485	$835	$349	$1,184
Standard Ground Source Heat Pump	$8,201	$807	$397	$1,204
Advanced Air Source Heat Pump (Present Cost)	$8,215	$809	$353	$1,162
Advanced Air Source Heat Pump (Low Cost)	$6,690	$659	$353	$1,012
High Efficiency Air Source Heat Pump	$5,965	$587	$494	$1,081
Standard Air Source Heat Pump	$5,315	$523	$555	$1,078
Electric Resistance/ Standard AC	$5,415	$533	$871	$1,404
Gas-Fired Heat Pump	$9,000	$886	$425	$1,311
Advanced Gas Furnace/ High Efficiency AC	$7,200	$709	$461	$1,170
Standard Gas Furnace/ Standard AC	$5,775	$568	$558	$1,127

* Includes duct work ($1800) and water heater ($315 for electric and $400 for gas)

** Cost based on 1991 residential prices in the area -- $05./kWh for electricity and $0.55/therm, as estimated by Barakat & Chamberlin

Exhibit C.43



Exhibits C.42 and C.43 also indicate that, due to the moderate climate, the operating efficiency advantages of the GAS-FIRED HEAT PUMP do not overcome its higher capital cost relative to the STANDARD GAS FURNACE; consequently, the latter has a lower overall annual cost under current energy prices. The same can be said for the EMERGING GROUND SOURCE HEAT PUMP/SLINKY™ system relative to the LOW-COST ADVANCED AIR SOURCE HEAT PUMP.

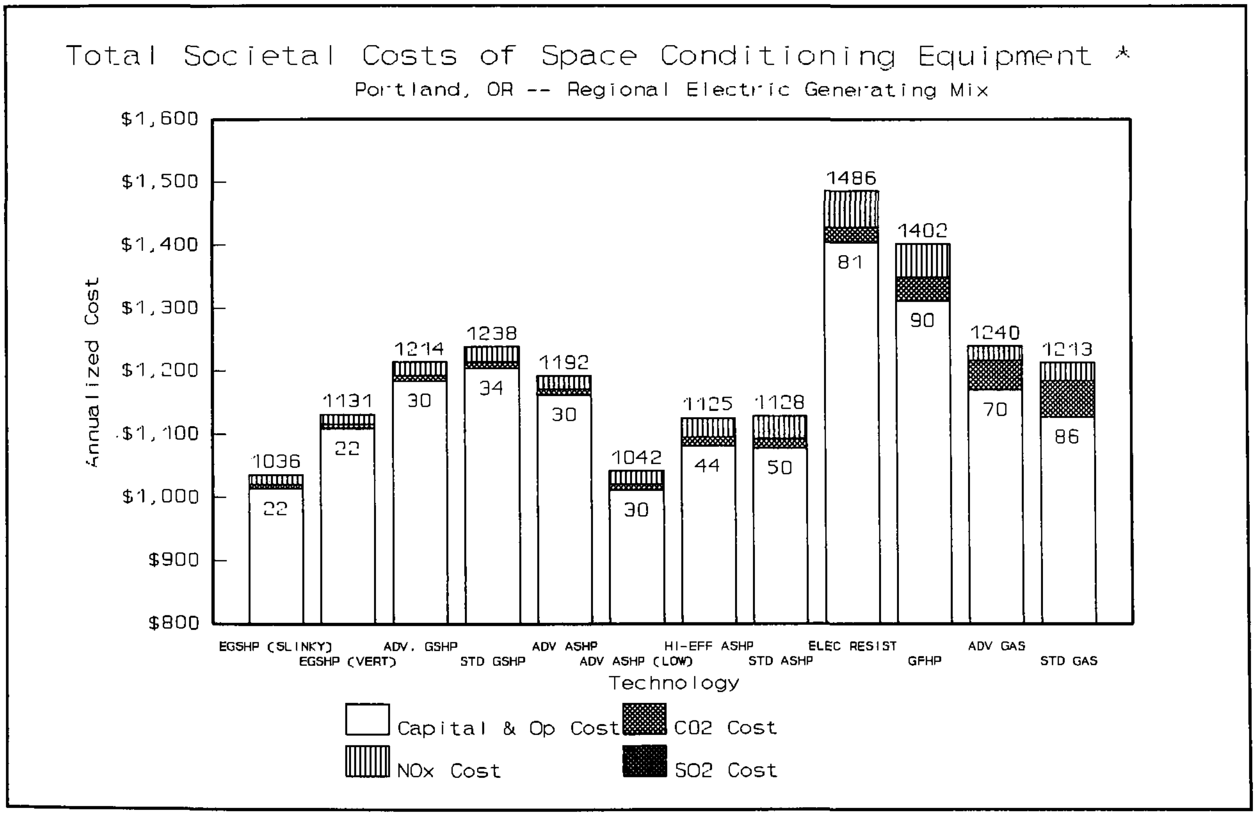
ENVIRONMENTAL EFFECTS AND TOTAL SOCIETAL COST

Regional Electricity Generation Fuel Mix: Electricity generation in the Northwest is dominated by hydroelectric power, which accounts for almost 84% of the projected 2000 regional fuel mix. Thus, electricity generation emissions factors for the three air pollutants considered here are the lowest among the regions (Appendix B). Consequently, the cost-attractiveness of electricity versus natural gas is increased by consideration of externality factors in the REGIONAL scenario.

As indicated in Exhibit C.44 and Appendix D, the gas technologies all have higher emissions of CO_2 than any of the electric technologies. The EMERGING GROUND SOURCE HEAT PUMP reduces CO_2 emissions by 2,433 kg/yr (83%) over the lowest CO_2-emitting gas technology, the GAS-FIRED HEAT PUMP. It also reduces NOx emissions by 70% over the GAS-FIRED HEAT PUMP.

The EMERGING GROUND SOURCE HEAT PUMP reduces CO_2, NO_x, and SO_2 emissions by 26% over the ADVANCED AIR SOURCE HEAT PUMP, 55% over the STANDARD AIR SOURCE HEAT PUMP, and 73% over ELECTRIC RESISTANCE. Again, this advantage is the same for all generation scenarios.

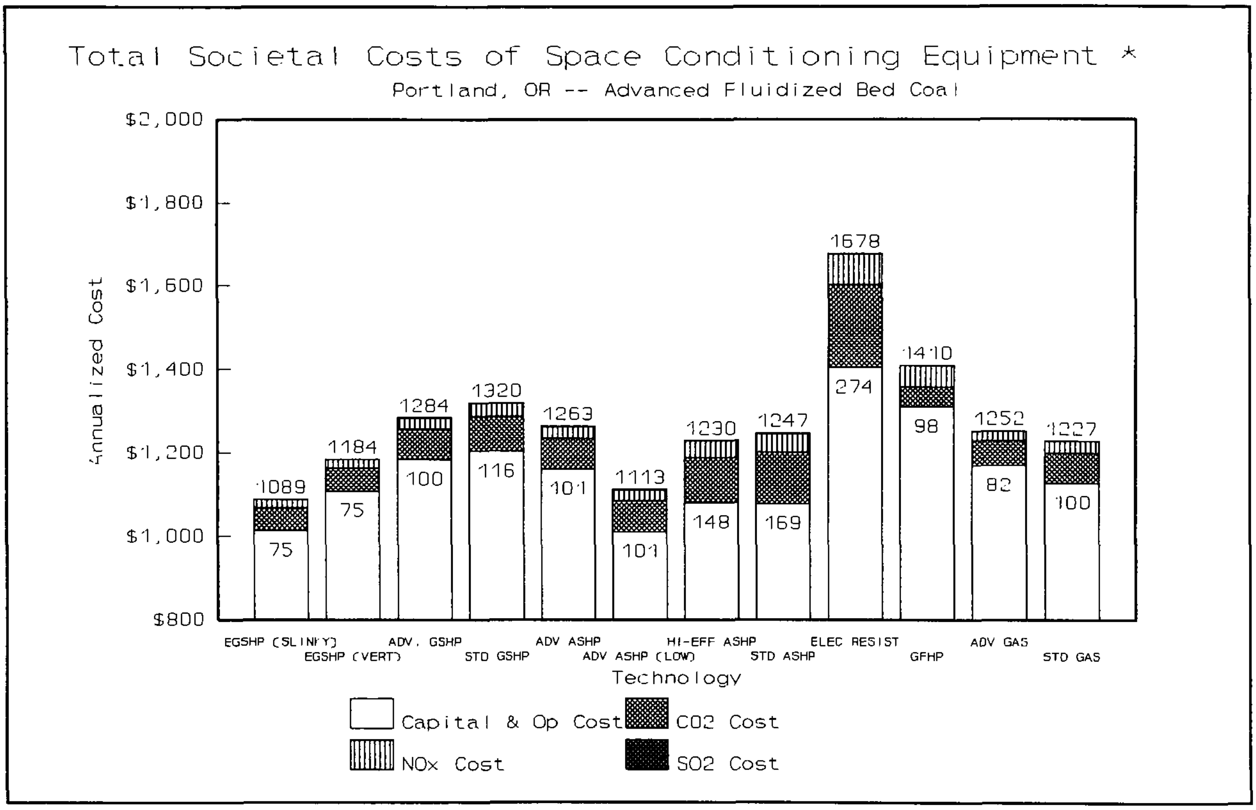
Exhibit C.44



* Number inside column refers to total externality cost.

Advanced Fluidized Bed Coal Scenario: As one would expect, carbon dioxide emissions and their associated externality costs increase drastically for the electric technologies under this scenario (Exhibit C.45 and Appendix D). As the most efficient gas technology overall in this climate, the GAS-FIRED HEAT PUMP has the lowest CO_2 emissions. However, the advantage that the GAS-FIRED HEAT PUMP now has with lower CO_2 emissions relative to the EMERGING GROUND SOURCE HEAT PUMP -- about 702 kg/yr, or 17% -- is entirely cancelled out on an externality cost basis by its higher NOx emissions. Consequently, its overall externality costs are higher than for the EMERGING GROUND SOURCE HEAT PUMP and similar to those of the ADVANCED GROUND SOURCE HEAT PUMP and ADVANCED AIR SOURCE HEAT PUMP.

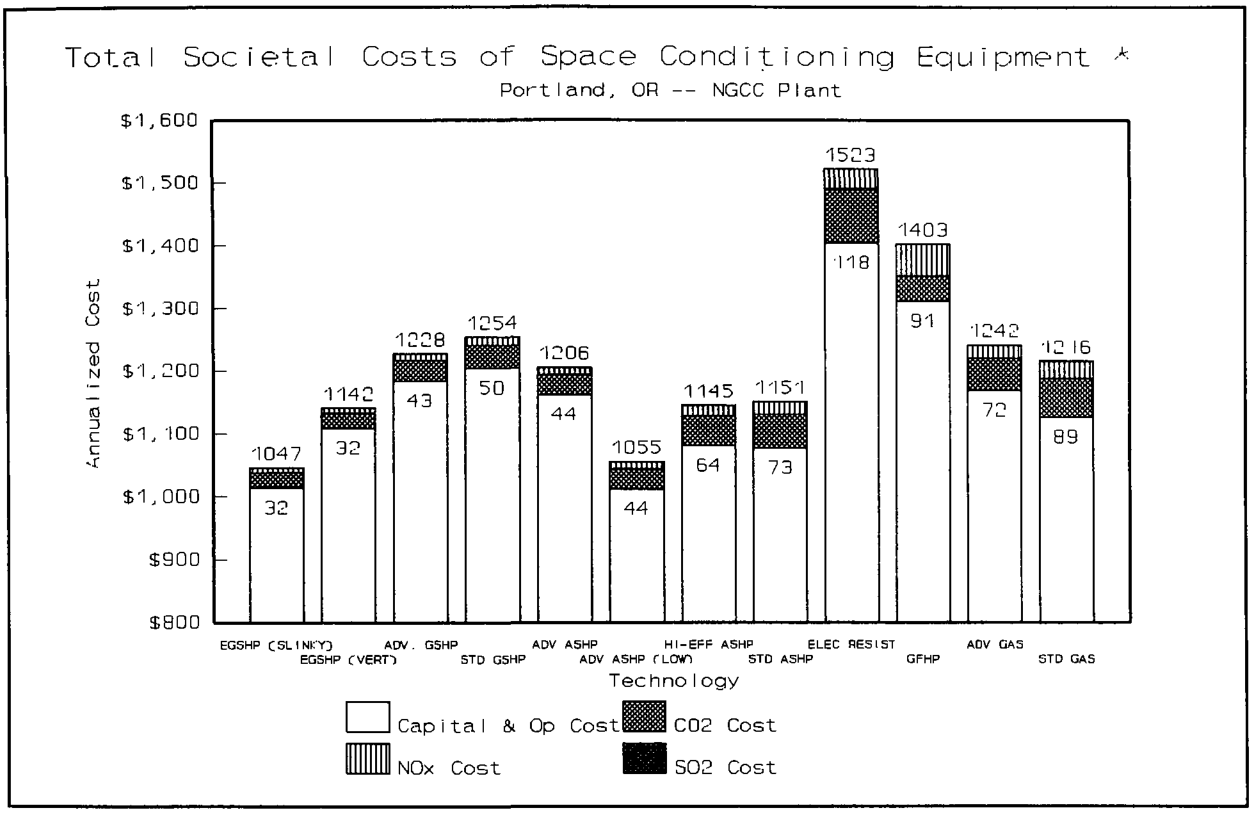
Exhibit C.45



* Number inside column refers to total externality cost.

Advanced Natural Gas Combined Cycle: Not surprisingly, this scenario reverses the results of the ADVANCED COAL scenario above; now the EMERGING GROUND SOURCE HEAT PUMP has CO_2 emissions that are 42% lower than the best gas technology, the GAS-FIRED HEAT PUMP (Exhibit C.46 and Appendix D). Since its NO_x emissions are also only one-sixth the GAS-FIRED HEAT PUMP'S, the EMERGING GROUND SOURCE HEAT PUMP has overall externality costs that are fully one-third those of the GAS-FIRED HEAT PUMP. Other advanced electric technologies, notably the ADVANCED AIR SOURCE HEAT PUMP, also have low overall externality costs under this scenario.

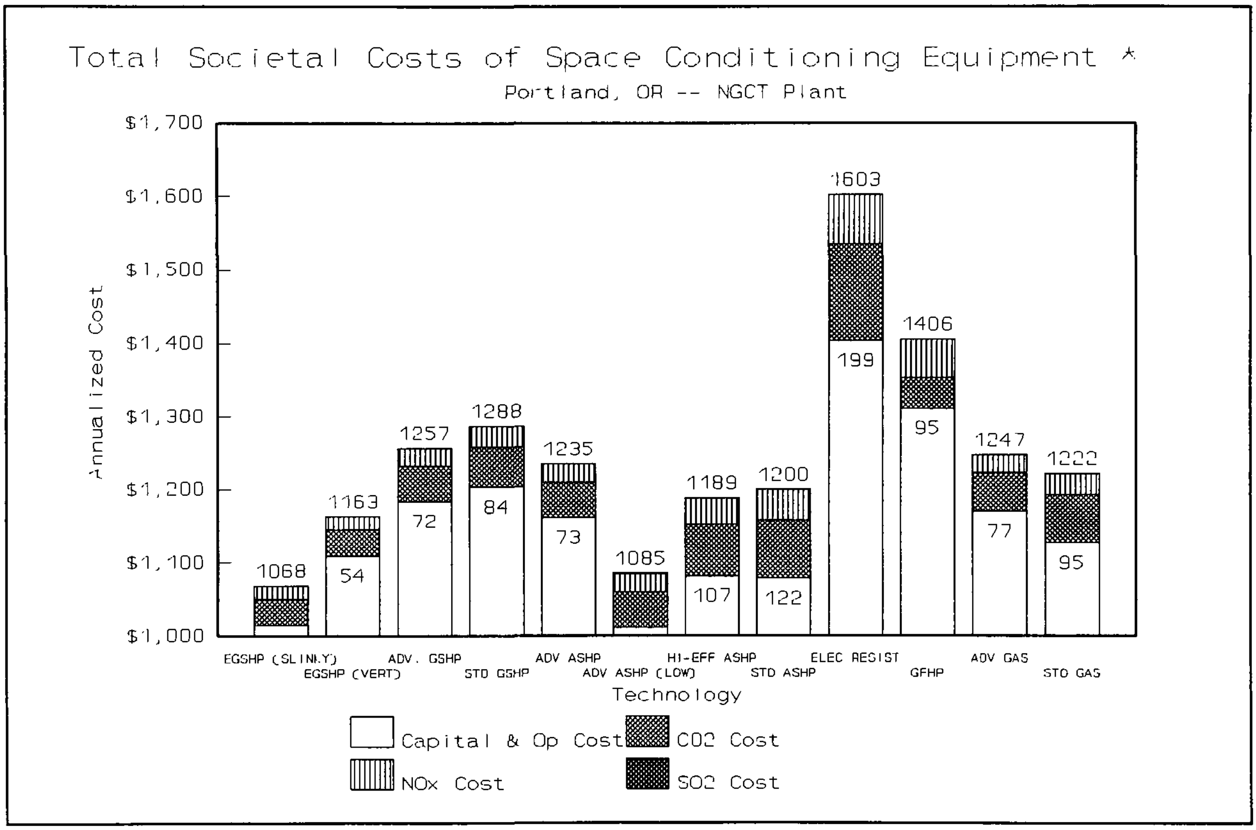
Exhibit C.46



* Number inside column refers to total externality cost.

Natural Gas Combustion Turbine: Under this scenario, the EMERGING GROUND SOURCE HEAT PUMP has CO_2 emissions that are about 15% lower than the GAS-FIRED HEAT PUMP and NO_x emissions that are about two-thirds lower. Also, while the GAS-FIRED HEAT PUMP in turn has 12% lower CO_2 emissions than the ADVANCED GROUND SOURCE HEAT PUMP, its present NO_x emissions cause it to have higher overall externality costs.

Exhibit C.47



* Number inside column refers to total externality cost.

CHOICES FOR UTILITIES: COST-EFFECTIVENESS SCREENING

The cost-effectiveness of various utility programs will depend on a realistic assessment of which technologies compete in a particular residence, and at what costs.

The utility cost-effectiveness analysis and estimate of utility program effect on payback, as described in Chapter 3, was performed for various equipment substitutions and is presented in Exhibit C.48. ELECTRIC RESISTANCE, STANDARD AIR SOURCE HEAT PUMPS and STANDARD GAS FURNACES were selected as the base technologies for which substitutions would be evaluated.

For houses with electric heating, there may not be easy access to gas service; in such cases, the cost of adding gas service will likely be prohibitive. The results of utility cost-effectiveness screening presented in this Appendix assume that gas service is available to the household.

As discussed in Chapter Three, the results for Portland are driven by the avoided energy costs for a typical utility in its area (Portland General Electric). Externality costs are not included in these marginal energy costs. The analysis factors in an avoided capacity value of about $102/yr, which accounts for generating capacity factor and transmission and distribution costs and losses.

Administrative costs are assumed to be $150 per household. The utility incentive is assumed to cover the entire incremental cost of the equipment whenever the Total Resource Cost Test ratio is 1 or greater. In those cases in which the TRC ratio is below 1, no utility incentive is assumed.

Exhibit C.48 indicates that EMERGING GROUND SOURCE HEAT PUMPS, ADVANCED GROUND SOURCE HEAT PUMPS and LOW-COST ADVANCED AIR SOURCE HEAT PUMPS have the highest TRC ratios, net present values, and reduced emissions when replacing ELECTRIC RESISTANCE and STANDARD AIR SOURCE HEAT PUMPS.

The LOW-COST ADVANCED AIR SOURCE HEAT PUMP also has a relatively high TRC ratio, as well as a high net present value. Its cost-effectiveness is enhanced in this location by the moderate winter climate and less reliance on electric resistance backup heating than in the colder climate zones previously reviewed. However, it does not reduce emissions of CO_2, NO_x, or SO_2 as much as the EMERGING GROUND SOURCE HEAT PUMPS do.

In substituting for a STANDARD GAS FURNACE, the GAS-FIRED HEAT PUMP has a marginal TRC ratio and its net present value yield is not as high as the advanced heat pump technologies. It also does not reduce CO_2 emissions as much as the EMERGING GROUND SOURCE HEAT PUMP or the ADVANCED AIR SOURCE HEAT PUMP under the REGIONAL generation mix scenario. It also increases NO_x emissions relative to the STANDARD GAS FURNACE.

Exhibit C.48
Utility Program Cost Effectiveness
Portland, Oregon

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)			Without Incentive	With Incentive	CO2	NOx	SO2
Replace Electric Resistant Heating/AC with:**													
Emerging Ground Source Heat Pump (SLINKY)	$3,455	$3,455	11,941	8.8	5.1	0.0	3.22	$8,016	6.89	0.00	1,341	6.51	0.00
Emerging Ground Source Heat Pump (Vertical)	$4,420	$4,420	11,941	8.8	5.1	0.0	2.54	$7,051	8.81	0.00	1,341	6.51	0.00
Advanced Ground Source Heat Pump	$4,420	$4,420	10,437	8.8	5.1	0.0	2.40	$6,407	10.08	0.00	1,172	5.69	0.00
Advanced Air Source Heat Pump (Present Cost)	$4,150	$4,150	10,357	2.1	5.0	0.0	1.80	$3,460	9.54	0.00	1,163	5.65	0.00
Advanced Air Source Heat Pump (Low Cost)	$2,625	$2,625	10,357	2.1	5.0	0.0	2.80	$4,985	6.03	0.00	1,163	5.65	0.00
Advanced Gas Furnace/ High Efficiency AC***	$3,050	$3,050	15,358	10.7	4.5	-651.0	1.48	$4,460	10.19	0.00	(1,739)	5.36	(0.07)
3as Air-to-Air Heat Pump	$4,850	$4,850	15,753	10.4	6.9	-531.0	1.44	$4,509	14.71	0.00	(1,092)	0.84	(0.06)

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)			Without Incentive	With Incentive	CO2	NOx	SO2
...eplace Standard Air ...ource Heat Pump with:													
...nerging Ground Source ...eat Pump (SLINKY)	$2,205	$2,205	5,620	7.7	5.1	0.0	3.57	$6,043	9.34	0.00	631	3.06	0.00
...nerging Ground Source ...eat Pump (Vertical)	$3,170	$3,170	5,620	7.7	5.1	0.0	2.53	$5,078	13.43	0.00	631	3.06	0.00
Advanced Ground Source Heat Pump	$3,170	$3,170	4,116	7.7	5.1	0.0	2.34	$4,433	18.34	0.00	462	2.24	0.00
Advanced Air Source Heat Pump (Present Cost)	$2,900	$2,900	4,036	1.0	5.0	0.0	1.49	$1,487	17.11	0.00	453	2.20	0.00
Advanced Air Source Heat Pump (Low Cost)	$1,375	$1,375	4,036	1.0	5.0	0.0	2.98	$3,012	8.11	0.00	453	2.20	0.00
Advanced Gas Furnace/ High Efficiency AC	$1,800	$1,800	9,037	9.6	5.0	-651.0	1.34	$2,721	>20	0.00	(2,449)	1.91	(0.07)
Gas Air-to-Air Heat Pump	$3,600	$3,600	9,432	9.3	6.9	-531.0	1.28	$2,535	>20	0.00	(1,802)	(2.61)	(0.06)

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)			Without Incentive	With Incentive	CO2	NOx	SO2
Replace Standard Gas Furnace/AC with:													
Emerging Ground Source Heat Pump (SLINKY)	$1,830	$1,830	(3,278)	-1.9	0.6	815.0	1.89	$3,561	6.20	0.00	3,948	1.97	0.08
Emerging Ground Source Heat Pump (Vertical)	$2,795	$2,795	(3,278)	-1.9	0.6	815.0	1.52	$2,596	9.47	0.00	3,948	1.97	0.08
Advanced Ground Source Heat Pump	$2,795	$2,795	(4,782)	-1.9	0.6	815.0	1.35	$1,952	12.05	0.00	3,779	1.15	0.08
Advanced Air Source Heat Pump (Present Cost)	$2,525	$0	(4,861)	-8.6	0.5	815.0	0.88	($994)	11.05	11.05	3,770	1.11	0.08
Advanced Air Source Heat Pump (Low Cost)	$1,000	$1,000	(4,861)	-8.6	0.5	815.0	1.08	$531	4.37	0.00	3,770	1.11	0.08
Advanced Gas Furnace/ High Efficiency AC***	$1,425	$1,425	140	0.0	0.5	164.0	1.15	$239	15.33	0.00	868	0.82	0.02
Gas Air-to-Air Heat Pump	$3,225	$3,225	535	-0.3	2.4	284.0	1.01	$54	>20	0.00	1,515	(3.70)	0.03

If TRC <1, no incentive program is assumed. Where TRC test is greater than 1, entire incremental cost is covered by the incentive.

Results reflect replacement of existing ELECTRIC RESISTANCE at the end of the central AC's service life. This scenario assumes that the ELECTRIC RESISTANCE does not need replacement. Thus, analysis compares the capital cost of the entire advanced system against only the replacement AC. In the case of new construction, a much higher TRC is obtained, since in this case the cost of the ELECTRIC RESISTANCE system would have to be factored in as well.

* Measured by itself, the HIGH-EFFICIENCY AIR CONDITIONER has a TRC of 0.97 when replacing a STANDARD AIR CONDITIONER. Likewise, the ADVANCED GAS FURNACE has a TRC of 1.19 when replacing a STANDARD GAS FURNACE.

A FOCUS ON CARBON DIOXIDE REDUCTIONS

Exhibits C.49 through C.52 order the technologies according to their CO_2 emissions under the three generating scenarios. The most striking result of Exhibit C.49, the REGIONAL generating scenario, the highest emitter of CO_2 is the STANDARD GAS FURNACE, followed by the two advanced gas technologies. The advanced electric technologies are grouped together among the best CO_2 reducers, and are all cost-effective for replacing baseline space conditioning equipment. The third and fourth generating scenarios, ADVANCED NATURAL GAS COMBINED CYCLE and NATURAL GAS COMBUSTION TURBINE (Exhibit C.51 and C.52), also highlight the best electric technologies, although the later graphic slows a prominent place for GAS-FIRED HEAT PUMPS as well.

The more carbon-intensive ADVANCED COAL scenario changes the order even more drastically relative to the REGIONAL mix scenario; from the perspective of reducing CO_2 under this scenario, the GAS-FIRED HEAT PUMP is the best, with the ADVANCED GAS FURNACE grouped among the advanced electric technologies.

Exhibit C.49

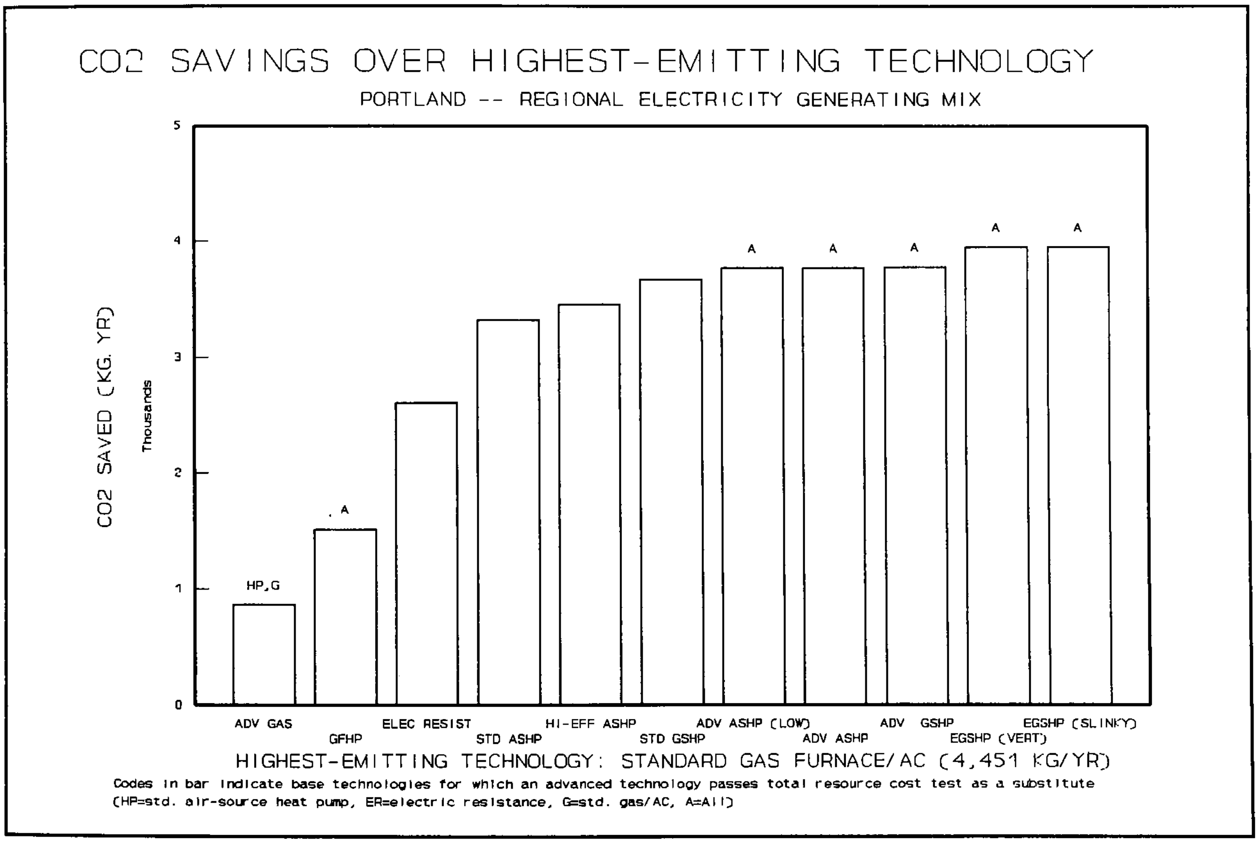


Exhibit C.50

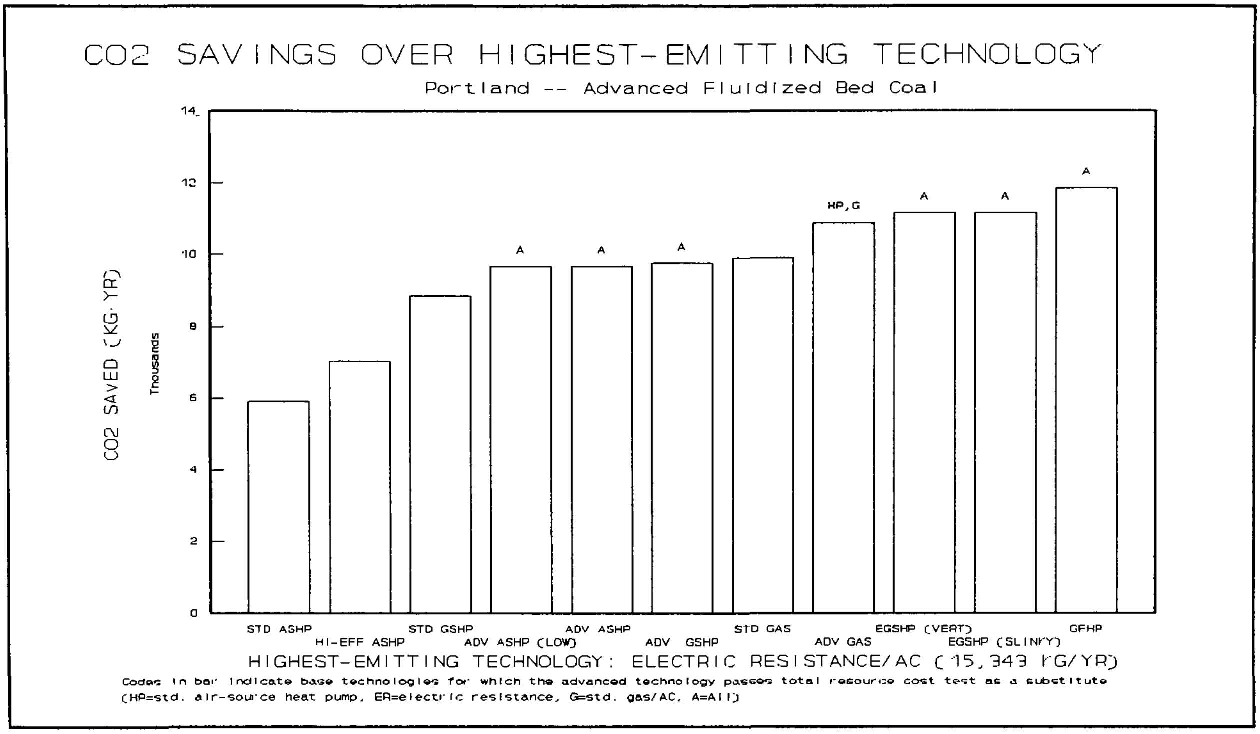


Exhibit C.51

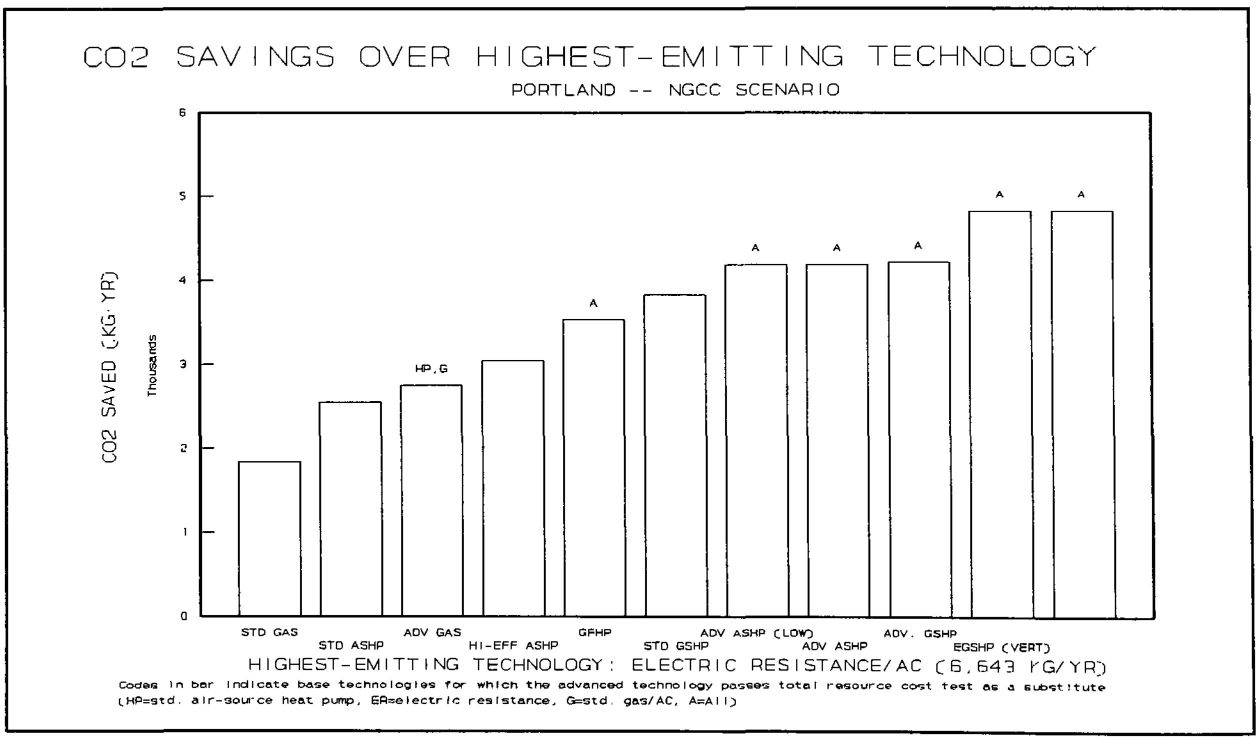
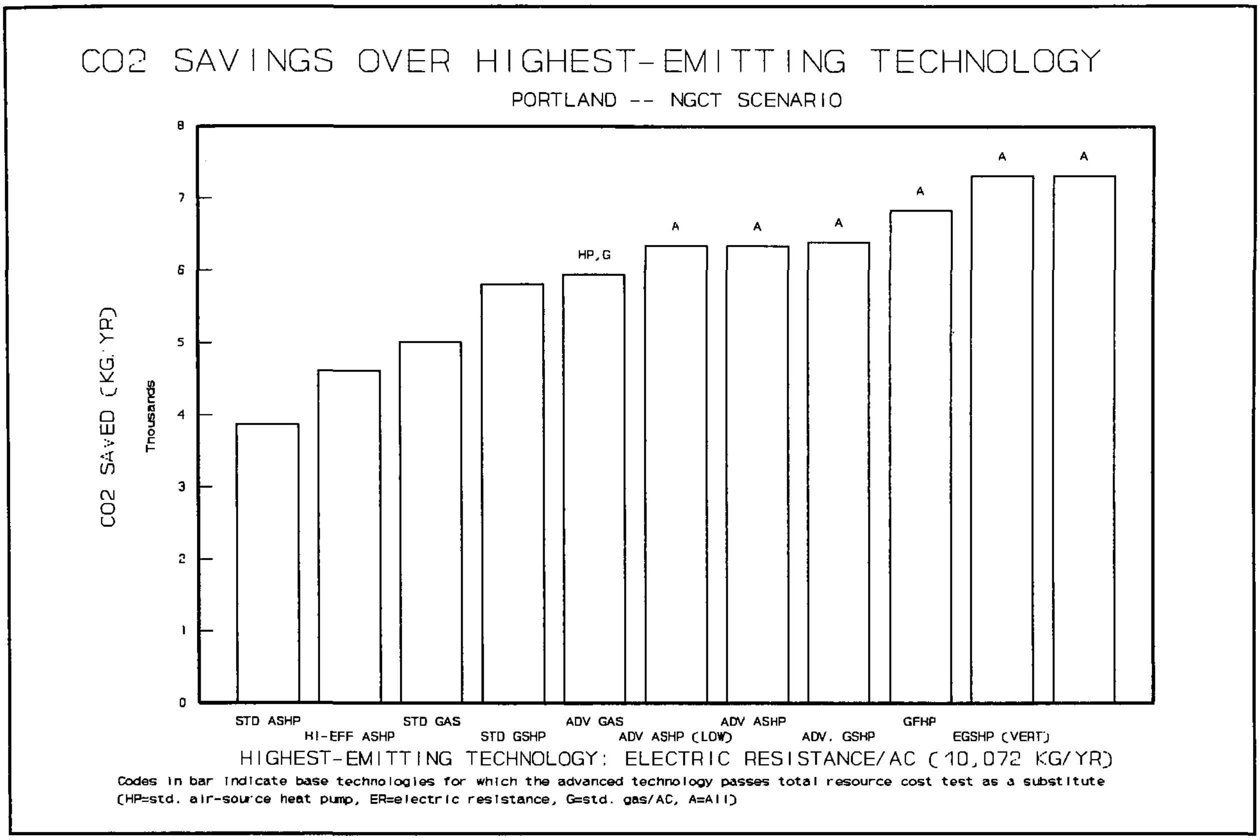


Exhibit C.52



CO2 SAVINGS OVER HIGHEST-EMITTING TECHNOLOGY
PORTLAND -- NGCT SCENARIO
CO2 SAVED (KG/YR)
Thousands
0
1
2
3
4
5
6
7
8
HP,G
A
A
A
A
A
A
STD ASHP
HI-EFF ASHP
STD GAS
STD GSHP
ADV GAS
ADV ASHP (LOW)
ADV ASHP
ADV. GSHP
GFHP
EGSHP (VERT)
HIGHEST-EMITTING TECHNOLOGY: ELECTRIC RESISTANCE/AC (10,072 KG/YR)
Codes in bar indicate base technologies for which the advanced technology passes total resource cost test as a substitute
(HP=std. air-source heat pump, ER=electric resistance, G=std. gas/AC, A=All)

CLIMATE ZONE 4: ATLANTA, GEORGIA

Climate Zone 4 covers sections of the Southeast, the Texas Panhandle, Southern Arizona and New Mexico, and much of coastal California. For the representative location, Atlanta, the prototypical home required 29.80 MMBtu for heating, 23.00 MMBtu for cooling, and 8.80 MMBtu for water heating annually, for a total demand of 61.60 MMBtu. Compared to the locations covered previously, the heating season is mild, but cooling loads are much higher.

PERFORMANCE AND COST

Exhibit C.53 compares the operating performance of all of the representative space conditioning technologies described in Chapter 2. The three columns on the left indicate each equipment's modeled end-use seasonal performance factor (SPF, calculated by dividing the number of Btu's demanded in the location for heating, cooling or water heating by the number of Btu's of energy input the equipment required to meet that demand). The higher the SPF, the higher the technology's end-use efficiency.

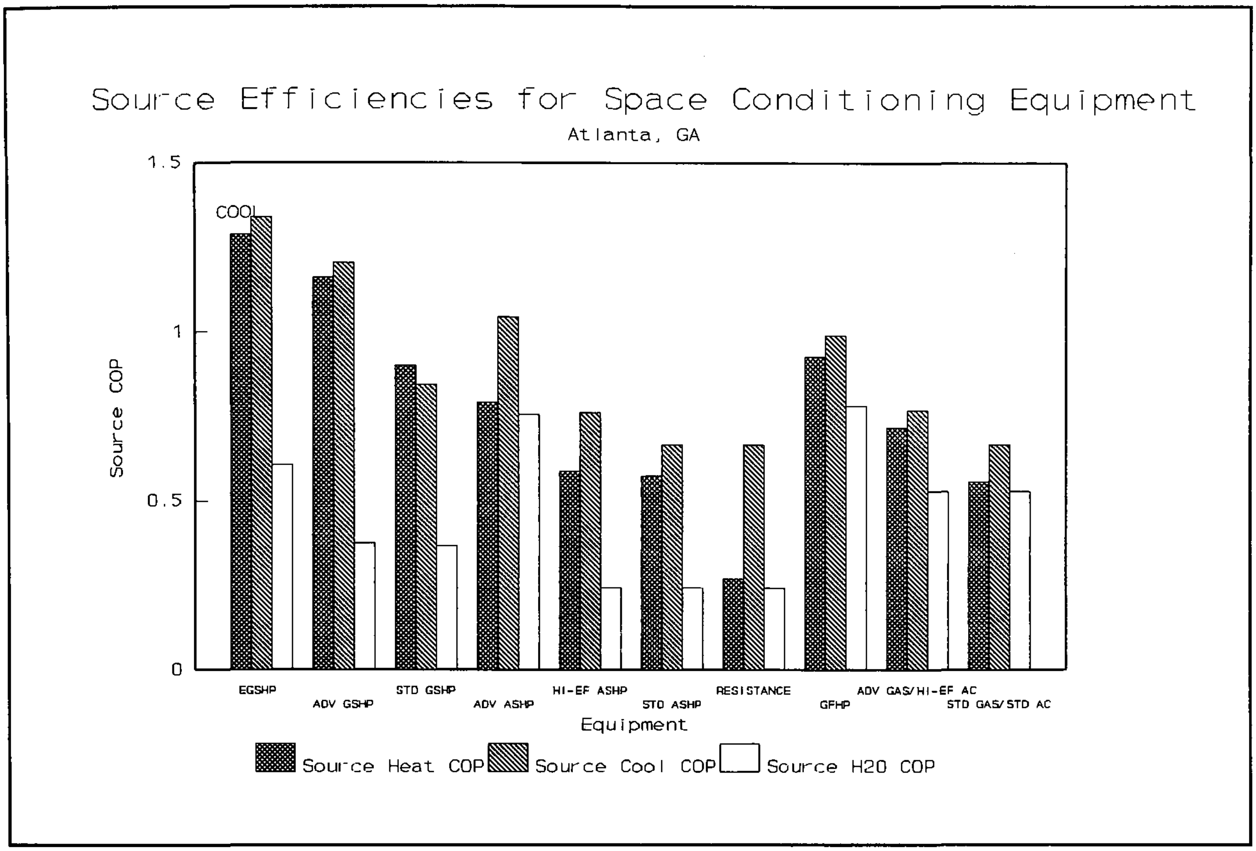
The three right-hand columns of Exhibit C.53, and Exhibit C.54, show source SPF, accounting for the losses in the generation, transmission and distribution system for each fuel type. The two best net energy performers in each category are highlighted:

Exhibit C.53
Performance of Space Conditioning Equipment
Atlanta, GA (including water heating)

	END USE EFFICIENCY			SOURCE EFFICIENCY		
	HEAT	COOL	H20	HEAT	COOL	H20
EQUIPMENT TYPE	SPF	SPF	SPF	SPF	SPF	SPF
Emerging Ground Source Heat Pump	4.78	4.96	2.25	1.29	1.34	0.61
Advanced Ground Source Heat Pump	4.30	4.46	1.39	1.16	1.20	0.38
Standard Ground Source Heat Pump	3.34	3.13	1.36	0.90	0.84	0.37
Advanced Air Source Heat Pump	2.93	3.87	2.80	0.79	1.04	0.76
High Efficiency Air Source Heat Pump	2.18	2.82	0.90	0.59	0.76	0.24
Standard Air Source Heat Pump	2.13	2.47	0.90	0.57	0.67	0.24
Electric Resistance/ Standard AC	1.00	2.47	0.90	0.27	0.67	0.24
Gas-Fired Heat Pump	1.15	1.24	0.86	0.93	0.99	0.78
Advanced Gas Furnace/ High Efficiency AC	0.86	2.85	0.58	0.72	0.77	0.53
Standard Gas Furnace/ Standard AC	0.66	2.47	0.58	0.56	0.67	0.53

The emerging GSHP listed in this table reflects the operating performance of the SLINKY™ or the vertical system.

Exhibit C.54



Again, the EMERGING GROUND SOURCE HEAT PUMP has the highest source heating and cooling efficiencies of all equipment, followed by the ADVANCED GROUND SOURCE HEAT PUMP. As in all other locations, the GAS-FIRED HEAT PUMP and ADVANCED AIR SOURCE HEAT PUMP technologies are superior in water heating mode.

Exhibits C.55 and C.56 examine the total annual cost for each space conditioning technology. Exhibit C.55 highlights the two least expensive technologies with respect to annual capital, annual operating and total costs. A combination of a cooling-dominated climate and relative energy prices cause more standard electric technologies to have higher costs than the EMERGING GROUND SOURCE HEAT PUMPS and the LOW-COST ADVANCED AIR SOURCE HEAT PUMPS. Given relative capital costs and current fuel prices, the STANDARD GAS FURNACE has the lowest overall annual costs among gas equipment.

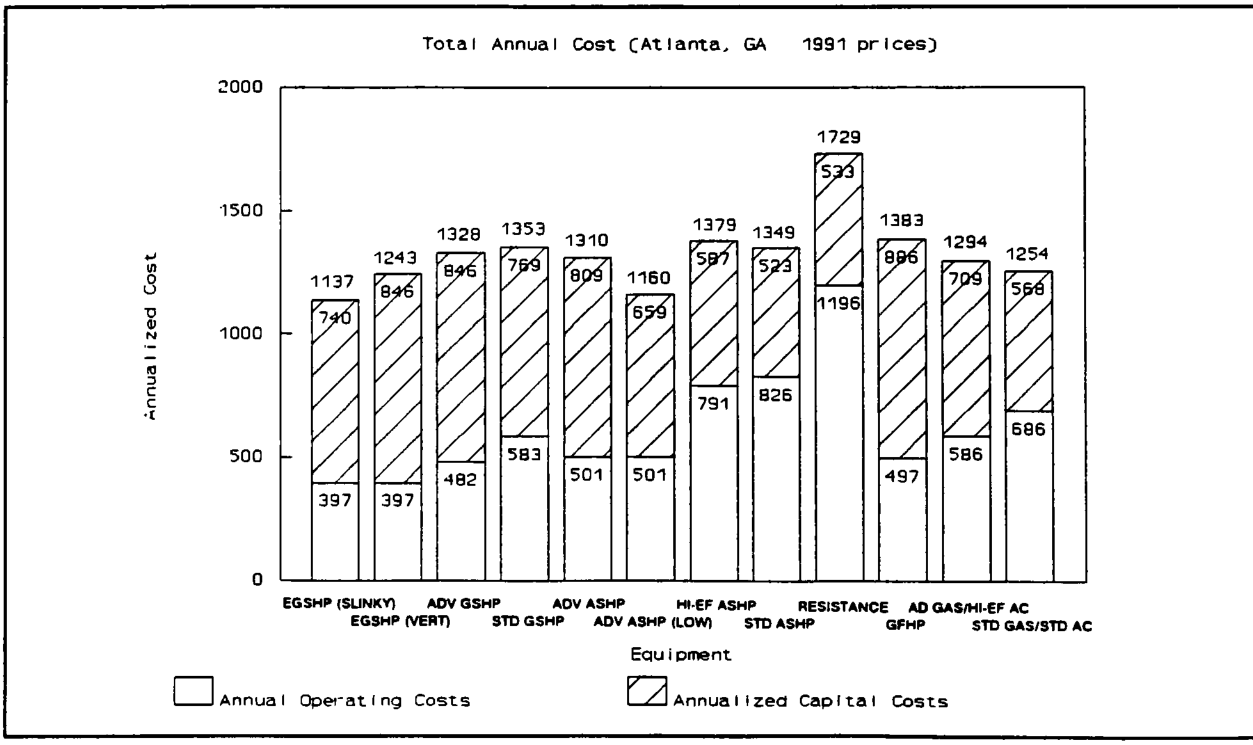
Exhibit C.55
Annual Costs Of Space Conditioning Equipment
Atlanta, GA

EQUIPMENT TYPE	INSTALLED COST*	ANNUAL CAPITAL	ANNUAL OPERATING	TOTAL COST
Emerging Ground Source Heat Pump (SLINKY)	$7,520	$740	$397	$1,137
Emerging Ground Source Heat Pump (Vertical)	$8,595	$846	$397	$1,243
Advanced Ground Source Heat Pump	$8,595	$846	$482	$1,328
Standard Ground Source Heat Pump	$7,814	$769	$583	$1,353
Advanced Air Source Heat Pump (Present Cost)	$8,215	$809	$501	$1,310
Advanced Air Source Heat Pump (Low Cost)	$6,690	$659	$501	$1,160
High Efficiency Air Source Heat Pump	$5,965	$587	$791	$1,379
Standard Air Source Heat Pump	$5,315	$523	$826	$1,349
Electric Resistance/ Standard AC	$5,415	$533	$1,196	$1,729
Gas-Fired Heat Pump	$9,000	$886	$497	$1,383
Advanced Gas Furnace/ High Efficiency AC	$7,200	$709	$586	$1,294
Standard Gas Furnace/ Standard AC	$5,775	$568	$686	$1,254

* Includes duct work ($1800) and water heater ($315 for electric and $400 for gas)

** Based on average 1991 residential prices: $.08/kWh electric and $.65/therm gas (Barakat and Chamberlin)

Exhibit C.56

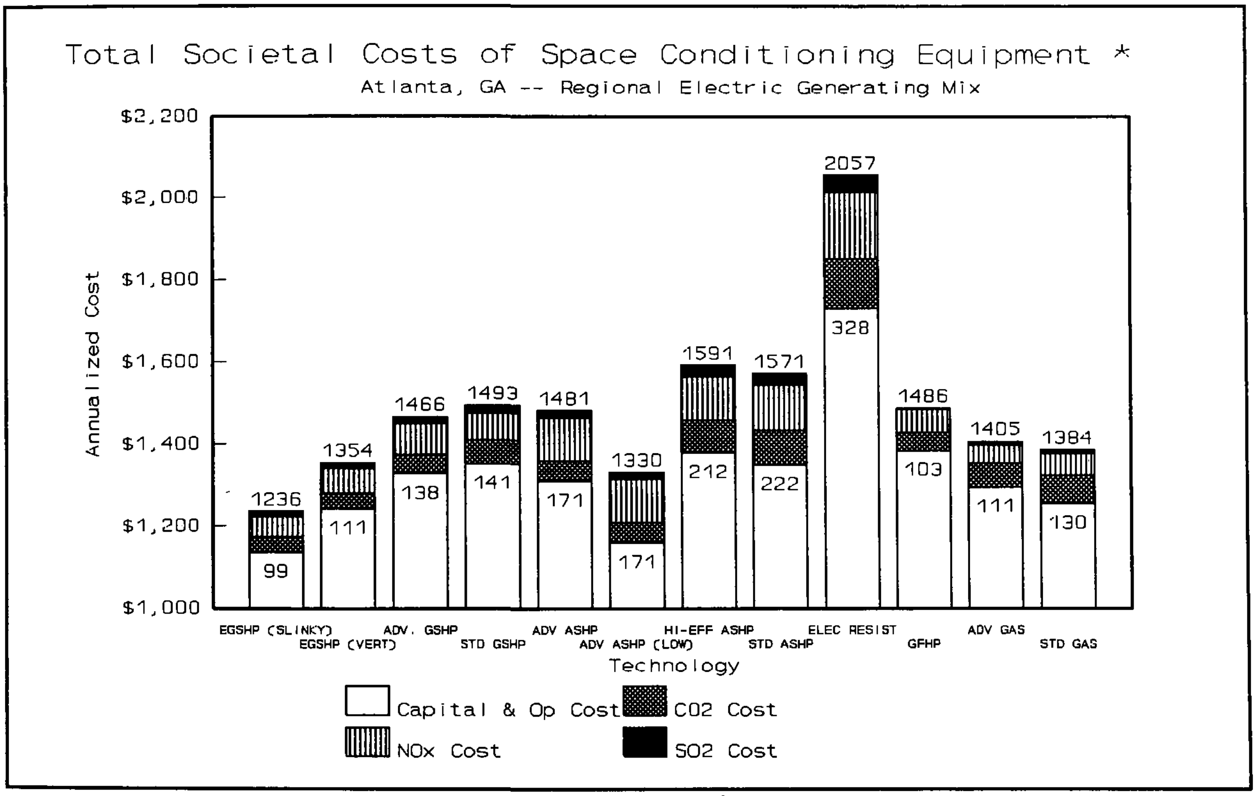


ENVIRONMENTAL EFFECTS AND TOTAL SOCIETAL COST

Regional Electric Generation Mix Scenario: The projected regional fuel mix for the Southeast for 2000 has relatively high emissions compared to other regions (Appendix B). Under the REGIONAL scenario, the GAS-FIRED HEAT PUMP has overall externality costs similar to those of EMERGING GROUND SOURCE HEAT PUMPS, despite the fact that the EMERGING GROUND SOURCE HEAT PUMP has 14% less CO_2 emissions. This is because the GAS-FIRED HEAT PUMP emits only about one-sixth the SO_2. The externality cost for the GAS-FIRED HEAT PUMP are low enough to make its total societal cost about equal to ADVANCED GROUND SOURCE HEAT PUMPS and the LOW-COST ADVANCED AIR SOURCE HEAT PUMP (Exhibit C.57 and Appendix D). However, the STANDARD GAS FURNACE remains the lowest societal cost option under current fuel pricing.

The most efficient electric technology, the EMERGING GROUND SOURCE HEAT PUMP, reduces CO_2, NO_x, and SO_2 emissions over the ADVANCED AIR SOURCE HEAT PUMP by 23%; over the STANDARD AIR SOURCE HEAT PUMP by 56%; and over ELECTRIC RESISTANCE by 71%. These percentage reductions hold true for all three generating scenarios.

Exhibit C.57

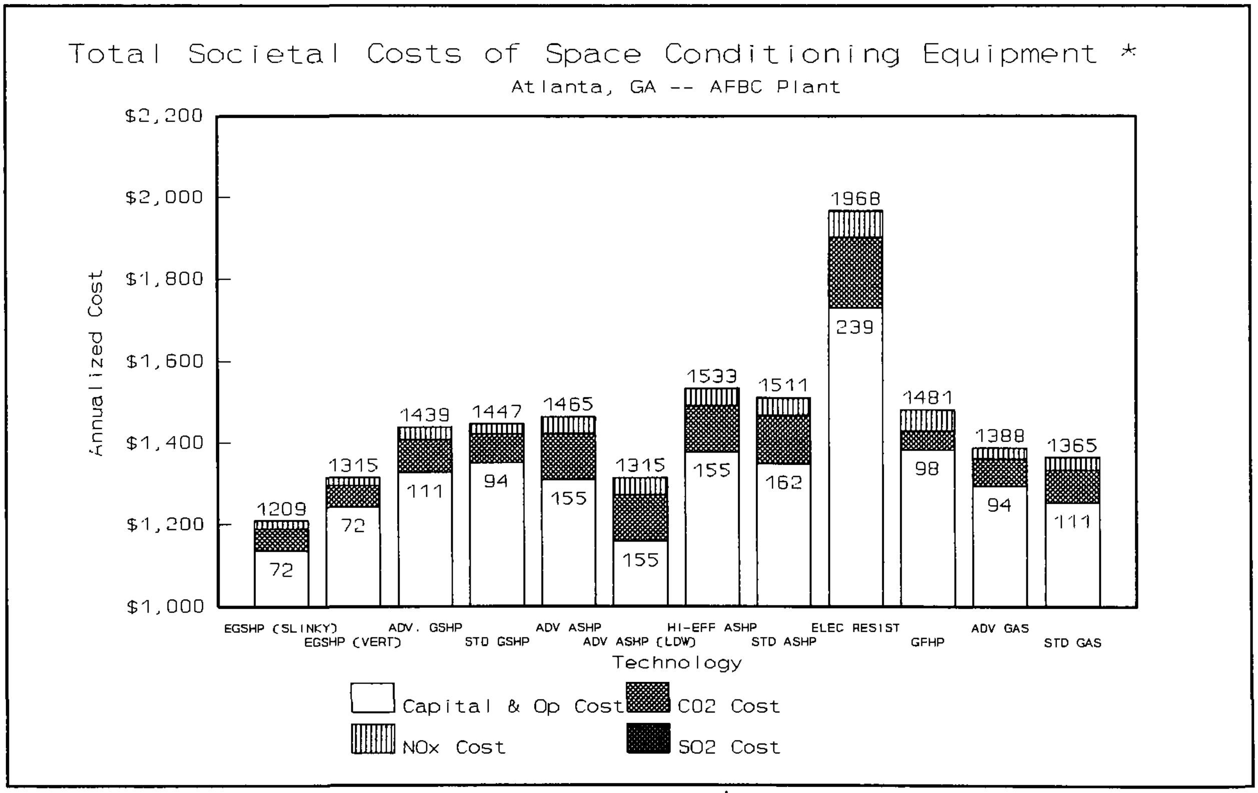


* Number inside column refers to total externality cost.

Advanced Fluidized Bed Coal Scenario: Even though this scenario results in higher externality costs associated with CO_2 emissions from electric technologies, it reduces the costs associated with NO_x and SO_2 even more relative to the REGIONAL scenario. Thus, the overall externality costs are lowest for the most advanced electric technologies, the EMERGING GROUND SOURCE HEAT PUMPS. The GAS-FIRED HEAT PUMP enjoys a slight (13%) CO_2 emission advantage over the next lowest CO_2 emitter, the EMERGING GROUND SOURCE HEAT PUMP; however, the EMERGING GROUND SOURCE HEAT PUMP'S NO_x emissions are 63% lower than those of the GAS-FIRED HEAT PUMP (Exhibit C.58 and Appendix D).

The GAS-FIRED HEAT PUMP also does not enjoy an overall emissions advantage over the ADVANCED GAS FURNACE under this scenario; while the GAS-FIRED HEAT PUMP'S CO_2 emissions are 32% less, the ADVANCED GAS FURNACE produces about 40% less NO_x emissions. Thus, their overall externality costs are about the same.

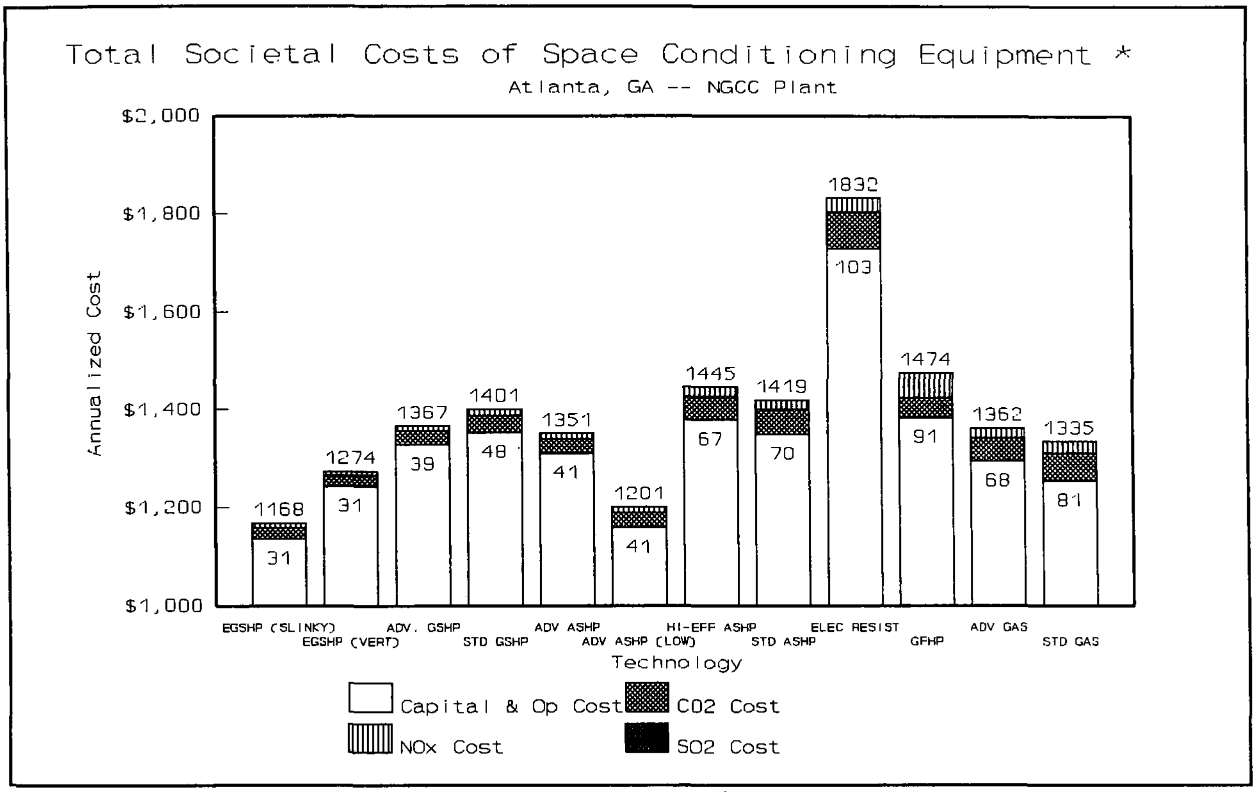
Exhibit C.58



* Number inside column refers to total externality cost.

Advanced Natural Gas Combined Cycle Scenario: As in the regions analyzed above, this scenario clearly favors electric technologies over natural gas ones, with the EMERGING GROUND SOURCE HEAT PUMP producing 44% less CO_2 and 84% less NOx than the GAS-FIRED HEAT PUMP. Given their market cost advantages, EMERGING GROUND SOURCE HEAT PUMPS and LOW-COST AIR SOURCE HEAT PUMPS are even more strongly favored under this scenario (Exhibit C.59 and Appendix D).

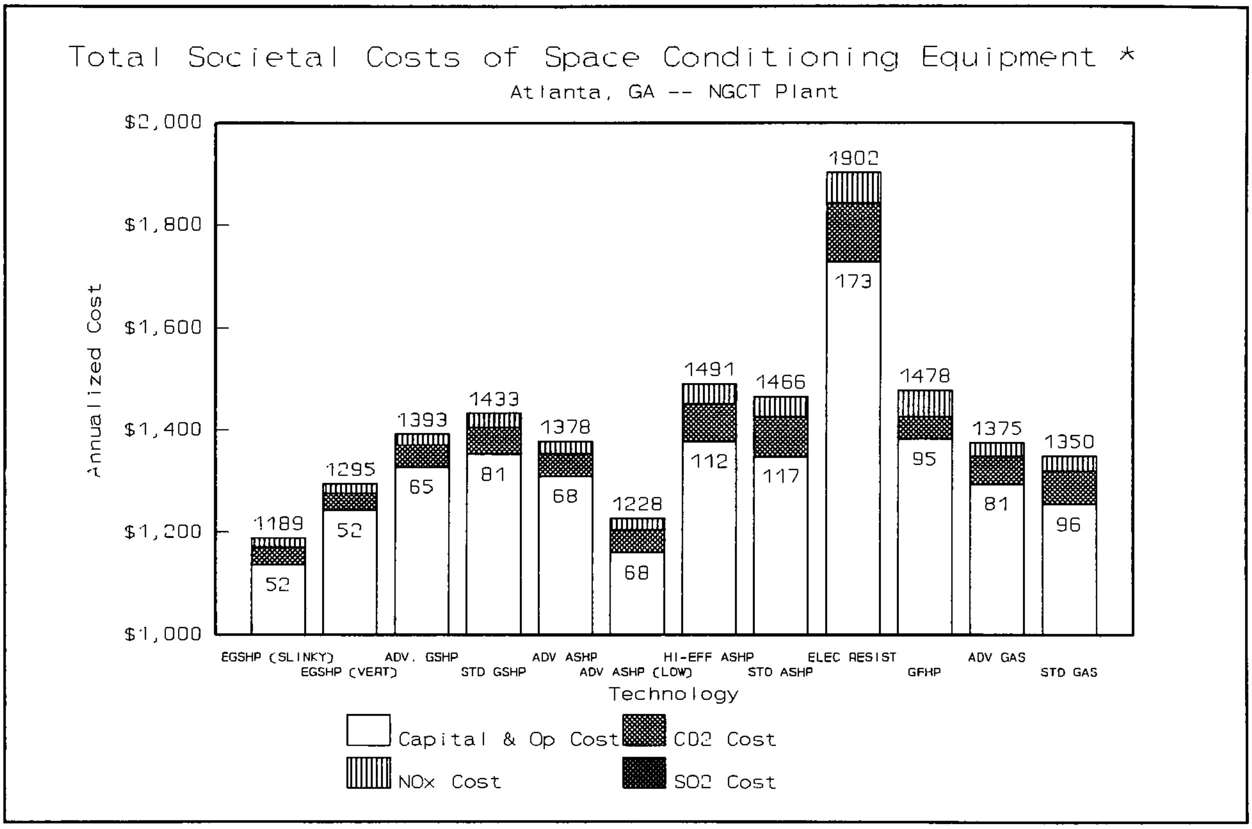
Exhibit C.59



* Number inside column refers to total externality cost.

Natural Gas Combustion Turbine Scenario: As in other regions, this scenario still favors advanced electric end-use technologies, but not to the degree as the previous scenario. The EMERGING GROUND SOURCE HEAT PUMP again has the lowest externality costs, with CO_2 emissions that are 19% less and NO_x emissions that are two-thirds less than the GAS-FIRED HEAT PUMP.

Exhibit C.60



* Number inside column refers to total externality cost.

CHOICES FOR UTILITIES: COST-EFFECTIVENESS SCREENING

The cost-effectiveness of various utility programs will depend on a realistic assessment of which technologies compete in a particular residence, and at what costs.

The utility cost-effectiveness analysis and estimate of utility program effect on payback, as described in Chapter 3, was performed for various equipment substitutions and is presented in Exhibit C.61. ELECTRIC RESISTANCE, STANDARD AIR SOURCE HEAT PUMPS and STANDARD GAS FURNACES were selected as the base technologies for which substitutions would be evaluated.

For houses with electric heating, there may not be easy access to gas service; in such cases, the cost of adding gas service will likely be prohibitive. The results of utility cost-effectiveness screening presented in this Appendix assume that gas service is available to the household.

As discussed in Chapter Three, the results for Atlanta are driven by the avoided energy costs for a typical utility in its area (Georgia Power). Externality costs are not included in these marginal energy costs. The analysis factors in an avoided capacity value of about $102/yr, which accounts for generating capacity factor and transmission and distribution costs and losses.

Administrative costs are assumed to be $150 per household. The utility incentive is assumed to cover the entire incremental cost of the equipment whenever the Total Resource Cost Test ratio is 1 or greater. In those cases in which the TRC ratio is below 1, no utility incentive is assumed.

The results in Exhibit C.61 indicate that EMERGING GROUND SOURCE HEAT PUMPS and LOW-COST ADVANCED AIR SOURCE HEAT PUMPS are consistently cost-effective substitutes for all baseline technologies. In substituting for baseline electric technologies the LOW-COST ADVANCED AIR SOURCE HEAT PUMP has TRC ratios that are as high or higher than the EMERGING and ADVANCED GROUND SOURCE HEAT PUMP technologies; however, the EMERGING GROUND SOURCE HEAT PUMPS have higher net present values and reduce air emissions more.

An important consideration indicated by Exhibit C.61 is that the PRESENT-COST ADVANCED AIR SOURCE HEAT PUMP is not nearly as cost-effective in replacing baseline electric technologies as EMERGING GROUND SOURCE HEAT PUMPS are in this location. This may be an important competitive factor in Climate Zone 4 markets over the next decade, given the high penetration of electric space conditioning. If ADVANCED AIR SOURCE HEAT PUMPS do not come down in price like they are assumed to in the LOW-COST scenario, they may have difficulty in competing in this crucial market.

As substitutes for STANDARD GAS FURNACES, the EMERGING and ADVANCED GROUND SOURCE HEAT PUMPS and the LOW-COST ADVANCED AIR SOURCE HEAT PUMP have higher TRC ratios and net present values than the GAS-FIRED HEAT PUMP in the economic tests. However, the ADVANCED GROUND SOURCE HEAT PUMP and the LOW-COST ADVANCED AIR SOURCE HEAT PUMP do not have a clear advantage in reducing air emissions, assuming the REGIONAL fuel mix. It is notable that the ADVANCED GAS FURNACE as a stand-alone measure does not pass the utility cost-effective test as a substitute for a STANDARD GAS FURNACE.

Exhibit C.61
Utility Program Cost-Effectiveness and Paybacks
Atlanta, Georgia

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)			Without Incentive	With Incentive	CO2	NOx	SO2
Replace Electric Resistant Heating/AC with:**													
Emerging Ground Source Heat Pump (SLINKY)	$3,455	$3,455	9,991	9.7	5.1	0.0	2.20	$4,334	8.25	0.00	6,563	17.80	33.05
Emerging Ground Source Heat Pump (Vertical)	$4,530	$4,530	9,991	9.7	5.1	0.0	1.70	$3,259	10.82	0.00	6,563	17.80	33.05
Advanced Ground Source Heat Pump	$4,530	$4,530	8,930	9.7	5.1	0.0	1.62	$2,878	12.30	0.00	5,865	15.91	29.54
Advanced Air Source Heat Pump (Present Cost)	$4,150	$4,150	8,685	1.1	4.4	0.0	1.60	$2,574	11.39	0.00	5,703	15.47	28.73
Advanced Air Source Heat Pump (Low Cost)	$2,625	$2,625	8,685	1.1	4.4	0.0	2.48	$4,099	7.20	0.00	5,703	15.47	28.73
Advanced Gas Furnace/ High Efficiency AC***	$3,450	$0	11,557	11.3	5.0	-483.0	0.99	($94)	>20	>20	5,026	18.35	38.17
Gas Air-to-Air Heat Pump	$4,850	$4,850	13,590	11.0	6.9	-520.8	1.04	$457	>20	0.00	6,104	16.56	44.90

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)			Without Incentive	With Incentive	CO2	NOx	SO2
Replace Standard Air Source Heat Pump with:													
Emerging Ground Source Heat Pump (SLINKY)	$2,205	$2,205	5,362	9.5	5.4	0.0	2.94	$4,570	8.91	0.00	3,523	9.55	17.74
Emerging Ground Source Heat Pump (Vertical)	$3,280	$3,280	5,362	9.5	5.4	0.0	2.02	$3,495	13.26	0.00	3,523	9.55	17.74
Advanced Ground Source Heat Pump	$3,280	$3,280	4,301	9.5	5.4	0.0	1.91	$3,114	16.64	0.00	2,825	7.66	14.23
Advanced Air Source Heat Pump (Present Cost)	$2,900	$2,900	4,056	0.9	4.7	0.0	1.92	$2,809	15.01	0.00	2,663	7.22	13.41
Advanced Air Source Heat Pump (Low Cost)	$1,375	$1,375	4,056	0.9	4.7	0.0	3.84	$4,334	7.12	0.00	2,663	7.22	13.41
Advanced Gas Furnace/ High Efficiency AC	$1,800	$1,800	6,928	11.1	5.3	-483.0	1.08	$542	>20	0.00	1,986	10.11	22.86
Gas Air-to-Air Heat Pump	$3,600	$3,600	8,961	10.8	7.2	-520.8	1.08	$692	>20	0.00	3,064	8.32	29.58

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)			Without Incentive	With Incentive	CO2	NOx	SO2
Replace Standard Gas Furnace/AC with:													
Emerging Ground Source Heat Pump (SLINKY)	$1,830	$1,830	(1,184)	-1.6	0.6	590.0	3.09	$4,130	5.07	0.00	2,343	0.61	(3.85)
Emerging Ground Source Heat Pump (Vertical)	$2,905	$2,905	(1,184)	-1.6	0.6	590.0	2.00	$3,055	8.05	0.00	2,343	0.61	(3.85)
Advanced Ground Source Heat Pump	$2,905	$2,905	(2,244)	-1.6	0.6	590.0	1.87	$2,675	9.36	0.00	1,645	(1.28)	(7.36)
Advanced Air Source Heat Pump (Present Cost)	$2,525	$2,525	(2,490)	-10.2	-0.1	590.0	1.70	$2,370	8.24	0.00	1,484	(1.72)	(8.18)
Advanced Air Source Heat Pump (Low Cost)	$1,000	$1,000	(2,490)	-10.2	-0.1	590.0	3.10	$3,895	3.26	0.00	1,484	(1.72)	(8.18)
Advanced Gas Furnace/ High Efficiency AC***	$1,425	$1,425	382	0.0	0.5	107.0	1.07	$103	15.44	11.93	807	1.16	1.27
Gas Air-to-Air Heat Pump	$3,225	$3,225	2,416	-0.3	2.4	69.2	1.07	$253	>20	0.00	1,884	(0.62)	8.00

* If TRC <1, no incentive program is assumed. Where TRC test is greater than 1, entire incremental cost is covered by the incentive.

** Results reflect replacement of existing ELECTRIC RESISTANCE at the end of the central AC's service life. We assume in this scenario that the ELECTRIC RESISTANCE does not need replacement. Thus, we compare the capital cost of the entire advanced system against only the replacement AC. In the case of new construction, a much higher TRC is obtained, since in this case the cost of the ELECTRIC RESISTANCE system would have to be factored in.

*** Measured by itself, the HIGH-EFFICIENCY AIR CONDITIONER has a TRC of 2.17 when replacing a STANDARD AIR CONDITIONER. Likewise, the ADVANCED GAS FURNACE has a TRC of 0.82 when replacing a STANDARD GAS FURNACE.

A FOCUS ON CARBON DIOXIDE EMISSIONS

Exhibits C.62 through C.65 rank the space conditioning equipment covered in the report according to their CO_2 emissions under the three electricity generating scenarios. As in other locations, they show a clustering of cost-effective technologies at the high end of the CO_2 reduction scale. The GAS-FIRED HEAT PUMP is the lowest CO_2 emitting technology in the ADVANCED FLUIDIZED BED COAL SCENARIO and is just behind the EMERGING GROUND SOURCE HEAT PUMP in the REGIONAL and NATURAL GAS COMBUSTION TURBINES. As can be expected, it is further back in the pack in the ADVANCED NATURAL GAS COMBINED CYCLE scenario.

Exhibit C.62

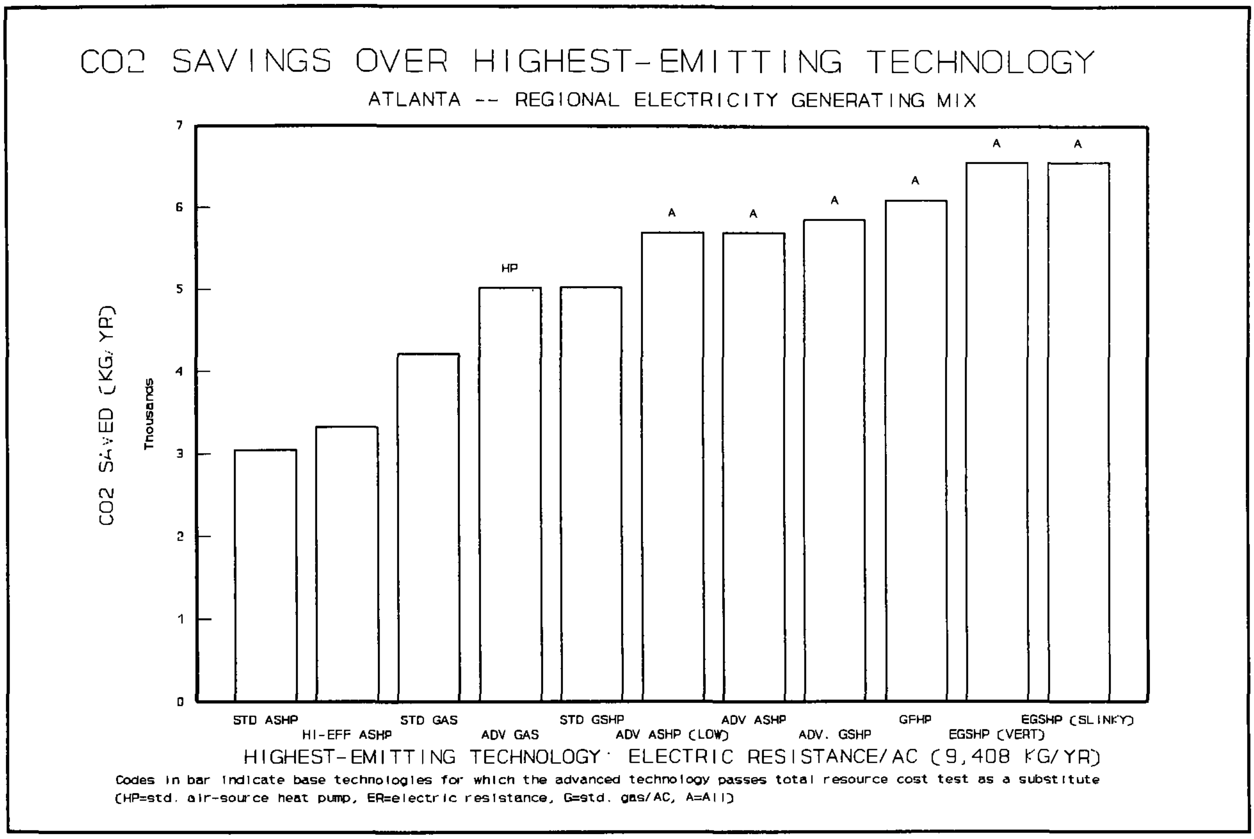


Exhibit C.63

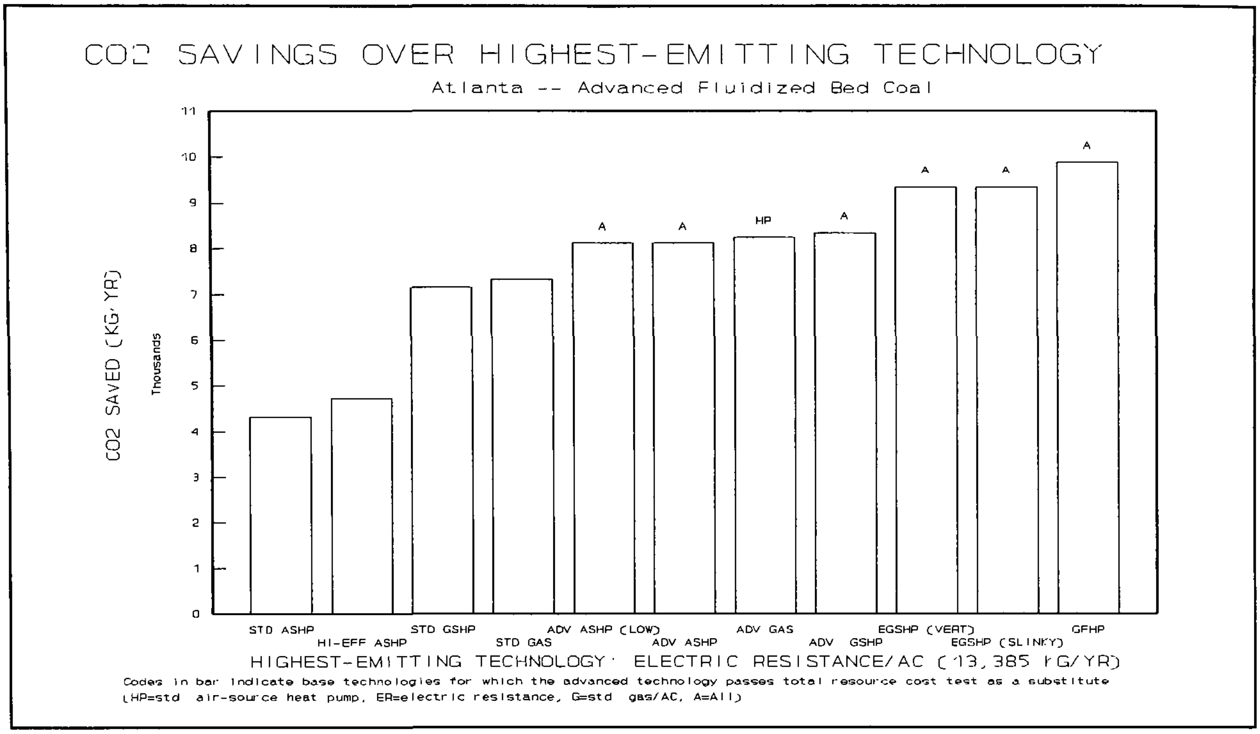


Exhibit C.64

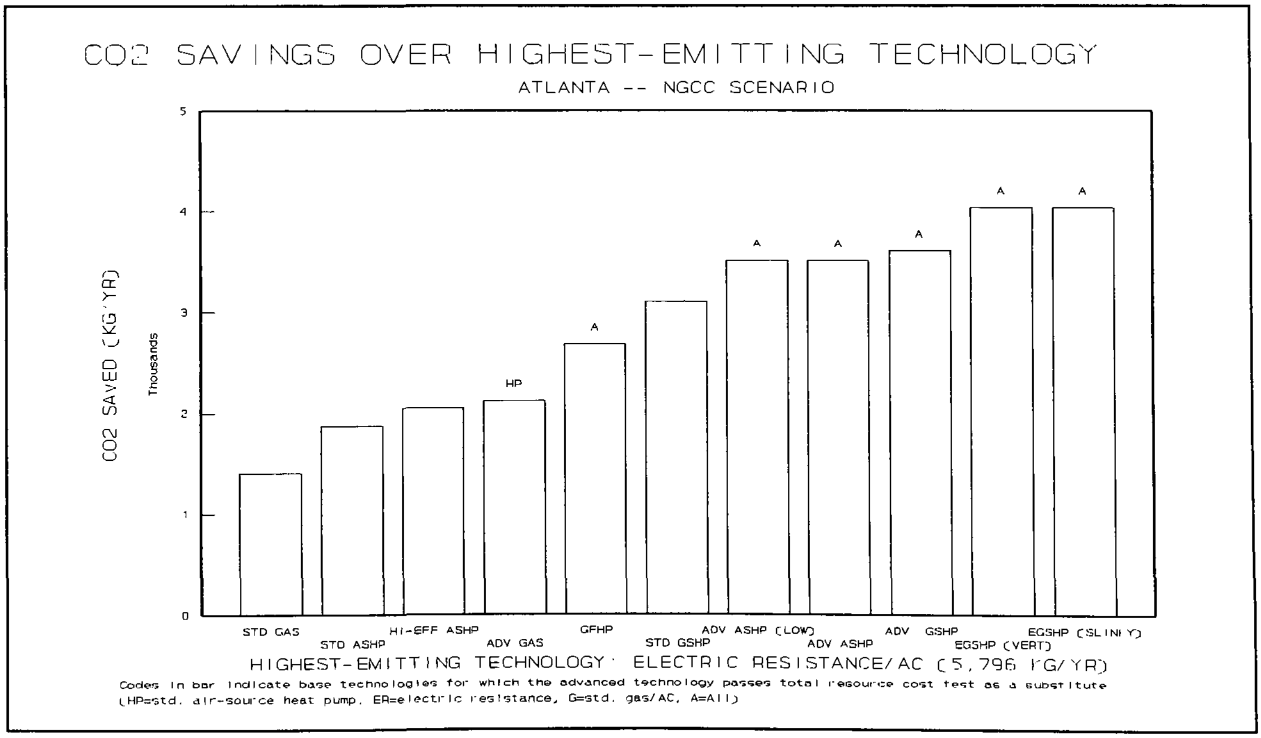
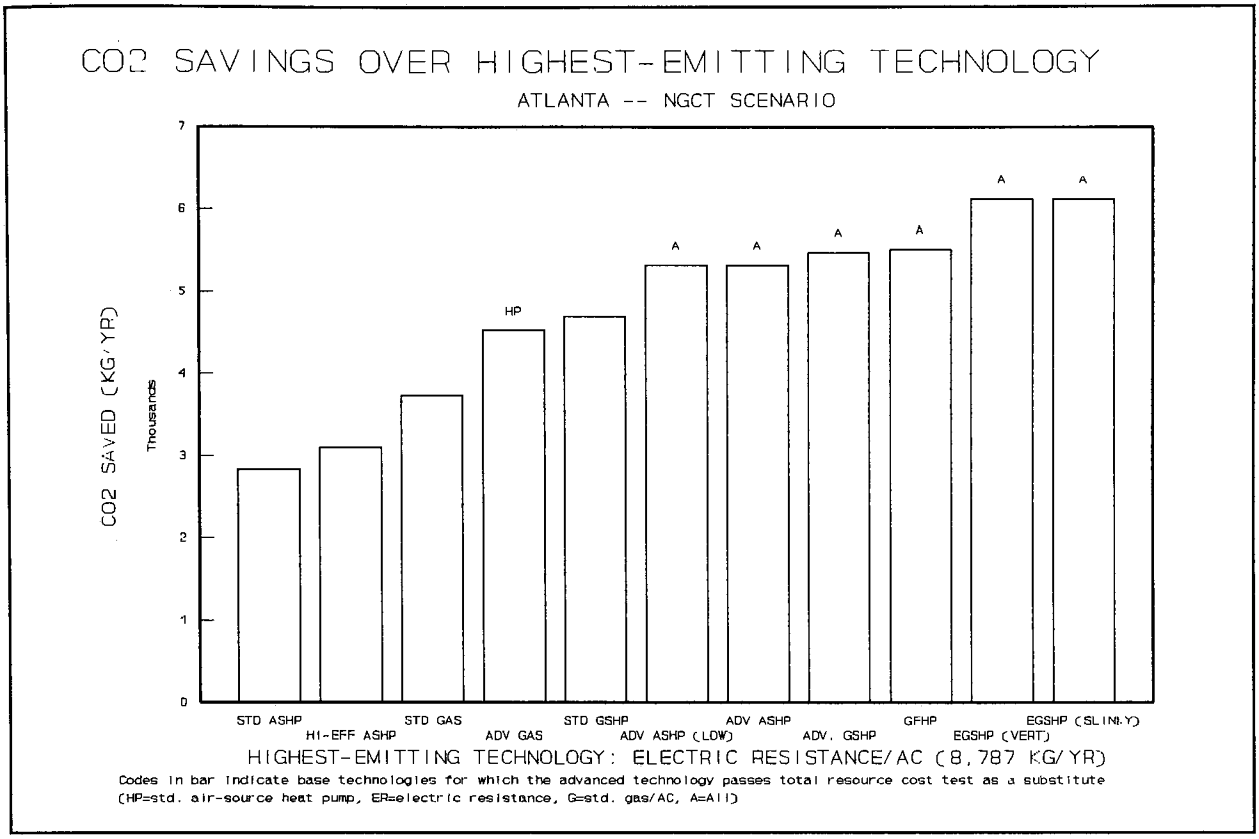


Exhibit C.65



CO2 SAVINGS OVER HIGHEST-EMITTING TECHNOLOGY
ATLANTA -- NGCT SCENARIO
CO2 SAVED (KG/YR)
Thousands
0
1
2
3
4
5
6
7
HP
A
A
A
A
A
A
STD ASHP
HI-EFF ASHP
STD GAS
ADV GAS
STD GSHP
ADV ASHP (LOW)
ADV ASHP
ADV. GSHP
GFHP
EGSHP (VERT)
EGSHP (SLINKY)
HIGHEST-EMITTING TECHNOLOGY: ELECTRIC RESISTANCE/AC (8,787 KG/YR)
Codes in bar indicate base technologies for which the advanced technology passes total resource cost test as a substitute
(HP=std. air-source heat pump, ER=electric resistance, G=std. gas/AC, A=All)

CLIMATE ZONE 5: PHOENIX, ARIZONA

Climate Zone 5 includes the Deep South, most of Oklahoma, and the desert areas of Southern California, Southern Nevada, and Western Arizona. For the representative location (Phoenix), the home used for the analysis was modeled to require 17.20 MMBtu for heating, 54.40 MMBtu for cooling, and 7.10 MMBtu for water heating annually, for a total demand of 78.70 MMBtu. The cooling load here is by far the heaviest and the heating load the lightest among any of the locations analyzed.

PERFORMANCE AND COST

Exhibit C.66 compares the operating performance of all of the representative space conditioning technologies described in Chapter 2. The three columns on the left indicate each equipment's modeled end-use seasonal performance factor (SPF, calculated by dividing the number of Btu's demanded in the location for heating, cooling or water heating by the number of Btu's of energy input the equipment required to meet that demand). The higher the SPF, the higher the technology's end-use efficiency.

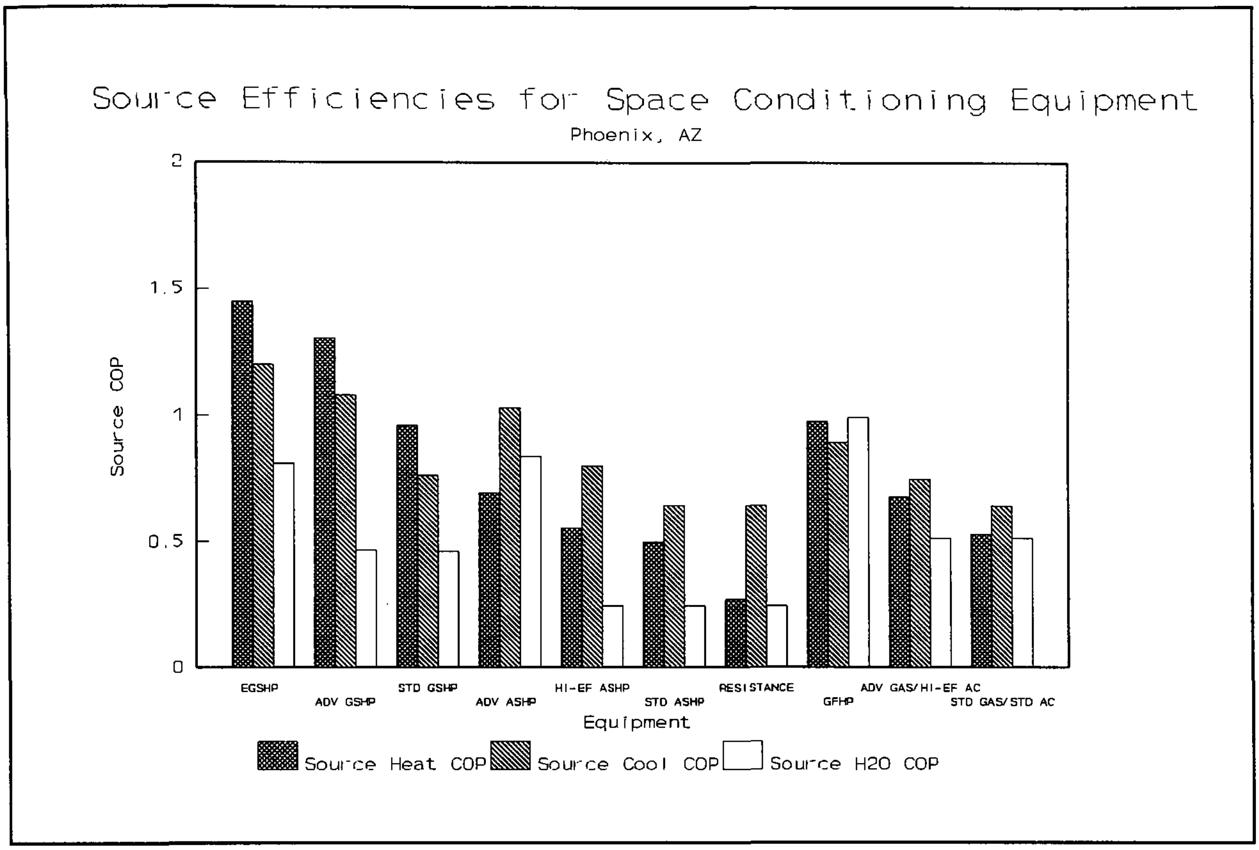
The three right-hand columns of Exhibit C.66, and Exhibit C.67, show source SPF, accounting for the losses in the generation, transmission and distribution system for each fuel type. The two best net energy performers in each category are highlighted:

Exhibit C.66
Performance of Space Conditioning Equipment
Phoenix, AZ (including water heating)

	END USE EFFICIENCY			SOURCE EFFICIENCY		
	HEAT	COOL	H20	HEAT	COOL	H20
EQUIPMENT TYPE	SPF	SPF	SPF	SPF	SPF	SPF
Emerging Ground Source Heat Pump	5.37	4.45	3.00	1.45	1.20	0.81
Advanced Ground Source Heat Pump	4.83	4.00	1.72	1.30	1.08	0.46
Standard Ground Source Heat Pump	3.55	2.82	1.70	0.96	0.76	0.46
Advanced Air Source Heat Pump	2.56	3.82	3.10	0.69	1.03	0.84
High Efficiency Air Source Heat Pump	2.05	2.96	0.90	0.55	0.80	0.24
Standard Air Source Heat Pump	1.84	2.37	0.90	0.50	0.64	0.24
Electric Resistance/ Standard AC	1.00	2.37	0.90	0.27	0.64	0.24
Gas-Fired Heat Pump	1.20	1.12	1.09	0.98	0.89	0.99
Advanced Gas Furnace/ High Efficiency AC	0.85	2.77	0.56	0.68	0.75	0.51
Standard Gas Furnace/ Standard AC	0.65	2.37	0.56	0.53	0.64	0.51

* The emerging GSHP listed in this table reflects the operating performance of the SLINKY™ or the vertical system.

Exhibit C.67



Here the EMERGING GROUND SOURCE HEAT PUMP performs extremely well compared to all other equipment, with a source efficiency on the heating and cooling side that is slightly better than the ADVANCED GROUND SOURCE HEAT PUMP, and a water heating efficiency comparable to the ADVANCED AIR SOURCE HEAT PUMP, although not nearly as high as the GAS-FIRED HEAT PUMP in water heating mode.

The annual costs of the equipment, as presented in Exhibits C.68 and C.69, indicate that the EMERGING GROUND SOURCE HEAT PUMP/SLINKY™ system has the lowest annual cost of any equipment. It is followed by the LOW-COST ADVANCED AIR SOURCE HEAT PUMP, which benefits from a combination of relatively low capital costs and a high source operating performance in this cooling-dominated climate. The GAS-FIRED HEAT PUMP enjoys the lowest annual <u>operating</u> cost of all equipment, and therefore has a total annual cost (including capital) that is slightly lower than the EMERGING GROUND SOURCE HEAT PUMP/VERTICAL LOOP system. Exhibit C.68 highlights the two least expensive technologies with respect to annual capital, annual operating and total costs.

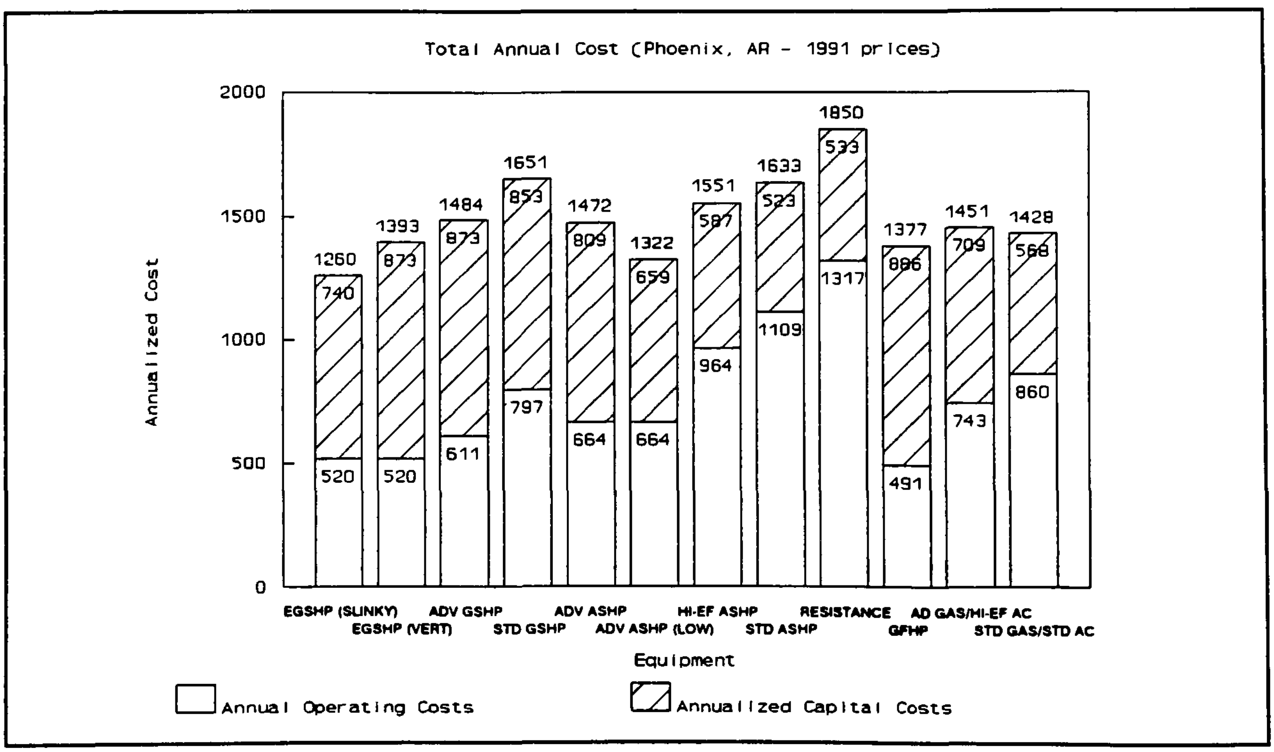
Exhibit C.68
Annual Costs Of Space Conditioning Equipment
Phoenix, AZ

EQUIPMENT TYPE	INSTALLED COST*	ANNUAL CAPITAL	ANNUAL OPERATING	TOTAL COST
Emerging Ground Source Heat Pump (SLINKY)	$7,520	$740	$520	$1,260
Emerging Ground Source Heat Pump (Vertical)	$8,870	$873	$520	$1,393
Advanced Ground Source Heat Pump	$8,870	$873	$611	$1,484
Standard Ground Source Heat Pump	$8,669	$853	$797	$1,651
Advanced Air Source Heat Pump (Present Cost)	$8,215	$809	$664	$1,472
Advanced Air Source Heat Pump (Low Cost)	$6,690	$659	$664	$1,322
High Efficiency Air Source Heat Pump;	$5,965	$587	$964	$1,551
Standard Air Source Heat Pump	$5,315	$523	$1,109	$1,633
Electric Resistance/ Standard AC	$5,415	$533	$1,317	$1,850
Gas-Fired Heat Pump	$9,000	$886	$491	$1,377
Advanced Gas Furnace/ High Efficiency AC	$7,200	$709	$743	$1,451
Standard Gas Furnace/ Standard AC	$5,775	$568	$860	$1,428

* Includes duct work ($1800) and water heater ($315 for electric and $400 for gas).

** Based on 1991 residential prices for energy: $.09/kWh electric and $0.45/therm for gas.

Exhibit C.69

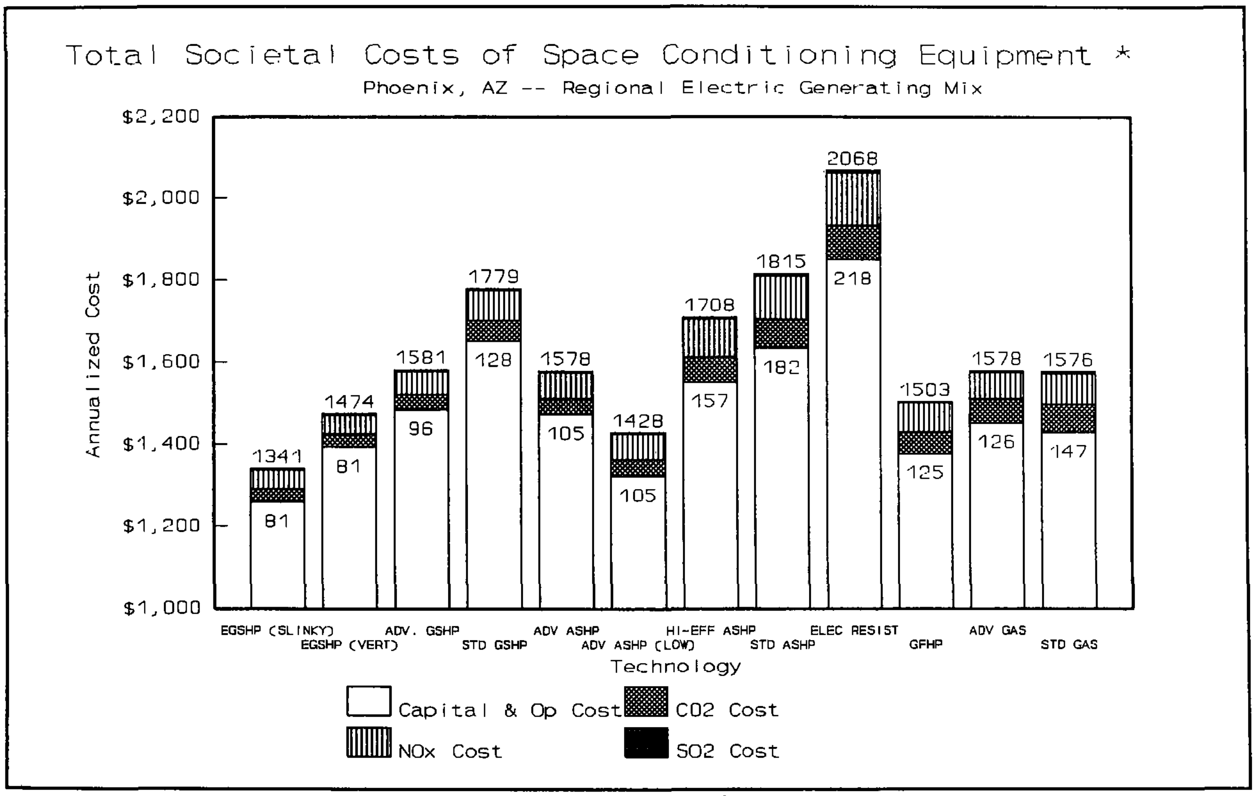


ENVIRONMENTAL EFFECTS AND TOTAL SOCIETAL COST

Regional Electric Generation Fuel Mix Scenario: The region for which emissions in the Arizona were taken, the West, has a relatively low concentration of coal (19%) in its project fuel mix for 2000; 46% is comprised of nuclear and renewables. Combined with a high cooling demand, this means that many of the electric technologies considered in this analysis have the lowest CO_2 emissions and overall externality costs (Exhibit C.70 and Appendix D). The EMERGING GROUND SOURCE HEAT PUMPS emit 41% less CO_2 and 35% less NO_x than the lowest-cost gas equipment, the GAS-FIRED HEAT PUMPS, while their SO_2 emissions are four times higher. Despite higher externalities, however, the GAS-FIRED HEAT PUMP's total societal cost is still comparable with the EMERGING GROUND SOURCE HEAT PUMP/VERTICAL system, and less than the ADVANCED GROUND SOURCE HEAT PUMP and the LOW-COST ADVANCED AIR SOURCE HEAT PUMP.

The EMERGING GROUND SOURCE HEAT PUMP reduces emissions of CO_2, NO_x, and SO_2 by 23% compared to ADVANCED AIR SOURCE HEAT PUMPS; by 57% compared to STANDARD AIR SOURCE HEAT PUMPS; and by 63% compared to ELECTRIC RESISTANCE. These percentage reductions hold across all electric generation scenarios.

Exhibit C.70

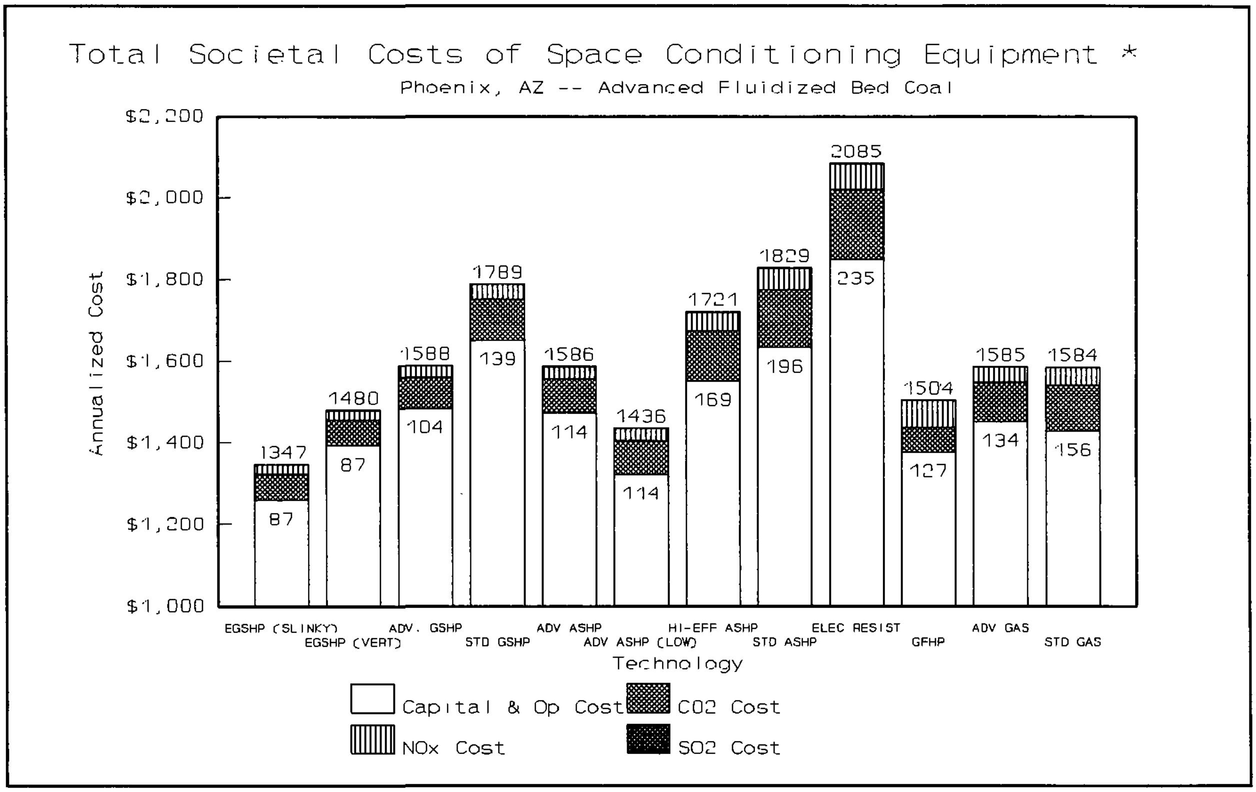


* Number inside column refers to total externality cost.

Advanced Fluidized Bed Coal Scenario: Because of the high cooling load in this location, the GAS-FIRED HEAT PUMP only emits 6% less CO_2 than the EMERGING GROUND SOURCE HEAT PUMPS under the ADVANCED COAL scenario; since it also has three times the NOx emissions, its overall environmental externality costs are higher (Exhibit C.71 and Appendix D). All of the advanced ground source and air source heat pumps have lower total externality costs than the gas technologies under this scenario.

A trade-off between CO_2 and NO_x between the GAS-FIRED HEAT PUMP and the ADVANCED GAS FURNACE result in approximately equal externality costs for those two leading gas technologies.

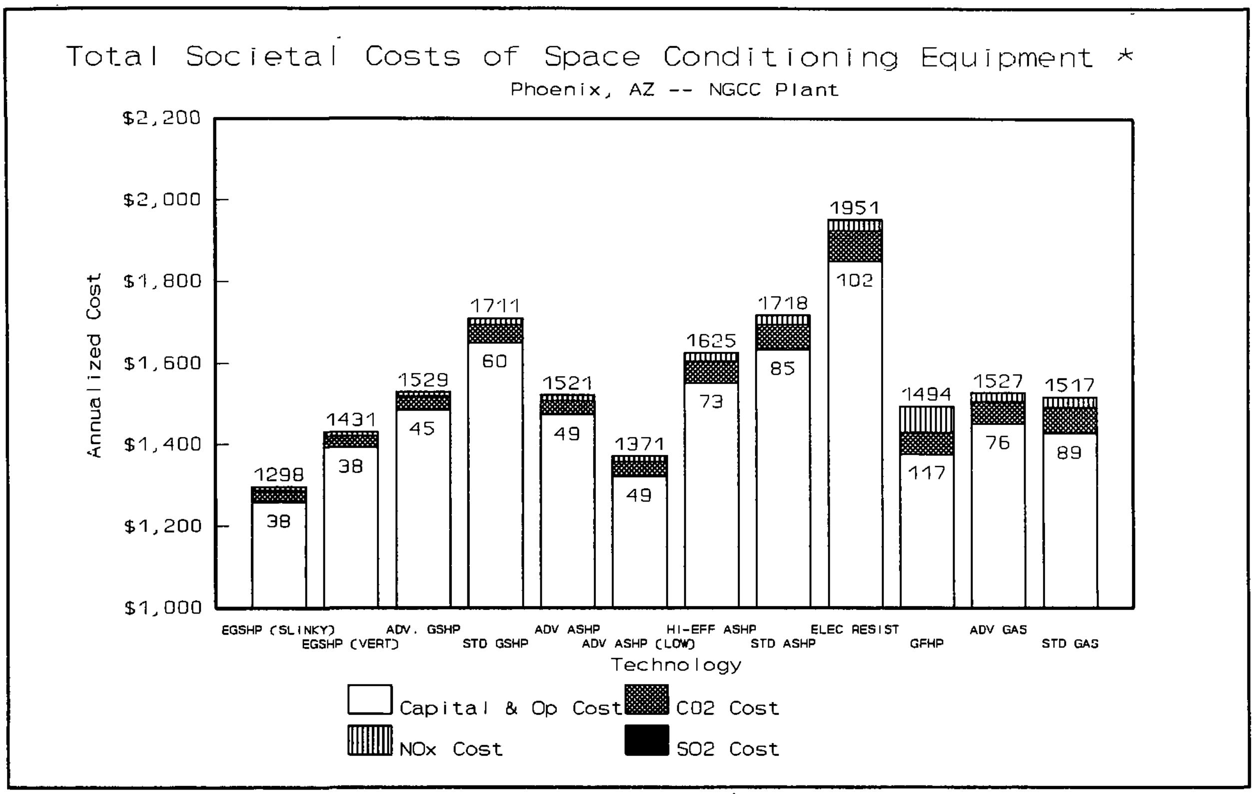
Exhibit C.71



*Number inside column refers to total externality cost.

Advanced Natural Gas Combined Cycle Scenario: As one might expect from the two prior scenarios, the environmental costs for gas systems are higher compared to electric technologies under the ADVANCED NATURAL GAS generation scenario (Exhibit C.72).

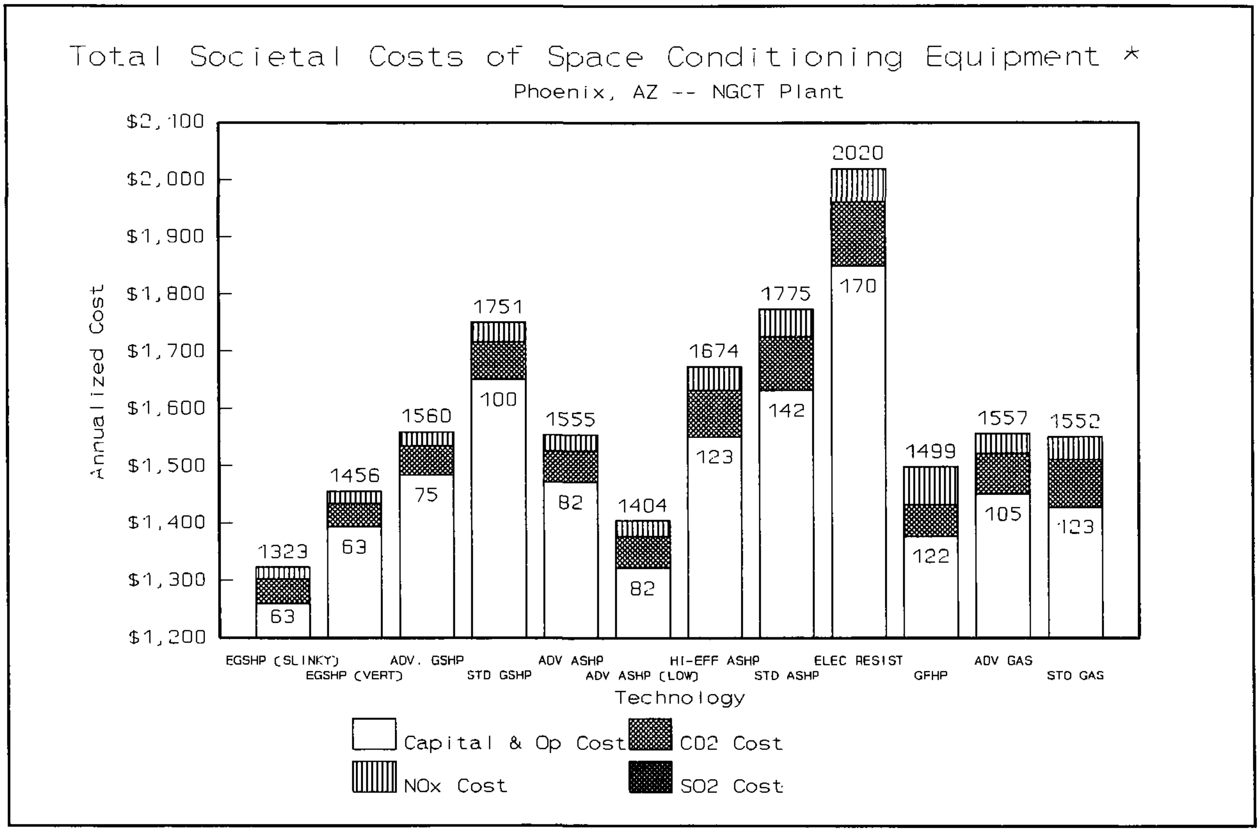
Exhibit C.72



* Number inside column refers to total externality cost.

Natural Gas Combustion Turbine Scenario: Although not as favorable to electric equipment as the ADVANCED NATURAL GAS COMBINED CYCLE scenario, this scenario results in lower externalities for all advanced electronic equipment because of their relatively strong cooling performance. The EMERGING GROUND SOURCE HEAT PUMP has lower CO_2 emissions and two-thirds lower NO_x emissions than the GAS-FIRED HEAT PUMP in this scenario. Other advanced electric equipment, including the ADVANCED AIR SOURCE HEAT PUMP, also have lower CO_2 and NO_x emissions.

Exhibit C.73



* Number inside column refers to total externality cost.

CHOICES FOR UTILITIES: COST-EFFECTIVENESS SCREENING

The cost-effectiveness of various utility programs will depend on a realistic assessment of which technologies compete in a particular residence, and at what costs.

The utility cost-effectiveness analysis and estimate of utility program effect on payback, as described in Chapter 3, was performed for various equipment substitutions and is presented in Exhibit C.74. ELECTRIC RESISTANCE, STANDARD AIR SOURCE HEAT PUMPs, and STANDARD GAS FURNACES were selected as the base technologies for which substitutions would be evaluated.

For houses with electric heating, there may not be easy access to gas service; in such cases, the cost of adding gas service will likely be prohibitive. The results of utility cost-effectiveness screening presented in this Appendix assume that gas service is available to the household.

As discussed in Chapter Three, the results for Phoenix are driven by the avoided energy costs for a typical utility in the Phoenix area (Arizona Public Service). Externality costs are <u>not</u> included in these energy costs. The analysis factors in an avoided capacity value of about $102/yr, which accounts for generating capacity factor and transmission and distribution costs and losses.

Administrative costs are assumed to be $150 per household. The utility incentive is assumed to cover the entire incremental cost of the equipment whenever the Total Resource Cost Test ratio is 1 or greater. In those cases in which the TRC ratio is below 1, no utility incentive is assumed.

The results displayed in Exhibit C.74 continue the trend toward higher cost-effectiveness for electric equipment in warmer climates, relative to gas equipment. As substitutes for ELECTRIC RESISTANCE and STANDARD AIR SOURCE HEAT PUMPS, the LOW-COST ADVANCED AIR SOURCE HEAT PUMP is extremely cost effective from the perspective of the TRC ratio. It also yields a net present value comparable to that of the EMERGING GROUND SOURCE HEAT PUMP/VERTICAL LOOP system. However, it does not reduce air emissions as much as the EMERGING GROUND SOURCE HEAT PUMP technologies. Nonetheless, as in Atlanta, the cost-effectiveness results in Exhibit C.74 suggest that, with price breakthroughs, the ADVANCED AIR SOURCE HEAT PUMP could be a major competitor in the South's large electric space conditioning market over the next few decades.

The results for substituting for STANDARD GAS FURNACES suggest that both the EMERGING GROUND SOURCE HEAT PUMPS and the LOW-COST ADVANCED AIR SOURCE HEAT PUMP would be highly cost-effective in Climate Zone 5, although the GAS-FIRED HEAT PUMP is also cost-effective. Under the REGIONAL generation mix scenario, these technologies also would significantly cut air emissions relative to the STANDARD GAS FURNACE system. Although the ADVANCED GAS FURNACE/HIGH EFFICIENCY AIR CONDITIONER system is cost-effective as an entire system, closer analysis reveals that the furnace alone does not pass the TRC. Therefore, no utility incentive program is assumed.

Exhibit C.74
Utility Program Cost Effectiveness
Phoenix, AZ

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)			Without Incentive	With Incentive	CO2	NOx	SO2
Replace Electric Resistant Heating/AC with:**													
Emerging Ground Source Heat Pump (SLINKY)	$3,455	$3,455	8,856	7.5	5.1	0.0	2.99	$7,170	4.28	0.00	4,078	12.41	4.96
Emerging Ground Source Heat Pump (Vertical)	$4,805	$4,805	8,856	7.5	5.1	0.0	2.17	$5,820	5.96	0.00	4,078	12.41	4.96
Advanced Ground Source Heat Pump	$4,805	$4,805	7,841	7.5	5.1	0.0	2.03	$5,124	6.78	0.00	3,609	10.98	4.39
Advanced Air Source Heat Pump (Present Cost)	$4,150	$4,150	7,260	2.9	4.4	0.0	2.10	$4,743	6.24	0.00	3,342	10.17	4.07
Advanced Air Source Heat Pump (Low Cost)	$2,625	$2,625	7,260	2.9	4.4	0.0	3.26	$6,268	3.95	0.00	3,342	10.17	4.07
Advanced Gas Furnace/ High Efficiency AC***	$3,050	$3,050	7,970	9.2	4.5	-318.0	1.55	$3,406	6.15	0.00	1,968	9.68	4.43
Gas Air-to-Air Heat Pump	$4,850	$4,850	13,019	9.4	6.9	-657.7	1.33	$3,829	6.30	0.00	2,407	8.52	7.22

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)			Without Incentive	With Incentive	CO2	NOx	SO2
Replace Standard Air Source Heat Pump with:													
Emerging Ground Source Heat Pump (SLINKY)	$2,205	$2,205	6,551	4.9	5.8	0.0	4.21	$7,555	3.54	0.00	3,017	9.18	3.67
Emerging Ground Source Heat Pump (Vertical)	$3,555	$3,555	6,551	4.9	5.8	0.0	2.67	$6,205	5.70	0.00	3,017	9.18	3.67
Advanced Ground Source Heat Pump	$3,555	$3,555	5,536	4.9	5.8	0.0	2.49	$5,509	6.76	0.00	2,548	7.75	3.10
Advanced Air Source Heat Pump (Present Cost)	$2,900	$2,900	4,955	0.3	5.1	0.0	2.68	$5,129	6.02	0.00	2,281	6.94	2.78
Advanced Air Source Heat Pump (Low Cost)	$1,375	$1,375	4,955	0.3	5.1	0.0	5.36	$6,654	2.86	0.00	2,281	6.94	2.78
Advanced Gas Furnace/ High Efficiency AC	$1,800	$1,800	5,665	6.6	5.1	-318.0	1.76	$3,698	5.75	0.00	907	6.45	3.14
Gas Air-to-Air Heat Pump	$3,600	$3,600	10,714	6.8	7.6	-657.7	1.41	$4,215	6.14	0.00	1,346	5.29	5.93

Base Equipment & Comparison Equipment	Incremental Installed Cost	Utility Incentive*	kWh Saved Per Year	Electric Demand Savings		Gas Savings	Total Resource Cost Test	TRC Net Present Value	Simple Consumer Payback Period		Emissions Reduced Regional Electric Generation Mix		
				Winter (kW)	Summer (kW)	(Therms)			Without Incentive	With Incentive	CO2	NOx	SO2
Replace Standard Gas Furnace/AC with:													
Emerging Ground Source Heat Pump (SLINKY)	$1,830	$1,830	1,870	-1.7	1.3	381.0	3.08	$4,116	4.05	0.00	2,891	4.39	1.09
Emerging Ground Source Heat Pump (Vertical)	$3,180	$3,180	1,870	-1.7	1.3	381.0	1.83	$2,766	7.03	0.00	2,891	4.39	1.09
Advanced Ground Source Heat Pump	$3,180	$3,180	855	-1.7	1.3	381.0	1.62	$2,070	8.97	0.00	2,422	2.97	0.52
Advanced Air Source Heat Pump (Present Cost)	$2,525	$2,525	274	-6.3	0.6	381.0	1.63	$1,690	8.14	0.00	2,154	2.15	0.19
Advanced Air Source Heat Pump (Low Cost)	$1,000	$1,000	274	-6.3	0.6	381.0	3.80	$3,215	3.22	0.00	2,154	2.15	0.19
Advanced Gas Furnace/ High Efficiency AC***	$1,425	$1,425	984	0.0	0.6	63.0	1.16	$259	10.07	9.81	781	1.66	0.56
Gas Air-to-Air Heat Pump	$3,225	$3,225	6,032	0.2	3.1	-276.7	1.12	$775	7.77	0.00	1,220	0.50	3.35

* If TRC <1, no incentive is assumed. Where TRC test is greater than 1, entire incremental cost is covered by the incentive.

** Results reflect replacement of existing ELECTRIC RESISTANCE at the end of the central AC's service life. We assume in this scenario that the ELECTRIC RESISTANCE does not need replacement. Thus, we compare the capital cost of the entire advanced system against only the replacement AC. In the case of new construction, a much higher TRC is obtained, since in this case the cost of the ELECTRIC RESISTANCE system would have to be factored in.

*** Measured by itself, the HIGH-EFFICIENCY AIR CONDITIONER has a TRC of 3.88 when replacing a STANDARD AIR CONDITIONER. Likewise, the ADVANCED GAS FURNACE has a TRC of 0.46 when replacing a STANDARD GAS FURNACE.

A FOCUS ON CARBON DIOXIDE EMISSIONS

Exhibits C.75 through C.78 rank the various space conditioning technologies by their relative CO_2 emissions under the three electricity generating scenarios. These show favorable results in the REGIONAL, NATURAL GAS COMBINED CYCLE, and NATURAL GAS COMBUSTION TURBINE scenarios for the various advanced electric technologies, led by the lowest CO_2 emitters, the EMERGING GROUND SOURCE HEAT PUMPS. In the AFBC scenario, the GAS-FIRED HEAT PUMP appears to offer the best CO_2 emission reductions among all cost-effective equipment.

Exhibit C.75

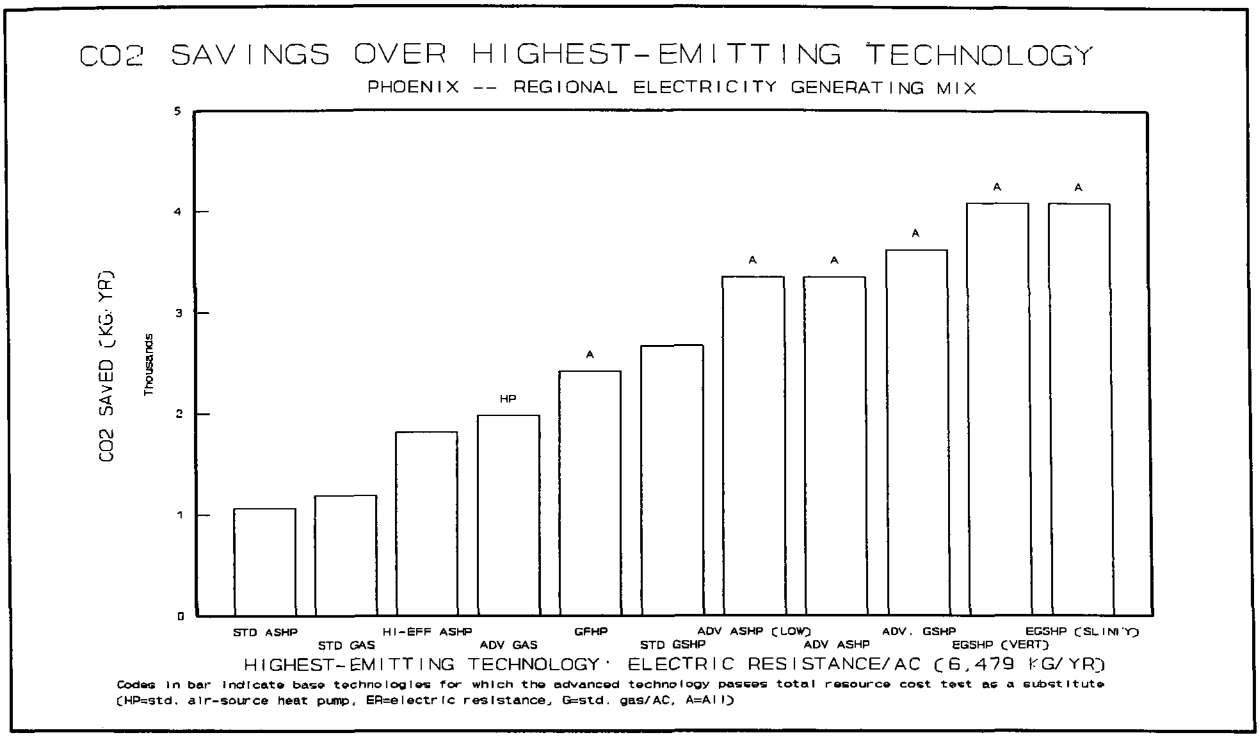


Exhibit C.76

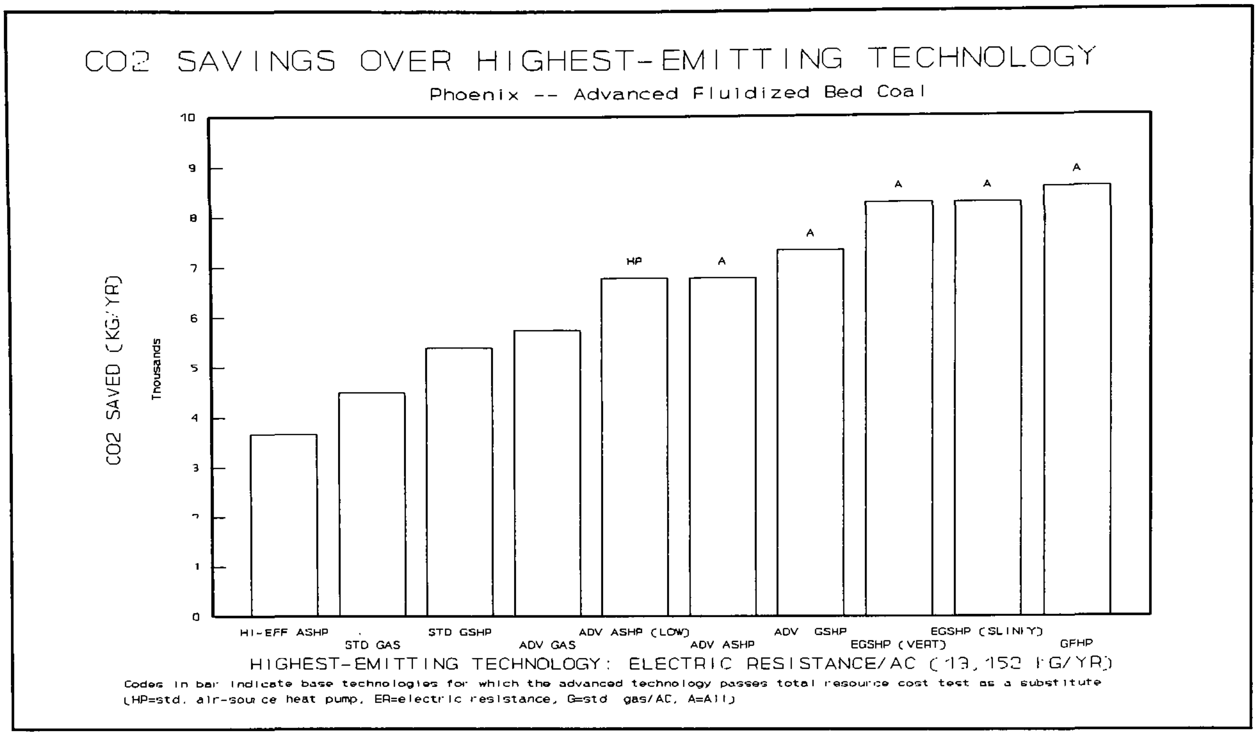


Exhibit C.77

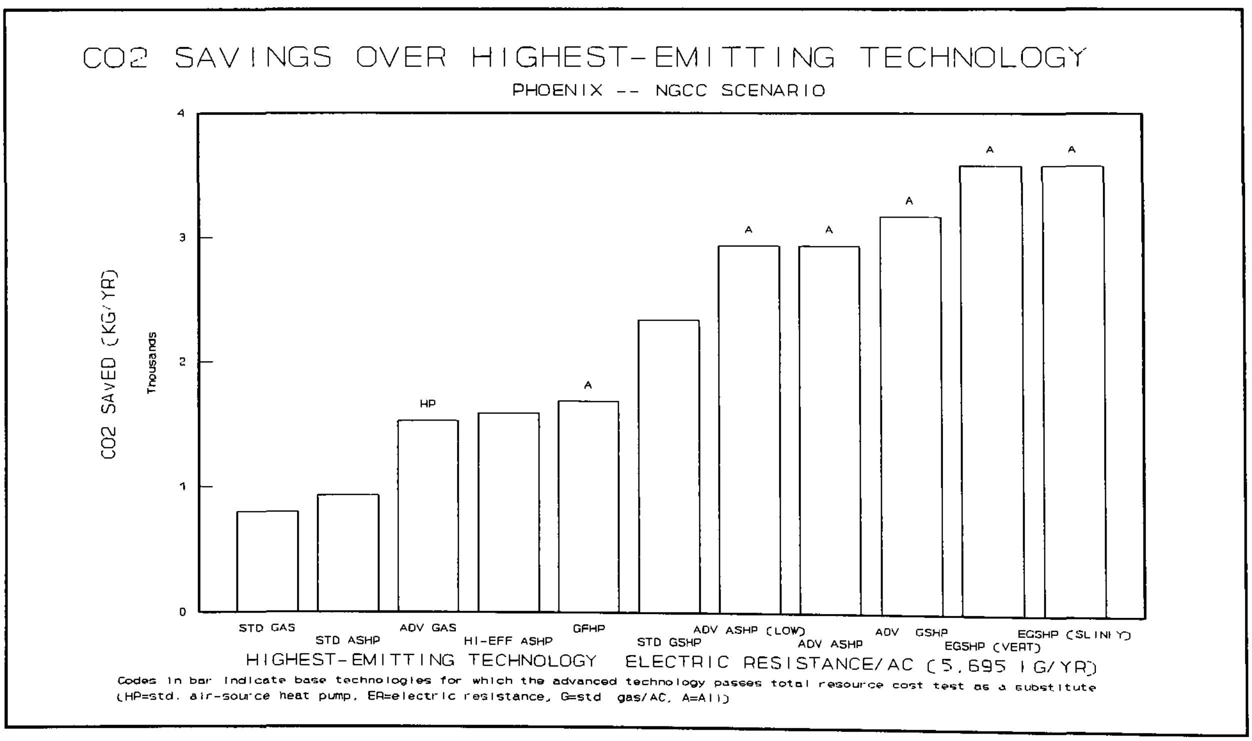
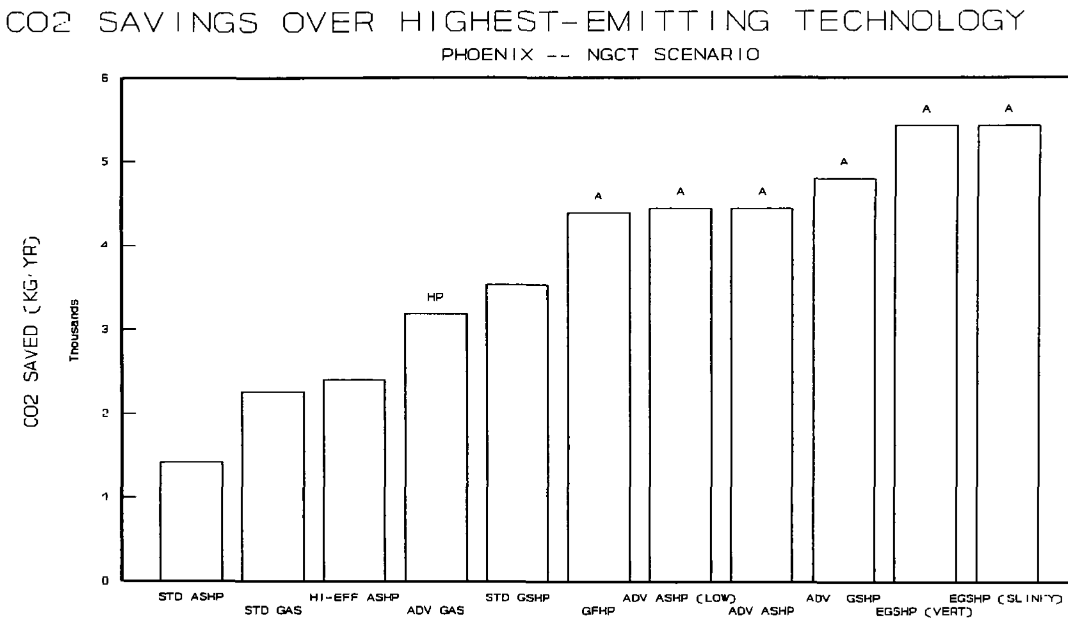


Exhibit C.78



Codes in bar indicate base technologies for which the advanced technology passes total resource cost test as a substitute (HP=std air-source heat pump, ER=electric resistance, G=std. gas/AC, A=All)

APPENDIX D

EXTERNALITIES ASSOCIATED WITH SPACE CONDITIONING EQUIPMENT

BURLINGTON Regional	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	2,579	7,517	6.5	26.05	$33.53	$41.82	$22.93	$98	$1,781	$1,879
Emerging Ground Source Heat Pump (VERTICAL)	2,579	7,517	6.5	26.05	$33.53	$41.82	$22.93	$98	$1,918	$2,016
Advanced Ground Source Heat Pump	3,137	6,959	7.9	31.69	$40.79	$50.86	$27.89	$120	$2,094	$2,214
Standard Ground Source Heat Pump	3,585	6,511	9.1	36.21	$46.61	$58.12	$31.87	$137	$2,194	$2,331
Advanced Air Source Heat Pump	4,574	5,522	11.6	46.20	$59.46	$74.16	$40.66	$174	$2,504	$2,678
Advanced Air Source Heat Pump (Low Cost)	4,574	5,522	11.6	46.20	$59.46	$74.16	$40.66	$174	$2,302	$2,477
High-Efficiency Air Source Heat Pump	5,956	4,141	15.0	60.16	$77.42	$96.55	$52.94	$227	$2,607	$2,834
Standard Air Source Heat Pump	6,382	3,715	16.1	64.46	$82.96	$103.46	$56.72	$243	$2,661	$2,904
Electric Resistance	9,194	903	23.2	92.87	$119.52	$149.05	$81.72	$350	$3,497	$3,848
Gas-Fired Heat Pump	6,011	4,085	16.2	4.47	$78.14	$104.04	$3.93	$186	$1,752	$1,938
Advanced Gas Furnace	6,463	3,633	6.5	5.20	$84.02	$41.58	$4.58	$130	$1,812	$1,942
Standard Gas Furnace	8,138	1,959	8.1	6.28	$105.79	$52.06	$5.53	$163	$1,945	$2,108
Oil Furnace	10,096	0	10.0	32.88	$131.25	$64.29	$28.94	$224	$2,011	$2,236

BURLINGTON AFBC	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	7,588	19,458	5.6	0.83	$98.64	$36.12	$0.73	$135	$1,781	$1,916
Emerging Ground Source Heat Pump (VERTICAL)	7,588	19,458	5.6	0.83	$98.64	$36.12	$0.73	$135	$1,918	$2,054
Advanced Ground Source Heat Pump	9,230	17,816	6.8	1.01	$119.99	$43.94	$0.89	$165	$2,094	$2,259
Standard Ground Source Heat Pump	10,547	16,500	7.8	1.16	$137.11	$50.21	$1.02	$188	$2,194	$2,382
Advanced Air Source Heat Pump	13,456	13,590	10.0	1.47	$174.93	$64.06	$1.30	$240	$2,504	$2,744
Advanced Air Source Heat Pump (Low Cost)	13,456	13,590	10.0	1.47	$174.93	$64.06	$1.30	$240	$2,302	$2,543
High-Efficiency Air Source Heat Pump	17,520	9,526	13.0	1.92	$227.76	$83.40	$1.69	$313	$2,607	$2,920
Standard Air Source Heat Pump	18,773	8,273	13.9	2.06	$244.05	$89.37	$1.81	$335	$2,661	$2,996
Electric Resistance	27,046	0	20.1	2.96	$351.60	$128.75	$2.61	$483	$3,497	$3,980
Gas-Fired Heat Pump	6,814	20,232	16.1	0.17	$88.58	$103.07	$0.15	$192	$1,752	$1,944
Advanced Gas Furnace	6,809	20,237	6.3	0.20	$88.52	$40.45	$0.17	$129	$1,812	$1,941
Standard Gas Furnace	9,337	17,709	7.9	0.24	$121.38	$50.70	$0.21	$172	$1,945	$2,117
Oil Furnace	13,259	13,787	9.5	16.96	$172.37	$60.70	$14.92	$248	$2,011	$2,259

BURLINGTON NGCT	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	4,981	12,774	5.2	0.03	$64.76	$33.39	$0.02	$98	$1,781	$1,879
Emerging Ground Source Heat Pump (VERTICAL)	4,981	12,774	5.2	0.03	$64.76	$33.39	$0.02	$98	$1,918	$2,016
Advanced Ground Source Heat Pump	6,059	11,696	6.3	0.03	$78.77	$40.62	$0.03	$119	$2,094	$2,213
Standard Ground Source Heat Pump	6,924	10,832	7.2	0.04	$90.01	$46.42	$0.03	$136	$2,194	$2,331
Advanced Air Source Heat Pump	8,834	8,922	9.2	0.05	$114.84	$59.22	$0.04	$174	$2,504	$2,678
Advanced Air Source Heat Pump (Low Cost)	8,834	8,922	9.2	0.05	$114.84	$59.22	$0.04	$174	$2,302	$2,476
High-Efficiency Air Source Heat Pump	11,502	6,253	12.0	0.06	$149.52	$77.11	$0.05	$227	$2,607	$2,834
Standard Air Source Heat Pump	12,324	5,431	12.9	0.07	$160.21	$82.62	$0.06	$243	$2,661	$2,904
Electric Resistance	17,755	0	18.5	0.09	$230.82	$119.03	$0.08	$350	$3,497	$3,847
Gas-Fired Heat Pump	6,420	11,335	16.0	0.03	$83.46	$102.61	$0.03	$186	$1,752	$1,938
Advanced Gas Furnace	6,940	10,815	6.2	0.04	$90.22	$39.90	$0.03	$130	$1,812	$1,942
Standard Gas Furnace	8,713	9,042	7.8	0.05	$113.27	$50.04	$0.04	$163	$1,945	$2,108
Oil Furnace	11,613	6,142	9.2	16.45	$150.97	$58.98	$14.47	$224	$2,011	$2,236

BURLINGTON NGCC	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	3,285	8,425	2.5	0.03	$42.71	$15.84	$0.02	$59	$1,781	$1,839
Emerging Ground Source Heat Pump (VERTICAL)	3,285	8,425	2.5	0.03	$42.71	$15.84	$0.02	$59	$1,918	$1,977
Advanced Ground Source Heat Pump	3,996	7,714	3.0	0.03	$51.95	$19.26	$0.03	$71	$2,094	$2,165
Standard Ground Source Heat Pump	4,567	7,144	3.4	0.04	$59.37	$22.01	$0.03	$81	$2,194	$2,276
Advanced Air Source Heat Pump	5,826	5,884	4.4	0.05	$75.74	$28.08	$0.04	$104	$2,504	$2,607
Advanced Air Source Heat Pump (Low Cost)	5,826	5,884	4.4	0.05	$75.74	$28.08	$0.04	$104	$2,302	$2,406
High-Efficiency Air Source Heat Pump	7,586	4,125	5.7	0.06	$98.62	$36.57	$0.06	$135	$2,607	$2,742
Standard Air Source Heat Pump	8,129	3,582	6.1	0.07	$105.67	$39.18	$0.06	$145	$2,661	$2,806
Electric Resistance	11,711	0	8.8	0.10	$152.24	$56.45	$0.09	$209	$3,497	$3,706
Gas-Fired Heat Pump	6,131	5,579	15.5	0.11	$79.71	$99.62	$0.10	$179	$1,752	$1,932
Advanced Gas Furnace	6,603	5,107	5.7	0.12	$85.84	$36.42	$0.11	$122	$1,812	$1,934
Standard Gas Furnace	8,307	3,404	7.1	0.15	$107.99	$45.84	$0.13	$154	$1,945	$2,099
Oil Furnace	10,542	1,168	7.5	16.45	$137.05	$47.89	$14.48	$199	$2,011	$2,211

CHICAGO Regional	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	5,484	13,245	17.0	25.47	$71.29	$109.02	$22.42	$203	$1,431	$1,633
Emerging Ground Source Heat Pump (VERTICAL)	5,484	13,245	17.0	25.47	$71.29	$109.02	$22.42	$203	$1,528	$1,730
Advanced Ground Source Heat Pump	6,753	11,976	20.9	31.37	$87.79	$134.25	$27.60	$250	$1,655	$1,905
Standard Ground Source Heat Pump	7,795	10,934	24.1	36.20	$101.33	$154.96	$31.86	$288	$1,720	$2,008
Advanced Air Source Heat Pump	8,331	10,397	25.8	38.70	$108.31	$165.63	$34.05	$308	$1,818	$2,126
Advanced Air Source Heat Pump (Low Cost)	8,331	10,397	25.8	38.70	$108.31	$165.63	$34.05	$308	$1,637	$1,945
High-Efficiency Air Source Heat Pump	11,293	7,436	35.0	52.45	$146.81	$224.50	$46.16	$417	$1,867	$2,285
Standard Air Source Heat Pump	12,428	6,301	38.5	57.73	$161.56	$247.07	$50.80	$459	$1,902	$2,361
Electric Resistance	18,729	0	58.0	86.99	$243.47	$372.33	$76.55	$692	$2,486	$3,179
Gas-Fired Heat Pump	5,518	13,211	15.3	4.65	$71.73	$98.46	$4.10	$174	$1,404	$1,578
Advanced Gas Furnace	6,297	12,431	9.1	7.56	$81.87	$58.40	$6.66	$147	$1,361	$1,508
Standard Gas Furnace	7,686	11,043	10.9	8.76	$99.92	$69.83	$7.71	$177	$1,355	$1,532

CHICAGO AFBC	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	6,441	15,556	4.8	0.71	$83.73	$30.66	$0.62	$115	$1,431	$1,546
Emerging Ground Source Heat Pump (VERTICAL)	6,441	15,556	4.8	0.71	$83.73	$30.66	$0.62	$115	$1,528	$1,643
Advanced Ground Source Heat Pump	7,931	14,066	5.9	0.87	$119.01	$43.58	$0.88	$163	$1,655	$1,819
Standard Ground Source Heat Pump	9,155	12,842	6.8	1.00	$127.21	$46.58	$0.94	$175	$1,720	$1,895
Advanced Air Source Heat Pump	9,785	12,212	7.3	1.07	$172.43	$63.14	$1.28	$237	$1,818	$2,054
Advanced Air Source Heat Pump (Low Cost)	9,785	12,212	7.3	1.07	$172.43	$63.14	$1.28	$237	$1,637	$1,874
High-Efficiency Air Source Heat Pump	13,264	8,734	9.8	1.45	$172.43	$63.14	$1.28	$237	$1,867	$2,104
Standard Air Source Heat Pump	14,597	7,400	10.8	1.60	$189.76	$69.49	$1.41	$261	$1,902	$2,162
Electric Resistance	21,997	0	16.3	2.41	$285.96	$104.72	$2.12	$393	$2,486	$2,879
Gas-Fired Heat Pump	5,692	16,305	13.1	0.15	$73.99	$84.22	$0.13	$158	$1,404	$1,562
Advanced Gas Furnace	6,581	15,416	5.5	0.23	$85.55	$35.21	$0.21	$121	$1,361	$1,482
Standard Gas Furnace	8,014	13,983	6.7	0.27	$104.18	$42.97	$0.24	$147	$1,355	$1,502

CHICAGO NGCT	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	4,228	10,212	4.4	0.02	$54.97	$28.35	$0.02	$83	$1,431	$1,514
Emerging Ground Source Heat Pump (VERTICAL)	4,228	10,212	4.4	0.02	$54.97	$28.35	$0.02	$83	$1,528	$1,611
Advanced Ground Source Heat Pump	5,207	9,234	5.4	0.03	$67.69	$34.91	$0.02	$103	$1,655	$1,758
Standard Ground Source Heat Pump	6,010	8,431	6.3	0.03	$78.13	$40.29	$0.03	$118	$1,720	$1,839
Advanced Air Source Heat Pump	6,424	8,017	6.7	0.03	$83.51	$43.07	$0.03	$127	$1,818	$1,944
Advanced Air Source Heat Pump (Low Cost)	6,424	8,017	6.7	0.03	$83.51	$43.07	$0.03	$127	$1,637	$1,764
High-Efficiency Air Source Heat Pump	8,707	5,733	9.1	0.05	$113.19	$58.37	$0.04	$172	$1,867	$2,039
Standard Air Source Heat Pump	9,583	4,858	10.0	0.05	$124.57	$64.24	$0.04	$189	$1,902	$2,091
Electric Resistance	14,441	0	15.1	0.08	$187.73	$96.81	$0.07	$285	$2,486	$2,771
Gas-Fired Heat Pump	5,290	9,151	13.1	0.03	$68.76	$83.79	$0.02	$153	$1,404	$1,556
Advanced Gas Furnace	5,926	8,515	5.4	0.03	$77.04	$34.53	$0.03	$112	$1,361	$1,473
Standard Gas Furnace	7,255	7,185	6.6	0.04	$94.32	$42.18	$0.03	$137	$1,355	$1,492

CHICAGO NGCC	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	2,789	6,736	2.1	0.02	$36.26	$13.44	$0.02	$50	$1,431	$1,480
Emerging Ground Source Heat Pump (VERTICAL)	2,789	6,736	2.1	0.02	$36.26	$13.44	$0.02	$50	$1,528	$1,577
Advanced Ground Source Heat Pump	3,434	6,090	2.6	0.03	$44.64	$16.55	$0.03	$61	$1,655	$1,717
Standard Ground Source Heat Pump	3,964	5,561	3.0	0.03	$51.53	$19.11	$0.03	$71	$1,720	$1,791
Advanced Air Source Heat Pump	4,237	5,288	3.2	0.04	$55.08	$20.42	$0.03	$76	$1,818	$1,893
Advanced Air Source Heat Pump (Low Cost)	4,237	5,288	3.2	0.04	$55.08	$20.42	$0.03	$76	$1,637	$1,713
High-Efficiency Air Source Heat Pump	5,743	3,782	4.3	0.05	$74.66	$27.68	$0.04	$102	$1,867	$1,970
Standard Air Source Heat Pump	6,320	3,204	4.7	0.05	$82.17	$30.47	$0.05	$113	$1,902	$2,014
Electric Resistance	9,525	0	7.2	0.08	$123.82	$45.91	$0.07	$170	$2,486	$2,656
Gas-Fired Heat Pump	5,028	4,497	12.6	0.09	$65.36	$81.08	$0.08	$147	$1,404	$1,550
Advanced Gas Furnace	5,500	4,025	4.7	0.10	$71.50	$30.12	$0.09	$102	$1,361	$1,463
Standard Gas Furnace	6,762	2,763	5.8	0.12	$87.91	$37.07	$0.11	$125	$1,355	$1,480

NEW YORK Regional	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	3,126	7,597	6.3	15.77	$40.64	$40.51	$13.88	$95	$1,566	$1,661
Emerging Ground Source Heat Pump (VERTICAL)	3,126	7,597	6.3	15.77	$40.64	$40.51	$13.88	$95	$1,663	$1,758
Advanced Ground Source Heat Pump	3,870	6,854	7.8	19.53	$50.31	$50.14	$17.18	$118	$1,807	$1,925
Standard Ground Source Heat Pump	4,713	6,010	9.5	23.78	$61.27	$61.07	$20.93	$143	$1,948	$2,091
Advanced Air Source Heat Pump	4,586	6,138	9.3	23.14	$59.62	$59.42	$20.36	$139	$1,945	$2,085
Advanced Air Source Heat Pump (Low Cost)	4,586	6,138	9.3	23.14	$59.62	$59.42	$20.36	$139	$1,770	$1,909
High-Efficiency Air Source Heat Pump	6,298	4,425	12.7	31.78	$81.88	$81.61	$27.96	$191	$2,084	$2,275
Standard Air Source Heat Pump	6,947	3,777	14.0	35.05	$90.31	$90.01	$30.84	$211	$2,143	$2,354
Electric Resistance	10,724	0	21.6	54.11	$139.41	$138.94	$47.61	$326	$2,905	$3,231
Gas-Fired Heat Pump	4,859	5,864	12.8	2.81	$63.17	$82.07	$2.48	$148	$1,640	$1,788
Advanced Gas Furnace	5,488	5,235	5.8	4.38	$71.35	$37.05	$3.86	$112	$1,640	$1,752
Standard Gas Furnace	6,779	3,945	7.0	5.06	$88.12	$45.25	$4.46	$138	$1,706	$1,844
Oil Furnace	8,743	1,980	9.4	24.64	$113.66	$60.09	$21.68	$195	$1,803	$1,998

NEW YORK AFBC	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	6,270	15,238	4.6	0.69	$81.51	$29.85	$0.60	$112	$1,566	$1,678
Emerging Ground Source Heat Pump (VERTICAL)	6,270	15,238	4.6	0.69	$81.51	$29.85	$0.60	$112	$1,663	$1,774
Advanced Ground Source Heat Pump	7,762	13,746	5.8	0.85	$100.90	$36.95	$0.75	$139	$1,807	$1,946
Standard Ground Source Heat Pump	9,454	12,055	7.0	1.04	$122.90	$45.00	$0.91	$169	$1,948	$2,117
Advanced Air Source Heat Pump	9,198	12,310	6.8	1.01	$119.58	$43.79	$0.89	$164	$1,945	$2,110
Advanced Air Source Heat Pump (Low Cost)	9,198	12,310	6.8	1.01	$119.58	$43.79	$0.89	$164	$1,770	$1,934
High-Efficiency Air Source Heat Pump	12,633	8,876	9.4	1.38	$164.22	$60.14	$1.22	$226	$2,084	$2,309
Standard Air Source Heat Pump	13,933	7,575	10.3	1.53	$181.13	$66.33	$1.34	$249	$2,143	$2,392
Electric Resistance	21,508	0	15.9	2.36	$279.60	$102.39	$2.07	$384	$2,905	$3,289
Gas-Fired Heat Pump	5,415	16,093	12.5	0.14	$70.40	$80.19	$0.13	$151	$1,640	$1,791
Advanced Gas Furnace	6,357	15,151	5.3	0.21	$82.65	$34.11	$0.19	$117	$1,640	$1,757
Standard Gas Furnace	7,782	13,726	6.5	0.25	$101.16	$41.85	$0.22	$143	$1,706	$1,849
Oil Furnace	11,229	10,279	8.0	12.71	$145.98	$51.66	$11.19	$209	$1,803	$2,012

NEW YORK NGCT	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	4,116	10,003	4.3	0.02	$53.51	$27.60	$0.02	$81	$1,566	$1,647
Emerging Ground Source Heat Pump (VERTICAL)	4,116	10,003	4.3	0.02	$53.51	$27.60	$0.02	$81	$1,663	$1,744
Advanced Ground Source Heat Pump	5,095	9,024	5.3	0.03	$66.24	$34.16	$0.02	$100	$1,807	$1,907
Standard Ground Source Heat Pump	6,206	7,913	6.5	0.03	$80.68	$41.61	$0.03	$122	$1,948	$2,071
Advanced Air Source Heat Pump	6,038	8,081	6.3	0.03	$78.50	$40.48	$0.03	$119	$1,945	$2,064
Advanced Air Source Heat Pump (Low Cost)	6,038	8,081	6.3	0.03	$78.50	$40.48	$0.03	$119	$1,770	$1,889
High-Efficiency Air Source Heat Pump	8,293	5,827	8.7	0.04	$107.81	$55.60	$0.04	$163	$2,084	$2,247
Standard Air Source Heat Pump	9,147	4,973	9.6	0.05	$118.91	$61.32	$0.04	$180	$2,143	$2,323
Electric Resistance	14,119	0	14.7	0.07	$183.55	$94.66	$0.07	$278	$2,905	$3,183
Gas-Fired Heat Pump	5,034	9,085	12.4	0.03	$65.45	$79.79	$0.02	$145	$1,640	$1,786
Advanced Gas Furnace	5,762	8,357	5.2	0.03	$74.91	$33.48	$0.03	$108	$1,640	$1,749
Standard Gas Furnace	7,095	7,025	6.4	0.04	$92.23	$41.13	$0.03	$133	$1,706	$1,840
Oil Furnace	9,526	4,594	7.8	12.19	$123.84	$49.88	$10.72	$184	$1,803	$1,987

NEW YORK NGCC	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	2,715	6,598	2.0	0.02	$35.29	$13.09	$0.02	$48	$1,566	$1,614
Emerging Ground Source Heat Pump (VERTICAL)	2,715	6,598	2.0	0.02	$35.29	$13.09	$0.02	$48	$1,663	$1,711
Advanced Ground Source Heat Pump	3,361	5,952	2.5	0.03	$43.69	$16.20	$0.02	$60	$1,807	$1,867
Standard Ground Source Heat Pump	4,093	5,220	3.1	0.03	$53.21	$19.73	$0.03	$73	$1,948	$2,021
Advanced Air Source Heat Pump	3,983	5,330	3.0	0.03	$51.78	$19.20	$0.03	$71	$1,945	$2,016
Advanced Air Source Heat Pump (Low Cost)	3,983	5,330	3.0	0.03	$51.78	$19.20	$0.03	$71	$1,770	$1,841
High-Efficiency Air Source Heat Pump	5,470	3,843	4.1	0.05	$71.11	$26.37	$0.04	$98	$2,084	$2,181
Standard Air Source Heat Pump	6,033	3,280	4.5	0.05	$78.43	$29.08	$0.04	$108	$2,143	$2,251
Electric Resistance	9,313	0	7.0	0.08	$121.07	$44.89	$0.07	$166	$2,905	$3,071
Gas-Fired Heat Pump	4,786	4,526	12.0	0.09	$62.22	$77.22	$0.08	$140	$1,640	$1,780
Advanced Gas Furnace	5,375	3,938	4.6	0.10	$69.87	$29.47	$0.08	$99	$1,640	$1,740
Standard Gas Furnace	6,647	2,665	5.7	0.12	$86.42	$36.50	$0.10	$123	$1,706	$1,829
Oil Furnace	8,418	895	6.0	12.19	$109.43	$38.41	$10.73	$159	$1,803	$1,961

PORTLAND Regional	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	504	3,948	2.4	0.00	$6.55	$15.69	$0.00	$22	$1,014	$1,036
Emerging Ground Source Heat Pump (VERTICAL)	504	3,948	2.4	0.00	$6.55	$15.69	$0.00	$22	$1,109	$1,131
Advanced Ground Source Heat Pump	672	3,779	3.3	0.00	$8.74	$20.95	$0.00	$30	$1,184	$1,214
Standard Ground Source Heat Pump	779	3,673	3.8	0.00	$10.12	$24.27	$0.00	$34	$1,204	$1,238
Advanced Air Source Heat Pump	681	3,770	3.3	0.00	$8.86	$21.23	$0.00	$30	$1,162	$1,192
Advanced Air Source Heat Pump (Low Cost)	681	3,770	3.3	0.00	$8.86	$21.23	$0.00	$30	$1,012	$1,042
High-Efficiency Air Source Heat Pump	998	3,453	4.8	0.00	$12.97	$31.10	$0.00	$44	$1,081	$1,125
Standard Air Source Heat Pump	1,135	3,317	5.5	0.00	$14.75	$35.36	$0.00	$50	$1,078	$1,128
Electric Resistance	1,845	2,607	9.0	0.00	$23.98	$57.49	$0.00	$81	$1,404	$1,486
Gas-Fired Heat Pump	2,937	1,515	8.1	0.02	$38.17	$52.12	$0.01	$90	$1,311	$1,402
Advanced Gas Furnace	3,584	868	3.6	0.02	$46.59	$23.09	$0.02	$70	$1,170	$1,240
Standard Gas Furnace	4,451	0	4.4	0.02	$57.87	$28.35	$0.02	$86	$1,127	$1,213

PORTLAND AFBC	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	4,188	11,154	3.1	0.46	$54.45	$19.94	$0.40	$75	$1,014	$1,089
Emerging Ground Source Heat Pump (VERTICAL)	4,188	11,154	3.1	0.46	$54.45	$19.94	$0.40	$75	$1,109	$1,184
Advanced Ground Source Heat Pump	5,591	9,752	4.1	0.61	$72.69	$26.62	$0.54	$100	$1,184	$1,284
Standard Ground Source Heat Pump	6,477	8,866	4.8	0.71	$84.20	$30.83	$0.62	$116	$1,204	$1,320
Advanced Air Source Heat Pump	5,666	9,677	4.2	0.62	$73.66	$26.97	$0.55	$101	$1,162	$1,263
Advanced Air Source Heat Pump (Low Cost)	5,666	9,677	4.2	0.62	$73.66	$26.97	$0.55	$101	$1,012	$1,113
High-Efficiency Air Source Heat Pump	8,300	7,042	6.2	0.91	$107.91	$39.51	$0.80	$148	$1,081	$1,230
Standard Air Source Heat Pump	9,437	5,906	7.0	1.03	$122.68	$44.92	$0.91	$169	$1,078	$1,247
Electric Resistance	15,343	0	11.4	1.68	$199.46	$73.04	$1.48	$274	$1,404	$1,678
Gas-Fired Heat Pump	3,486	11,857	8.2	0.14	$45.32	$52.75	$0.12	$98	$1,311	$1,410
Advanced Gas Furnace	4,457	10,885	3.8	0.13	$57.95	$24.10	$0.11	$82	$1,170	$1,252
Standard Gas Furnace	5,440	9,903	4.6	0.15	$70.72	$29.48	$0.13	$100	$1,127	$1,227

PORTLAND NGCT	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	2,750	7,323	2.9	0.01	$35.75	$18.43	$0.01	$54	$1,014	$1,068
Emerging Ground Source Heat Pump (VERTICAL)	2,750	7,323	2.9	0.01	$35.75	$18.43	$0.01	$54	$1,109	$1,163
Advanced Ground Source Heat Pump	3,671	6,402	3.8	0.02	$47.72	$24.61	$0.02	$72	$1,184	$1,257
Standard Ground Source Heat Pump	4,252	5,820	4.4	0.02	$55.27	$28.51	$0.02	$84	$1,204	$1,288
Advanced Air Source Heat Pump	3,720	6,353	3.9	0.02	$48.35	$24.94	$0.02	$73	$1,162	$1,235
Advanced Air Source Heat Pump (Low Cost)	3,720	6,353	3.9	0.02	$48.35	$24.94	$0.02	$73	$1,012	$1,085
High-Efficiency Air Source Heat Pump	5,449	4,623	5.7	0.03	$70.84	$36.53	$0.03	$107	$1,081	$1,189
Standard Air Source Heat Pump	6,195	3,877	6.5	0.03	$80.53	$41.53	$0.03	$122	$1,078	$1,200
Electric Resistance	10,072	0	10.5	0.05	$130.94	$67.52	$0.05	$199	$1,404	$1,603
Gas-Fired Heat Pump	3,228	6,844	8.2	0.02	$41.97	$52.52	$0.02	$95	$1,311	$1,406
Advanced Gas Furnace	4,116	5,956	3.7	0.02	$53.51	$23.74	$0.02	$77	$1,170	$1,247
Standard Gas Furnace	5,054	5,018	4.5	0.03	$65.70	$29.08	$0.02	$95	$1,127	$1,222

PORTLAND NGCC	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	1,814	4,830	1.4	0.02	$23.58	$8.74	$0.01	$32	$1,014	$1,047
Emerging Ground Source Heat Pump (VERTICAL)	1,814	4,830	1.4	0.02	$23.58	$8.74	$0.01	$32	$1,109	$1,142
Advanced Ground Source Heat Pump	2,421	4,222	1.8	0.02	$31.47	$11.67	$0.02	$43	$1,184	$1,228
Standard Ground Source Heat Pump	2,804	3,839	2.1	0.02	$36.46	$13.52	$0.02	$50	$1,204	$1,254
Advanced Air Source Heat Pump	2,453	4,190	1.8	0.02	$31.89	$11.83	$0.02	$44	$1,162	$1,206
Advanced Air Source Heat Pump (Low Cost)	2,453	4,190	1.8	0.02	$31.89	$11.83	$0.02	$44	$1,012	$1,055
High-Efficiency Air Source Heat Pump	3,594	3,049	2.7	0.03	$46.72	$17.32	$0.03	$64	$1,081	$1,145
Standard Air Source Heat Pump	4,086	2,557	3.1	0.03	$53.12	$19.70	$0.03	$73	$1,078	$1,151
Electric Resistance	6,643	0	5.0	0.06	$86.36	$32.02	$0.05	$118	$1,404	$1,523
Gas-Fired Heat Pump	3,103	3,540	8.0	0.06	$40.34	$51.08	$0.05	$91	$1,311	$1,403
Advanced Gas Furnace	3,894	2,749	3.3	0.07	$50.62	$21.44	$0.06	$72	$1,170	$1,242
Standard Gas Furnace	4,803	1,840	4.1	0.09	$62.44	$26.48	$0.08	$89	$1,127	$1,216

ATLANTA Regional	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	2,845	6,563	7.7	14.33	$36.99	$49.55	$12.61	$99	$1,137	$1,236
Emerging Ground Source Heat Pump (VERTICAL)	2,845	6,563	7.7	14.33	$36.99	$61.70	$12.61	$111	$1,243	$1,354
Advanced Ground Source Heat Pump	3,544	5,865	9.6	17.85	$46.07	$76.23	$15.71	$138	$1,328	$1,466
Standard Ground Source Heat Pump	4,378	5,030	11.9	22.05	$56.92	$64.51	$19.41	$141	$1,353	$1,493
Advanced Air Source Heat Pump	3,705	5,703	10.0	18.66	$48.17	$105.98	$16.42	$171	$1,310	$1,481
Advanced Air Source Heat Pump (Low Cost)	3,705	5,703	10.0	18.66	$48.17	$105.98	$16.42	$171	$1,160	$1,330
High-Efficiency Air Source Heat Pump	6,086	3,322	16.5	30.66	$79.12	$105.98	$26.98	$212	$1,379	$1,591
Standard Air Source Heat Pump	6,368	3,040	17.3	32.08	$82.79	$110.88	$28.23	$222	$1,349	$1,571
Electric Resistance	9,408	0	25.5	47.39	$122.31	$163.81	$41.70	$328	$1,729	$2,057
Gas-Fired Heat Pump	3,305	6,104	9.0	2.45	$42.96	$57.49	$2.16	$103	$1,383	$1,486
Advanced Gas Furnace	4,382	5,026	7.2	9.18	$56.96	$46.00	$8.07	$111	$1,294	$1,405
Standard Gas Furnace	5,189	4,219	8.3	10.44	$67.45	$53.48	$9.19	$130	$1,254	$1,384

ATLANTA AFBC	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	4,048	9,337	3.0	0.44	$52.63	$19.27	$0.39	$72	$1,137	$1,209
Emerging Ground Source Heat Pump (VERTICAL)	4,048	9,337	3.0	0.44	$52.63	$19.27	$0.39	$72	$1,243	$1,315
Advanced Ground Source Heat Pump	5,042	8,344	3.7	0.55	$80.98	$29.65	$0.60	$111	$1,328	$1,439
Standard Ground Source Heat Pump	6,229	7,156	4.6	0.68	$68.53	$25.10	$0.51	$94	$1,353	$1,447
Advanced Air Source Heat Pump	5,272	8,114	3.9	0.58	$112.57	$41.22	$0.84	$155	$1,310	$1,465
Advanced Air Source Heat Pump (Low Cost)	5,272	8,114	3.9	0.58	$112.57	$41.22	$0.84	$155	$1,160	$1,315
High-Efficiency Air Source Heat Pump	8,660	4,726	6.4	0.95	$112.57	$41.22	$0.84	$155	$1,379	$1,533
Standard Air Source Heat Pump	9,060	4,325	6.7	0.99	$117.79	$43.13	$0.87	$162	$1,349	$1,511
Electric Resistance	13,386	0	9.9	1.47	$174.01	$63.72	$1.29	$239	$1,729	$1,968
Gas-Fired Heat Pump	3,509	9,877	8.2	0.09	$45.62	$52.35	$0.08	$98	$1,383	$1,481
Advanced Gas Furnace	5,151	8,235	4.2	0.30	$66.96	$26.65	$0.26	$94	$1,294	$1,388
Standard Gas Furnace	6,064	7,322	4.9	0.34	$78.83	$31.46	$0.30	$111	$1,254	$1,365

ATLANTA NGCT	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	2,658	6,130	2.8	0.01	$34.55	$17.82	$0.01	$52	$1,137	$1,189
Emerging Ground Source Heat Pump (VERTICAL)	2,658	6,130	2.8	0.01	$34.55	$17.82	$0.01	$52	$1,243	$1,295
Advanced Ground Source Heat Pump	3,310	5,478	3.5	0.02	$43.03	$22.19	$0.02	$65	$1,328	$1,393
Standard Ground Source Heat Pump	4,089	4,698	4.3	0.02	$53.16	$27.42	$0.02	$81	$1,353	$1,433
Advanced Air Source Heat Pump	3,461	5,327	3.6	0.02	$44.99	$23.20	$0.02	$68	$1,310	$1,378
Advanced Air Source Heat Pump (Low Cost)	3,461	5,327	3.6	0.02	$44.99	$23.20	$0.02	$68	$1,160	$1,228
High-Efficiency Air Source Heat Pump	5,685	3,103	5.9	0.03	$73.90	$38.11	$0.03	$112	$1,379	$1,491
Standard Air Source Heat Pump	5,948	2,839	6.2	0.03	$77.32	$39.88	$0.03	$117	$1,349	$1,466
Electric Resistance	8,787	0	9.2	0.05	$114.24	$58.91	$0.04	$173	$1,729	$1,902
Gas-Fired Heat Pump	3,273	5,515	8.1	0.02	$42.54	$52.10	$0.02	$95	$1,383	$1,478
Advanced Gas Furnace	4,262	4,526	4.0	0.02	$55.40	$25.72	$0.02	$81	$1,294	$1,375
Standard Gas Furnace	5,052	3,735	4.7	0.03	$65.68	$30.40	$0.02	$96	$1,254	$1,350

ATLANTA NGCC	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	1,753	4,043	1.3	0.01	$22.79	$8.45	$0.01	$31	$1,137	$1,168
Emerging Ground Source Heat Pump (VERTICAL)	1,753	4,043	1.3	0.01	$22.79	$8.45	$0.01	$31	$1,243	$1,274
Advanced Ground Source Heat Pump	2,183	3,613	1.6	0.02	$28.38	$10.52	$0.02	$39	$1,328	$1,367
Standard Ground Source Heat Pump	2,697	3,099	2.0	0.02	$35.06	$13.00	$0.02	$48	$1,353	$1,401
Advanced Air Source Heat Pump	2,283	3,513	1.7	0.02	$29.67	$11.00	$0.02	$41	$1,310	$1,351
Advanced Air Source Heat Pump (Low Cost)	2,283	3,513	1.7	0.02	$29.67	$11.00	$0.02	$41	$1,160	$1,201
High-Efficiency Air Source Heat Pump	3,750	2,046	2.8	0.03	$48.74	$18.07	$0.03	$67	$1,379	$1,445
Standard Air Source Heat Pump	3,923	1,873	2.9	0.03	$51.00	$18.91	$0.03	$70	$1,349	$1,419
Electric Resistance	5,796	0	4.4	0.05	$75.35	$27.94	$0.04	$103	$1,729	$1,832
Gas-Fired Heat Pump	3,119	2,677	7.9	0.06	$40.55	$50.51	$0.05	$91	$1,383	$1,474
Advanced Gas Furnace	3,683	2,113	3.1	0.06	$47.88	$19.73	$0.05	$68	$1,294	$1,362
Standard Gas Furnace	4,394	1,402	3.7	0.07	$57.12	$23.58	$0.06	$81	$1,254	$1,335

PHOENIX Regional	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	2,401	4,078	7.3	2.92	$31.22	$46.92	$2.57	$81	$1,260	$1,341
Emerging Ground Source Heat Pump (VERTICAL)	2,401	4,078	7.3	2.92	$31.22	$46.92	$2.57	$81	$1,393	$1,474
Advanced Ground Source Heat Pump	2,870	3,609	8.7	3.49	$37.31	$56.08	$3.07	$96	$1,484	$1,581
Standard Ground Source Heat Pump	3,822	2,657	11.6	4.65	$49.69	$74.68	$4.09	$128	$1,651	$1,779
Advanced Air Source Heat Pump	3,138	3,342	9.5	3.82	$40.79	$61.31	$3.36	$105	$1,472	$1,578
Advanced Air Source Heat Pump (Low Cost)	3,138	3,342	9.5	3.82	$40.79	$61.31	$3.36	$105	$1,322	$1,428
High-Efficiency Air Source Heat Pump	4,675	1,804	14.2	5.69	$60.78	$91.34	$5.01	$157	$1,551	$1,708
Standard Air Source Heat Pump	5,419	1,061	16.5	6.60	$70.44	$105.86	$5.80	$182	$1,633	$1,815
Electric Resistance	6,480	0	19.7	7.89	$84.23	$126.59	$6.94	$218	$1,850	$2,068
Gas-Fired Heat Pump	4,072	2,407	11.2	0.61	$52.94	$71.88	$0.54	$125	$1,377	$1,502
Advanced Gas Furnace	4,511	1,968	10.0	3.43	$58.65	$64.43	$3.02	$126	$1,451	$1,578
Standard Gas Furnace	5,292	1,187	11.7	3.98	$68.80	$75.11	$3.51	$147	$1,428	$1,576

PHOENIX AFBC	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	4,874	8,278	3.6	0.53	$63.37	$23.20	$0.47	$87	$1,260	$1,347
Emerging Ground Source Heat Pump (VERTICAL)	4,874	8,278	3.6	0.53	$63.37	$23.20	$0.47	$87	$1,393	$1,480
Advanced Ground Source Heat Pump	5,826	7,326	4.3	0.64	$75.74	$27.74	$0.56	$104	$1,484	$1,588
Standard Ground Source Heat Pump	7,759	5,394	5.8	0.85	$100.86	$36.94	$0.75	$139	$1,651	$1,789
Advanced Air Source Heat Pump	6,370	6,783	4.7	0.70	$82.81	$30.32	$0.61	$114	$1,472	$1,586
Advanced Air Source Heat Pump (Low Cost)	6,370	6,783	4.7	0.70	$82.81	$30.32	$0.61	$114	$1,322	$1,436
High-Efficiency Air Source Heat Pump	9,490	3,663	7.0	1.04	$123.37	$45.18	$0.92	$169	$1,551	$1,721
Standard Air Source Heat Pump	10,999	2,154	8.2	1.21	$142.98	$52.36	$1.06	$196	$1,633	$1,829
Electric Resistance	13,153	0	9.8	1.44	$170.98	$62.61	$1.27	$235	$1,850	$2,085
Gas-Fired Heat Pump	4,574	8,578	10.4	0.13	$59.46	$67.07	$0.11	$127	$1,377	$1,504
Advanced Gas Furnace	7,406	5,746	5.7	0.63	$96.28	$36.67	$0.56	$134	$1,451	$1,585
Standard Gas Furnace	8,654	4,499	6.7	0.74	$112.50	$42.88	$0.65	$156	$1,428	$1,584

PHOENIX NGCT	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	3,200	5,434	3.3	0.02	$41.60	$21.45	$0.01	$63	$1,260	$1,323
Emerging Ground Source Heat Pump (VERTICAL)	3,200	5,434	3.3	0.02	$41.60	$21.45	$0.01	$63	$1,393	$1,456
Advanced Ground Source Heat Pump	3,825	4,810	4.0	0.02	$49.72	$25.64	$0.02	$75	$1,484	$1,560
Standard Ground Source Heat Pump	5,093	3,541	5.3	0.03	$66.21	$34.15	$0.02	$100	$1,651	$1,751
Advanced Air Source Heat Pump	4,182	4,453	4.4	0.02	$54.36	$28.03	$0.02	$82	$1,472	$1,555
Advanced Air Source Heat Pump (Low Cost)	4,182	4,453	4.4	0.02	$54.36	$28.03	$0.02	$82	$1,322	$1,404
High-Efficiency Air Source Heat Pump	6,230	2,404	6.5	0.03	$80.99	$41.77	$0.03	$123	$1,551	$1,674
Standard Air Source Heat Pump	7,220	1,414	7.5	0.04	$93.87	$48.41	$0.03	$142	$1,633	$1,775
Electric Resistance	8,634	0	9.0	0.05	$112.25	$57.89	$0.04	$170	$1,850	$2,020
Gas-Fired Heat Pump	4,234	4,400	10.4	0.02	$55.05	$66.72	$0.02	$122	$1,377	$1,499
Advanced Gas Furnace	5,446	3,188	5.4	0.03	$70.80	$34.62	$0.03	$105	$1,451	$1,557
Standard Gas Furnace	6,378	2,256	6.3	0.03	$82.91	$40.50	$0.03	$123	$1,428	$1,552

PHOENIX NGCC	CO2 (kg)	CO2 Saved Over Worst	NOx (kg)	SO2 (kg)	CO2 ($)	NOx ($)	SO2 ($)	Externality Cost	Annual Operating Cost	Total Societal Cost
Emerging Ground Source Heat Pump (SLINKY)	2,111	3,584	1.6	0.02	$27.44	$10.17	$0.02	$38	$1,260	$1,298
Emerging Ground Source Heat Pump (VERTICAL)	2,111	3,584	1.6	0.02	$27.44	$10.17	$0.02	$38	$1,393	$1,431
Advanced Ground Source Heat Pump	2,523	3,172	1.9	0.02	$32.80	$12.16	$0.02	$45	$1,484	$1,529
Standard Ground Source Heat Pump	3,359	2,336	2.5	0.03	$43.67	$16.19	$0.02	$60	$1,651	$1,711
Advanced Air Source Heat Pump	2,758	2,937	2.1	0.02	$35.85	$13.29	$0.02	$49	$1,472	$1,521
Advanced Air Source Heat Pump (Low Cost)	2,758	2,937	2.1	0.02	$35.85	$13.29	$0.02	$49	$1,322	$1,371
High-Efficiency Air Source Heat Pump	4,109	1,586	3.1	0.03	$53.42	$19.81	$0.03	$73	$1,551	$1,625
Standard Air Source Heat Pump	4,762	933	3.6	0.04	$61.91	$22.96	$0.04	$85	$1,633	$1,718
Electric Resistance	5,695	0	4.3	0.05	$74.03	$27.45	$0.04	$102	$1,850	$1,951
Gas-Fired Heat Pump	4,013	1,682	10.0	0.07	$52.17	$64.43	$0.06	$117	$1,377	$1,494
Advanced Gas Furnace	4,171	1,524	3.3	0.05	$54.22	$21.41	$0.05	$76	$1,451	$1,527
Standard Gas Furnace	4,897	798	3.9	0.06	$63.66	$25.17	$0.06	$89	$1,428	$1,517

APPENDIX E

WATERFURNACE MODEL

The modeling framework in this report uses the output from a WaterFurnace International model[1] as the basis for its energy analysis of most of the space conditioning systems. The WaterFurnace model uses the ASHRAE TC 4.7 method for its analysis which is a modified bin analysis. The standard bin method divides up weather data according to the total number of hours annually at a particular location which fall into bins of 5° F. Its tracking of total hours in a given temperature bin is particularly appropriate for a heat pump suitability analysis since heat pumps are sensitive to hourly variations in temperature and such a method better captures actual heat pump energy requirements than, for example, a degree day method which only tracks mean temperature on a daily basis. Heat gains or losses are calculated for each bin and then the bins are summed to obtain total annual consumption. This bin method, however, neglects cloud cover and other variations which affect consumption in the summer as well as solar and internal heat gains for heating purposes. These shortcomings must be compensated for by a correction factor which corrects the consumption needed for heating although auxiliary energy estimates are then biased incorrectly.

The ASHRAE TC 4.7 method uses the concept of temperature bins but loads are calculated using a different method than the standard bin analysis. The following loads are determined:

- **Solar Heat Gains** are averaged by the hour using percent sunshine in summer and winter and are then interpolated to the bins using a linear relationship.

- **Internal Heat Gains** from lighting, equipment and occupants are averaged on an hourly basis.

- **Transmission Losses and Gains** are based upon the building's heat transfer per degree as well as the difference between the bin temperature and the indoor temperature.

- **Infiltration Losses and Gains** are determined using binned outdoor average humidity data and average summer and winter wind speeds.

These loads provide greater realism than the standard Manual J design loads which in the cooling case assume peak temperature, humidity, sunshine and internal loads concurrently and in the heating case does not account for solar or internal gains or wind conditions. The ASHRAE approach allows for a more accurate determination of annual energy consumption in any particular geographic location. The effect of this method is to move the "balance point" of a particular building away from an average of 65° F used in the other methods and towards a more accurate reflection of what the building's equilibrium conditions are between heat losses and heat gains.

The prototypical house modeled by WaterFurnace had the following characteristics: all houses were 1800 square feet single-story houses built on concrete slabs with tight construction; Chicago, Burlington and New York were modeled as having insulation properties of R30/R11 with double glazed windows, while Atlanta, Portland and Phoenix were modeled as R19/R11, with double glazed windows.

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[1] Model information is based on WaterFurnace International technical bulletin #TB8501, March 10, 1985.

APPENDIX F

GAX ABSORPTION GAS HEAT PUMP[1]

The basic GAX (Generator-Absorber heat eXchange)cycle was first patented in Germany in 1913 by E. von Altenkirch. Since then a wide variety of advanced GAX cycles have been proposed[2], but to date none of these has been commercialized.

A GAX system is an adaptation of the simple absorption cycle, in which an absorber, a solution pump and a generator replace the function of the vapor compression cycle's compressor. After leaving the evaporator, the gaseous refrigerant (in this case ammonia) is absorbed into a water solution in the low-pressure absorber, before being pumped to a high pressure and temperature by a solution pump. The higher-temperature and -pressure solution then enters the generator, where heat from gas combustion is applied and the ammonia boils out of solution. Now the high-temperature and high-pressure ammonia is ready to go into the condenser, where it gives off its heat and condenses back into a liquid. After moving through an expansion valve, the liquid ammonia is ready to pick up heat in the evaporator again, thereby completing the cycle.

The proximity of components in a simple absorption cycle creates several opportunities for using recovered heat to increase the ammonia refrigerant flow per unit of gas consumption. The basic GAX system innovates on the simple absorption cycle by implementing several heat recovery paths. The basic GAX system configuration employs a secondary heat transfer fluid (HTF), such as a 40% ethylene glycol solution, to transfer heat between the absorption module and the rest of the unit. This allows a compact absorption module containing the GAX cycle to be located entirely in the outdoor unit. An eight-way valve controlling the HTF flow serves as the mechanism for switching between heating and cooling mode and the defrost cycle, without affecting the absorption module's flow. The GAX system design allows for heat to be recovered and re-used internally to the module to maximize the efficiency of gas utilization.

Replacement of an electric compressor with gas combustion offers another opportunity to combine more efficient gas space and water heating with fuel-switching from electric cooling during summer, when gas local distribution companies experience lower demand and many electric companies experience yearly peaks. In addition, the GAX system does not use any ozone-depleting refrigerants.

DOE-sponsored technology development efforts at the Phillips Engineering Company in St. Joseph, MI, have reached the proof-of-concept stage. A major American manufacturer is currently evaluating hardware.

Exhibit F-1 provides estimates for the basic GAX space heating and cooling seasonal performance factors (both end-use and source) for the six representative locations covered in the report. Domestic hot water heating performance is much more speculative at this point, since this function has not yet been demonstrated in GAX equipment. However, it is expected that GAX systems will offer this function, as do other advanced electric and gas heat pump technologies. Advanced GAX cycles and working fluids have been proposed that offer significant potential improvements in this performance, particularly in cooling mode.

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[1] The information provided in this Appendix, including the consumption estimates for a GAX system, was provided by Patrick J. Hughes, P.E., Building Equipment Research, Oak Ridge National Laboratory.

[2] For a summary, see D.C. Erickson and M.V. Rane, "GAX Absorption Cycles - Recent Developments Have Sparked Renewed Interest," IEA Heat Pump Centre Newsletter, Volume 10, Number 4, pp. 22-26.

EXHIBIT F-1
Estimated Basic GAX System Seasonal Performance
for Six Locations

	End-Use SPF Heating	Source SPF Heating
Burlington	1.27	1.00
Chicago	1.30	1.02
New York Area	1.32	1.04
Portland	1.40	1.10
Atlanta	1.40	1.10
Phoenix	1.41	1.08

	End-Use SPF Cooling	Source SPF Cooling
Burlington	0.82	0.63
Chicago	0.79	0.61
New York Area	0.80	0.61
Portland	0.79	0.61
Atlanta	0.78	0.60
Phoenix	0.73	0.54

A comparison between the source seasonal performance factor estimates for the basic GAX and the engine-driven **GAS-FIRED HEAT PUMP** shows somewhat higher space heating performance for the basic GAX. However, the basic GAX has a lower source SPF in the cooling mode than the engine-driven **GAS-FIRED HEAT PUMP**, with a low-range estimated performance that is only about one-half that of the **GAS-FIRED HEAT PUMP**.

One principal potential attraction of the basic GAX system has to do with NO_x emissions. The GAX has a NO_x emission rate that is much lower than the uncontrolled **GAS-FIRED HEAT PUMP** -- .023 kg/MMBtu input, as opposed to .140 kg/MMBtu. Of course, work to decrease NO_x emissions in the **GAS-FIRED HEAT PUMP** will result in a somewhat more favorable comparison. Comparative CO_2 emissions, on the other hand, will depend on operating efficiency, with the GAX system likely experiencing higher emissions relative to the **GAS-FIRED HEAT PUMP** in cooling-dominated climates.

A second potential advantage of the basic GAX system may have to do with price. So far, there is insufficient data for a reliable comparison to be made. However, some independent manufacturing cost estimates indicate that the GAX may have very little or no price premium over a **STANDARD GAS FURNACE/AIR CONDITIONER** combination. If realized, this pricing scenario could result in major market opportunities for the GAX system.