# Innovative Air-Conditioning and Refrigeration Research: Meeting Global Opportunities

*A Program Submission to the*
*National Institute of Standards and Technology*
*Advanced Technology Program*

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**Submitted by:**

**The Air-Conditioning and Refrigeration Institute**
**4301 North Fairfax Drive**
**Arlington, VA 22203**

**The Association of Home Appliance Manufacturers**
**20 North Wacker Drive**
**Chicago, IL 60606**

**The International Institute of Ammonia Refrigeration**
**1101 Connecticut Avenue, N.W.**
**Washington, DC 20036**

# *AIR-CONDITIONING AND REFRIGERATION RESEARCH*

## SPONSORS

The Air-Conditioning and Refrigeration Institute (ARI) is the national trade association representing manufacturers of over 90 percent of U.S.-produced central air-conditioning and commercial refrigeration equipment. The Association of Home Appliance Manufacturers (AHAM) is the national trade association representing manufacturers of major and portable appliances sold in the U.S. The International Institute of Ammonia Refrigeration (IIAR) is an international non-profit trade association formed to promote the safe use of ammonia as a refrigerant.

ARI, AHAM, and IIAR are submitting the following program suggestion on behalf of their members.

## PROPOSED PROGRAM IDEA

The program identified herein represents a consensus from industry manufacturers of air-conditioning and refrigeration (AC&R) equipment.

**Industry recommends that a coordinated research program be established with the goal of developing cost-effective air conditioning and refrigeration products that would enhance the U.S. industry's competitiveness in the world market.**

The research path is to identify and develop novel air-conditioning and refrigeration systems that improve comfort, health, and ancillary cooling, refrigeration and process applications in a cost-effective manner. World competitiveness requires that U.S. manufacturers produce equipment that meets the needs of the marketplace by being ultra-efficient, environmentally acceptable, and available at an affordable price. It is anticipated that the program will require ATP funding of approximately $10 million/year for six years.

## BACKGROUND

The U.S. AC&R industry is a mature business in which product penetration is nearing market saturation. Additionally, in the U.S., industry's products are viewed as commodities where sales are extremely price sensitive; a small price difference will sway a purchase decision. As a result, industry is not well-capitalized to perform long-term research in high-risk areas. Yet, in the long-term, industry's dominance in the world market is dependent upon the development of radical, breakthrough technologies. Examples of revolutionary technologies are alternate air-conditioning and refrigeration cycles, oil-free compressors, and electrohydrodynamic (EHD) heat transfer. Innovative products will serve to expand international sales and to stave-off sales of foreign-manufactured products in the U.S. market.

The manufacturing of air-conditioning and refrigeration equipment in the U.S. represents a $22 billion per year industry. The value of exports has risen dramatically in recent years, and now totals over $4 billion annually. U.S. producers have

historically been the leaders in this industry and have consistently recorded a positive balance of trade.

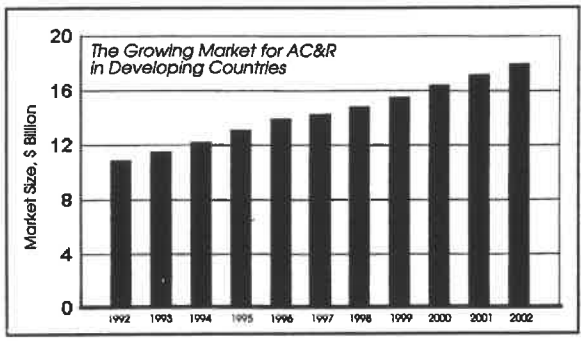


**Figure 1:** Predicted Foreign Market Demand for AC&R Equipment

The international air-conditioning and refrigeration industry is undergoing a period of revolutionary change. The worldwide phaseout of the ozone-depleting refrigerants used in nearly all equipment is imminent. This phaseout is occurring at the same time that demand for AC&R products is sharply increasing in developing countries. Figure 1 illustrates the growth expected to occur in these developing countries. The manufacturers of AC&R equipment, located mainly in Japan, Europe, and the U.S., will be competing for these new markets. The stakes are huge for the U.S. AC&R industry:

> **The demand for AC&R products in developing countries alone is estimated to be $150 billion over the next 10 years!**

The Japanese AC&R manufacturing sector has grown to the same size as that of the U.S. However, their research and development programs are heavily supported by the Japanese government. This fact has serious consequences for U.S. industry's long-term competitiveness, strength and vitality. Only through an aggressive R&D program to develop U.S. capabilities will U.S. manufacturers garner a large share of the developing market.

In the U.S., the payback from improved AC&R products is also dramatic. Annual U.S. energy bills for AC&R equipment are approximately $52 billion. Increasing average AC&R efficiency by 25% (a reasonable goal if a concentrated research program is pursued) could ultimately yield an annual energy savings of $13 billion. There would also be a proportionate decrease in the emissions of gases that are associated with global warming, as $CO_2$ emissions from power plants would decrease by over 12 million kg per year.

## CHALLENGE

The equipment and refrigerants that have been successfully utilized for decades are now undergoing radical changes caused by a two-pronged assault from both environmental and market forces:

Environmental Forces:

> The Montreal Protocol calls for a phaseout of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) production. Although several candidates have been identified as intermediate-term replacements to CFCs (e.g., HCFC-123 replaces CFC-11 and hydrofluorocarbon(HFC)-134a replaces CFC-12 in many applications), these replacements may also have a limited life. Uncertainty will continue through the rest of the 1990s as the world's governments negotiate further modifications to the Montreal Protocol and begin to implement national

programs to reduce greenhouse gas emissions as required by the Climate Change Convention.

Market Forces:

The U.S. economy has become highly dependent on modern air-conditioning and refrigeration equipment. Whether for cooling individual homes, air conditioning new office buildings, maintaining environmental conditions for manufacturing processes, preserving food, or the refrigeration of medical supplies, industry products have become ubiquitous in the marketplace. It is expected that these products will continue to find new applications in the U.S. Foreign markets also will expand dramatically as developing countries capitalize on the benefits of air-conditioning and refrigeration products. As the world's markets expand, U.S. manufacturers of air-conditioning and refrigeration equipment will continue to compete for these growing markets.

U.S. industry must move quickly to deal with the challenges of satisfying environmental laws and energy concerns in a business environment where most existing technologies are now viewed as temporary solutions. Slow introduction of new products will adversely impact industry's ability to exploit the expanding markets in the developing countries.

## TECHNICAL IDEAS

Through the Advanced Technology Program, it is anticipated that the development and marketplace introduction of advanced equipment will be greatly accelerated. Examples of the types of technological advances which can be made, listed in priority order, are:

(1) Alternate AC&R Equipment

Today, the vast majority of the air-conditioning and refrigeration equipment produced utilizes vapor compression technology. Over the years, improvements in the performance, reliability, and serviceability of vapor compression systems have made them the most economically viable AC&R products. However, as a result of new materials and other technological advances, older, alternate technologies may now be feasible, while other new technologies continue to be advanced.

Many types of alternate systems have been proposed. These technologies include absorption and adsorption cycles, Brayton cycles, Lorentz cycles, magnetic refrigeration, Malone cycles, Stirling refrigeration, thermoacoustic refrigeration, thermoelectric refrigeration, and others. These technologies are being championed by various university, industry, and government entities. However, each has specific concerns or limitations that need to be addressed before product introduction can be initiated.

ATP funding in cycle investigations will accelerate the efforts to screen new concepts and reveal the most promising ones for subsequent commercialization. Adsorption cycles, for example, are receiving attention because of their apparent simplicity compared to engine-driven heat pumps. However, the control problems associated with cycling solid adsorbent beds between adsorption and desorption portions of the cycle are not easy to

solve in a cost effective manner. Other problems include cost and long-term reliability of the adsorbent material. A concerted research effort could solve these technological difficulties.

(2) Cost-effective, ultra-high energy efficient AC&R equipment
Energy efficiency improvements in AC&R equipment have been steady but incremental in nature. A significant government/industry research program is needed to substantially reduce energy consumption.

a). *20 SEER air conditioners and heat pumps*: Unitary air-conditioners and heat pumps generally sold today have seasonal energy efficiency ratios (SEERs) between 10 and 14. However, since efficiency improvements generally mean higher equipment costs to the consumer, the average efficiency of unitary equipment sold is only about 10.5 SEER. For all unitary equipment in the field (median life of 15-19 years), the average efficiency is less than 9 SEER. Figure 2 shows the seasonal energy efficiency rating (SEER) of heat pumps manufactured in the U.S. for the last ten years. Achieving an SEER of 20 in a cost-effective system will require an impressive effort and will revolutionize the AC&R market.

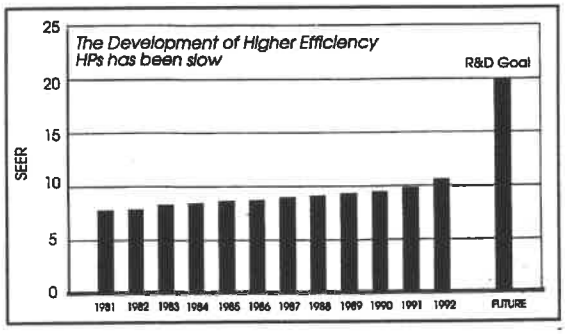


**Figure 2:** Shipment-Weighted Seasonal Energy Efficiency Ratings (SEER) of Unitary Air-Source Heat Pumps

b). *Improved chiller efficiency*: Water chilling equipment (used to condition large commercial, institutional, and industrial facilities) has steadily improved in efficiency and performance in recent years. However, the relatively easy design changes have been accomplished and further improvements will require radical departure from conventional technology. Today, the best energy efficiency for a chiller is 0.55 KW/ton. The goal is to improve performance by 20% by developing chillers that operate at about 0.45 KW/ton.

c). *Improved refrigeration equipment*: Current supermarket refrigeration systems have excessive refrigerant leak rates and high power consumption. The industry may need a radical departure from current practice, away from built-up systems with long refrigerant piping, towards packaged systems with a secondary fluid. Packaged systems will dramatically reduce the leak rates, and the use of a cascade system with intermediate water loop gives the designer the flexibility to choose different high and low temperature refrigerants which may overcome the penalty of secondary heat exchange. The goal is to develop new refrigeration equipment with dramatically reduced leak rates and markedly improved energy consumption.

Achieving the efficiency goals outlined above will require massive research efforts. However, in so doing, the U.S. AC&R industry will be dramatically infused with new vigor. To develop these higher efficiency AC&R products,

a number of significant hurdles must be surmounted. Some specific examples are:

- *Oil-free compressors*: AC&R equipment utilize compressors that require oil for lubrication, compression sealing, heat absorption, and noise abatement. However, the lubricant adds a number of complex technical problems to the operation of a system. Performance of heat exchangers are degraded, complicated and expensive oil return/equalization schemes are necessary, and power consumption is increased due to the oil's viscous sheer. Additionally, numerous materials compatibility concerns arise from the interaction of the lubricant with the materials present. Hence, the elimination of the oil from the operating system will greatly enhance equipment performance and allow the use of other refrigerants and/or new materials. Revolutionary advances in AC&R equipment will occur with the development of compressors that require no oils or lubricants to operate; perhaps, liquid refrigeration could satisfy the role of lubrication oils.

- *Heat transfer research*: Preliminary research by Japanese and American researchers indicate that electrohydrodynamic (EHD) heat transfer augmentation techniques may be a cost-effective way to achieve ultra-high efficiency products. Additionally, research is in its infancy on whether refrigerant composition shifting can be advantageously utilized to permit different circulating mixtures for summer cooling and winter heating operations. Optimization of the compositions for both operating modes will be very challenging, but could yield large efficiency gains. Finally, research on optimizing the flow configurations and surface geometries of heat exchangers are also vitally important for efficient operation.

- *Affordable high-efficiency motor systems*: Currently, AC&R equipment are available that utilizes two-speed compressor motors and multi-speed blower motors. Variable-speed motors and their associated control packages have been available for many years. However, as a result of their higher initial costs, these enhancements are not easily accepted in the marketplace. Research is needed to develop motor systems that cost one-half of those available today.

(3) Advanced Building Distribution Systems

Improvement in the delivery of conditioned air or water is necessary to insure that advances in equipment efficiencies are not negated by inefficient distribution systems.

a). *Advanced controllers*: Sensors and controllers are increasingly being utilized by the industry to make AC&R equipment more energy efficient, reliable, and to provide improved diagnostic capability. Hardware and software improvements enable larger systems to be remotely operated and diagnosed. Building automation software which is adaptive and easy to implement needs to be advanced. The development of "fuzzy logic" controls that adapt and respond to different operating constraints within buildings will further improve the effectiveness of AC&R equipment.

b). *Improved duct systems*: The majority of residential and commercial buildings built in the U.S. today utilize central AC&R systems with ducted distribution networks. Improvements in duct design, fabrication, installation, and insulation techniques are required to maximize the effectiveness of high efficiency AC&R equipment. The development of cost-effective zoning techniques will ensure that energy is not needlessly wasted on the conditioning of unoccupied rooms. Additionally, one estimate places U.S. energy loss at 3 quads per year due to leaking or improperly designed/installed air-ducts.

(4) Indoor Air Quality

Indoor air quality and its relationship to occupant comfort, health, and productivity has received increased attention in recent years. As a result, defining, recognizing, measuring, and controlling indoor air contaminants are now becoming significant issues. A more complete understanding of what, and how, contaminants affect occupants, and how these contaminants are introduced to occupied areas is urgently needed. It is envisioned that advanced control and sensor technologies will allow space conditions to be adjusted for individual comfort and for differing activities in occupied areas. This breakthrough would enable AC&R equipment to play a larger role in monitoring and reducing the levels of indoor air pollutants and other air-borne irritants. It also is anticipated that better understanding of airborne contaminants will allow for the development and application of more effective control and mitigation techniques (i.e., beyond today's ventilation and filtration methods). Reliable, cost-effective, energy efficient solutions to the complex problems of indoor environmental control are needed.

(5) Development of New Environmentally-Friendly Chemicals

As the industry shifts its focus from CFCs and HCFCs, global warming concerns may also necessitate a change from HFCs. New chemicals will have to be developed for many applications; refrigerants, lubricants and foam blowing agents. These chemicals may be familiar "natural" species such as hydrocarbons or ammonia, or new synthetic ones such as fluorinated ethers. The development and screening of new chemicals must be performed to accelerate the implementation of innovative AC&R technologies.

Many issues are associated with the use of these chemicals in new applications, the most crucial of which is safety. The toxicity, flammability, and long-term breakdown products must be carefully determined. Studies of the toxicity and flammability would speed the path to the open market for many products containing alternative chemicals.

## POTENTIAL FOR U.S. ECONOMIC BENEFIT

As noted earlier, the U.S. AC&R industry is undergoing a period of great change and is now in an international battle to see who will first provide the next generation of products to an expanding world market. ATP funding can benefit the U.S. economy by accelerating the introduction of well-engineered AC&R products that are environmentally attractive and affordable. This will strengthen the U.S. market while enhancing industry's position in the emerging foreign markets. Failure of the U.S. industry to aggressively develop and market affordable, environmentally-friendly

products will allow foreign competitors to obtain an increasing share of the world business.

Size of the U.S. Air-Conditioning and Refrigeration Industry:

Equipment manufactured by the U.S. air-conditioning and refrigeration industry consists of unitary air conditioners, heat pumps, heat transfer equipment, chillers, commercial and residential refrigeration equipment, compressors, and a variety of component products. The value of U.S. industry shipments for 1992 was over $22 billion: roughly 40% of the world's total production of AC&R equipment. Figure 3 shows the major producers of AC&R equipment and their relative size.

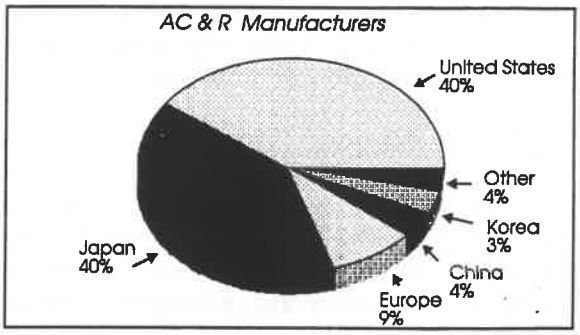


**Figure 3:** Relative Size of World AC&R Manufacturing Sectors

International trade is integral to continued AC&R industry growth. The industry's past export success is a result of the increased globalization of the air conditioning and refrigeration business. In recent years, U.S. firms have come to rely increasingly on international sales to offset any periods of slow economic activity in the U.S. For many companies, international sales now account for 25-35 percent of total revenues. In the time period from 1988 to 1992, industry exports doubled to approximately $4.1 billion. However, this rapid growth only allowed the industry to retain its worldwide market share.

It is worth noting that any improvements developed by the air-conditioning and refrigeration industry have applications to other sectors of the U.S. economy. Any process, application, or operation that depends on air-conditioning or refrigeration will also benefit. Hence, advances in the AC&R industry will impact the overall U.S. economy and the international competitiveness of U.S. industry.

## COMMITMENT BY INDUSTRY

Industry, through a responsive nonpartisan committee structure composed of industry experts, coordinates industry/government pre-competitive research of technologies that will accelerate development of manufactured goods by U.S. AC&R producers. The overall goal is to ensure that strategic technologies are addressed, and to increase the benefits of the resultant research to the industry and the public.

Prior industry commitment

Industry members have already demonstrated that they are capable and willing to commit substantial financial and in-kind resources to ensure that essential research to the industry is undertaken. Two specific examples are:

- *ARI R-22 Alternative Refrigerants Evaluation Program (AREP)* -- AREP is an unprecedented industry effort to provide data on the performance of air-conditioning and refrigeration equipment using non-ozone depleting alternatives to HCFC-22 and R-502. A consortium of about 30 equipment

manufacturers participated in this multi-million dollar program entirely at their own expense. For the maximum benefit of the entire industry, participants made the AREP results publicly available, and will continue to do so until the program's conclusion. This activity has provided preliminary data that will allow industry to accelerate introduction of new equipment.

- *Materials Compatibility and Lubricants Research (MCLR) Program* -- The MCLR program, begun in 1991, is an extensive, $8 million, multi-year research effort jointly funded by the U.S. Department of Energy and the air-conditioning and refrigeration industry. Its function is to perform critical research on compatibility, stability, miscibility, and ancillary investigations on newly identified refrigerant candidates and associated lubricants. Detailed results from completed projects have been made publicly available and already have led to the introduction of new products.

ATP Commitment

An on-going, multi-year ATP-backed research program that is geared towards accelerating the ideas highlighted in this proposal would provide a unique opportunity to accomplish many research goals under one "umbrella." Industry support for the program includes the willingness to provide cost sharing to assure that the program objectives are reached or exceeded. Cost sharing will be of direct monetary support and of in-kind support. Specific examples of in-kind support might include:

- research undertaken in specific manufacturing companies by dedicated staff and resources,
- donation (as appropriate) of equipment, materials, supplies, and manpower resources to laboratories performing specific project investigations,
- creation of a dedicated industry monitoring and advisory committee to assist in the management of individual research projects,
- the dedicated services of ARI staff to seek competitive bids for individual projects, award merit-based contracts, provide guidance and direction, and to ensure that results are completely and fairly shared with all program collaborators.

To further reinforce industry's suggestion for an ATP program, member companies are currently formulating a defined body of research needed to move the industry forward in the near-term and to competitively position it in the future for the world market.

## OPPORTUNITY FOR ATP FUNDS TO MAKE A SIGNIFICANT DIFFERENCE

Industry currently performs a great deal of research on AC&R issues; alone, or in consortium with other interested parties. However, these endeavors generally are aimed at obtaining incremental product improvements. ATP funds are needed for the high-risk research that industry cannot afford to fully fund on its own.

The research envisioned are on the "cutting-edge" of the AC&R industry and entails a high degree of technical risk. Currently, individual companies' personnel and testing resources are spread thin because of the pace of product changes required by CFC

phaseouts and efficiency improvement requirements, with global warming implications to come. In general, AC&R companies do not have the capabilities to fully develop the project areas on their own. Collaboration with other companies would enable significant resources to be applied to the desired product development goals.

> By providing a solid basis for industry collaboration in pre-competitive technology areas, the ATP can catalyze progress in a range of developments which individual U.S. companies are unable to undertake.

The most important factor of the ATP support is that the research and development process will be accelerated. This has significant implications in a competitive world market. Time is a very important factor as emerging markets are developing rapidly.

> The ATP program will allow the industry to respond now to the needs of its customers worldwide.

## CONCLUSION

The air-conditioning and refrigeration industry, which has been experiencing evolutionary growth for the last 40 years, is suddenly undergoing a period of unprecedented change. The pressures driving these changes -- protection of the environment and conservation of our natural resources -- will only become more severe in the future. The development of new technologies needed to meet these rigid environmental standards will require a large concerted effort. No single company has the resources to accomplish the development of these new technologies alone. A joint, cooperative effort between industry, academia and the government is required to solve many of the large problems that currently lie before the industry.

Time is of the essence. Emerging economies of the developing nations are beginning to demand the modern equipment which we take for granted. Cooperation among U.S. industries is necessary to maintain or increase our market share in these growing foreign countries. To meet this challenge industry needs to maximize its research efforts. A small investment in the research and development of innovative AC&R technologies will lead to a large return in the future: the U.S. industry can maintain its dominant role in the world market. ATP funds can assist industry in the preservation of the global environment, while adding to the capital production of the nation. We are confident that successful conclusion of this program will add significant value to the U.S. economy, both through reduced energy consumption and increased export revenue. We are prepared to move swiftly once this program has received your approval and we look forward to the opportunity to discuss this proposal with you personally.

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