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Research and Development Needs for Desiccant Cooling Technology, 1992-1997

(Supplement to the NREL Report *Desiccant Cooling: State-of-the-Art Assessment*)

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Preface

Desiccant cooling and dehumidification have received much attention as viable alternatives for the air conditioning of buildings. Over the last 15 years, technological advances have occurred through national and international research, development, and demonstration efforts, and the technology has successfully entered into some niche markets. Despite these advances, the technology has not achieved widespread acceptance and mass-market penetration. A comprehensive overview of the technology is provided in a recent report titled "*Desiccant Cooling: The State-of-the-art Assessment*" by Pesaran, Penney and Czanderna (NREL/TP-254-4147) Golden, CO: National Renewable Energy Laboratory. The report discusses the work accomplished to date and the R&D needs that affect the widespread acceptance of the desiccant cooling technology.

In this document we have described a detailed program assuming sufficient funding to implement the R&D activities needed. Desiccant dehumidification is a mature technology for industrial applications, and in recent years the technology has been successfully used for air conditioning a number of institutional and commercial buildings. Our proposal is based on argumentative discussions at various national meetings with leaders of the technology. The goal is the penetration of the broad air conditioning market. The program proposal needs to be annually reviewed and revised to be responsive to the needs of the industry and users. This work was funded by the Building Technologies Office of the U.S. Department of Energy.

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1.0 Introduction

This introduction is the Executive Summary of another NREL report (Pesaran, Penney, and Czanderna, Oct 1992, *Desiccant Cooling: State-of-the-Art Assessment*, NREL/TP-254-4147, Golden CO: National Renewable Energy Laboratory). We include it here to serve as a background for what we are proposing for desiccant cooling technology R&D needs.

Why Desiccant Cooling?

In 1990 about 3.9 quads of primary energy were used for air conditioning (cooling and ventilation) of buildings. The energy used for air conditioning buildings is expected to rise in the 1990s and beyond as the population shifts to the warmer southern states and personal computer use increases in office buildings. In the 1990s, the air conditioning industry is faced with several challenges: increased energy efficiencies, improved indoor air quality, growing concern for improved comfort and environmental control, increased ventilation requirements, reduction of chlorofluorocarbons (CFCs), and rising peak demand charges. New approaches to space conditioning will be required to resolve these economic, environmental, and regulatory issues. Desiccant cooling and dehumidification, a technology known for some time, may provide important advantages in solving air conditioning problems.

How Do Desiccant Cooling Systems Work?

In a typical desiccant system, the moisture (latent load) in the process air is removed by a desiccant material in a dehumidifier, then the temperature (sensible load) of the dried process air is reduced to the desired comfort conditions by sensible coolers (e.g., heat exchangers, evaporative coolers, cooling coils). The latent and sensible loads are handled separately and more efficiently in components designed to remove that load. The desiccant in the dehumidifier is regenerated (reactivated) by application of heat to release the moisture, which is exhausted to the outdoors. The heat for regeneration can be provided from a number of energy sources such as solar, waste heat, natural gas, and off-peak electricity. The desiccant can be either solid or liquid. In solid desiccant systems, air is passed through a bed of adsorptive material. Air is dried and moisture is adsorbed by the desiccant. When the desiccant is saturated, hot air is passed through the bed, releasing the moisture. Typically, the desiccant is loaded into a disc that rotates between the process and regeneration airstreams. In a liquid desiccant system, a concentrated liquid desiccant is sprayed in a contactor (containing cooling coils or packing materials) to absorb moisture from humid air stream passing through the contactor. The liquid desiccant leaving the contactor is diluted with removed water. The diluted liquid desiccant is heated or sprayed into the regeneration air stream to remove and release the moisture and reconcentrate the liquid desiccant.

The Major Advantages

- Desiccant systems offer significant potential for energy savings and reduced consumption of fossil fuels. The electrical energy consumption is small, and the source of thermal energy can be diverse (i.e., solar, waste heat, natural gas).

- With desiccant systems the use of CFCs is eliminated (if used in conjunction with evaporative coolers) or reduced (if integrated with vapor compression units). CFCs contribute to depletion of earth's ozone layer and will be banned by the end of the century.

- Indoor air quality is improved because of higher ventilation and fresh air rates associated with desiccant systems. Such systems also offer lower humidity levels and the capability to remove airborne pollutants.

- With desiccant systems, air humidity and temperature are controlled separately, enabling better control of humidity.

Applications

The best circumstances for use of desiccant cooling and dehumidification technology are: need for humidity control, economic benefits to low humidity, high latent load versus sensible load, low thermal energy cost versus high electric energy cost, and need for dry cooling coils and duct work to avoid microbial growth.

Desiccant cooling and dehumidification can be applied to many types of buildings: supermarkets, hotels and motels, office buildings, hospitals and nursing homes, restaurants, health clubs and swimming pools, and residences. The success of desiccant cooling is being realized in supermarkets, which use four times more energy per unit floor space than most commercial buildings. Use of desiccant technology to provide dry, cool air for hotels and motels in humid climates (to avoid mold and mildew damage as a result of excess moisture) is expected to be the next major application of the technology.

Status of Technology

More than 15 years of research and development, funded by the Department of Energy, Gas Research Institute, utilities, and the private sector, have resulted in significant improvements in the performance, cost, and reliability of desiccant dehumidification and cooling systems. Currently, they are competitive in the market for a few specialized applications such as in supermarkets. Investigation of desiccant cooling systems during past decades have revealed that such systems have great potential to compete with and complement the conventional, electrically driven vapor comparison systems. There are approximately 900 citations in the literature on the subject of desiccant cooling. The following are some of the recent advances and findings for desiccant cooling technology.

Materials

- Type 1 M (moderate) isotherm has been identified as the "preferred" shape of isotherm for solid desiccants in cooling applications. The higher performance with Type 1M isotherm is usually obtained when staged regeneration is used.

- Several Type 1 M desiccants have been identified/synthesized, and R&D efforts are underway to incorporate these materials into inexpensive dehumidifier structures.

- Desiccant materials have the potential to remove airborne pollutants, thereby improving indoor air quality.

- Desiccant degradation/contamination is not expected to be a barrier/problem for HVAC application of solid desiccant cooling technology.

Components

- Rotary dehumidifiers with laminar flow passages (e.g., corrugated, honey comb, or parallel plate) have become the choice for solid desiccant cooling systems.

- Low-pressure-drop, relatively inexpensive, laminar-flow, corrugated dehumidifiers using silica gel or molecular sieves have been entered into the market.

- Low-cost solid desiccant dehumidifiers using Type 1 M material are being manufactured by a few organizations.

- A "humidity pump" gas-fired liquid desiccant dehumidifier module has been developed that can be added to the electrically driven refrigeration air conditioner for removing latent load.

Systems

- The concept of "staged regeneration" for solid desiccant dehumidifiers has been reintroduced. Combined with Type 1 M desiccant and high regeneration temperatures, staged regeneration is expected to reduce the size of air-to-air heat exchangers, thus reducing system size and cost.

- Advanced desiccant cycles have been proposed that have COPs above 1.7. Higher COPs are achieved through use of a larger number of components.

- A gas-fired prototype closed-cycle desiccant heat pump unit has been developed using Zeolite/water with a cooling COP above 1.2.

- A variety of modeling tools for analyzing the performance of desiccant cooling systems and components have been developed and validated.

- Integrated desiccant cooling systems using desiccants for dehumidification and conventional vapor compression for cooling have been successfully demonstrated for a few commercial buildings and many supermarkets.

Future Research and Development Needs

While significant progress has been made in efficiency and cost effectiveness of desiccant cooling systems for air conditioning, commercial systems and designs are available only for special applications such as supermarkets and other low-humidity applications. Lowering costs and improvements in the efficiency, size, reliability, and life-expectancy of components and systems are necessary to advance penetration of the desiccant cooling technology into broader commercial air conditioning market.

The results of the last 15 years of R&D and the goal of mass market penetration have given desiccant cooling technology a direction for the future and shaped R&D needs. In our opinion, the high priority R&D areas are:

Materials

- Development of low-cost solid desiccant materials with optimum properties for high-, medium-, and low-temperature regeneration applications

- Fundamental research on water/vapor desiccant interaction for improving sorption behavior

- Development of low-cost noncorrosive, low-vapor pressure, and safe liquid desiccants with desirable sorption properties

- Study of desiccants as air purifiers for improving indoor air quality.

Components

- Developing low-cost, high-performance, compact solid and liquid dehumidifiers
- Reducing the cost and energy requirements for desiccant regeneration device
- Development of control strategies and components.

Systems

- Demonstration of the state-of-the-art desiccant systems for air conditioning of various buildings
- Conducting system performance and economic analysis studies
- Development of efficient, cost-effective systems utilizing waste heat for desiccant regeneration
- Development of user-friendly design and analysis tools
- Transfer of technology to consultant engineers, building community, and HVAC designers and manufacturers.

Concluding Remarks

Desiccant cooling technology has the potential to significantly affect the air conditioning market and its energy use. Desiccant cooling has many benefits including lower energy consumption, lower use of CFCs, and improved indoor air quality. Advances in the last decade have resulted in successful application of the technology in niche markets. However, penetration into the air conditioning mass market requires further improvement in efficiency and reliability, reduction in size and cost, and improvement in technology acceptance by the building community. Investments in further research and development in materials, components, and systems are needed and justified considering the potential of the desiccant cooling technology. In the next two sections, we have identified R&D needs and proposed a program for advancing the desiccant cooling technology into the broad air conditioning market.

2.0 Research and Development Needs

2.1 Scope

While significant progress has been made in efficiency and the cost effectiveness of desiccant cooling systems for air conditioning, commercially available systems and designs are available only for special and niche applications such as supermarkets and numerous other applications requiring low humidity. Improvements are necessary in the efficiency, cost, size, reliability, and life-expectancy of components and systems to penetrate the broad commercial air conditioning (A/C) market.

In our opinion, the critical performance and cost goals for successful penetration of desiccant cooling systems into this competitive broad market are:

- For open-cycle solid desiccant cooling systems: thermal COP of 1.3 or higher; electrical COP of 12 or higher; flow cooling capacity of 225 cfm/ton or lower; life expectancy of 15 years or more; compact size (slightly larger than conventional A/C equipment); cost competitive with conventional A/C equipment; reduction in the use of CFCs.

- For open-cycle liquid desiccant cooling systems: development of noncorrosive, low-vapor-pressure, efficient, and inexpensive liquid desiccant materials; thermal COP of 1 or higher; electrical COP of 8 or higher; life expectancy of 20 years or more; compact size; cost competitive with alternative technologies, reduction in the use of CFCs.

- For closed-cycle solid cooling systems: thermal COP of 1.3 or higher; electrical COP of 10 or higher; flow cooling capacity of 225 cfm/ton or lower; compact size (slightly larger than conventional A/C equipment); cost competitive with conventional A/C equipment; reduction in the use of CFCs.

- For hybrid and integrated desiccant cooling systems: cost-effective and reliable components to reduce life-cycle cost of the integrated system relative to the conventional A/C system; reduction in the use of CFCs.

Achieving these performance goals will require advances in materials, components, and systems. In this section, we identify R&D needs and then propose a program to implement the R&D activities needed.

It should be noted that a matured $40-50 million desiccant dehumidification industry exists in the United States that mostly services industrial applications. In recent years, the industry has been successful in implementing the technology for air conditioning of some institutional and commercial buildings. Future development and advancement of the technology may have profound impact on the commercialization of the technology for broader air conditioning markets. Depending on the industry's particular needs and strategy, better materials, components, or systems may need to be employed. The R&D needs identified here are based on argumentative discussions at various meetings we had with the leaders of the technology. We have summarized what could be accomplished with sufficient resources. The R&D needs and the program plan have to be reviewed and revised annually to be responsive to the needs of the industry and users.

2.2 Summary of Research and Development Needs

Based on the previous R&D activities, we have identified some future R&D needs for achieving cost-effective, high-performance, and reliable desiccant cooling systems.

2.2.1 Desiccant materials

- Fundamental research on water vapor/desiccant interactions for improving sorption behavior
- Synthesis of new materials or modification of existing ones for improving sorption performance and reducing cost
- Synthesis and/or preparation of composite desiccants
- Characterization of materials and development of models to predict equilibrium and dynamic performance
- Identification of optimum properties of liquid and solid desiccants for cooling and dehumidification for low-, medium-, and high-temperature applications
- Development of noncorrosive, low-vapor-pressure, and environmentally acceptable liquid desiccants with desirable sorption properties
- Determination of durability of new desiccants with regard to thermal cycling and exposure to contaminants
- Study of desiccants as air purifiers for improving indoor air quality.

2.2.2 Components

- Improving heat- and mass-transfer rate in solid and liquid desiccant dehumidifiers while keeping the pressure drops low
- Developing low-cost, high-performance, compact solid dehumidifiers
- Developing low-cost, high-performance, compact liquid dehumidifiers
- Developing high-effectiveness (>0.89), compact, low-cost heat exchangers
- Investigation of materials and methods for improving storage techniques for liquid desiccant cooling systems for peak-shifting application.
- Developing low-cost, high-performance, compact direct and indirect evaporative coolers
- Developing advanced liquid desiccant absorbers and regenerators for higher thermal COP
- Improving performance and reducing cost of regeneration equipment such as solar collectors, boilers, and other advanced regenerators
- Improving performance and reducing cost of humidity measuring sensors and instruments for control applications.

2.2.3 Systems

- Developing compact systems with reduced cost and improved performance

- Developing systems with advanced configurations so the size of components can be reduced

- Development of modular, easy-to-use system models that can be easily incorporated into HVAC and building simulation programs

- Evaluation of economic potential of various desiccant cooling systems for comparing with conventional cooling alternatives

- Development of easy-to-use design tools such as handbooks, look-up tables, charts, and user-friendly computer software for general use

- Development of control strategies for full-load, part-load, and off-design operations

- Investigation of using waste heat for desiccant regeneration, particularly for industrial applications

- Investigation of the possibility of using desiccant cooling and dehumidification for utility demand-side management applications

- Demonstrating the potential of desiccant-cooling systems for various applications and markets.

3.0 Proposed R&D Desiccant Cooling Program

To be successful in advancing the desiccant cooling systems in the A/C market, two types of efforts are needed: short-term and long-term. The short-term activities can be accomplished with existing technologies and equipment and are of a demonstration and educational nature. These activities can be accomplished in 1 to 3 years, and they fulfill the program implementation needs to show proof of concept. The long-term efforts are R&D-related and will advance the state of the existing technologies. These long-term efforts will fulfill the critical cost and performance R&D goals. For successful implementation of these activities, a program management element is needed. Figure 3-1 shows an overview of the elements of the proposed desiccant cooling program. These will be discussed in detail in the following subsections. It should be noted that some elements of this program and R&D activities are based on the work of Schlepp and Penney (*Five-year Research Plan for the Solar Desiccant Cooling Program*, 1983, Draft Report, SERI/PR-252-2061, Golden, CO: Solar Energy Research Institute) and Zangrando (*Active Systems Multi-year Research Plan - Solid Desiccant Cooling Systems Technical Plan*, 1985, Draft Report, Golden, CO: Solar Energy Research Institute).

3.1 Research and Development Program

The R&D activities required to achieve the desired technical improvements are identified in this section. The results of the last 15 years of R&D and long-term goals have shaped the needs for R&D and program planning.

The following are elements of the desiccant cooling technology R&D program:

- Materials research and development
- Heat- and mass-transfer research
- Components research and development
- Systems research and development
- Durability and contamination research
- Innovative concepts
- Collaborative research and technology transfer.

3.1.1 Materials research and development

Materials R&D is a major element of this program. Development of solid and liquid desiccant materials for open-cycle cooling systems will be considered here. For the materials research for open-cycle solid desiccant systems, the program will include fundamental research on water vapor/solid interactions and advanced solid desiccant materials development. It is very important for the success of the technology in the market to produce the desired desiccant materials and matrices (with Type 1M sorption behavior) at low cost. For the open-cycle liquid desiccant systems, it is very important to produce high-moisture capacity liquid desiccants that have no corrosive properties. The materials research for this system include fundamental research on water vapor/liquid interactions and advanced solid desiccant materials development.

Fundamental Research on Water Vapor/Solid Interactions. The focus of this element will be to understand the basic mechanisms of sorption and how the water vapor/surface/solid interactions control the isotherm shape and heat of adsorption. The nature of the dipole (water) interactions with ions (e.g., anionic polymers or doped silica gel surfaces) or electric fields from "uniform" solid surfaces (e.g., silica) will be investigated for carefully controlled surfaces and solid (porous) materials. The forces of these

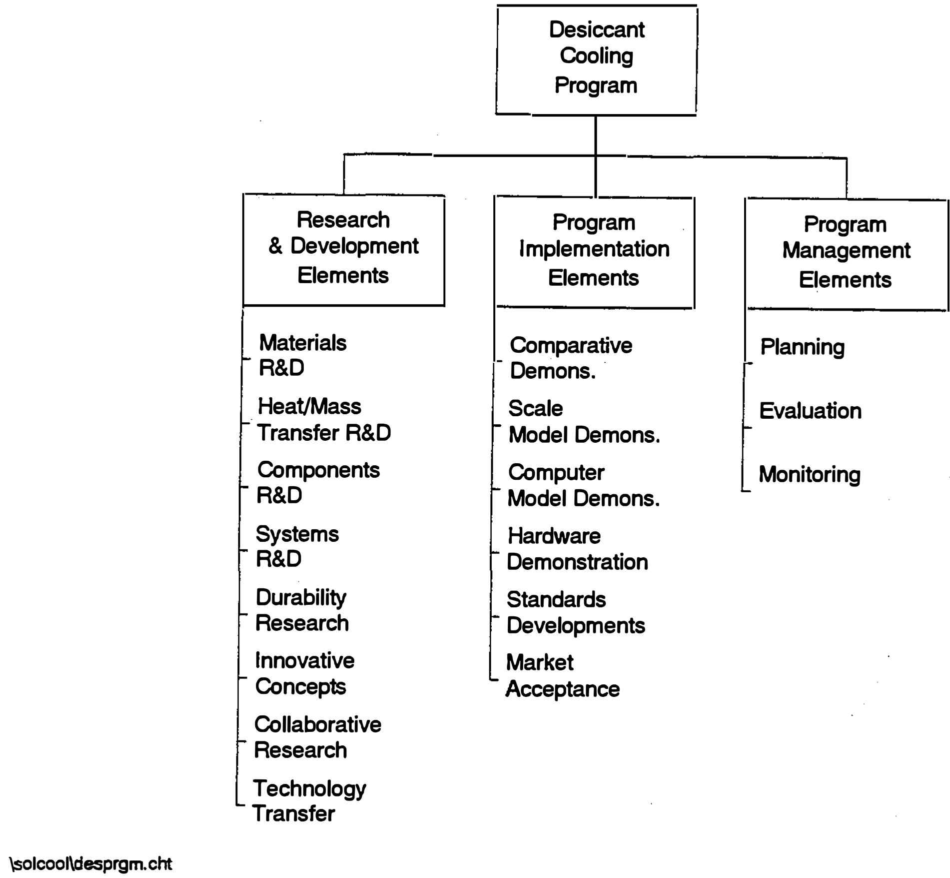

Figure 3-1. Elements of desiccant cooling program

interactions ultimately control the isotherm shape, which depends on both the enthalpy and entropy of adsorption. The experimental effort will include determining the coverage dependence of the heat of adsorption, which also is important for controlling the isotherm shape. Theoretically based computational efforts will elucidate the anticipated clustering of water molecules around ions in solids (e.g., polymers) and on surfaces (e.g., silica gel as a practical surface) and with organized molecular assemblies (OMA) for model surfaces.

The influence of different ionic size, charge, and surface (solid) concentrations will also be understood by systematically varying these parameters on model surfaces (e.g., Li+, Na+, K+, Cs+, Mg++, and Al+++ on silica and OMA surfaces).

The surfaces and materials will be characterized for their (a) adsorption/desorption behavior using micro-balance and thermal desorption techniques, (b) correlation with surface composition, (c) bonding using infrared, x-ray photoelectron spectroscopy (XPS), and UPS techniques; (d) topography with scanning electron microscopy (SEM), and (e) contact potential changes. A correlation of the surface coverage, surface composition, bonding, and energetics will be made to provide a unified understanding of isotherm shapes. For both model and practical surfaces, scanning tunneling and atomic force microscopy will be attempted to elucidate the cluster size and regularity of the clusters. By varying the factors that influence water sorption capacity (e.g., surface area; surface charge ion concentration and size; impurities; solid materials), an understanding of the limits of modifying surfaces or solids will be sought. This understanding will ultimately be useful for anticipating sorption capacity losses from contamination of desiccant surfaces/ materials.

Advanced Solid Desiccant Materials. This project includes (a) synthesis and preparation of new desiccant materials and concepts, (b) modification of existing materials to improve their sorption performance properties, (c) synthesis of composite desiccant materials, (d) characterization and experimental studies of potential and candidate desiccant materials, and (e) testing of the efficiency of desiccant materials for correlating the influence of isotherm shapes capacity, and other properties with the conclusions from Collier's (1988) system analysis studies.

(a) Synthesis and preparation of new desiccant materials and concepts.

Both polymeric and inorganic desiccants will be synthesized in the search for the "ideal" material. New polymeric materials will be molecularly engineered to produce new classes of desiccants. Possibilities that will be explored include:

- Synthesizing new super-hydrophilic polymers (or gels) that may be grafted onto structural polymers

- Synthesizing new polymers that may be regenerated by a photo-induced triggered-collapse phenomenon

- Preparing cross-linked hydrophilic polymers that may be more readily attached to structural polymers

- Preparing model inorganic surfaces with appropriate organic functional groups (OFG) attached via organized molecular assemblies. The OFG may have a known hydrophilic character (e.g., C=O, COOH) or may be exchanged with cations to form an ionic salt of an acid group (e.g., R-COONa), but can be used to convert a high area inorganic surface to one with a high concentration of the needed water sorption sites

- Preparing inorganic surfaces with new surface species that enhance the water sorption properties of existing desiccants (e.g., doping silica gel surfaces)

- Developing new or improving existing synthesis routes for providing more consistent products formed (e.g., better control at molecular weight, percent sulfonate, and counterion concentration of PSSASS).

(b) Modification of existing materials to improve their sorption performance properties.

Both existing polymeric and inorganic desiccants will be modified to improve sorption properties of the material. Possibilities that will be explored include:

- Modifying the various anionic salts of candidate polymeric acids (e.g., salts of PSSA and AMPS) with cations of different charge and size (e.g., Mg++, Al+++)

- Modifying the various cationic salts of potential candidate polymers (e.g., PVBTAC) with anions with different charge and size (e.g., F^-, $C1^-$, Br^-, $O^=$)

- Preparing cross-linked products of hydrophilic polymers that have sorption behavior like Type 1M desiccants.

(c) Synthesis and preparation of composite desiccant materials.

This effort will involve identifying, synthesizing, fabricating or preparing advanced composite desiccants. Because some of the advanced desiccants may not be in a form that can be directly used in a dehumidifier, they have to be supported by an inert material. For example, desiccant particles can be captured within a polymeric substrate using various technologies without adversely affecting their sorption properties. Possibilities that will be explored include:

- Identifying advanced desiccant materials not suitable for direct fabrication into a dehumidifier

- Identifying processes and supporting inert materials to integrate desiccant materials and inserts into a single desiccant composite that preserves the sorption capacity of the desiccants

- Preparing desiccant composites

(d) Characterization and experimental studies of advanced desiccant materials.

The polymers synthesized or modified in (a) and (b) and composite desiccants in (c) as well as the most attractive candidate desiccants already identified must be characterized or subjected to further experimental studies. In addition to determining the sorption properties of the desiccants, the following will be carried out as required or as needed:

- Characterizing polymers for their molecular weight, percent of actual functional groups, and percent of active ionic species

- Measuring the isotherms from 15 to 35°C to obtain heats of adsorption and dependence of heat of adsorption on adsorbed surface coverage

- Measuring isotherms of the candidate materials at the anticipated regeneration temperature for the desiccant

- Evaluating the cyclic stability of candidate ADM by accelerated or abbreviated testing or both

- Evaluating the sorption performance of ADM under cyclic conditions

- Performing theoretically based computer simulation of diffusivity measurements and comparing the calculations with data taken with microbalances

- Determining the temperature dependence of adsorption and desorption for candidate materials

- Establishing the optimum adsorption and regeneration temperatures for candidate ADMs

- Performing controlled studies to investigate the causes of sorption performance degradation

- Conducting tests for studying co-adsorption by desiccants to evaluate their possible simultaneous or sequential use for removing environmentally undesirable gases or vapors. (This work should be coordinated and be complementary to current research now being funded.)

- Initiating the use of thermal gravimetric analysis equipment for rapid cyclic studies of water vapor sorption/desorption to test for cyclic stability

- Perfecting additional experimental procedures as needed.

(e) Testing ADM for correlation with a Type 1M behavior.

Until additional systems analysis work is completed, the sorption properties of the ideal desiccant will be based on those identified by Collier. Candidate ADM, state-of-the-art desiccant materials will be subjected to evaluation in NREL's cyclic test facility. These results will be evaluated interactively with results from systems analysis studies, components research, and other results in this section.

Fundamental Research on Water Vapor/Liquid Interactions. The focus of this project will be to understand the basic mechanisms of absorption of water vapor by organic and inorganic liquids and how the water-vapor/liquid-interface interactions control the isotherm shape, capacity, and heat of absorption. The rate of moisture uptake by the liquids will be investigated to understand the mechanisms that influence the moisture diffusion rate. The nature of the dipole (water) interactions with molecules of the liquids will be investigated. The relative size of the molecules and the forces of these interactions ultimately control the moisture equilibrium capacity. Proper additives for improving heat and mass transfer performance need to be identified. The investigation will include both experimental and theoretical efforts. The results from this project will be useful for modifying the chemical structure of liquid desiccants for improving their sorption behavior.

Advanced Liquid Desiccant Materials. Corrosion is the primary concern in the liquid desiccant systems. The objective of this activity is to develop noncorrosive liquid desiccant materials with the low vapor pressure and sorption properties of the sate-of-the-art liquid desiccants (mainly lithium chloride). The liquid desiccant should be also nontoxic, nonflammable, odorless, and should have low viscosity and low costs. This project will include the following:

(a) Identification of optimum liquid properties. A basic understanding of key properties and their effects on cooling system performance will be developed.

(b) Development of new improved liquid desiccants. New candidate materials (such as salt mixtures and adding additives to existing materials) that have the potential to reduce system cost, improve system performance, and reduce corrosion problems should be studied. The use of mixtures of existing liquid desiccant salts to improve performance and reduce cost should be investigated.

(c) Development of advanced polymeric liquid desiccants. Potential benefits of this approach include the possibility of molecularly engineering the desired sorption capacity, isotherm shape, and kinetics with no corrosive properties. Existing liquid polymers will be evaluated and modified, and new polymers with desired properties will be synthesized.

Both theoretical and experimental activities will support this project.

3.1.2 Heat- and mass-transfer research

In the efforts to improve the efficiency and reduce the cost and size of desiccant cooling system components, it is important to understand the basic heat- and mass-transfer processes involved in each process step. Knowledge of these mechanisms can be used to identify changes in component design such as integration of the new desiccant materials in advanced dehumidifier configurations, the effect of operating conditions on the efficiency of the processes. Development of methods to increase the heat- and mass-transfer coefficients of dehumidifiers bridges the gap between improved desiccant properties and component design. This effort is an intermediate research activity between materials R&D and components R&D. The advanced desiccant materials identified in materials R&D will be evaluated experimentally and theoretically in a context of a dehumidifier configuration. The desiccant/configuration combinations that show promise will be further evaluated in a component form in the component R&D projects. Two research areas have been identified to address these issues: solid desiccant heat and mass transfer, and liquid heat and mass transfer. Validated heat- and mass-transfer models of desiccant materials in a specific geometry or configuration will be identified for both liquid and solid systems.

Solid Desiccant Heat and Mass Transfer. The performance of a solid desiccant material in operation is affected by the physical design of the dehumidifier component and operating conditions. Some of the factors that come into play include the geometry of flow passages, amount of inert heat capacity, method of regeneration, and method of constraint or attachment used to bind the desiccant in the dehumidifier. These factors affect the efficiency of the desiccant used in its adsorption and desorption of water vapor.

In this project, dehumidifier matrices from advanced desiccant materials identified in materials R&D projects will be fabricated. The goal of this task is to characterize the fundamental thermal and moisture behavior and the pressure drop characteristics of these advanced dehumidifier matrices. The project will also identify design parameters that maximize efficiency.

Liquid Desiccant Heat and Mass Transfer. The performance of a liquid desiccant dehumidifier, in addition to the properties of the desiccant, depends on the physical design of the exchanger component. The rate of heat and moisture transfer determines the performance. The complex mechanisms of heat and mass transfer of advanced liquid desiccants identified in the materials R&D section should be investigated in various component designs. The purpose of this research is to experimentally and analytically investigate the heat- and mass-transfer mechanisms in advanced liquid desiccant exchangers and identify changes in component designs to maximize the associated heat transfer coefficients and reduce the pressure drop.

3.1.3 Component research and development

It is extremely important to develop low-cost, efficient components to advance the desiccant cooling technology successfully in the HVAC market. The strategy to achieve this goal entails identifying and verifying designs that will greatly improve performance and, more importantly, reduce cost and size. The efforts in this area will key on advanced solid desiccant dehumidifiers, advanced liquid desiccant dehumidifiers, high-efficiency heat exchangers, and liquid desiccant storage. All R&D activities in this category must be conducted with involvement of manufacturers, particularly the investigation of cost-effective manufacturing techniques.

Advanced Solid Desiccant Dehumidifiers. It is very important to use cost-effective manufacturing techniques to develop low-cost dehumidifiers. In addition, a dehumidifier should be easily integrated into the system, have low pressure drop for low parasitic power consumption, and have highly uniform flow passages for high heat- and mass-transfer performance. The major part of this effort is fabrication and testing of prototype dehumidifiers. Rotary, fixed-bed, and switched-bed dehumidifiers should be considered. This effort should take advantage of the findings and results of materials R&D and heat- and mass-transfer research. All types of cost-effective manufacturing techniques such as injection molding, casting, and extrusion should be used. The performance of prototype dehumidifiers should be evaluated experimentally and the results should be used to validate and improve the current analytical models. These models then will be used extensively in industry.

Advanced Liquid Desiccant Dehumidifiers. For successful commercialization of liquid desiccant systems, the liquid dehumidifier should be highly efficient, low in cost, and without corrosion problems. To eliminate corrosion problems, new desiccant materials resulting from the materials R&D will be used in the dehumidifier. The dehumidifier will utilize various designs and configurations (such as spray-packed column or spray-coil designs) for contacting the liquid and air to be dehumidified.

The removal of heat of absorption by a heat exchanger is an integral part of a dehumidifier. Two designs will be investigated: air source and water source. Air-source designs use indirect, evaporatively cooled air as a heat sink, while water-source designs use groundwater or a cooling tower as the sink. It is necessary to evaluate these alternatives in terms of cost and performance. Various designs and concepts for desiccant regeneration should be considered and evaluated for cost, performance, and applicability.

High-Efficiency, Low-Cost Heat Exchangers. Several studies have identified the critical role that low-cost high-efficiency, low-pressure-drop heat exchangers play in developing efficient desiccant cooling systems. Compact rotary heat exchangers have provided a high level of performance and low pressure drops. However, high costs and air leakage problems have to be resolved with this design. Costs lower than state-of-the-art designs must be obtained without a decrease in efficiency.

The goal of research in this area is to identify design concepts that will achieve high performance with acceptable levels of size, cost, and reliability. This will include the investigation of alternative materials and innovative concepts. Proof-of-concept testing and evaluation for candidate designs will be conducted.

Liquid Desiccant Storage. One of the advantages of liquid desiccant cooling systems is the ability to store energy in the form of concentrated solution, thereby eliminating the need for insulated storage and inefficiencies associated with thermal heat loss. However, further advantages can be gained by using stratified storage to separate concentrated and dilute solutions and by using isothermal phase-change materials (PCMs) in the storage to limit temperature swings from solution regeneration.

The liquid storage system can be used in conjunction with solar collectors or low-cost off-peak electricity. In recent years, utilities encourage and support strategies that use off-peak electricity, particularly in the cooling season. It is an opportune time to combine desiccant cooling and regeneration strategies using off-peak electricity. Liquid desiccant storage is one concept that may utilize off-peak electricity.

Work in this area will investigate materials and methods of improving storage techniques for liquid desiccant cooling systems.

Auxiliary Components. Although major attention should be paid to dehumidifiers and heat exchangers, improving other components should not be overlooked. These components include direct and indirect evaporative coolers, air fans, regeneration units (such as boilers, gas burners, and solar collectors), instrumentation, and control devices. Their costs and size need to be reduced and component performance and reliability should be increased. Particular attention should be given to ease of integration of these components into a complete system.

3.1.4 Systems research and development

Success in establishing a technology base suitable for commercialization by industry requires verification of the performance of critical components, subsystems, and integrated systems. The objectives of the system R&D are to (1) develop systems with improved performance and reduced size and cost by considering different configurations and operating conditions, (2) evaluate the potential of new innovative system concepts, (3) experimentally verify the integrated performance of components and subsystems into systems, (4) develop design tools, and (5) develop and evaluate control strategies for operation of the cooling systems. Solid and liquid cooling systems and hybrid or integrated desiccant cooling systems need to be considered. Most of the activities of this R&D effort should be done in collaboration with manufacturers.

Systems Performance Analysis. Considerable effort has been directed toward developing analytical models to use in evaluating desiccant cooling systems. This effort needs to be continued. New system concepts and innovative combinations of subsystems and components will be evaluated on a common base of application. In this way the relative merits of a system concept can be judged, and the evaluation will provide a consistent basis for decisions regarding further R&D. High-potential concepts such as staged regeneration, unbalanced flow, and hybrid and integrated systems will be evaluated. Various operating conditions such as full load and part load also will be analyzed. Existing mathematical models for various components will be modified to become modular so they can be easily used for different system designs. Particularly, these models should be incorporated into HVAC and building simulation programs.

The analysis techniques will also be used to direct future research and identify research opportunities for materials, components, and subsystems.

Systems Economic Analysis. The economic performance of desiccant cooling systems will be evaluated based on the first cost and operating and maintenance costs. The economic analysis will be based on design-point or seasonal performance, primary energy costs, and various climatic conditions. Economic comparisons with conventional cooling systems will be made. The objectives of this effort are to evaluate the economic potential of various designs and to provide feedback on cost targets for commercial market penetration of desiccant systems. All benefits of desiccant systems such as energy savings, reduction in use of CFCs, improved comfort conditions, and possibly improved indoor air quality should be considered in the economic analysis.

Advanced Cooling Systems Development. Based on the results of systems performance and economic analysis activities, desiccant cooling systems will be fabricated using the advanced components and cost-effective manufacturing techniques. The objective is to produce low-cost, compact, efficient, and reliable desiccant systems. Easy and cost-effective integration of components is an important step in this activity. Manufacturers should be involved in fabrication of advanced components and cost-effective manufacturing techniques.

Systems Testing and Evaluation. Invaluable information has been gained by testing components in a system arrangement, revealing interactions and operational problems not foreseen. Also, the experience gained from systems testing has led to the identification of future research issues. However, systems testing activities have been limited and should be expanded.

Each of the systems discussed previously (solid/liquid open-cycle cooling and hybrid or integrated) will, at an appropriate stage of the proof-of-concept, be tested in fully instrumented system test facilities. The systems that show the greatest promise will be tested and monitored at various field site locations. New and innovative concepts also will be tested and evaluated. The data obtained in these activities will be used to verify systems models.

The objectives of the R&D in this area are to verify the performance of desiccant cooling systems and demonstrate the potential of these systems. Such information is crucial to acceptance of the products by industry and end-users.

Design Tools. Development of design tools is one of the most important aspects of bridging the gap between the new technologies developed by the research community and the needs of the private sector for information. Analytical tools that permit prototype design performance predications and optimization can be of great value in the successful development of commercial products. Design and calculations tools such as handbooks, look-up tables and charts, and computer programs will be developed. The computer programs should be relatively accurate and fast to be useful to the end-users. Work in this area will be on hybrid, solid, and liquid desiccant systems.

Control Strategies. The overall performance of a desiccant cooling system depends on the control strategy and the method of operation. Successful full-load and part-load operation depends on the control strategies and quality of system/buildings sensors. Only a few studies have investigated the control strategies for desiccant cooling systems.

The goal of this project is to develop and implement control systems and methods for all cooling system concepts (solid, liquid, and hybrid). The latest developments in instrumentation and microprocessing will be adopted in the control strategies.

3.1.5 Durability and contamination research

The reliability and service life of desiccant cooling systems, particularly those of desiccant dehumidifiers, are of concern to industry. One research project to date has investigated the effect of cigarette smoke contamination on several existing solid desiccant materials. For new desiccants, similar research projects need to be conducted to obtain experimental data to evaluate potential impact of desiccant degradation on system performance. Desiccant degradation is caused because of thermal cycling and exposure to airborne contaminants. As new advanced desiccant materials, solid or liquid, are developed, they have to be investigated for their durability on thermal cycling and exposure to contaminants. Experimental data should be obtained both in the laboratory under controlled conditions and in actual working environments in the field.

Because the performance of desiccants may degrade, strategies to alleviate or eliminate the degradation problem should be devised and evaluated experimentally. Alleviation strategies include filtering, replacing, reconditioning, adjusting operating conditions, and deep regeneration.

3.1.6 Using desiccants for improving indoor air quality

If a desiccant degrades on exposure to contamination, it may occur because the contamination is adsorbed or absorbed by the desiccant. Although this may reduce the service life of a desiccant, it means that the desiccant can be used as a means to remove airborne contaminants and improve indoor air quality. A research project has been conducted (at the University of Missouri-Columbia, funded by GRI and ASHRAE) to investigate this aspect of desiccants as air purifiers. Coordinated research projects should be conducted to establish whether or not desiccants can be used for improving indoor air quality in addition to dehumidification. As part of this effort, existing and new desiccants (such as Type 1M inorganic desiccants and polymeric desiccants) will be tested for their ability to sorb pollutants in the presence of water vapor. Both solid and liquid desiccants will be considered. Integration of these desiccants in components and systems will also be pursued.

3.1.7 Innovative concepts

In addition to conventional concepts that have been developed to varying degrees, there are a number of new and innovative concepts that have not been addressed sufficiently. The objective of this project is to study the merits of these new concepts and identify future directions for research. Descriptions of some of these concepts follow.

PCM-Desiccant Combinations. In this new project, potential benefits of combining PCMs with desiccants will be investigated. Desiccants release heat on sorption of moisture. This heat can be transferred to and stored in a PCM for later regeneration of desiccant. As a result, the amount of energy for regeneration is significantly reduced. Another advantage may be reduced temperature increase during the dehumidification process, which allows smaller downstream temperature and reduces sensible load. The dehumidification process may also be completed almost isothermally, which improves the efficiency of the dehumidification process. A key issue is the thermal coupling of the heat of sorption of desiccant to the heat storage in a properly triggered PCM. Liquid and solid desiccants and all types of PCMs will be considered.

The fundamental mechanisms of heat and mass transfer of various PCM-desiccants should be investigated theoretically and the best combinations identified. The promising combinations need to be studied experimentally. Further R&D directions will be identified as the work progresses.

Desiccant-Cogeneration Systems. In this project, the potential of integrating desiccant dehumidification, direct-indirect evaporative cooling, and cogeneration into a single system will be investigated. In the proposed system, a desiccant subsystem removes the latent load (moisture), the direct-indirect evaporative cooling subsystem removes the sensible load, and the useful heat and waste heat from the cogeneration subsystem provides the required heat for regenerating the desiccant subsystem. The cogeneration subsystem also provides the electricity requirements for running auxiliary units such as fans, pumps, control systems, and hot water systems for domestic use. This system will not only eliminate the use of CFCs but can lower the electricity demand, particularly during peak hours.

The objectives of this project are to (1) analyze the technical and economic viability of the concept, (2) fabricate and test a packaged system if the first objective is successful, and (3) field test a prototype and demonstrate the benefits. This project will be accomplished with cost sharing from utilities and manufacturers.

Desiccant Cooling For Utility Demand-Side Management. Peak-load reduction and load shifting are among the approaches that utilities are using to manage increases in power demand. Desiccant cooling offers potential for peak-load reductions and load shifting through the use of solar energy and natural gas. In this project, the potential of desiccant cooling to be integrated with demand-side management activities would be investigated. Utilities need to be involved in this project.

Desiccant Regeneration with Waste Heat. In this project, the potential of using waste heat from conventional vapor compression machines, heat pumps, thermally driven cooling devices, and industrial processes for desiccant regeneration would be investigated. The use of waste heat from industrial processes for dehumidification of air for various air conditioning or process control applications can have a significant energy impact.

3.1.8 Collaborative research and technology transfer

The principal elements of this part of the program are technology transfer and collaborative research. To accomplish these, we need to:

(a) Form an advisory committee
(b) Secure industry involvement, and
(c) Integrate collaborative efforts with industry, national laboratories, and universities.

Electric and gas utilities are attractive partners to support new technology development and field testing, so they must be convinced of the relevance and importance of the desiccant cooling systems in managing demand. Other industrial partners will include manufacturers, process equipment suppliers, and representatives from the buildings and transportation industries. Other federal agencies such as Housing and Urban Development (HUD), the Federal Energy Monitoring Program (FEMP), and the Environmental Protection Agency (EPA) will also be included.

For (a) above, NREL has routinely formed advisory committees in major research areas. For the desiccant cooling program, an appropriately balanced committee will be formed. For (b) above, industrial involvement will be secured via one of several possibilities; e.g., a consortium of industrial partners, separately arranged collaborators, or cost-shared subcontractors. Workshops, reviews, and meetings will be held to obtain assistance in planning and to provide technology transfer. Articles in peer-reviewed journals and trade magazines will be published, and results of the R&D program will be presented at pertinent meetings and conferences. Technical, marketing, and general documents about the technology will be distributed. NREL has successful experience with all these arrangements.

For (c) above, integrated coordination/collaboration will result from implementing (b). All existing domestic work will be monitored, and NREL will serve as the central repository for existing knowledge in industry (e.g., GRI, EPRI, Meckler, Kathabar, Cargocaire, Tecogen, ADL, Gard, Eaton, LaRouche Chemicals, Trane, Carrier, Semco, QDT, Bry-Air, Airflow Company, Niagara-Blower, etc.), national laboratories (e.g., ORNL and FSEC), and universities (e.g., Penn State University, Colorado State University, University of Wisconsin, University of Texas at Austin, Texas A&M, University of Pittsburgh, Arizona State University, University of Chicago, and IIT); and other federal agencies (HUD, EPA, and DOD).

A single information center is crucial because most of the desiccant dehumidifier manufacturers are small firms with minimal R&D budgets; it is necessary to work with them and their associations to get feedback on integrating desiccant units into building HVAC systems. The smaller firms may develop their own proprietary designs or use the DOE/NREL-developed technology.

With an enhanced funding scenario, active participation in R&D will be sought through cost-shared subcontracts for specific aspects of the work. For example, the field evaluation of prototype units and demonstration projects would require interaction with manufacturers and subcontracts. As the desiccant cooling R&D proceeds, intellectual property will be created, and more extensive industry participation will be sought.

3.2 Implementation and Demonstration Program

The projects that can demonstrate the advantages of desiccant cooling systems in less than 3 years using existing technologies and equipment can have a positive impact on the long-term advancement of the desiccant technology. Immediate and successful completion of such projects can provide technical and financial support from end-users (building owners and managers), contractors (engineers, A/E firms, etc.), manufacturers, utilities, state and local energy offices, professional societies (e.g., ASHRAE and ASME), universities, public and private organizations, and federal agencies (DOE, DOD, EPA, HUD, DOC, etc.). An important part of the desiccant cooling program is improving market acceptance for desiccant cooling systems. The following subsections describe elements of the program.

3.2.1 Comparative demonstration project

The purpose of this project is to demonstrate quickly the performance difference between a desiccant cooling system and a conventional refrigeration system using a side-by-side approach. In this project, two test rooms with similar construction, envelope conditions, and cooling load profiles will be built side by side. One test room will be conditioned with a vapor compression system, while the other will have a desiccant cooling system. The performance of the two systems at fixed-set points or fixed loads will be compared. The test rooms will be built so visitors can go from one test room to the other easily to observe and feel the differences between the two systems. This type of project could be funded collaboratively with the private sector and public utilities.

3.2.2 Scale model demonstration/education project

The purpose of this project is to build scale models of typical desiccant cooling systems for demonstration and educational purposes. These scale models can be used to educate individuals who are not familiar with the concept of desiccant cooling and to demonstrate effectively the operation of the concept. Three-dimensional and attractive scale models that resemble the final products are much more effective in conveying concepts and information to a general audience than other means. Collaborative efforts with the private sector would also be appropriate in the project.

3.2.3 Computer model demonstration/education project

The purpose of this project is to develop computer models that can quickly present the performance of typical desiccant cooling systems. The computer models can show the advantages/disadvantages of the desiccant system over conventional systems for different climate conditions and for different load profiles. Attractive computer graphics will be used to present the performance and economic results. This project is also aimed at establishing a baseline for comparison with competing technologies.

3.2.4 Hardware demonstration project

The objective of this project is to demonstrate the advantages of using desiccant cooling systems in buildings. These advantages are energy savings, lower operating and maintenance costs, reduction of CFC use, and improved comfort conditions. In this project, existing desiccant cooling and dehumidification equipment will be used for air conditioning federal or public buildings such as post offices or public schools. Initial capital and installation costs may be higher than those of conventional systems. The performance of the system, building energy consumption, and occupant response will be monitored in the cooling season. The results will be compared with the same type of buildings that use conventional A/C systems. This project may be cost-shared by manufacturers, utilities, or FEMP.

3.2.5 Standards development

There are a number of experimental and analytical methods for evaluating desiccant materials, components, and systems. The differences in the methods may provide different results that cannot be compared easily.

A standardized method of testing or analysis is needed so comparison of different products can become easier. Currently ASHRAE is developing a standard method for testing dehumidifiers.

In this project, with the assistance of interested organizations such as ASHRAE, the American Society of Mechanical Engineers, and the American Society for Testing and Materials, standard methods for testing and analysis of desiccant materials, dehumidifiers, other components, and desiccant systems will be developed.

3.2.6 Improving market acceptance

The majority of building owners, designers, HVAC consultants, and engineers do not specify desiccant cooling systems. As a result major air conditioning equipment manufacturers do not produce these systems. If the building community begins to request desiccant equipment, manufacturers will begin to produce them. Overcoming barriers to technology acceptance by designers, and HVAC consultants should be addressed in a balanced desiccant cooling program. In addition to reliability and performance improvement and system cost reduction (previously discussed), the building community needs to be convinced that desiccant cooling is a viable option (economically and technically). Efforts have to be directed toward educating and training professionals and demonstrating desiccant systems. Many systems should be field tested, and results should be shared with the building community. Educating and training can be achieved through professional society meetings, short courses and training classes, and state energy agency activities. Utilities need to take a role in promoting desiccant technology.

3.3 Program Management

Effective program management of this effort and existing DOE-funded desiccant cooling R&D can have a major impact on securing industrial involvement, collaboration, and support. NREL's program management experience in large programs such as Solar Thermal, PV, Wind, and Buildings has shown that a focused management effort facilitates and encourages industry participation.

We propose that the actual implementation of desiccant-cooling program objectives be performed by NREL. NREL will accomplish this through (1) management of program activities, (2) projects performed in-house, (3) contracted work in areas assigned to them by DOE Headquarters, and (4) interaction with other organizations such as GRI, EPRI, national laboratories and federal facilities, and others interested in funding pertinent desiccant cooling projects. Specific functional responsibilities of NREL will include:

- Responding appropriately to DOE policy, guidance, and directives
- Performing in-house technical research
- Awarding, monitoring, and managing technical research subcontracts
- Preparing annual detailed plans that show key objectives, milestones, assignments of responsibilities, and key accomplishments
- Disseminating information to DOE Headquarters, other DOE laboratories and centers, industry, and universities.

Table 3-1 presents the major elements of the proposed desiccant cooling program plan. An advisory group will be formed to assist in evaluation of the program and provide guidance on pertinent issues. Program assessment will be conducted routinely during regularly scheduled management review meetings.

However, evaluations made by special task forces and advisory committees during special studies and at topical and technical meetings also will contribute to the program assessment process.

3.4 Outcome

This proposed research program presents a realistic, comprehensive approach to establishing desiccant cooling as a significant air conditioning alternative. It is designed to maintain momentum in the development of the industry with short-term results while continuing to develop long-term options that show the greatest promise for practical applications.

The program plan is realistic. It is consistent with the National Energy Strategy, thus ensuring continued support for planned research activities.

The program also acknowledges the importance of private-sector participation, yet accepts the fact that industry's ability to assume risks is limited. This recognition ensures that research will be complementary to private-sector activities and that industry will be prepared to adopt successful research results.

Moreover, the program is based on sound technical objectives that have evolved from 15 years of research experience. Although the ultimate success of research activities is subject to uncertainty, the insight gained from previous research has been used to substantiate selected research paths, enhancing the likelihood that successful results will yield practical applications.

Finally, the proposed program is realistic because it is flexible. It not only provides mechanisms for reevaluation through continued technical assessments and program reviews, but also incorporates a set of technical goals based on the integrated performance and projected costs of all major system components. This planning consideration offers flexibility by providing a range within which cost and performance trade-offs can be optimized. A continuing review process by industry representatives in the context of topical review meetings will also be used to maintain proper research directions.

The program is also comprehensive. It represents a balanced approach to research and development by addressing all major areas of desiccant cooling research, including the most promising known technology options as well as mechanisms for developing innovative ideas for liquid, solid, and hybrid options.

The options under consideration have been carefully selected based on years of research and experience. Although the degree of uncertainty for several options remains high, the carefully designed multiple approach makes the risk of total program failure very low. In essence, the plan consolidates individual risks that industry is unable to assume into a program that has a high probability of overall success.

It is difficult to predict the specific future of a technology whose outcome will be affected by both the risks inherent in research and the uncertain future status of competing alternatives. Furthermore, this proposed program addresses technology development for the ensuing 5 years, which is a relatively short time in the development of a major new technology.

3.5 R&D Priorities

In order for the desiccant cooling technology to have a significant penetration in the HVAC market, components and systems costs should be reduced, performance and reliability of systems should be improved, and market acceptance of the products by the building community should be increased. In previous sections, we have laid out a program for achieving these objectives. The program consists of

Table 3-1. Elements of Proposed Desiccant Cooling Program

RESEARCH AND DEVELOPMENT ELEMENTS	ACTIVITY #
Materials Research and Development	
Fundamental Solid Desiccant Research	1
Advanced Solid Desiccant Materials	2
Fundamental Liquid Desiccant Research	3
Advanced Liquid Desiccant Materials	4
Heat- and Mass-Transfer Research	
Solid Desiccant Heat and Mass Transfer	5
Liquid Desiccant Heat and Mass Transfer	6
Components Research and Development	
Advanced Solid Desiccant Dehumidifiers	7
Advanced Liquid Desiccant Dehumidifiers	8
High-Efficiency Heat Exchangers	9
Liquid Desiccant Storage	10
Auxiliary Components	11
Systems Research and Development	
Systems Performance Analysis	12
Systems Economic Analysis	13
Advanced Cooling Systems Development	14
Systems Testing and Evaluation	15
Design Tools	16
Control Strategies	17
Durability and Contamination Research	18
Using Desiccants for Improving Indoor Air Quality	19
Innovative Concepts	
PCM-Desiccant Combinations	20
Desiccant-Cogeneration Systems	21
Desiccant Cooling for Utility Demand-Side Management	22
Desiccant Regeneration with Waste Heat	23
Collaborative Research and Technology Transfer	24
PROGRAM IMPLEMENTATION ELEMENTS	
Comparative Demonstration Project	25
Scale Model Demonstration/Education Project	26
Computer Model Demonstration/Education Project	27
Hardware Demonstration Project	28
Standards Development	29
Improving Market Acceptance	30
PROGRAM MANAGEMENT	

many R&D activities, and execution of these activities depends on the availability of funding. The R&D activities need to be prioritized to select the ones with the most significant impacts in case of limited resources. The following is the list of our prioritized R&D activities for the first 2 years of 5-year program (please refer to Table 3-1 for the corresponding activity number).

1. Demonstration of the state-of-the-art desiccant systems for air conditioning of various buildings (activities #25, #22, #28, and #30).

2. Development of low-cost, high performance, compact solid dehumidifiers (activities #1, #2, #5 and #7).

3. Development of noncorrosive, low-vapor-pressure, and low-cost liquid desiccant materials (activities #3, #4, and #6).

4. Development of low-cost, high performance, and compact solid and liquid systems (activities #7, #8, #14, #15).

5. Conducting system performance and economic analysis studies (activities #12 and #13).

6. Development of systems utilizing waste heat for desiccant regeneration, particularly for industrial application (activity #23).

3.6 Summary

In this section, we identified research, development, and demonstration needs for advancing desiccant-cooling technology and ensuring its increased penetration in the marketplace. We identified R&D needs in the area of desiccant materials, components, systems, and applications. The major need for desiccant-cooling technology is the development of a low-cost, high-performance, and reliable desiccant system for mainstream HVAC applications. We have identified a comprehensive R&D plan and implementation program to achieve results that satisfy these needs. Though desiccant cooling technology has developed significantly in recent years, the continuation and strengthening of the federal/industry partnership addressed in this program establishes the necessary framework for stimulating even greater technical progress. It is, however, the mutual commitment to and continuing confidence in desiccant cooling as a viable, near-term option as well as formulation of a logical approach to achieving technical goals that are critical to overall success.

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report is a supplement to Desiccant Cooling: State-of-the-Art Assessment (NREL/TP-254-4147, DE93000013). In this supplement document we have described a detailed program assuming sufficient funding to implement the R&D activities needed. Desiccant dehumidification is a mature technology for industrial applications, and in recent years the technology has been used for air conditioning a number of institutional and commercial buildings. Our proposal is based on argumentative discussions at various national meetings with leaders of the technology. The goal is the penetration of the broad air conditioning market. This work is funded by the Buildings technology Office of the U.S. Department of Energy.

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