THERMALLY ACTIVATED TECHNOLOGIES

TECHNOLOGY ROADMAP

Developing new ways to use thermal energy to meet the energy needs of homes, offices, factories, and communities

May 2003

Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

Executive Summary

The purpose of this Technology Roadmap is to outline a set of actions for government and industry to develop thermally activated technologies for converting America's wasted heat resources into a reservoir of pollution-free energy for electric power, heating, cooling, refrigeration, and humidity control. Fuel flexibility is important. The actions also cover thermally activated technologies that use fossil fuels, biomass, and ultimately hydrogen, along with waste heat.

The Bush Administration's National Energy Policy (May 2001) outlines a course of action for America to increase energy supplies and modernize conservation while strengthening the economy, national security, and protecting the environment. The Strategic Plan of the Office of Energy Efficiency and Renewable Energy (October 2002) provides a vision of America's energy future where:

"...Our homes, businesses, and communities will generate much of their own power from renewable resources and sell excess energy back to local generators..."

On January 6-9, 2003 a technology roadmap workshop was held in Dallas Texas.[1] At this event, 53 practitioners from industry, government, universities, and national laboratories came to general agreement on:

- a shared vision of the future for thermally activated technologies,
- the technical and institutional barriers that interfere with achieving the vision,
- research, development, demonstration, and technology transfer actions to address the barriers, and
- paths forward for industry and government partnerships to address the top priority actions

> **Vision**
>
> **Thermally Activated Technologies**
>
> *Why waste a good thing?*
>
> *In 2020, recycling the Nation's vast reservoir of waste heat will be a significant source of pollution-free energy. Consumers will be able to choose from an array of clean, reliable, and affordable thermally activated technologies that will increase the efficiency, productivity, security, and quality of their indoor environments.*

Major Findings and Conclusions

- Thermally activated technologies are an important part of the Nation's strategy for accomplishing critical energy and environmental goals.
- In fact, there exists a renewable and pollution-free energy resource that thermally activated technologies are uniquely able to tap. Unfortunately policy makers and energy developers are mostly unaware of this resource. Its potential for development is poorly understood. That resource is waste heat.

[1] The proceedings for this workshop can be downloaded in PDF format from www.eere.energy.gov/der. A list of the participants can be found in Appendix A.

- Thermally activated technologies consist of equipment that use thermal energy for heating, cooling, humidity control, and power (mechanical and electric) in buildings, factories, campuses, industrial parks, and district systems. They include, for example, absorption chillers, desiccant humidity control and organic rankine energy recovery devices. Combined heat and power systems are a major user of thermally activated technologies, systems in which TAT equipment is integrated with power generation equipment to generate energy services for customers.

- Thermally activated technologies can be directly fired or operate using waste heat in combined heat and power applications.

- Today's thermally activated product lines are largely focused upon burning of fossil fuels as their source of thermal energy. These current products reflect markets, end-use applications, and manufacturing capabilities that currently sustain profitable business operations. They produce measurable public benefits: higher energy efficiency, higher indoor air quality, lower air emissions, and lower peak demand for electricity.

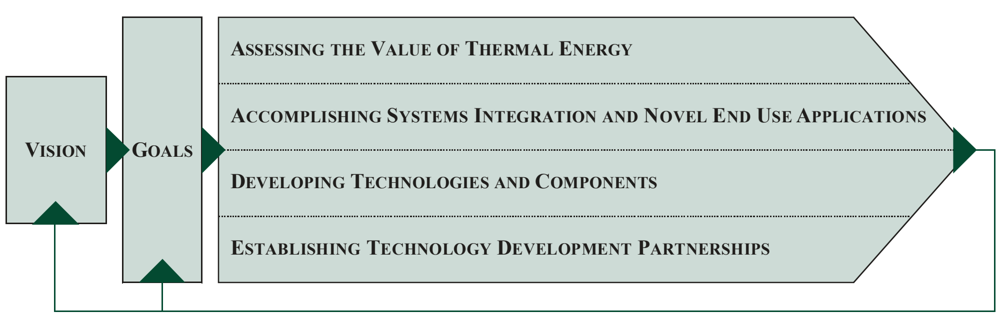
- Needed are more efficient, reliable, and focused thermally activated technologies that are capable of operating using a variety of energy sources including integration with low temperature waste heat, CHP systems, clean fossil fuels, biomass, and eventually hydrogen.

Path Forward

The Technology Roadmap for thermally activated technologies is organized into four main areas of activity as shown in the graphic below.

Government, industry, universities, and national laboratories need to work together to achieve the vision for thermally activated technologies, develop profitable markets, and produce public benefits such as higher energy efficiency, lower air emissions, healthier and more secure indoor environments, and more efficient electric grid operations. Committing to the collective pursuit of the actions outlined in this Roadmap marks a critical step in achieving a cleaner, more reliable, affordable, healthy, and secure energy future for America.

Thermally Activated Technology Roadmap Logic Flow



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1 Introduction

The *National Energy Policy* (May 2001) outlines a course of action for America to increase its energy supplies and energy efficiency while improving national security, the economy, and the environment. To carry out this policy, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) is working toward an energy future in which America's…

> "...homes, businesses, and communities will generate much of their own power from renewable resources and sell excess energy back to local generators…"
>
> *EERE Strategic Plan* (October 2002)

To help realize this vision, EERE is working with industry to explore the potential of thermally activated technologies to supply electric power, heating, cooling, refrigeration, and humidity control. These technologies are distributed energy resources located on-site that can be directly fired using fossil fuels, waste heat, biomass, and ultimately hydrogen. Since onsite thermally activated technologies reduce the need to transmit and distribute electricity, peak electric load to provide heating, cooling, and humidity control can also be reduced.

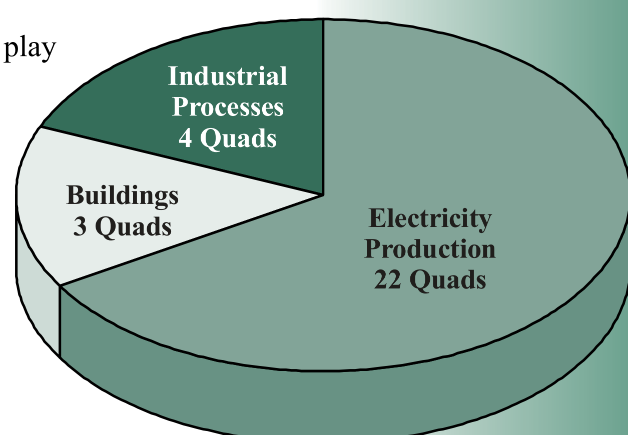
Thermally Activated Technologies

Thermally activated technologies use thermal energy for heating, cooling, humidity control, and power (mechanical and electric). These technologies can be developed to use heat from a wide variety of sources, including the waste heat available in U.S. buildings, factories, campuses, industrial parks, and district systems.

Common examples of thermally activated technologies include absorption chillers, desiccant humidity control and organic Rankine energy recovery devices.

These technologies can also utilize *waste heat*. This economical, renewable, and pollution-free energy resource is generated by energy processes in every sector of our economy, including buildings, industrial processes, transportation, and electricity generation. America's power producers, buildings, and industrial sectors annually vent *29 quadrillion Btu* of thermal energy into the atmosphere, lakes, and rivers. These thermal losses in the conversion of fuel to electric power esceed the amount of energy annually consumed by the U.S. transportation sector or by the entire Japanese economy.

Thermally activated technologies have an integral role to play in tapping this overlooked resource and accomplishing national energy and environmental goals. It is time for policy makers and energy developers to recognize and appreciate the potential for development of these technologies.



Estimated Waste Heat by Sector

With the notable exception of combined heat and power systems (CHP), most of today's heating and cooling technologies for industry, buildings, and community heating systems are not designed to make use of waste heat. This failure is attributable to the generally low temperature and poor quality of most waste heat. These characteristics have traditionally restricted the usefulness of waste heat in engines and other equipment. New, thermally activated waste heat recovery and recycling technologies could open the door for turning this resource into useful energy.

This *Thermally Activated Technology Roadmap* outlines actions that government and industry can take to develop thermally activated technologies for converting America's wasted heat into pollution-free energy for electric power, heating, cooling, refrigeration, and humidity control. The development effort will also expand U.S. fuel flexibility by producing technologies that can be directly fired using a wide range of fuels as alternatives to waste heat.

To begin the process of developing this Roadmap, the Department of Energy convened a *Vision Meeting* in November 2002. Twenty-five leaders of the thermally activated technology research, development, and deployment (RD&D) community discussed the current status of technologies, markets, and products and services. The discussion covered direct and associated technologies, such as desiccants, heat pumps, absorption chillers, sensors and controls, mass exchangers, heat exchangers, waste heat recovery equipment, and novel heat utilization concepts. This meeting produced a set of vision statements for the thermally activated technologies industry and a broad commitment to move forward in developing a technology roadmap.

A world eager for clean energy solutions can no longer afford to overlook this important opportunity. Americans have learned how to recycle paper, plastic, glass, steel, and aluminum — why not energy?

Subsequently, in January 2003, a roadmap workshop was held in Dallas, Texas. At this event, 53 practitioners from industry, government, universities, and national laboratories came to general agreement on the following:

- a shared vision of the future for thermally activated technologies,
- technical and institutional barriers to achieving this vision,
- research, development, demonstration, and technology transfer actions to address the barriers and high priority needs, and
- pathways to address priority actions through industry and government partnerships.

Participants in the Vision and Roadmap workshops are listed in Appendix A. Proceedings of the Roadmap Workshop may be downloaded at *www.eere.energy.gov/der*. This *Thermally Activated Technologies Roadmap* is based on the discussions that took place during the Roadmap Workshop and follow-on review by participants.

2 Thermally Activated Technology and Market Baseline

Thermally Activated Technologies have a long history and have seen generations of service both in direct-fired systems (where fossil fuels are used directly) to produce chilled water for air conditioning or in refrigeration and dehumidification as well as in equipment using steam or hot water to provide these services. Further advances in efficiency, size, and cost will result in greater use of Thermally Activated Technologies and in progress toward national energy and environmental goals. This is particularly true in the development of TATs that are powered by recovered waste heat. Few markets recognize the value of recycling heat energy on-site by converting it into other forms of heating, cooling, humidity control, or power. A range of thermally activated technologies can profitably serve these potential markets in which energy represents a significant cost factor and in distributed energy markets. Distributed energy consists of near and onsite, grid connected or stand-alone technology systems that can be integrated into residential, commercial, or institutional buildings and/or industrial facilities.

The industrial sector and the combined heat and power community are generally recognized as the biggest users of recycled *high-temperature* thermal energy (>1,000°F), while some institutional and government facilities have developed relatively advanced solutions in campus, healthcare, and building systems. Commercial businesses, by contrast, generally make limited use of energy recovery.

The various thermally activated technologies available today are reviewed below, followed by a brief discussion of key markets and non-technical factors that have hindered further technology development by the private sector.

Thermally Activated Technology Baseline

Thermally activated technologies represent a diverse portfolio of equipment that uses heat for heating, cooling, humidity control, thermal storage, or shaft/ electrical power. Combined heat and power systems are widely recognized as the "next wave" of energy-efficient devices that will help supplement central electric power stations by providing economical, reliable, and secure distributed power generation.

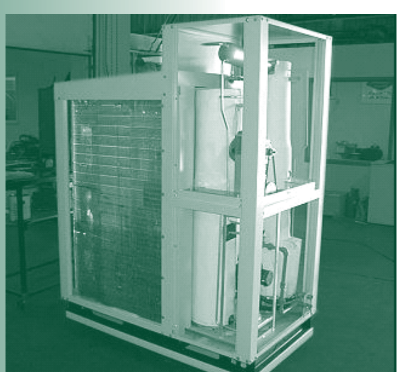
Thermally activated technologies are the essential building blocks for integrated systems that can help maximize energy savings and economic return. Thermally activated systems also offer customers reduced seasonal peak electric demand and enable future electric and gas grids to operate with more level loads.

Lithium Bromide Chiller

Table 1: Today's Thermally Activated Technologies

Applications	Technologies
Cooling/Refrigeration	• Lithium bromide/water absorption equipment • Advanced ammonia water
Heating/Hot Water	• Absorption heat pumps and chiller heaters
Humidity Control	• Solid and liquid desiccant dehumidification systems
Heat/Mass Transfer	• Graphite foam heat transfer material
Thermal Storage	• Thermal storage tanks
Power	• Organic Rankine Cycles • Stirling Engines • Steam Expanders • Thermophotovoltaics
Bio-fuels	• Biodigesters
Integrated Energy Systems	• Combined turbine/reciprocating engine/fuel cell with chiller/desiccant/ heat pump

Cooling/Refrigeration



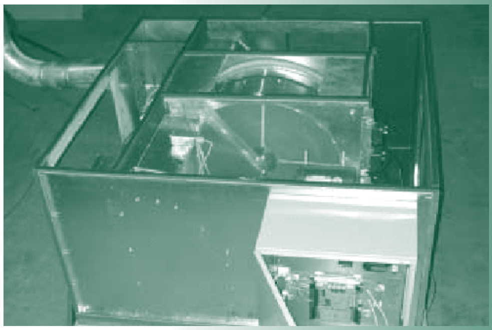
Ammonia/water chiller prototype

Absorption Chillers

The use of absorption chiller technology, popular in the 1960's, faded from the American scene during the energy crisis of the 1970's. In Asia, however, the technology was used during the 1980's and 90's to reduce summer electric peaks that were slowing the Asian economy. Today, absorption chillers continue to be significant energy tools in Japan, Korea, and China, and are again being recognized in the United States as an important and immediate grid support tool. Lithium bromide/water absorption equipment (greater than 100 refrigeration tons) can be used in large commercial buildings.

Advanced ammonia-water absorption equipment (designed for residential and small commercial applications—typically less than 15 refrigeration tons) has been developed in the laboratory with U.S. Department of Energy and industry support. This technology is currently moving out of the laboratory into pre-production prototype development and field-testing. By providing below-freezing refrigeration temperatures, this technology is significantly expanding potential applications (refrigeration, freezers).

Absorption equipment can be optimized to recycle thermal energy from power generation equipment. This combination offers significant opportunities for maximizing fuel efficiency. Distributed power generation sites can benefit from integration with absorption chillers, especially for gas turbine inlet cooling, process cooling, and air-conditioning of buildings.



Novel Applied Development Solid Desiccant Prototype

Heating

Absorption Heat Pumps

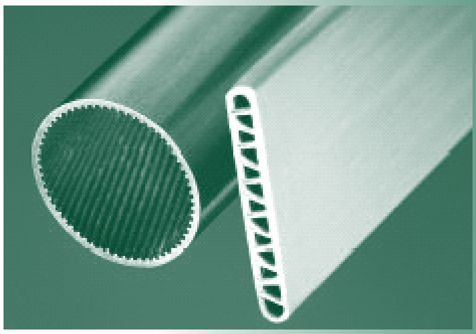
Ammonia/water absorption systems are being developed in the laboratory as a technology that can potentially offer dramatically increased efficiency for heat pumps.

Humidity Control

Desiccant Dehumidification

Desiccant-based dehumidification equipment provides an efficient and effective solution for many of the environmental, economic, and regulatory issues faced by owners/operators of modern buildings. Current, commercially available desiccant systems have not been designed for convenient integration with conventional vapor compression refrigeration air conditioning or distributed power generation (DG) technologies that also produce waste heat. Desiccant Technologies use chemical absorption processes to remove moisture from air and are regenerated with heat. Advanced ventilation air conditioning designs using recovered energy are the key to efficiently controlling indoor humidity and environmental quality/safety.

Accelerated development of improved desiccant-based ventilation air conditioning technologies (designs, components, and systems) will aid the building and construction industries compliance with the American Society of Heating, Refrigerating and Air-Conditioning Engineers Standard 62, "Ventilation for Acceptable Indoor Air Quality".



Internal Finned Copper Tube and Microchannel

Desiccant technologies can also include air washing and biocidal capabilities. In addition to controlling indoor humidity, these capabilities can protect the indoor environment from common airborne pollutants and from extraordinary circumstances.

Stand-alone desiccant technology in the commercial sector is a young technology with a premium product price. It needs important additional component, system and application research to reach economic viability. Using recycled thermal energy is seen as an important path forward for desiccant systems.

Conventional Thermal Storage Tanks

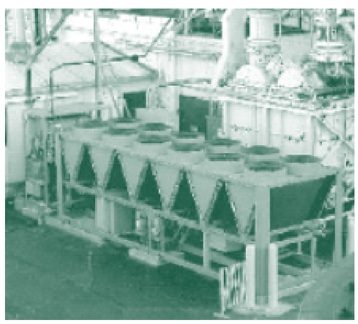
Heat/Mass Transfer

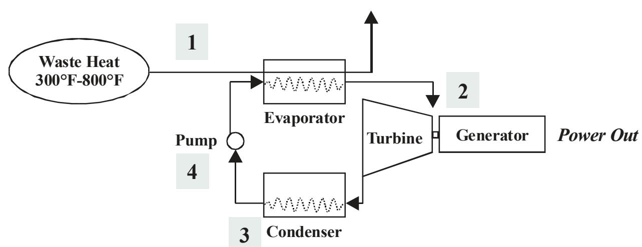
Significant advancements in heat and mass transfer have been made in the past two decades that allow for more efficient recycling of thermal energy. For example, Oak Ridge National Laboratory in Tennessee has developed a version of carbon foam that acts as a super-conductor rather than an insulator of heat.

Heat and mass transfer material developed for other industries like automobiles, have brought forth technologies that may significantly impact thermal energy recycling. One such innovation is the microchannel heat exchanger which was initially designed to reduce the size, weight and cost of radiators.

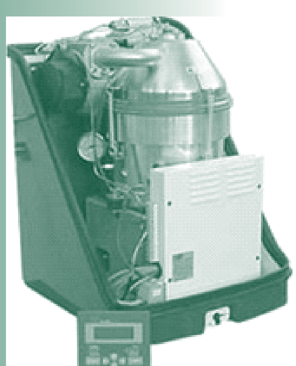
Thermal Storage

One of the most promising aspects of thermal storage is the ability to store "cooling" during off peak periods so that it can be used to offset cooling needs during daytime peak demand periods. Factors limiting such systems include high initial cost and a large footprint. However, Thermal Storage will be needed to balance thermal and electrical loads in future integrated energy (CHP) systems and promises to be even more beneficial in those heat recovery systems applications.





Power: Heat Cycles



750 W Stirling Engine

Power: Heat Cycles

Heat to power cycles begin as simply as applying a steam turbine to a thermal energy resource. One would think this is a common practice anywhere there is steam or thermal energy to capture at the right temperature; however few system developers focus on this opportunity.

Organic rankine cycle equipment is emerging from research and development laboratories. Operation of these cycles can extract heat energy from a source in the range of 250-800°F and convert it into electricity. Power system efficiency of 8-15% is expected depending on feed heater options and ambient conditions. Lower cost organic rankine cycle systems could be targeted for combined heat and power bottoming cycles to increase net electrical output or toward low/moderate temperature waste heat streams.

Stirling engines are classed as external combustion engines. They are sealed systems with an inert working fluid, usually either helium or hydrogen. They are generally found in small sizes (0.5 - 50 kW) and are currently being produced in small quantities for specialized applications.

Pennsylvania Anaerobic Digester CHP System

Bio-fuels

Biodigester technology for converting manure into methane for fuel is neither new nor uncommon. In many parts of Asia, Central America and Europe, biodigester use is widespread. Biodigesters are applied in these areas in response to organic waste (manure) disposal problems and/or high-energy costs. The possibility of future climate change emissions trading is leading toward rethinking the cost of green house gas emitting activities like manure spreading. This provides an incentive for researching combined heat and power bio-digestion, as a means of energy production and waste disposal, that could become economically viable.

DOE Integration Test Center at University of Maryland

Integrated Energy Systems

Integration of thermally activated technologies into one system is essential for the future of recycling thermal energy. System integration involves component interoperability, transition elements (heat exchangers, ductwork, valving, etc.), controls, building/process

Today's Thermally Activated Technology Markets

Markets	Description
Industrial (including Agriculture)	Heavy industry recycles high temperature thermal resources; electric power generation[1], light industry and electronics do not. Market potential for recycled waste heat exists in petrochemical, food products, bio-products, and biotech industries, particularly pharmaceuticals.
Commercial	Most existing commercial buildings do not recycle thermal energy; however, the drive toward improved indoor air quality is leading some to apply exhaust air energy recycling.
District Energy	College campuses are leading the way with campus wide energy plants (district energy) usually consisting of heat and power with a few moving toward cooling. Major urban centers are a market for district energy. Major airports use waste heat for de-icing, heating, cooling, etc.
Government	The U.S. government has over 500,000 facilities across the nation. The Energy Policy Act of 1992, recent Executive Orders, and Presidential Directives all require Federal agencies to reduce their energy use by 35% by 2010 in comparison to 1985 levels. Thermally activated technologies help federal facilities achieve these goals and improve indoor environmental quality.

interface, energy management and storage, design to cost, and human interface. Integrated energy systems not only include combined heat and power (CHP) systems, but also other cooling and humidity control technologies. These systems can currently provide power and space conditioning solutions to industrial, commercial, district energy, and government facilities.

Thermally Activated Technology Market Overview

The choices customers make today when managing energy reflect their value streams. *Winning Value Propositions* usually equals two or more of the following:

Winning Value Proposition = $V_{Electric} + V_{Thermal} + V_{Reliability} + V_{Flair} + V_{Odor\ Emissions} + V_{Security} + V_{T\&D\ Deferral} + V_{Emissions} + V_{Power\ Quality} + V_{\ldots\ldots}$

However, today's marketplace has no means of valuing reliability greater than the grid's 99.9% (other than data centers), reduction in multi-pollutants (including CO_2), transmission and distribution system deferrals (often more expensive than generation by itself), etc. Even the price of electricity and fossil fuels cannot be measured accurately by time of day (peak, mid-range and off-peak) or over the useful life of the equipment in order to calculate an internal rate of return. Therefore, successful value propositions today are in niche markets where these values are overwhelming or have a known value.

Industrial/Agricultural Markets

Heavy industry (paper, chemical, refinery, etc.) has generally taken advantage of thermal energy recovery using waste streams above 1,000°F. It is believed that there are significant thermal resources available for recycling into many useful forms of energy. This potential needs to be researched and quantified. The petrochemical industry represents about 40% of existing combined heat and power capacity. Additional thermally activated technologies growth in the pharmaceutical, specialty chemicals, and bio-products industries could address processing, heating, and cooling needs. Such systems in the food industry could be used for greenhouses, aquaculture, or water treatment systems. Increasing scarcity and value of water in the food growing and processing industries may also encourage the use of thermal energy for wastewater treatment and desalination of seawater.

Commercial Markets

Commercial facilities offer a vast array of thermal recycling opportunities, from onsite combined heat and power base loaded plants to building air exhaust recovery. Supermarkets have significant dehumidification loads to keep water from condensing on freezer displays. Hotels and motels, as well as restaurants, could use thermally activated technologies for laundry and food preparation/ cleaning, and large retail could use the technology for space conditioning. Power parks are a possible configuration for thermally activated technologies, with thermal energy used to cool and dehumidify critical research and development facilities, computers and server racks, clean rooms, etc.

For the market to grow, however, less technically-advanced operating and control technologies need to be designed and test-driven for commercial buildings with smaller, less technically sophisticated staffs. These potential markets need to be researched and quantified, and evaluated through field tests in a variety of markets and geographic locations.

District Energy Markets

According to the International District Energy Association, colleges and universities are experiencing an increase in heating and cooling loads on campuses throughout the country. Steam-driven chillers and other thermal recycling technologies are being evaluated and installed to avoid peak electric charges and to utilize available steam from boilers and cooling, heating, and power facilities. Since colleges and universities operate central utility systems year-round, excess thermal energy is available at non-peak times. Thermally activated systems could capture that excess for laundry water heating, domestic hot water, swimming pool heating, food preparation, and sanitation, improving campus operational utility and flexibility. Additionally, campus steam distribution systems can dispatch back pressure steam turbines throughout campus to improve electric distribution, using excess steam pressure at locations where steady thermal loads exists (athletic centers; natatoriums; research laboratories; and food service centers.)

Most major urban centers in the United States operate distributed energy systems, in most cases producing and distributing steam to multiples customer buildings, as well as chilled water for air conditioning. These district systems aggregate the thermal energy requirements of dozens or hundreds of buildings. This thermal loop provides a platform for many different technologies, including cogeneration, steam-driven cooling, thermal storage, on-site (distributed) generation and other uses of lower grade thermal energy.

Airports and health care centers have large space conditioning and electrical load with long hours of operation. Waste heat from combined cooling, heating, and power facilities could be used to condition terminal spaces, cool jetways and idling aircraft, de-ice planes, support food preparation, and support laundry and cleaning services. Likewise, health care centers and critical care facilities are frequently district energy customers in major urban settings, offering opportunities to utilize otherwise waste heat for laundry, food preparation, sterilization, etc.

Government Markets

Government buildings and facilities generally offer significant thermal recycling opportunities, the largest of which may be at military facilities managed by various agencies within the U.S. Department of Defense.

Financial Barriers

The lack of greater development can be attributed to several key factors:

- Volatile energy prices foster risk-averse behavior, dampening interest in large capital investments such as thermally activated technologies, which could involve a 10-to-20-year payback period.

- The development of manufacturing equipment for which no market currently exists places enormous risk on the investor.

- Successful development and marketing of technologies for recyclable energy generally requires a partnering arrangement. In the case of combined heat and power, for example, few system integrators exist to package the combined heat and power systems required by today's market to assure reliability, functionality, performance, and cost. Developers must create such entities or partner with them.

- Data on recoverable energy potential by market segment is extremely limited, severely restricting meaningful analysis of the financial potential for new products that can recover and use that energy.

- Manufacturers engaged in production activities today have difficulty justifying the expenditure of time and money to take advantage of breakthroughs in other fields. For example, lithium bromide absorption chillers are large, capital-intensive pieces of equipment that continue to use the same basic design offered fifty years ago (shell and tube heat exchangers). Although these chillers could dramatically benefit from new heat and mass transfer devices, the current U.S. market is too small to consider a radical redesign. The larger Japanese market (spurred by the Ministry of International Trade and Industry to equalize electric and gas demand cycles) has attracted investment in such redesign efforts.

- Although thermally activated technologies have the potential to significantly reduce emissions, actual reduction data is scarce, poorly understood, or not seen as credible.

However, once a commitment has been made to the collective pursuit of actions outlined in this Roadmap, it will mark a critical step in breaking down the aforementioned barriers. The market needs will push the envelope for existing and emerging thermally activated technologies.

3 Overview of the Roadmap

This Roadmap provides a plan for developing thermally activated technologies so that they can contribute a larger share to the nation's energy mix. Specifically, the Roadmap is designed to guide collaborative, public-private research and development efforts in achieving the vision described in Chapter 4. Achievement of those goals will also directly help to realize the broader goals for energy efficiency and renewable energy described in the *Strategic Plan* of the DOE Office of Energy Efficiency and Renewable Energy.

The structure of this Roadmap is shown in Figure 3-1 below. The core of this Roadmap for Thermally Activated Technologies is an *Action Agenda,* which consists of the following four major areas of activity:

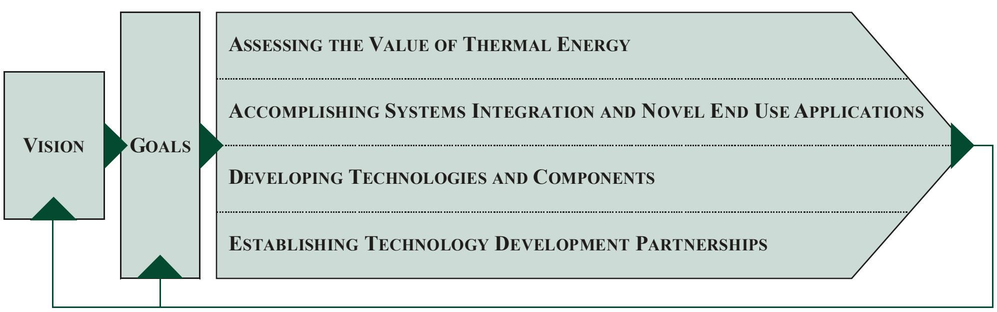
• Assessing the Value of Thermal Energy

• Accomplishing Systems Design, Integration, and Novel End-Use Applications

• Developing Technologies, Components, and Subsystems

• Establishing Technology Development Partnerships

Figure 3-1. Thermally Activated Technologies Roadmap Logic Flow



Assessing the Value of Recovered Thermal Energy

To determine the potential technical and economic value of using recovered thermal energy for both existing and new applications, researchers must first estimate the magnitude of waste heat resources in electric power production, industrial processes, and buildings. In addition, technical analyses are needed to characterize the thermal energy streams and to assess the quality of the heat. Subsequent analyses must evaluate the ability of storage, conversion, and delivery technologies to capture and recycle it.

Market analyses will help to determine the most desirable product attributes for thermally activated technologies and the corresponding design specifications for manufacturers. Business analyses will be helpful in identifying profitable projects. Policy analysts will need to assess regulatory and institutional barriers and also develop market-based mechanisms for monetizing the significant public benefits of the technologies, such as lower emissions, lower peak electricity demand, and higher indoor environmental security.

Accomplishing Systems Design, Integration, and Novel End-Use Applications

Developing novel end-use applications for thermal energy will require advanced concepts development, systems design, analysis, and integration. The objective is to develop a suite of thermally activated technologies that are user-friendly to install, relatively "hassle-free" to maintain, and capable of "plug and play" operation. Efforts will focus on determining the needs for advanced technologies, components, and subsystems based on systems-level requirements and end-user needs.

Simulation modeling will be required to evaluate the trade-offs among design parameters and to develop design tools for optimizing performance in key areas, such as fuel processing, efficiency, and heat recovery. Interface devices will be essential to enable inter-operability of components for heating, cooling, refrigeration, humidity control, and power generation. Data acquisition and system control algorithms are needed for remote diagnostics and implementation of maintenance schemes.

Novel concepts are needed for using waste heat and other forms of thermal energy. Case studies, tests, and demonstrations will be required to prove the feasibility of new ideas. New applications potentially include water and wastewater treatment and desalinization, aquaculture and agriculture, food processing, and hydrogen production.

Developing Technologies, Components, and Subsystems

Advanced designs for thermally activated systems, subsystems, and components will entail extensive research, development, field-testing, and demonstration. Advanced designs can enhance existing applications such as heating, cooling, refrigeration, humidity control, and direct fuel-fired activities, as well as potential new applications. The objective is to develop "next generation" designs, prototypes, and demonstration-scale devices.

Technologies will need to be developed for transmitting, storing, and converting low-grade waste heat ($<100^{o}$ C). Advanced thermal energy management, storage, and delivery technologies with better designs and materials will lower the cost and improve the performance of heating, cooling, refrigeration, ventilation, air cleaning, and humidity control technologies.

Establishing Technology Development Partnerships

This area includes activities aimed at achieving effective technical coordination among Federal and state agencies and activities to increase the leverage of Federal resources (funding, manpower, laboratory facilities) with those of private companies through cost-shared R&D projects. It also includes education and outreach activities to key stakeholders and interest groups to raise awareness about the potential public benefits that can be derived from thermally activated technologies and steps that can be taken to address regulatory and institutional barriers.

4 National Vision and Goals

Thermally activated technologies will increase the Nation's energy efficiency by harnessing previously wasted thermal energy. In addition, these thermally activated technologies will expand the nation's fuel flexibility by running on fossil fuels, biomass, or hydrogen to provide electric power and space conditioning. For all of these technologies, waste heat will be the fuel of choice as a clean, abundant, reliable, and affordable energy source widely available in U.S. transportation, buildings, industrial, and power generation sectors.

Plant managers and building owners will install thermally activated technologies to increase the energy efficiency and environmental performance of their facilities, while decreasing costs. Corporate executives will be able to select from an array of these affordable technologies to increase the productivity of their workplaces and decrease energy costs, ultimately strengthening productivity. Policy makers and regulators will appreciate the way thermally activated technologies efficiently recycle thermal energy streams that contain harmful pollutants. By using energy more efficiently, these technologies will also reduce the peak load on the heavily burdened electric grid.

Thermally activated systems using waste heat will either incorporate a set of cascaded thermally activated technologies or form a combined heat and power system. A cascaded technology system, for example, might use the heat that must be rejected from an absorption chiller to drive a desiccant dehumidifier. A key application for these technologies will be space conditioning (cooling, heating, or dehumidification) to meet established criteria for indoor environmental quality.

The development and deployment of thermally activated technologies will achieve the following four strategic goals:

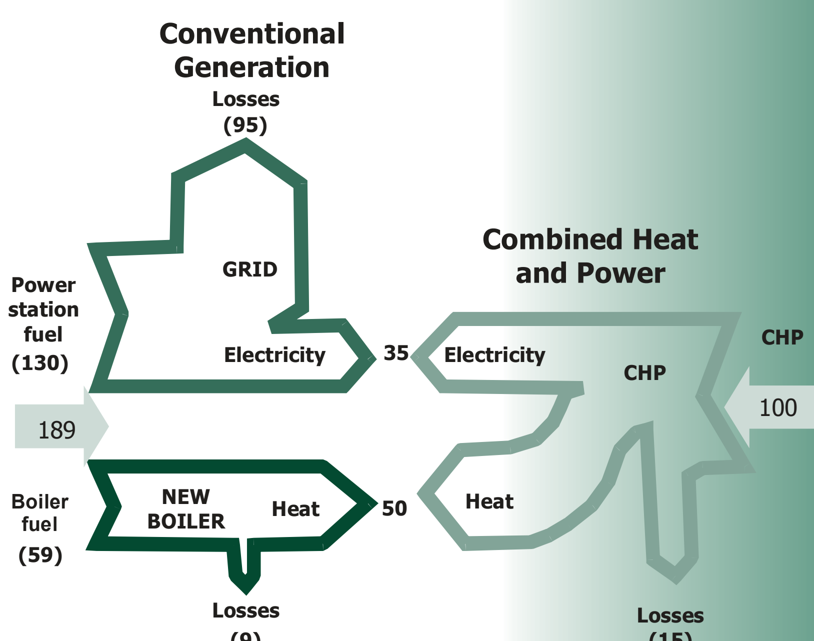
1. Increase the energy efficiency and productivity of commercial buildings, industrial plants, and government facilities.

   Thermally activated technologies can greatly improve the energy

Vision Statement

In 2020, recycling the Nation's vast reservoir of waste heat will be a significant source of pollution-free energy. Consumers will be able to choose from an array of clean, reliable, and affordable **thermally activated technologies** that will increase the efficiency and productivity of energy use, improve the security of energy resources, and enhance the quality of indoor environments.

Figure 4-1. This figure compares the typical fuel input needed to produce 35 units of electricity and 50 units of heat using conventional separate heat and power.



efficiency of commercial buildings, industrial facilities and government complexes. Commercial buildings account for about one-third of U.S. electricity use, and an even greater portion of peak electricity consumption. Industrial facilities will welcome thermally activated technologies as their productivity is sensitive to energy consumption and prices. The U.S. government also constitutes a major market with over 500,000 facilities across the country. Thermally activated technologies can either supplement or replace traditional electric heating and cooling technologies, which currently account for 67% of the electricity consumed in the United States.

The displacement of electricity used to power heating and cooling appliances will increase the nation's energy efficiency as well as reduce harmful air emissions released from conventional power production. Improving energy efficiency and indoor environments across the nation will also reduce harmful air pollutants and help mitigate the impact of electricity price upswings.

SUCCESS INDICATOR Showcase the environmental and efficiency benefits of thermally activated technologies in selected integrated CHP applications in key market segments. Installations of thermally activated technologies will increase the energy efficiency of commercial buildings, industrial plants, government facilities, district and institutional energy systems, and agricultural markets.

2. Characterize the quantity, quality, and value of America's thermal energy resources.

   The quality, quantity, and value of America's oil, gas, coal, and nuclear reserves are well documented. The quality and quantity of America's renewable energy resources are similarly documented in publications and databases such as the *Wind Energy Resource Atlas of the United States* and the *National Solar Radiation Database*. No similar resources currently provide data on the quality, quantity, or value of thermal energy resources in America.

   SUCCESS INDICATOR A well-documented and widely available resource is needed to provide information on the quantity and quality of America's thermal energy streams. These thermal energy streams will have a monetary value ($/BTU).

3. Improve grid reliability through the use of thermally activated technologies.

   Our high-technology, digital economy depends on high-quality, highly reliable power, and power shortages can cost millions of dollars. A one-day power outage in the San Francisco Bay Area, for example, is reported to have cost manufacturers in Silicon Valley over $75 million in lost production. As a distributed energy resource, thermally activated technologies are located on-site, reducing the need to transmit and distribute electricity across the grid. Since electric air conditioning is the largest contributor to peak electricity demand, widespread deployment of thermally activated technologies will also reduce electric load peaks on the grid. Lowering the electric load at peak times reduces the susceptibility of the grid to power disturbances and improves system reliability.

SUCCESS INDICATOR Reduce peak demand for heating, cooling, and humidity control in buildings through expanded use of thermally activated technologies and recovery of wasted heat.

4. Develop novel approaches to using thermal energy resources.

   New approaches and applications are needed to address situations in which more thermal energy is available than can be practically used for conventional heating and cooling functions. To capitalize more fully on an otherwise wasted energy resource, for example, thermal energy might be used to treat water or sewage on site; generate hydrogen; generate shaft power for driving pumps or blowers; or generate electricity. Many other approaches are possible as well.

   SUCCESS INDICATOR Research, development, and deployment efforts must be directed toward developing novel approaches to make full use of available waste heat.

5. Reduce the footprint, volume and/or weight of TAT's.

   In the field of low temperature energy recovery, that is particularly represented by CHP systems, volume, footprint and weight are important indicators of energy efficiency, technical feasibility, application flexibility and economic viability. Therefore, the program should focus upon significantly reducing volume, footprint and/or weight of three key thermally activated technology pathways (absorption technologies, desiccant dehumidification and heat transfer, and mass transfer and thermal recovery.

   SUCCESS INDICATOR Thermally activated technologies that will be reduced in footprint, volume and/or weight by a factor of two.

Specific strategies to reach these five goals are described in the following chapters of this Roadmap.

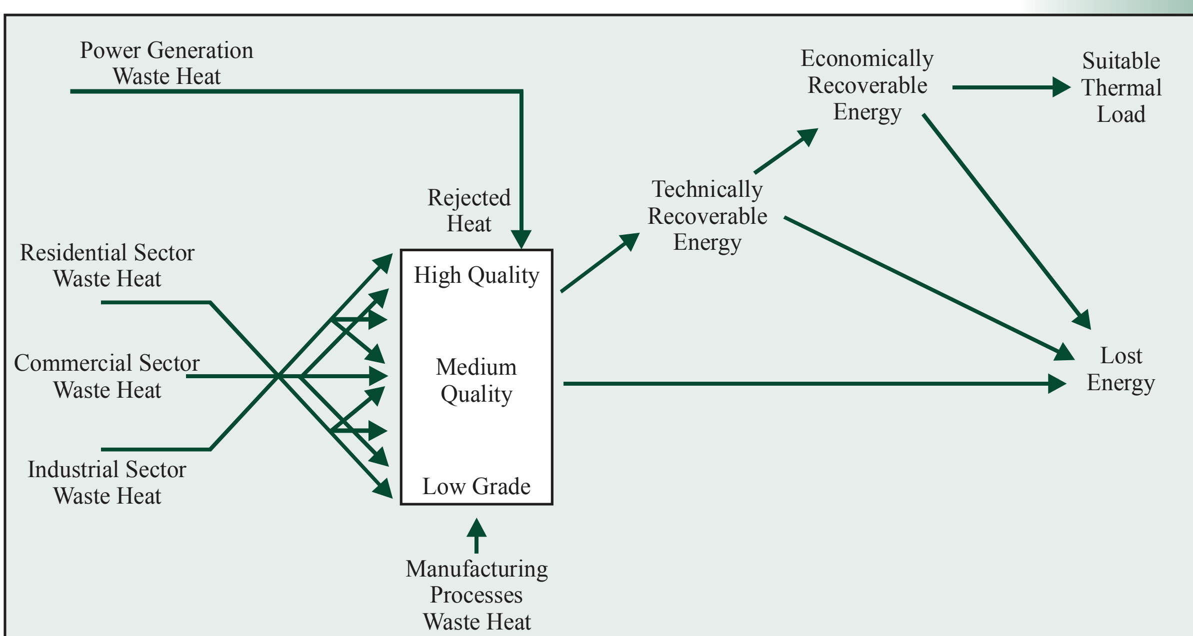
5 Assessing the Value of Thermal Energy

Introduction

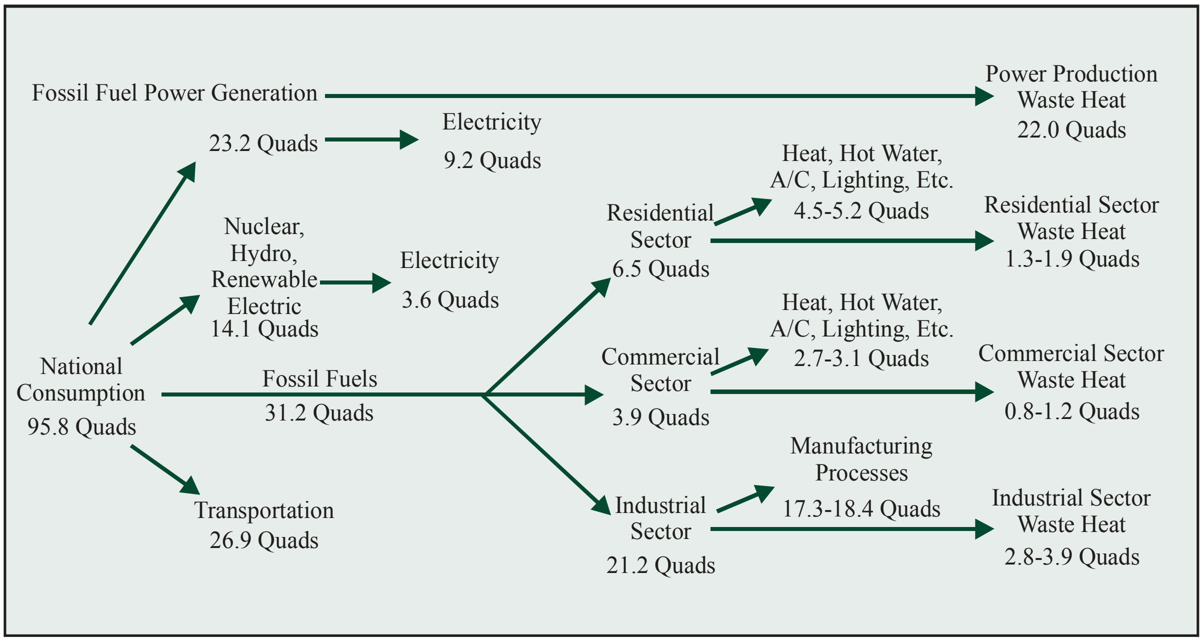
National statistics on energy production and consumption are maintained for every form of energy except thermal energy. The U.S Geological Survey, for example, publishes statistics on U.S. reserves of coal, oil, and natural gas. The Energy Information Administration of the U.S. Department of Energy augments those data collections with comparable information on nuclear power and conventional forms of renewable energy, as well as data on energy production, delivery, and end-use consumption. Published statistics on thermal energy resources, flows, and use are not available.

The lack of thermal energy statistics is not surprising: while used in virtually every energy process, thermal energy is not a commodity, is rarely traded in markets, and is not generally considered a source of energy. If thermal energy technologies are to play a greater role in meeting the nation's energy needs, and if waste heat resources are to be used more intensively, all stakeholders need a much greater understanding of thermal energy flows in the economy, a taxonomy for classifying thermal energy resources, and methods (and markets) for gauging the economic value. Figure 5-1 shows the flow of waste heat thermal energy from its sources to economically feasible applications.

Figure 5-1. The Flow of Waste Heat in the U.S. Economy



The quality of thermal energy refers to its heat content. High-quality thermal energy involves temperatures of 1000°C, or greater. Medium quality involves temperatures of 100-1000°C, and low-grade thermal energy involves temperatures of less than 100°C. The higher the quality of the thermal energy, the higher its economic value because it can be used to accomplish more work.



Gross estimates indicate that as much as 29 quads is going up our smokestacks and chimneys each year and that 4 to 5 quads might be able to be recovered.

Challenges

Thermal energy is a poorly understood resource. Energy decision makers lack information on the magnitude, economic value, and techniques for capturing it. As mentioned above, reliable statistics on thermal energy flows are unavailable. For example, there is no information on how much recoverable energy is lost in the hot exhaust gases vented from industrial boilers or ovens. Similarly, no data exist on how much heat is lost from fossil fuel-fired furnaces and water heaters in commercial buildings and residences.

This lack of data extends to the economic value of thermal energy as well. No standard methodologies or accounting techniques exist for measuring the value of thermal energy flows. The limited commercial value of waste heat today has failed to stimulate the development of reliable and affordable sensors and metering devices for measuring thermal energy flows.

Paths Forward

Compile accurate and timely statistics on thermal energy sources and flows in the United States. These efforts should address waste heat from power production, industrial processes, and residential and commercial buildings. Information is also needed on sources and flows of direct-fired thermal energy. To enhance the value of these data collection efforts, a classification system is needed to grade the quality of thermal energy resources.

Develop a financial analysis tool and methodology for estimating the value of thermal energy. Valuation efforts are needed to estimate the economic value of thermal energy. This tool would include algorithms for estimating the costs of providing thermal energy and its value to the end user. It would include direct economic benefits such as lower energy consumption, higher efficiencies, and lower energy bills, as well as non-economic or difficult-to-quantify economic benefits, such as pollution avoidance, lower environmental emissions, better power quality, and higher energy and environmental security. This tool would be used in financial models and accounting methods that would be subsequently standardized, verified, and validated by the financial and economic communities

Assess thermal energy opportunities from the end-user perspective. Studies are needed to assess the technical and market potential of the nation's thermal energy resources for meeting consumer energy needs. Technical studies should use the 2nd law of thermodynamics as a screening tool for matching the quality of heat to the application. Market studies should assess alternative thermal energy technologies and applications from the consumer perspective. The government could fund a national technology and market study with cost sharing from industry and trade associations. The study would cover all regions of the country and all sectors of the economy, including residential and small commercial users. It would include an assessment of opportunities based on a 2nd law ranking of thermal cascade potential and would produce a national inventory of all sources of thermal energy by magnitude, quality, and potential applications.

Enhance available thermal energy metering equipment and data acquisition systems. Measurement technologies, sensors, and meters must be developed to support data collection, resource valuation, and technology and market assessments. These devices must be more reliable, affordable, and easier to install and maintain than existing thermal energy measurement devices.

Strategic Goals

Assessing the value of thermal energy involves the accomplishment of the following goals:

By 2005, thoroughly map the thermal energy flows in the United States and communicate to all energy decision makers the opportunities for using those flows in industrial, commercial, residential, governmental, and district energy markets.

By 2007, provide energy users with decision tools for assessing the economic value of using thermal energy for heating, cooling, refrigeration, and electric power, as well as for novel applications such as waste water treatment, desalination, and hydrogen production.

By 2008, make reliable and affordable solid-state thermal energy sensors and metering commercially available.

By 2010, publish annual statistics on U.S. thermal energy resources, including magnitude and economic value in all sectors of the economy and all regions of the country.

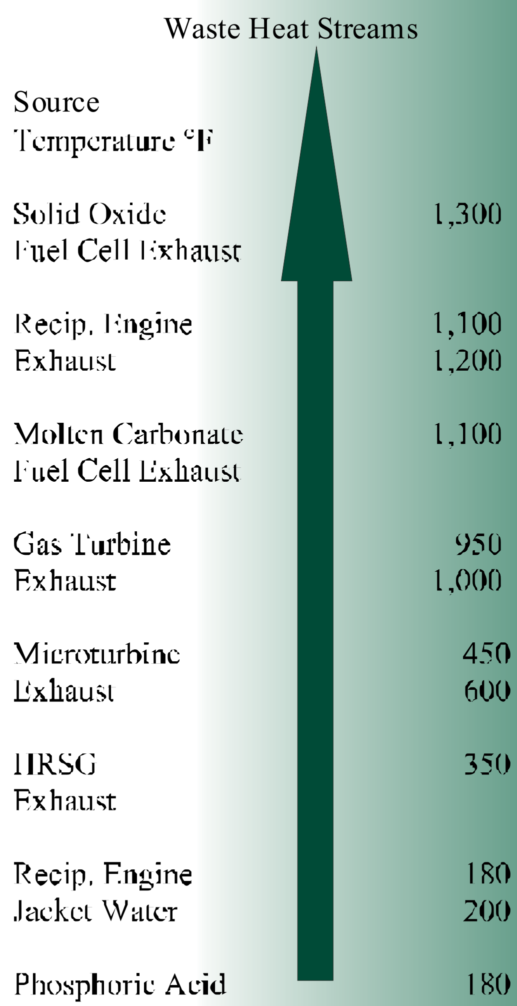
By 2012, establish commodity and service markets for trading quantities of thermal energy using standard contract terms and conditions.

6 Accomplishing Systems Integration and Novel End-Use Applications

Introduction

The synergism of integrating TAT into systems for end-users is key to the widespread use of TATs. A component will be any of the “building block” TAT technologies, from desiccant dehumidifiers and absorption chillers and heat pumps, to heat exchangers and thermal storage. A system will be the integration of any combination of these TAT “building block” technologies with other Heating, Ventilation, Air Conditioning and Refrigeration (HVAC&R) and/or CHP equipment.

Utilization of waste heat can range from low temperature sources such as building return/exhaust air, to high temperature sources from on-site power generation. Passive desiccant enthalpy exchangers can recover over 80% of the energy from an exhaust air stream and return it to the incoming fresh air stream for building ventilation. Active desiccant dehumidifiers, absorption chillers/heat pumps, and heat exchangers (for process and space heating) can be driven by recovered heat from on-site power production to increase overall fuel efficiency from the 27% to 40% efficiencies for the turbines, engines, or fuel cells themselves, to over 75% for an integrated CHP system. Such elevated fuel efficiencies on-site provide overall emissions reductions attributable to CHP. Desiccant components can also be integrated into Heating, Ventilation, Air Conditioning $ Refrigeration (HVAC&R) equipment packages to provide systems that are more efficient and effective at meeting wide ranging sensible (cooling) and latent (dehumidification) building loads, and help preclude moisture induced (mold) Indoor Environmental Quality (IEQ) problems. Desiccants are a subset of a larger class of heat regenerable sorbent materials, which on the whole offer the ability to clean air of particulates and chemical gases and vapors, and kill bacteria and viruses, under ordinary and extraordinary circumstances. New TAT, along with higher performance and more cost effective existing TAT, are needed for the marketplace to better utilize all of the above building equipment integrations and realize these elevated efficiencies, reduced emissions, improved air quality, better moisture/mold control, and enhanced security.



Integration of these pieces of equipment with their varied functions within a building – power production, heating, humidification, cooling, dehumidification, air cleaning, and water heating – into a diverse set of industrial, institutional, commercial and residential buildings necessitates a broader, even a whole building approach and beyond for the RD&D process.

Challenges

Accomplishing systems integration and expanding end-use applications face many technical challenges, as well as market and policy challenges.

Many CHP systems and HVAC&R systems are custom designed and engineered. While all of the necessary components are commercially available, integrating them into a CHP system currently requires custom engineering and installation of components purchased from separate contractors. Designing "Ready to Go" systems for CHP systems is critical to reducing the time and effort required to integrate system components. Simplified, pre-engineered, skid-mounted CHP equipment would make building owners responsible only for connecting power, piping, or ducting. Controls may be connected to a local network, permitting onsite personnel to operate the equipment directly from a desktop PC.

Lack of thermally activated technologies designed for CHP system integration. There are very few specifically designed and commercially available thermally activated products for CHP service. Today there are only rudimentary adaptations of current products that result in expensive, bulky, and less reliably solutions.

Lack of highly optimized, inexpensive controls for HVAC&R systems. Current controls lack the uniformity in the control systems between various TAT manufacturers, as well as differences between TAT technologies and current HVAC control protocol.

There are no user friendly building simulation programs. Current programs do not include moisture capacitance for improving the indoor environmental quality. The only way to evaluate design parameters and to optimize system performance is through actual test trials in a controlled environment. This is very inefficient and expensive way to evaluate HVAC&R system performance.

No lead federal agency or coordinated agency effort on IEQ research and codes and standards. IEQ can affect human health, worker productivity, and other factors that lead to the degradation of building materials. Without coordination and consensus on IEQ issues there will not be appropriate codes and standards needed to maintain a healthy indoor air environment.

No incentives for waste heat utilization. If a facility does offset emissions from the grid by installing renewable energy technologies they are rewarded by either tax breaks, contributing to the renewable portfolio standard, or other various state and federal incentives. There is no incentive to install packaged CHP systems that recognize the systems environmental performance. Output-based regulations, which may include CHP credits, would recognize the emissions offset from supplementing or replacing the heating and cooling load from electrical generation or gas-fired boilers.

Paths Forward

Accomplishing system integration and end use applications require specific actions that address the challenges ahead. These paths forward will help overcome the barriers and ultimately achieve the TAT vision.

Create linkage and standards between CHP system integrators and thermally activated technology manufacturers. Thermally activated technology manufactures need to understand the CHP market, its requirements and potential to move forward with essential research leading toward mass market CHP solutions.

Develop advanced control systems. The control and sensing systems will be capable of enhancing grid reliability, optimizing energy cost, predictive maintenance and steady/transient operation. Controls may be connected to a local network, permitting onsite personnel to operate the equipment directly from a desktop PC. The advanced control systems and algorithms will optimize the benefits of TATs, including through demand response. These controls are critical for integrating the individual components into a highly-optimized system.

Improve design and modeling tools for CHP systems. There is no easy to use engineering tool for modeling integrated CHP systems. This is very important and needs to be done now. The tool will allow users to model how the components interact as a system and how they interact with the grid, indoor air conditions, and various load profiles. The modeling tool will also allow engineers to changeoperating strategies of the system to find the best economic operating conditions.

Develop packaged CHP rooftop systems. A packaged rooftop system will reduce the engineering cost associated with installing CHP systems. The systems will be modular and can provide quick energy solutions to a facility, through lower installation time. Identifying the most promising early market applications by characterizing hot water loads, space heating and cooling, and electric loads will assess these applications for CHP use. The market assessment will break down usage patterns by geography and building type. A unitary packaged rooftop system will then be designed for these applications and will be able to easily be tweaked for other buildings and demographics. Develop user-friendly modular plug-n-play TAT packages and installation procedures for a range of applications and temperatures

Develop competitive, compact, quiet, and clean advanced residential/ commercial (3-500 kW) energy system. The system will incorporate a modular design, novel cycles, and next generation components. Competitive, compact, quiet, clean, and an advanced modular system addresses several of the top priority needs. This system will be the “leap frog” technology that advances TAT technologies throughout the 21st century. The research and development would be high risk, high return investment, that needs government support to leverage

Strategic Goals

By 2008, complete development and testing of a portfolio of TATs that will be reduced in footprint, volume and/or weight by a factor of 2**.**

By 2010, develop systems that use recovered theremal energy to produce potable water from seawater or waste water.

By 2018, develop integrated packaged residential systems providing power, cooling, heating, and humidity control with the same footprint as today's furnace.

the risk Developing advanced cycles, modular commodity components and interfaces, and integrated modules for specific thermal tasks will lead to a novel residential/commercial energy system.

Integrate TAT with wastewater treatment, desalination, and aquaculture applications. TAT is capable of providing thermal solutions to any facility or process. Water treatment is an energy intensive process. Heat can be utilized to help desalinate water, to treat wastewater streams, or provide effective aquaculture solutions. Conducting feasibility studies will show that there is great potential to develop TATs for water treatment purposes. Developing prototypes and conducting field evaluations will expand opportunities and applications for TAT.

7 Developing Technologies, Components, and Subsystems

Introduction

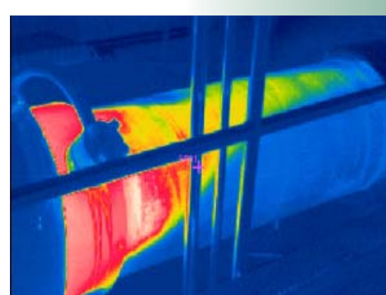
This chapter includes activities on three subsections—Thermal Management and Delivery, Heating Cooling and Refrigeration, and Humidity and Indoor Environmental Control. These activities include research, development, field-testing, and demonstration of advanced designs for thermally activated systems, subsystems, and components. They cover existing applications such as heating, cooling, refrigeration, and humidity control as well as potential new applications such as water treatment and desalination, aquaculture, food processing, and hydrogen production. The purpose is to develop "next generation" designs, prototypes, and demonstration-scale devices.

Thermal Management and Delivery

Thermal energy loss is the key reason that our electric grid efficiency remains at 32% efficiency and approximately 29 quadrillion BTUs is wasted—14 Quads from fossil fuel electricity production, 8 Quads from nuclear electricity, and 7 quads of thermal energy from other sectors of the economy We cannot expect to recycle all this thermal energy from the production of power and other sources, however by improving thermal delivery and management systems we can economically and dramatically increase the recycling of thermally energy.

Residential Thermal Energy Loss

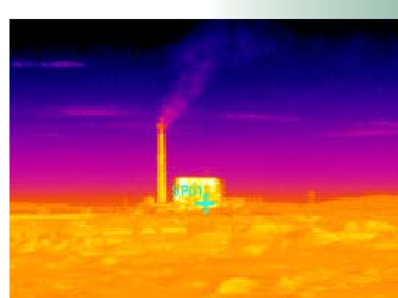
Commercial Thermal Energy Loss



Process Thermal Energy Loss

Industrial Thermal Energy Loss

Electric Circuit Thermal Energy Loss



Power Plant Thermal Energy Loss

Thermal Management and Delivery Strategic Goals

By 2004, identify sources, quantity magnitude and potential uses of thermal energy

By 2004, define the current status and targets needed to improve economic viability

By 2008, incorporate advanced materials and design concepts from other industries to thermal recovery, storage, and transport systems

By 2008, create cost-effective ability to capture, store, control, and make useful recovered energy

By 2010, increase industrial recycled energy use by a factor of X (TBD)

By 2010, increase application of desiccant systems by a factor of 3

By 2012, develop revolutionary desiccant technologies to integrate them into CHP systems

By 2012, reinvent absorption technologies and integrate them into CHP systems

By 2020, develop fully-integrated energy systems including enabling sensor technologies

In the process of living, working, producing electricity, making chemicals and plastics, processing and delivering food, making paper, formulating pharmaceuticals and making transportation fuels enormous amounts of thermal energy (hot and cold) is generated as a byproduct of creating safe and comfortable environments, converting fuel onto electricity or shaft power or merely as a part of the chemical conversion process. Some industries are recycling this thermal energy within their facility as they have found the energy savings economically rewarding. However, the bulk of commercial enterprises, industry, and homeowners have not been engaged in recycling thermal energy.

Two critical elements in increasing the utilization of thermal energy in the future are:

Thermal management focuses upon delivering thermal energy at the right time, in the right state and at the right price.

Thermal delivery deals with economically effective transmission of thermal energy from one place to another.

Challenges

The challenges facing increased use of thermal energy management and delivery systems fall into three categories.

1. Market Transactions

2. Policy Issues

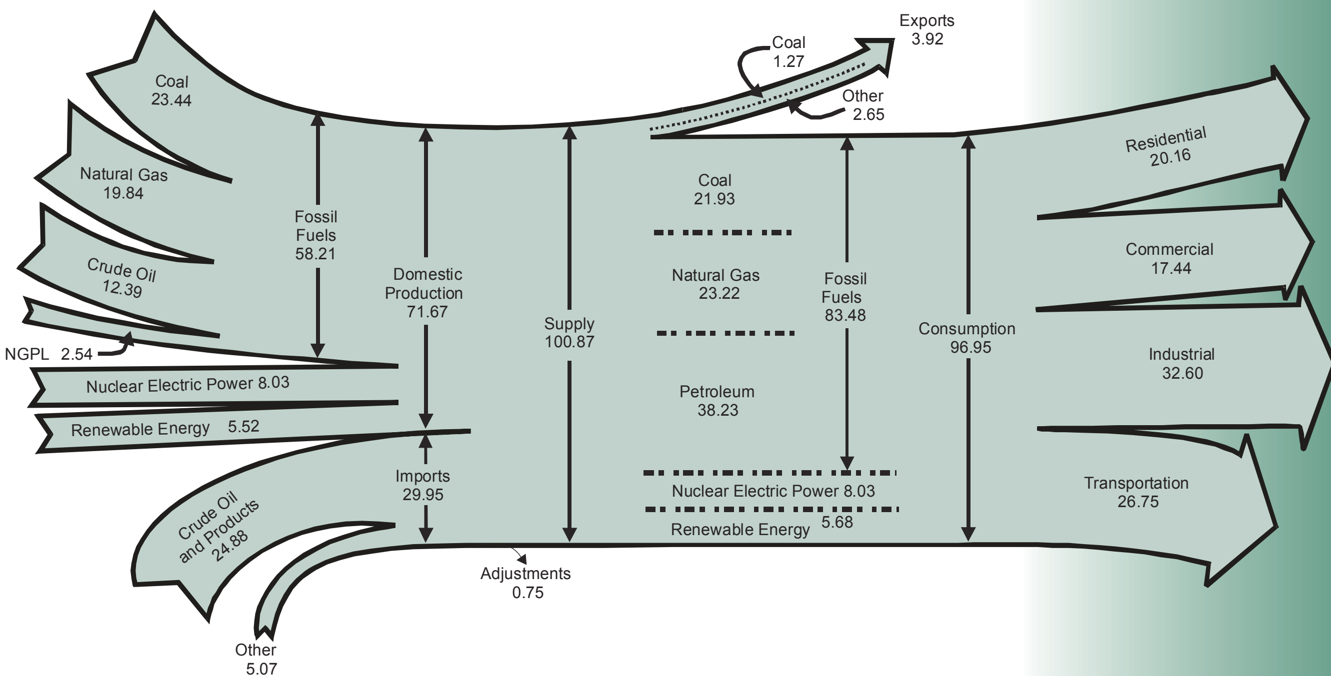
3. Technology Challenges

Market Transactions. Today's energy market places little economic value upon thermal energy conservation largely because the only benefit valued in a capital purchase transaction for recycling thermal energy is the fuel credit that the thermal energy displaces. This fuel credit income stream is usually not enough to overcome the capital cost of the thermal recycling solution. Even where this calculation today may work, such as in California, New York, New England and parts of the upper Midwest, uncertainty of future energy price often leads to market paralysis. Furthermore, thermal energy management and delivery systems can contribute to other value streams that when purchasers must evaluate energy systems differently

$$\text{Market Success} = V_{\text{Electricity}} + V_{\text{Thermal Energy}} + V_{\text{Reliability}} + V_{\text{Flairing}} + V_{\text{Odor Emissions}} + V_{\text{Security}} + V_{\text{T\&D Deferral}} + V_{\text{Emissions}} + V_{\text{Power Quality}} + V\ldots\ldots$$

than upon just the energy cost component, a vast market will open for thermal energy management and delivery systems.

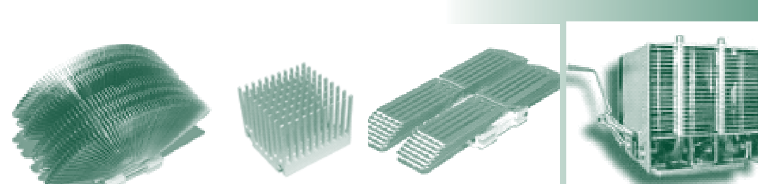
Policy Issues. Federal, state and local governments have yet to recognize the vast thermal energy potential. The Energy Information Agency (EIA) annually assesses the energy utilization in America. In the year 2001, EIA presented the chart below depicting the consumption of 96.95 quads of energy.



Examining regulatory and legislative policies, there is little attention being paid to this recurring potential energy resource. First and foremost, policy must be developed to value recycling this resource. For example, EPA, state and local air quality boards must provide simple output-based emission standards that value recycling thermal energy. Electric restructuring, including the FERC's Standard Market Design does not include or recognize thermal technologies, opportunities and benefits. Recycling thermal energy is not today recognized as a tool in Renewable Portfolio Standards. Finally, there is little research and development focused on this essential near term energy technology.

Technology Challenges. Thermal energy management and delivery systems have long been a part of our industrial base as there was strong incentive to move high grade heat or cold from one process area to another, however, interest waned as temperature states were lowered. Heat and mass transfer has tended to be very market specific with the greatest interest focusing on factors other than energy recovery.

The computer industry has created new technologies to quietly remove heat from laptop central processing units because of consumer demand for more processing power, in a smaller package and less noise than their predecessors.



Market Driven Computer Innovation in Heat Transfer

To transform waste heat into usable products to further industrial savings new technologies will have to be developed to take advantage of low grade waste heat. To apply thermal energy management and delivery systems to our buildings effective production from low temperature waste heat is required and low-grade heat and cool must be used for radiant space conditioning applications. To dramatically improve electricity delivery CHP systems require short-distance heat transfer and storage technology improvements (e.g., cool engine by removing heat and use it to generate H_2 in fuel cell or transforming microturbine exhaust gas directly to cooling in small distances). Thermal storage today requires large and costly tanks. Greater use of phase change media shows promise in reducing size and cost of storage. Increased complexity of systems will need to be addressed with improved integration and advanced controls. The most dramatic change required is cost reduction which can be achieved through improvements in heat and mass transfer.

Paths Forward

Develop a thermal energy value proposition. DOE will commission a comprehensive technical and market assessment of thermal energy utilization opportunities (potential sizes, sources and uses of waste heat and quantify benefits). High potential thermal energy management and delivery systems will be identified and defined. Present agreed-upon units of measurement to quantify the value of thermal energy use (includes value of saved energy and avoided emissions, other societal benefits) will be developed. Prepare a series of white papers to be issued by DOE on the findings.

Research and Develop Heat Exchangers. Heat exchangers will be radically redesigned, integrating enhanced surfaces e.g. - micro-channel – other evolutionary improvements. New materials such as ceramics, polymer based, coatings, membranes, and fluids will be applied to heat exchangers. Liquid to-air heat exchangers specifically designed for CHP applications will be drastically improved with minimal pressure losses. There will be a long range paradigm shift in heat exchanger technology (e.g., rotating heat exchangers and systems) to organic fluid systems in rotating heat exchangers and to compact heat exchanger technology employed in other fields such as in advanced automotive and military soldier personal cooling applications.

Develop techniques and technologies to efficiently use low grade waste heat. The technologies include: low temperature chilling, refrigeration applications, phase change materials, cooling of inlet air for turbines, and other options. Long term research for regeneration of desiccant systems will utilize low temperature sources from hot water district heating, radiant heating, snow melting, and heat absorbers.

Identify and develop new energy storage options. Using new fluid systems and advanced technologies will provide a cheaper, more compact and effective thermal storage. Developing heat transmission and delivery techniques to efficiently move heat from one place to another - phase change materials - heat pipes - heat pumps will further enhance thermal management and delivery options.

Heating, Cooling, and Refrigeration

Introduction

With the notable exception of combined heat and power systems, today's energy technologies are seldom being designed to use waste heat. Without viable technology to effectively use the waste heat energy rejected from the generation of electricity (and waste heat from other sources), there would be reduced benefits from CHP. Furthermore, merely using a portion of this thermal energy for a limited period of time during the year will not likely be economically viable.

Heating, Cooling, Water Heating Refrigeration, and Ventilation: Heating, cooling, water heating, refrigeration and ventilation account for more than 67% of the energy use in buildings (Chart 7.1, source: DOE Buildings Energy Databook). Process heating and cooling, boiler fuel, and HVAC services account for 48% of Industrial Energy Use (Chart 7.2, source: DOE BTS Core Data).

Thermally Activated Technologies: TAT focus on those primary building energy needs with technologies that have broadest utilization potential: heating, cooling, refrigeration, dehumidification, humidification, water heating, steam heating, drying and shaft power from heat energy. Therefore, thermally activated technologies represent the essential element in realizing the potential for effectively utilizing waste heat for CHP.

Advanced absorption technology will offer additional advantages for CHP applications beyond those achievable with the currently manufactured single-effect and double-effect absorption chiller products. The development of smaller air-cooled absorption chillers (10 to 150 refrigeration tons sizes) and ammonia-water absorption heat pumps specifically adapted to building cooling heating and power (BCHP) applications promise residential and small to medium size commercial BCHP systems at the highest possible energy efficiency levels. Recently developed triple-effect absorption chillers using recovered heat can add significant additional cooling capacity for large commercial building applications.

Engine Driven Chiller equipment can be economically used to provide cooling where gas rates are relatively low and electric rates are high.Engine driven chillers operate in a combined heat and power system when the waste heat from the engine is utilized by the absorption chiller for cooling or heating requirements.

Desiccant equipment is useful for mitigation of Indoor Air Quality problems and control of humidity in buildings. Commercial desiccant technologies have not been designed for integration into BCHP systems. Advanced Ventilation Air Conditioning designs using recovered energy are the key to efficiently improving buildings' indoor air quality.

The program works with the desiccant/enthalpy based Advanced Ventilation Air Conditioning industry to accelerate development of improved components and systems, as well as, contributing to the improved overall Advanced Ventilation Air Conditioning system design. This program will also assist industry's compliance to satisfy American Standard of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Standard 62.

Thermal Heat Recovery and Conversion Systems are important for optimizing the recovery of thermal energy from onsite power generation. Developing cost effective integration of thermal recovery/thermal use systems is a key element.

Challenges

New TAT/CHP Equipment. In new TAT/CHP equipment, there is a need for advanced thermally driven cooling, heating, ventilation, and energy storage systems. Advanced thermally driven cooling cycles need to be developed and incorporated into CHP system designs. Lower cost and more efficient thermal distribution is an important RD&D target. Lower cost and higher performance thermally driven cooling, heating, ventilation and dehumidification systems need to be developed. Lower cost electric, chemical, and thermal storage systems are needed for use in buildings. And, advanced TAT systems need to be designed for a plug & play marketplace, which will mean greater standardization and more modular and packaged systems. The "hassle factor" associated with existing custom engineered systems will need to be eliminated.

Communications and control systems. Communications and control systems will be needed to achieve "flexible interdependence" with the electricity and natural gas grids, and among building operations for district energy and other forms of load aggregation. Monitoring technologies will need to include artificial intelligence to enable automated operations and remote diagnostics. The communications and controls technology will need to be designed to enable real-time exchanges of operational information between the TAT equipment and the waste heat source(s), among multiple TAT participants, and between TAT/CHP users and their electricity and natural gas suppliers.

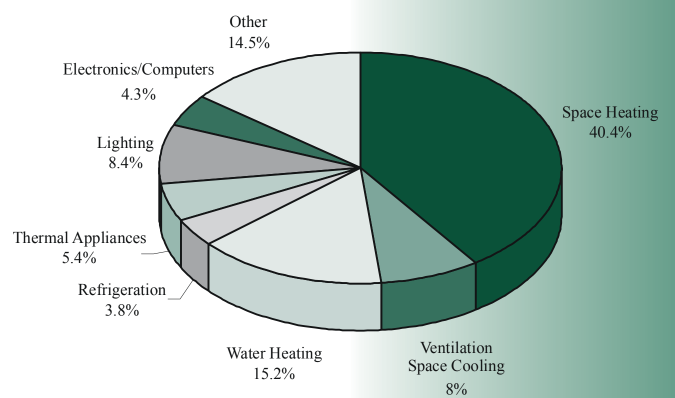
Paths Forward

Develop advanced TAT heating, cooling and refrigeration technologies for CHP applications. The path forward is to begin a multi-year RD&D process to develop advanced heating, cooling and refrigeration technologies specifically for next generation CHP applications. The approach is to refocus existing and launch new RD&D initiatives in the broad area of advanced TAT heating, cooling and refrigeration systems. The proposed effort would start as soon and possible and continue for at least five to ten years. The effort would encompass government and industrial research programs. The estimated funding requirements over five years would be approximately $50 million from the federal government and an equivalent amount in cost sharing from private industry.

Define program scope. The scope of the proposed program would include all types of TAT heating, cooling and refrigeration systems that can be fully integrated in CHP applications. Effort would be undertaken to develop advanced absorption cooling, desiccants, engine-driven chillers, thermal recovery, thermal energy storage, and compact enthalpy and desiccant wheels. Research and testing would be conducted to ensure system reliability and durability. Targets would be established for efficiency, costs, durability, maintenance, and environmental emissions. The program would involve a number of RD&D performers including the national laboratories, universities, and equipment manufacturers. Strengthening linkages with users, industry, and industrial laboratories and research organizations would be a top priority.

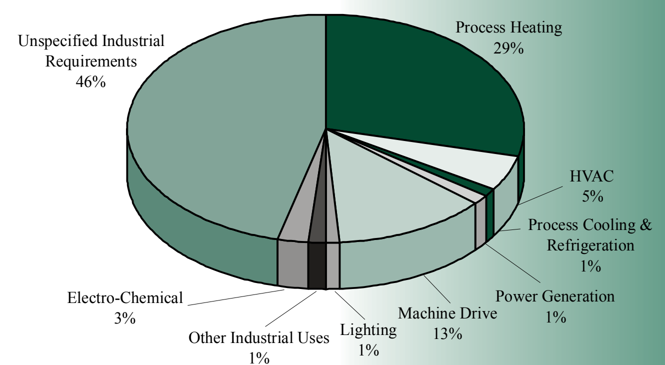
Coordinate with advanced power systems: The advanced TAT heating, cooling and refrigeration technologies that are produced by this program will be designed for plug & play CHP applications and incorporate appropriate monitoring and diagnostic systems. Field tests and demonstrations would be candidates for case studies. Efforts would involve extensive coordination with the parallel development of advanced power generation systems.

FIGURE 7-1. 2000 BUILDINGS ENERGY USES (QUADS)



Source: DOE BTS core data

FIGURE 7-2. 1998 INDUSTRIAL ENERGY USES



Source: EIA Manufacturing Consumption of Energy 1998, Table N6.1

Promote federal, state and local legislative,regulatory and utility support for combined heat and power systems and thermally activated technologies: This activity should include time of use rates, emissions credits, and output based standards with CHP credits for the use of thermally activated technologies. Currently onsite/ distributed generation (DG) and CHP systems are depreciated under rules designed for large utility power plants over time intervals vastly exceeding the lifetimes of small scale DG and CHP equipment. Tax incentives are also needed that allow for an accelerated depreciation for combined heat and power systems in addition to allowing tax-exempt entities to take depreciation credits.

Develop and sponsor educational programs for combined heat and power and thermally activated technologies: An educational and outreach activity should start that targets, but is not limited to, architectural/engineering firms, utility regulators, facility managers, building owners, and legislators. A website should also be created that provides information to consumers, professionals, and end-users.

HUMIDITY AND INDOOR ENVIRONMENTAL CONTROL

INTRODUCTION

The need to control our indoor environment has never been more important. Our homes and buildings are built ever tighter for maximum energy efficiency, while scientific progress makes us more acutely aware of the links between the quality of the air we breathe, our health, and national productivity. Even as we survey our stock of modern heating ventilation and air conditioning technologies with this knowledge and see its shortcomings, still more serious challenges are rising to become driving concerns. Increasing demands for healthy, productive work and living spaces are converging with a new, critical focus on Indoor Environmental Quality to shape the criteria by which we design buildings. Thermally Activated Technologies and their constituent disciplines directly address current and developing needs in adequate ventilation, waste energy recycling, thermal and chemical indoor environmental quality, and ultimately occupant health, and productivity.

HEATING, COOLING, VENTILATION AND REFRIGERATION

Strategic Goals

By 2004, create a communications and information program that identifies user benefits, applications, and emissions reductions attributable to CHP.

By 2005, develop modular absorption technologies that are integrated into CHP systems.

By 2005, demonstrate advanced thermally activated technologies and activated desiccant systems in all end-use sectors. This will reduce mold and improve IAQ.

By 2005, design and initiate an educational program for the academic, engineering and design communities on CHP systems.

By 2005, develop TAT heat pumps integrated into CHP systems.

By 2008, develop a national standard for evaluation of thermally activated technology systems.

By 2008, develop and incorporate advanced materials, and design concepts to thermal recovery, storage, and distribution systems for both large and small users.

By 2008, demonstrate a low-maintenance liquid dessicant <20 tons.

By 2010, develop an advanced, liquid desiccant system that is 30% more efficient than today.

By 2010, develop fully integrated energy systems including enabling sensor technologies.

By 2010, develop systems that use advanced Rankine or other innovative thermal cycles and that use low-grade heat.

By 2010, increase industrial recycled energy use by a factor of **3**.

By 2012, develop a commercially viable air-cooled absorption technology >20 tons.

By 2020, achieve >50% market penetration for >150 ton applications and 25% market penetration for <150 ton applications.

By 2020, achieve 25% market penetration for thermally activated commercial and industrial refrigeration.

Buildings heating, ventilation and air conditioning systems must strike a balance between energy, indoor environmental quality, and end-use functions. The U.S. Environmental Protection Agency (EPA) lists the hierarchy of indoor pollution mitigation strategies as source control, followed by dilution through sufficient ventilation, and finally direct filtration/treatment of contaminants. Next generation heating ventilation and air conditioning systems will need to provide energy efficient ventilation, including the incumbent moisture control associated with fresh air loads, removal of mundane pathogen/contaminants, either on-demand or continuously, based on user needs assessment and sensor availability/reliability. Some office buildings are currently using demand-controlled ventilation or incorporating direct air cleaner products for ventilation credits.

Moisture management is critically important to building science today**.** Moisture in buildings impacts energy and occupants at multiple levels, and is an issue that desiccant and enthalpy recovery systems are positioned to address. Today within the American Society of Heating, Refrigerating and Air Conditioning Engineers, the nation's central source for building technology expertise, there are a number of publications, research topics, and symposiums on moisture management. A new technical group, Moisture Management in Buildings, has been established in ASHRAE to advance the state of knowledge in this field. The need is clear considering the high profile of indoor environmental quality/health stories in the media, including the recent closure of a new hotel in Honolulu due to mold growth with an estimated forty million dollar remediation cost. Substantial debate centers on Standard 62 – Ventilation for Acceptable Indoor Air Quality, to the point that continuous maintenance status was imposed so issues could continue to be resolved.

A central theme at issue is conventional air conditioning's inability to economically manage the moisture loads inherent in higher ventilation rates. National Institute for Occupational Safety and Health studies have identified improper ventilation as the root cause of over 50% of sick building cases. Ventilation is a double-edged sword however; high levels of ventilation air will meet dilution Needs for IAQ, but introducing greater quantities of fresh air and energy is wasted to condition it while insufficient control of moisture carried in outside air invites microbial infestation in the building. Additionally, if fresh air is not supplied in adequate amounts, then indoor contaminants from chemical and biological sources rise to problem levels. There is a substantial and growing body of work making the connection between both the thermal and chemical aspects of Indoor Environmental Quality and productivity (Fisk 2002, and Fanger, et al. 2000). Energy Recovery Ventilators are the first step to good indoor environmental quality at reasonable cost. Desiccant-based equipment provides the additional opportunity to control moisture at enhanced levels of ventilation, while actively treating gaseous and particulate contaminants, as they currently do in industrial settings.

Sorption-based air cleaners will benefit from advances in commercial desiccant dehumidifiers. Progress made to date in bringing the cost, maintenance, and reliability of desiccant-based humidity control in-line with demands of commercial and residential markets can be leveraged to provide gaseous and particulate contaminant removal as well. The regenerable aspect of these systems is highly valuable when contaminants can be deactivated or purged, in contrast to current filter systems that must be replaced as they become loaded or expended.

High sensitivity, rapid response sensors are critical to the development and deployment of indoor environmental quality systems. Contaminant control approaches for both indoor environmental quality and humidity/ventilation control depend strongly on the development of broad-spectrum, low-cost, real-time air quality sensors. Without sensors for reliable warning of rising contaminant levels, any system would have to be operated on a continuous basis to offer its air cleaning benefit. With such means available, cleaning systems could be deployed only when necessary. This capability could extend to the balance of the heating ventilation and air conditioning system to conserve energy using demand-controlled ventilation. Current sensor technology is either too slow for broad use, or else not sensitive or selective enough. In addition, high accuracy rapid evaluation techniques are for adaptive or intelligent control.

Challenges

The building market and even the bulk of the heating ventilation and air conditioning/engineering community have not received a convincing value proposition and solid link between humidity control, indoor environmental quality, and health/productivity. Even as some within the engineering community avidly pursue viable approaches to indoor environmental quality and moisture management, most building owners and contractors, architectural engineers, and heating ventilation and air conditioning manufacturers clearly do not see the value in these services. While the links are increasingly supported by research, more needs to be done to make the value proposition widely known. Many paths forward address this issue.

The link between humidity control, indoor environmental quality, and health/productivity is complex and crosses many disciplines. Building science and engineering, architecture, chemistry, human physiology, microbiology, pathology, and business productivity are a cross section of the expertise needed to evaluate this link fully. These technical groups do not have forums for regular interaction and they rarely exist within a single entity.

Optimizing systems to achieve good indoor environmental quality is complex. A single packaged “black box” system that can automatically adjust its performance to achieve good indoor environmental quality in every climate and building type should be designed. Design software is not available that properly treats moisture loads and dehumidification performance for optimized vapor compression/ desiccant system combinations that utilize the strengths of both technologies.

There is a lack of appropriate sensors and rapid field and lab measurement techniques for evaluating indoor environmental quality. We cannot control what we cannot measure. Current chemical sensors for H_2O, CO_2, CO, and O_3 are too expensive, not sensitive enough, or not selective enough to help make a strong case for systems to improve indoor environmental quality. They focus on surrogates for occupancy (CO_2) or total levels of volatile organics. It is very difficult to broadly demonstrate the indoor environmental quality value proposition when the devices and techniques needed to determine the extent of a problem or effectiveness of a solution are expensive and time consuming.

Standards and Codes for indoor environmental quality and energy efficiency are either non-existent or not enforced. Humidity standards are lacking, and the U.S. Department of Energy and U.S. Environmental Agency limit their roles in building code development. Deficiencies in enforcement of standards perpetuate the lack of understanding among designers.

There remains a short-sighted focus on heating ventilation and air conditioning first costs. Investment in energy efficient systems without a strong indoor environmental quality value proposition is not generally justifiable by merely considering the energy economics.

Paths Forward

Summarize the existing body of work and continue clinical field research highlighting the indoor environmental quality and productivity link to moisture management and ventilation. Publish a position/white paper that has been broadly reviewed by all relevant professions to share what is currently known. Develop protocols with building, productivity, and medical science experts for indoor environmental quality & health/productivity studies in order to describe the body of data that finally defines the “value” of indoor environmental quality.

Produce educational materials detailing the state-of-the-art in indoor environmental quality equipment and system design. Target audiences include architecture and engineering firms, but suitable material that shows a strong value proposition must also be developed for government, utilities, and building owners, managers, operators, contractors, and others. Integrated system models and screening tools must be developed for use by the design community so that the performance benefits of systems that incorporate thermally activated indoor environmental quality systems can be broadly understood.

Research and develop low-cost indoor environmental quality sensors/ measurement techniques. Suitable sensor packages will be mass-producible for hundreds, if not tens of dollars, to measure enthalpy, CO, CO_2, and functional volatile organic compound groups with sufficient accuracy to make ventilation decisions in real time and will be self calibrating. Quantitative evaluation techniques will be rapid enough for cost-effective field diagnostic and lab certification services and sufficiently accurate in the sub-parts-per million range to rate different air cleaning technologies and strategies.

Establish TAT/CHP IEQ benefits and role with high profile building energy programs. The National labs will prepare the position paper on building IEQ and security for industry review. Protocols will be developed under DOE subcontract with peer review by industry and others such as EPA, NIH, or OSHA. Field tests will be conducted under multiple DOE subcontracts and made

Strategic Goals

By 2005, create category in waste heat accounting for exhaust air from buildings and processes.

By 2005, develop cost effective 500-3000 cubic feet per minute desiccant packaged unit for space, heating, cooling and humidity control.

By 2005, develop cost effective 3000-20,000 cubic feet per minute desiccant ventilation air pre-conditioner for commercial and institutional buildings.

By 2008, develop building system with minimized parasitic losses from air mover and pumps.

By 2008, optimized desiccant integrated CHP system that uses active desiccant technology to adsorb/absorb airborne contaminants from indoor/outdoor air.

By 2010, develop liquid desiccants that can be used to store thermal energy.

By 2012 Develop improved black box solutions for recovered heat < 100F.

available to cognizant ASHRAE technical committees for inclusion in appropriate standards. Programs such as Green Buildings and Energy Star offer a dissemination means for the value proposition developed in this effort.

8 Establishing Technology Development Partnerships

Introduction

Success in developing, manufacturing, and installing thermally activated technologies in the commercial, industrial, and institutional sectors will require collaborative partnerships among all stakeholders. Laboratory researchers, manufacturers, design-build engineers and architects, and building owners and managers all need to participate in the development of TAT products, technologies, deployment techniques, demonstrations, and market "pull" to make them acceptable in the marketplace. Technology partnerships among all players will improve the quality of research and development, improve laboratory testing, enhance manufacturer and end-user buy-in, and insure that integrated products and systems are developed in a cost-effective, energy-conscious, and environmentally friendly way.

A number of specific goals have been identified for TAT technology partnerships, spanning thermal management and delivery, indoor air quality and security, heating, cooling, ventilation, and refrigeration, and novel energy utilization. Cooperative outreach, education, technical cooperation, and regulatory activities, among all four disciplines, will lead to integrated TAT systems by 2020. Among the most critical goals are the following:

- Define and develop policy and education needs to expand the use of TATs
- Utilize an "output-based" standard for evaluation of emissions that results from power production at new generating plants, including combined heat and power facilities in commercial, industrial, and institutional sites
- Create tax and other financial incentives for energy efficient buildings
- Adopt a "green building" approach to construction, such that inefficiencies and losses associated with electricity generation, transmission and distribution are accounted for and conversely, that energy savings, and environmental measures such as recycling, are captured
- Create a more aggressive communications/education/training program that identifies the benefits, applications, and emissions reductions attributable to combined heat and power
- Design and initiate an educational program for the academic, engineering, and design communities on CHP systems
- Develop a national standard for evaluation of TATs

Technical results of work underway at federal and state research laboratories such as NREL, ORNL, as well as in the States of California (CEC) and New York (NYSERDA), and through cooperative ventures sponsored by the International District Energy Association (IDEA) and others must be shared with all members of the buildings, industry, equipment manufacturing, and energy establishment to move towards the integrated TAT concept so necessary for success.

Challenges

A number of barriers exist to successful development and deployment of thermally activated technologies which are further hindered by the lack of technology partnerships. First and foremost, those who design, build, and operate buildings, industrial sites, and institutional facilities are not yet aware of the opportunities presented by TATs. They need to understand that low temperature or low grade waste heat can be useful in certain applications, and that taking advantage of such a resource will not overly complicate the building operator or manager's job.

Secondly, the need for "custom engineered" solutions make TATs un-economic. Packaged, integrated waste heat recovery options are not widely available, and where available, not cost-effective. Partnerships among each element of this process – waste heat capture, storage, and distribution – are not yet common, and thus stand in the way of smooth, integrated system development and deployment.

Third, poor market data exists on the value of indoor air quality, humidity control, comfort, productivity, and health to workers and clients in buildings. TAT technology partnerships that span all of these disciplines will mitigate the impacts of unhealthy air and improve comfort and productivity for all.

Fourth, research and development on TAT technologies and systems, costs and benefits, implementation options, environmental impacts, and so forth, is still needed in a number of technical areas that should be addressed through partnerships. Heat pump, refrigeration, storage, controls – all of these disciplines need to be addressed through integrated R&D to result in effective thermally activated technologies and systems.

And finally, federal and state support for TATs, including combined heat and power, remains lacking. Lack of output-based emission standards for thermal energy, at the federal and state levels, result in poor environmental decision-making and stand in the way of development of new, innovative technology. Legal, regulatory, and interconnection standards create barriers to development. Technology partnerships among manufacturers, utilities, and end-users would help to overcome these barriers.

Paths Forward

The Department of Energy, in cooperation with industry, utilities, regulators, end users, researchers, and other stakeholders, need to design, develop, and implement outreach and education programs, and regulatory policies, that will address these barriers and, in a collaborative process, enhance the development and use of thermally activated technologies. Among the most important actions are the following:

- Conduct technical and market assessments of thermal energy utilization opportunities, including potential sizes, sources, and uses of waste heat, and widely publicize the results

- Create an "alliance" of TAT, CHP, green, and EnergyStar® buildings supporters to educate others on the market opportunities surrounding thermally activated technologies

- Pilot demonstration sites in various mainstream applications to measure and quantify energy, comfort, productivity, health, and safety benefits of TATs

- Develop and install integrated packaged CHP systems; conduct outreach/ education programs on them

- Promote federal, state and local legislative, regulatory and utility support for CHP and TAT, including TOU rates; emission credits; tax incentives; LDC wheeling charges; LDC distribution charges; interconnection regulations; output based emission standards; legislation to produce gas on public lands for CHP projects; and accelerated depreciation for CHP.

- Develop and sponsor educational programs for thermally activated technologies and CHP, for architects, engineers, the public, service technicians, legislators, and create a Web Site for all of these stakeholders

In summary, the paths forward will require determining where heat recovery opportunities are, identifying which fuels might be utilized to power thermally activated components and systems, keeping in mind fuel flexibility, organizing integrated development teams that are *customer focused,* and conducting evolutionary field demonstrations with increased industry funding. All "constituents" need to become more educated about TATs and made aware of technologies, through technical committees and organizations that already exist, such as the Engine Manufacturers of America (EMA), ASHRAE, Technology Assessment Centers, The Association of State Energy Research and Technology Transfer Institutions, International District Energy Association, American Public Power Association, United States Combined Heat and Power Association, etc. We must work together to develop integrated systems – collaborative education, outreach, and regulatory reform will help us do so.

9 Conclusions and Path Forward

The purpose of this Technology Roadmap is to outline a set of actions for government and industry to develop thermally activated technologies for converting America's wasted heat resources into a reservoir of pollution-free energy for electric power, heating, cooling, refrigeration, and humidity control. Fuel flexibility is important. The actions also cover thermally activated technologies that use fossil fuels, biomass, and ultimately hydrogen, along with waste heat.

Conclusions

- Thermally activated technologies are an important part of the Nation's strategy for accomplishing critical energy and environmental goals.

- In fact, there exists a renewable and pollution-free energy resource that thermally activated technologies are uniquely able to tap. Unfortunately policy makers and energy developers are mostly unaware of this resource. Its potential for development is poorly understood. That resource is waste heat.

- Thermally activated technologies consist of equipment that use thermal energy for heating, cooling, humidity control, and power (mechanical and electric) in buildings, factories, campuses, industrial parks, and district systems. They include, for example, absorption chillers and desiccant humidity control devices. Thermally activated technologies can be directly fired or operated using waste heat in combined cooling, heating, and power applications.

- Today's thermally activated product lines are largely focused upon burning of fossil fuels as their source of thermal energy. These current products reflect markets, end-use applications, and manufacturing capabilities that currently sustain profitable business operations. They produce measurable public benefits: higher energy efficiency, higher indoor air quality, lower air emissions, and lower peak demand for electricity.

- What is needed are more efficient, reliable, and focused thermally activated technologies that are capable of operating using a variety of energy sources including integration with low temperature waste heat, CHP systems, clean fossil fuels, biomass, and eventually hydrogen.

- Novel approaches for using thermal energy are needed to address situations in which more thermal energy is available than can be practically used for conventional heating and cooling functions.

Path Forward

The Technology Roadmap for thermally activated technologies is organized into four main areas of activity.

Government, industry, universities, and national laboratories need to work together to achieve the vision for thermally activated technologies, develop profitable markets, and produce public benefits such as higher energy efficiency, lower air emissions, healthier and more secure indoor environments, and more efficient electric grid operations. Committing to the collective pursuit of the actions outlined in this Roadmap marks a critical step in achieving a cleaner, more reliable, affordable, healthy, and secure energy future for America.

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The proceedings for the Thermally Activated Technologies Roadmap Meeting are available on the U.S. Department of Energy Distributed Energy and Electric Reliability Program site at www.eere.energy.gov/deer.html.

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