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Benefits from Energy Storage Technologies

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Ad Hoc Subcommittee on Position Paper of the Energy Storage and Transport Technologies Committee of the Advanced Energy Systems Division of ASME

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BENEFITS FROM ENERGY STORAGE TECHNOLOGIES

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ABSTRACT

The United States is continuing to rely upon nondomestic and nonsecure sources of energy. Large quantities of energy are lost as a result of time mismatches between the supply and the demand for power. Substantial improvements in energy efficiency are possible through the use of improved energy storage; advanced energy storage can also improve the utilization of domestic energy resources (coal, geothermal, solar, wind, and nuclear) by providing energy in accordance with a user's time-varying needs. Advanced storage technologies offer potentially substantial cost and performance advantages but also have significant technical risk. If even a fraction of the proposed technologies reach fruition, they will make an important contribution to better use of our domestic energy resources. The Energy Storage and Transport Technologies Committee of the American Society of Mechanical Engineers encourages research, development, and application of energy storage technologies to reduce imports and energy costs.

1.0 OVERVIEW

The United States relies on nondomestic and nonsecure sources of energy for its needs; this has caused major dislocations in our economy from embargoes, oil shortages, and increasing energy prices. While the current oil glut has resulted in price moderations, the conditions that caused the embargo could return. Even without a major disruption in imports, spending over $60 billion a year on imported oil has a significant impact on the U.S. economy and is a factor in the high number of unemployed Americans. Imports provide over 38% of the U.S. petroleum used in 1981, and use of natural gas exceeded domestic supply. All energy imports account for about 18% of our total energy consumption, although in 1982 the annual energy consumption dropped by 4.1% from 1981 levels and imports of petroleum were reduced to 28% of consumption. If we can achieve even more savings in these two premium fuels, there will be substantial improvements in our nation's economic and political security.

In 1981, the United States consumed in excess of 77 quadrillion Btu (81×10^{18} J) of energy. About half of that energy is lost, much of it as a result of time mismatches between the supply of and the demand for power. Storing energy in a readily available form is one way to compensate for that mismatch. The results can provide cost advantages to the user and reduce premium fuel use.

Substantial improvements in energy efficiency are possible with advanced energy storage devices in many sectors, but especially in transportation and residential/commercial sectors. We have abundant domestic resources in coal, geothermal, solar, wind, and nuclear energy. Substituting these alternative energy sources for premium fuels is very possible, provided that the system can economically meet users' time-varying demands. Improved energy storage could accommodate this time-varying demand and improve the competitive posture of alternative energy sources for transportation, electric power, industry, and residential energy consumers.

Energy storage technologies include batteries, flywheels, compressed air, thermal systems, and hydrogen. The state of the art of these technologies is quite varied. Some are already commercially ready (e.g., lead-acid batteries). Others are being developed (e.g., composite flywheels and molten-salt thermal storage). Still others are in research stages (e.g., thermochemically generated hydrogen).

Advanced technologies offer potentially significant cost and performance advantages and reductions in premium fuel use. However, significant technical risks are associated with those technologies, and some are expected to be unsuccessful. If even a fraction of these proposed technologies reaches fruition, however, that will be an important contribution to making better use of domestic energy resources.

The American Society of Mechanical Engineers (ASME) encourages research, development, and application of energy storage technologies to reduce imports and energy costs. ASME recognizes that the roles of government and the private sector are different. ASME encourages government support for development of advanced energy storage technologies to reduce risks and accelerate their acceptance. The society also encourages the private sector to assess the state of the art continually and to further develop and apply technologies that are economically viable as soon as possible.

2.0 INTRODUCTION

Storage involves the retention of a resource available now until a time when it will be needed more or can provide increased economic benefits. Man's transition from hunter and gatherer to sower and reaper—the agricultural revolution—was important because harvested grains and roots could be set aside for use in other seasons. Some common modern examples of storage are factory inventories, coal piles as a utility inventory, and refrigerated foods. Energy storage is actually a powerful means of conservation that reduces the capital and fuel costs of delivered energy. Energy storage both increases the use of capital equipment and enables us to use energy that otherwise would be wasted without this alternative.

Figure 1 represents energy supply and demand in the United States. Petroleum and natural gas are premium energy fuels because we must import a large share of our total requirements for them. A significant percentage of these imports comes from insecure sources subject to embargoes, shortages, and rapidly escalating prices. Importing large supplies of petroleum has severely affected inflation, significantly increased our cost of living, contributed to increased unemployment, and jeopardized our economic and political security.

Energy is a precious commodity; in its generally used forms, it is in limited supply. While energy consumption in the United States has decreased in recent years, the average increase for the world has been 3.6%. Third-world countries have typical increase rates of 5% to 8%. Thus, competition for energy among the nations of the world has and will continue to increase its cost. Some of the many limited sources of energy may even be depleted within the next century. Economic conditions require us to strive for efficient energy utilization and to shift our energy consumption to more abundant resources.

At 340 million Btu (359×10^9 J) per person (1981), the United States consumed more energy than any other country in the history of the world. Of what we consume, only 49% ends up as useful energy; 51% is rejected for one reason or another. Many of the reasons for such poor utilization are related to time. Solar energy is poorly utilized because it is not always available. Large utilities suffer inefficiencies because the power plants currently employed to meet peak demands are inefficient for a normal load. Automobiles suffer a similar malady because of the need to accelerate fairly rapidly; masses that are accelerated and decelerated regularly usually reject a certain amount of kinetic energy as heat through a braking system.

Storing energy is important because it reduces the detrimental effects of time. Storage is most effective when there is a very efficient and controllable time lag between energy conversion to a storable form and later utilization. This allows conversion to the stored form to take place when energy is cheap or abundant, or both, for later use when it is needed.

In this paper, we describe the benefits that various energy storage technologies could provide. The current state of the art of these technologies is briefly discussed, and specific devices are identified that require further research and development.

3.0 ADVANTAGES OF ENERGY STORAGE (AND TRANSPORT) TECHNOLOGIES

Premium fuel consumption and energy costs can be reduced in two ways by storing energy:

1. Enhanced Energy Conversion Efficiency. Storage improves conversion efficiency by shifting energy from when it is available but cannot be used to a time when it will be needed.
2. Alternative Energy Substitution. All of the energy-use sectors exhibit time-varying loads. Frequently, users select premium fuels (petroleum and natural gas) to meet the demand, because the capital costs associated with these fuels are low even though the fuel costs are high. Alternative low-cost energy sources (e.g., coal, nuclear, solar, wind) can be employed cost-effectively by using energy storage technologies to meet variable loads.

We describe potential benefits and how they might be achieved in this section. A successful commercial application requires research and development of storage technologies that have satisfactory (a) cost, (b) performance, (c) safety, and (d) operational characteristics. There is substantial doubt about whether any one technology, especially one in an early state of development, can meet all of these requirements; indeed, we expect that many will be unsuccessful for one reason or another. However, at this time, no one can identify exactly which technologies will be successful. If just some of the opportunities described below are fulfilled, the contribution to better use of our domestic energy resources will be an important one.

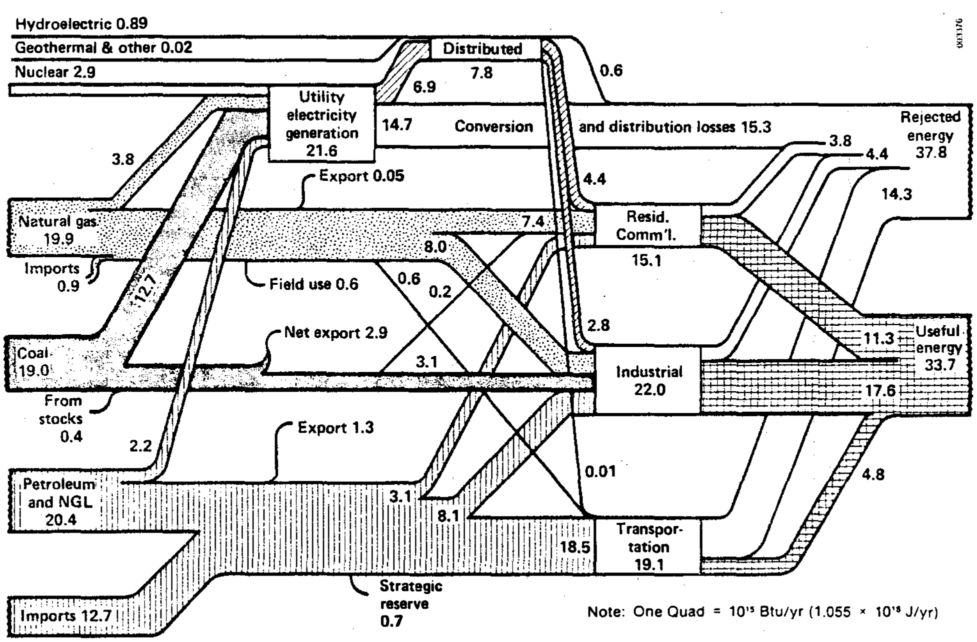

Figure 1. U.S. Energy Flow - 1981 (net primary resource consumption 77.1 quads)

3.1 The Transportation Sector

The transportation sector consumes one-fourth of the nation's energy and over 50% of its petroleum. Since this sector derives nearly all of its energy from petroleum, it is particularly sensitive to the fact that about 28% of our petroleum comes from imports. This sector also rejects most of the energy it consumes because of inefficiencies. Some losses are unavoidable, but a good deal of them are time-related and can be reduced by means of energy storage.

For example, each time a vehicle is stopped, the kinetic energy is discarded as heat through the brake linings. If we brake the vehicle regeneratively, the energy can be used to increase the speed of a flywheel, charge a battery, compress a fluid, wind a spring, or charge a superconducting coil. If storage techniques could be used to efficiently hold and then release the braking energy to accelerate the vehicle in its next cycle, gas mileage could increase as much as three times. Of course, fuel efficiency improvements would vary according to the application. An over-the-highway truck might show essentially no improvement, but the family commuter car could double its mileage. A taxicab driver in New York City, for example, could experience the threefold increase.

Electric cars employ electricity that is predominantly generated from nonpremium, nonimported sources. In the future, we anticipate that utilities will produce a greater share of their electricity from nonpremium fuels (coal, nuclear, solar, and wind). Energy storage in rechargeable batteries appears to be suitable for limited-range commuter and urban commercial vehicles; advanced batteries appear to be suitable for general-purpose or long-range automotive applications. Hydrogen can be generated from electricity (or coal or renewable energy sources) and stored in the vehicle. The hydrogen may be employed in a heat engine or fuel cell to achieve the energy-substitution effect.

Storage is also very important to hybrid propulsion vehicles, either to load level the heat engine to improve fuel economy or to use for short trips. Since short trips make up most of our mileage, a hybrid vehicle could markedly reduce petroleum consumption. The heat engine gives the vehicle full performance and range, and the hybrid should be more marketable than the limited-range all-electric vehicle.

Another concept gaining some interest is the Roadway Powered Electric Vehicle System. Electric power is carried in cables buried in the road. The magnetic field is inductively transferred to the vehicle, providing propulsion energy. Batteries or flywheels are carried on the vehicle for passing and driving off powered lanes and roads.

3.2 The Industrial Sector

The industrial sector is the largest energy use sector—the second largest user of oil, the largest user of natural gas, and a large electricity user. As shown in Figure 2, industrial plants vary in size from small (0.1 MW) to large (>300 MW). There are wide ranges in use (1, 2, and 3 shifts and 4-, 5-, 6-, and 7-day operations), and these operational patterns result in a low-capacity factor for many users. Coal is economically employed in large systems with high-capacity-factor users; but because there are many small or low-capacity-factor users, coal provides only about 15% of the total energy demand. For many industrial applications, the most cost-effective energy sources are premium fuels.

Energy storage can improve the economic attractiveness of substituting nonpremium for premium fuels. Coal or biomass might be burned at baseload, to charge storage whenever the industrial plant load is low. On demand, the stored energy would be discharged to meet the industrial load. Here, the advantage would be a reduction in the capital cost of the coal or biomass burner, possibly up to a factor of two, depending on the load. Most of the energy consumed in industrial applications is heat, and thermal energy storage is thus of primary interest. Cogeneration and on-site generation of electricity are also employed in industrial plants.

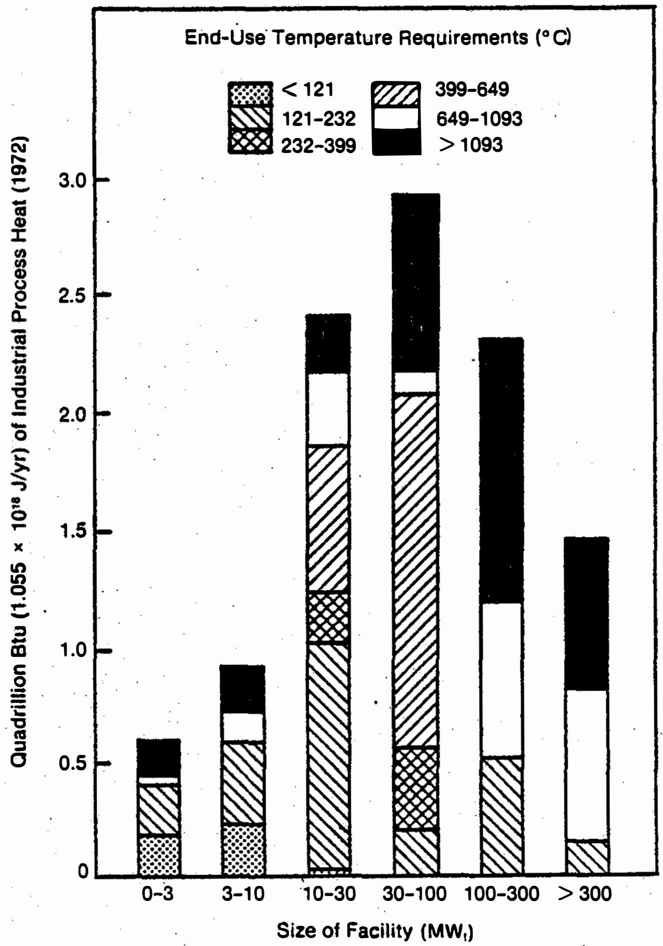

Figure 2. Distribution of Process Heat Used at Facilities (by size and temperature)

Electrical energy storage has the potential to meet a plant's variable electrical demands with a baseload cogeneration plant.

Thermal energy transport from large power plants to one or more industrial plants also has the potential to improve the economics of facilities fueled with coal or nuclear energy. Frequently, large power plants are not fully utilized; the excess capacity could be transported from these facilities to industrial users. Studies have shown that the system can be economically attractive for transport distances up to 10 miles; this distance could be increased or the end user's costs lowered by means of advanced thermal energy transport technologies.

Solar energy can be employed to meet any of the time-varying energy demands of industrial users. Wind, photovoltaics, solar thermal, and biomass energy can be employed to meet electricity energy requirements, and solar thermal and biomass can be employed to meet thermal demands. However, certain transients are inherent in solar energy: clouds and wind gusts, diurnal variations (nighttime and variations from sunrise to noon to sunset), and seasonal effects. Storage can accommodate continuous or peak demand with these time-varying supplies. Energy storage also improves the utilization of the solar resource (for example, by setting aside solar energy captured when the industrial plant was not operating, such as on weekends).

While the major role for energy storage in the industrial sector will probably be to promote switching from oil and gas to alternative energy, it will also play a role in promoting energy efficiency. For example "waste heat" from compressors, generators, furnaces, and other processes can be recovered, stored, and used on a different site.

3.3 The Residential/Commercial Sector

The residential/commercial sector comprises many users of small, highly time-varying heating, cooling, and electric loads. In this sector, opportunities to use coal or nuclear energy directly and safely are minimal. Energy storage can be employed to reduce energy requirements and to substitute alternative energy sources for premium fuels.

One storage method involves seasonal storage of winter chill. During the winter, water can be cooled and stored in underground aquifers, snow can be compacted, or ice can be made by running a heat pump that simultaneously meets the building's heating demand. During the summer, the cooled water, snow, or ice is used to meet the cooling load. Stored waste heat (e.g., from power plants or industrial plants or from solar collectors) can be employed to heat buildings. Aquifers, underground caverns, or tanks can store heat for winter use.

Low-cost electricity is available in many areas during off-peak periods; storing that off-peak power provides a means to meet time-varying loads. Solar energy is an inherently time-varying resource. Energy storage technologies can provide the necessary means to alleviate the mismatch between collected and needed energy. Advanced energy storage technologies can improve the economics of these systems by means of seasonal storage and more efficient chemical heat pumps. Electrical energy storage devices can be employed when available and used on demand. Because utilities pay less for power supplied by an individual than they charge that same individual as a consumer, the cost-effectiveness of a consumer-owned electrical power system potentially can be enhanced with appropriate energy storage techniques.

3.4 The Utility Electricity-Generation Sector

The demand for electricity varies from hour to hour, day to day, and season to season. This is as true for large-scale electricity-generating plants as for small-scale energy systems. Currently, oil and gas (premium fuels) meet the variable part of a load. Because of the variation in the demand for electric power, a portion of the utility's baseload generation capacity that uses coal and nuclear fuel, for example, is unused during off-peak or light-load periods. The availability of off-peak baseload generating capacity makes energy storage attractive because energy can then be saved for later use. In addition to improving efficiency, using off-peak baseload capacity could also reduce requirements for peaking systems and petroleum consumption. This would allow us to substitute domestically available coal and uranium for expensive petroleum. Energy storage provides similar advantages for solar systems which by their very nature provide a variable output.

Thus, energy storage is a means of load leveling that can be accomplished at a central plant or at distributed users' sites. In the centralized approach, storage is charged by a baseload power plant during low-load periods and discharged during high-load periods providing peak power. In the distributed approach, storage is charged during low-load periods at off-peak electricity rates, and discharged on demand by the user. The capital costs of large energy storage devices are projected to be one-half to one-third that of new generating plants. Consequently, using energy storage devices for load leveling, rather than building new power plants, could be economically attractive for utilities.

4.0 RESEARCH IN ADVANCED ENERGY STORAGE

The ideal energy storage medium has a high energy density, can convert the energy rapidly for high power density, and is inexpensive. Petroleum has met these criteria for many years but is becoming expensive. Advanced energy storage technologies are now being developed to meet many of the requirements of the applications we have discussed thus far. In the following sections, we will describe several of the most recent developments. This discussion is by no means complete; it excludes technologies currently in commercial applications. It is intended solely as a general description of the current state of advancement. For convenience, the technologies are grouped under four major headings: mechanical, electrochemical, thermal, and other technologies.

Table 1. Potential Energy Storage Improvements for Transportation Options

	Specific Energy (Wh/kg)		Specific Peak Power (80% Discharge) (W/kg)	
	1980–1985	1990–2000	1980–1985	1990–2000
Batteries				
Lead acid	42	49	66	98
Nickel/iron	55	65	102	130
Nickel/zinc	70	80	125	140
Sodium/sulfur[a]	90	108	100	120
Zinc/chlorine	90	105	95	120
Lithium metal sulfide[a]	110	120	115	130
Aluminum-air[a]	—	350	—	170
Mechanical[b]				
Flywheel (composite)	22	48	—	—[c]
Hydraulic accumulator	3	5	—	—[c]
Compressed air	26.4	33	—	—[c]
Hydrogen[d]				
Liquid hydrogen	675	1680	—	—[c]
Iron titanium hydride	64	96	1100	1320
Magnesium hydride	105	165	870	1380

[a]Still in the advanced research stage.

[b]Includes necessary components for proper operation; e.g., for flywheel it includes weights of container and vacuum pump as well as rotor.

[c]Peak power constrained by the power train components; in the case of liquid hydrogen, by the heat engine.

[d]Heat content values have been converted to their mechanical equivalent using 30% efficiency.

4.1 Mechanical Storage

Mechanical energy storage involves a change in the potential or kinetic energy state of matter. These devices provide a great amount of power and are particularly desirable in the transportation sector. Since mechanical storage devices have relatively low energy density, increasing it is one thrust of current research efforts. For instance, metallic flywheel rotors are limited by their ratios of ultimate strength to density. New composite materials such as Kevlar/epoxy have much higher ratios and could possibly double or triple the energy storage density of metallic rotors. Table 1 indicates the level of improvement that can be expected in these and other systems within the next decade.

Another area of comparable importance is the transmission system required for effective use of energy storage. For many applications (e.g., a flywheel car) a highly efficient, continuously variable transmission (CVT) is required for energy storage to be attractive. Although progress has been made, much work remains to be done before reliable CVTs are commercially available with a satisfactory range of efficiency characteristics.

Some mechanical methods have a high storage capacity and low power capability. These are more suited for applications such as load leveling electric utilities. One such technology under development is compressed air energy storage (CAES). Considerable progress has been made in the areas of reservoir stability and evaluation of advanced concepts. Research on unconventional CAES plants that promise to be more cost- and fuel-efficient is just being initiated. Extensive research and development will be required if these second-generation systems are to be commercialized in a timely fashion. Each conventional 1000-MW CAES plant saves approximately one million barrels of oil per year. Second-generation systems promise even greater petroleum fuel savings.

4.2 Electrochemical Storage

Electrochemical energy storage employs energy stored in chemicals; electricity is either produced from storage or the storage is charged by electricity. These technologies include batteries, fuel cells (in which hydrogen is produced from either fuels or electricity), and chemicals (e.g., hydrogen) produced from electricity but used to produce heat or another form of energy.

4.2.1 Batteries. A resurgence of research in battery technology has been taking place for some time. Batteries can potentially store large amounts of energy per unit weight. Thus, batteries are attractive in the transportation sector for electric vehicles and in the utility sector for load leveling.

Several battery systems are attractive candidates and some of them are noted in Table 1. Each has advantages as well as formidable technical barriers to widespread use. Most of the systems have achieved major technical advances in the past few years but still require a considerable amount of research. Some will not prove feasible or practical. Some of the types of batteries are listed here.

Nickel-Zinc. The nickel-zinc battery is the most promising of the alkaline systems. Its power capability and energy capacity are outstanding, but its cycle life is presently inadequate. Fundamental research is required to achieve improved understanding of the life-limiting mechanisms; such inquiries could uncover methods for improving system life without compromising other attractive features. The battery's primary applications are automotive.

Zinc-Bromine and Zinc-Chlorine. These zinc-halogen systems are viable candidates for utility load-leveling applications. System complexity and halogen safety raise key research issues in association with electric vehicle applications. Nevertheless, vehicle applications are receiving serious attention because of potentially significant cost advantages.

Sodium-Sulfur. Invented in the 1960's this high-temperature battery could perform quite well, using abundant, low-cost, active materials. The cycle life of the solid ceramic electrolyte must be improved to meet the demands of proposed stationary and mobile applications, however.

Aluminum-Air. Aluminum can be used with an opposing electrode that consumes oxygen from the air. This feature is attractive because the air electrode eliminates the need to carry part of the fuel in a mobile battery. The battery promises very high specific energy. Since it acts like a fuel cell requiring periodic additions of water and aluminum, it is rapidly rechargeable mechanically—an important feature for mobile applications. Development of low-cost, efficient aluminum anodes and long-life air electrodes are key long-term research issues.

4.2.2 Hydrogen. Hydrogen (and possibly other chemicals as well) can be employed to store chemical energy. Because of its high energy density, hydrogen offers many advantages in several applications:

1. Vehicular Transportation. Hydrogen is stored in the gaseous or liquid state or as hydrides. A conventional heat engine or a fuel cell is used to produce power.
2. Synthetic Fuel. Hydrogen can be transported large distances in pipelines and distributed like natural gas.
3. Electric Power Production. Hydrogen can be used with either heat engines or fuel cells to meet utility peak demands. The hydrogen may be supplied as a synthetic fuel or generated on site by electricity.
4. Chemical Uses. Hydrogen is a chemical feedstock for petroleum refining, ammonia productions, and other applications.

Hydrogen is not found naturally in a free state but must be produced from a primary energy source. Electrochemical production (electrolysis) with electricity supplied by coal, nuclear, solar, or wind energy currently shows promise. Improvements in cell resistance and cost are being sought that will improve efficiency and reduce capital costs.

Thermochemical production of hydrogen with a solar thermal or nuclear heat source is a potentially low-cost method, but it involves much greater risks than electrolysis. Verification of thermochemical cycles, materials compatibility, and system costs will require substantial research.

Methods of storing hydrogen are needed to meet load patterns. Liquid hydrogen storage is possible but expensive and hazardous. Hydrides chemically bond the hydrogen to a metal, and using them could reduce costs and improve safety, especially in vehicles.

4.3 Thermal Storage

Thermal storage uses the heat capacity of a solid, liquid, or phase-change medium to store energy. Table 2 presents typical costs for commercial applications. Thermal storage devices generally employ relatively inexpensive media, but containment and heat exchangers are expensive. Consequently, thermal storage research efforts currently focus on those areas.

Thermal storage technologies include hot water, rock bins, hot oil, phase-change salts, molten salts, ceramics, and others. Increasing temperature limits require increasingly advanced technologies. Thermal energy can be stored at very high temperatures, but extensive research is needed to verify the feasibility of media containment and heat exchangers.

The seasonal nature of space heating suggests that seasonal storage is desirable. Using tanks or other containment for seasonal storage for a single residence does not look promising. However, seasonal storage for a housing develop-

Table 2. Thermal Storage Projections

Technology	Maximum Temperature Limit, °C (°F)	Cost ($/kWh$_t$)
Low Temperature		
Hot water[a,b]	100 (212)	10
Rock bin[a]	149 (300)	10
Phase change[a,b,c]	66 (150)	10
Medium Temperature		
Oil[a]	316 (600)	30
Oil/rock[b]	316 (600)	20
Phase change[b,c]	316 (600)	15
High Temperature		
Nitrate salts[b]	566 (1050)	15
High-temperature molten salt[c]	1093 (2000)	20
Phase change[c]	816 (1500)	10

Technology Status

[a]Developed, commercial technology.

[b]Under development.

[c]In research phase.

Note: When more than one status is marked, there is more than one technology being researched and developed.

ment, a neighborhood, or a district heating system could have major economic benefits. Research is needed in the development of seasonal thermal energy storage (STES) systems so that we may take advantage of nature's seasonal thermal cycle. Seasonal storage in aquifers promises to be the most cost-effective (STES) system, where it is applicable. Research is currently being performed that would characterize the technical features of this technology and provide much-needed data on potential aquifer response and performance during long-term cycling.

Other STES technologies (such as ice generation and storage in ponds, lakes, caverns, and tanks) also could improve energy utilization and reduce petroleum use. Storage of winter ice to meet summer cooling needs in buildings is under development. These systems could supply needs for summer cooling at one-tenth the energy demanded by present-day air conditioners. Such natural sources of energy could replace fossil fuels and yield both environmental and economic benefits.

When available energy is not needed when and where it is produced, it may be needed or more useful at another place. The concept of energy transport is closely related to that of storage in that they both seek to use energy at the greatest economic benefit and least waste. The form of transport is obvious for some forms of storage; battery power output can be efficiently applied to an electricity supply grid. In transportation, mechanical or electrochemical storage must move with the vehicle. However, thermal energy, available as the waste heat of electricity generation or an industrial process, may be too low in temperature to be useful to the utility or industry generating it but eminently suitable for other industries or for residential and commercial heating and cooling. Many European countries, both East and West, make extensive use of thermal energy, transported as heated water for district heating. This dual use of fuel resources for district heating systems reduces energy waste from over 60% to less than 30%.

Transportation distances in Europe vary from just a few kilometers to as many as 50 km. Energy transport in industry may vary from pipe transport within plants to supply to other industries a few kilometers away. Substantial cost reductions are possible with advanced technologies, such as internally insulated piping and improvements in materials and fabrication and handling methods. With other advanced technologies we may be able to transport higher temperature heat by means of molten salts or certain thermochemical methods.

4.4 Other Energy Storage Technologies

4.4.1 Chemical Energy Storage. Chemical energy storage may be used for industrial process heat, space conditioning, or seasonal storage. Chemical heat pumps (CHP) (e.g., the sulfuric acid/water cycle) employ a heat source rather than electricity to drive the cycle. CHPs can provide more heat to the end use (buildings or process heat) than is input from the heat source. They can also be employed to provide cooling (i.e., air conditioning). Chemicals such as calcium hydroxide can also be employed to provide long-term storage of solar energy. These technologies work for small systems but must be tested for larger ones, and component costs must be reduced.

4.4.2 Magnetic Energy Storage. Superconducting Magnetic Energy Storage (SMES) is a direct method of storing electricity. Other storage devices require a conversion to chemicals (batteries), potential energy (compressed air), kinetic energy (flywheel), or thermal energy. SMES provides an opportunity for high-efficiency storage. The technology is still in research stages for large applications such as central-station electric utilities use.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The United States currently depends upon imported premium fuels (oil and natural gas) for much of its energy needs. Oil embargoes, rapidly rising prices, and oil shortages are bitter lessons of the consequences of that dependence. Implementation of advanced energy storage not only can be economically attractive but will also improve our economic and political national security. With energy storage technologies, the potential savings in imported oil and gas could be quite large but are still highly uncertain (i.e., they depend on both the future price of oil and on successful research and development). Some of this potential will be realized through currently available technologies. Advanced technologies will reduce the demand for imports and provide cost savings; with accelerated research and development, the benefits will occur earlier.

The state of the art of energy storage technologies requires additional research and development. Many of the technologies we have described in this paper may prove to be unsuccessful. Some of the risks involved are significant, but certainly the benefits to the nation will be worthwhile.

The American Society of Mechanical Engineers encourages research, development, and application of advanced energy storage technologies. The Committee on Energy Storage and Transport Technologies recognizes that the roles of federal, state, and local governments, and the private sector, differ substantially in motivation and ability to develop energy storage technologies. Therefore, the following roles and missions have been identified to support the research and development of energy storage technologies.

5.1 The Federal Government

Advanced storage technologies that are prime candidates for federally funded research and development are currently in early stages of development (relative to those in commercially funded research), could potentially be economical in commercial applications, and could significantly reduce energy and petroleum consumption. Many of the technologies mentioned here meet these criteria to various degrees. The ASME Committee on Energy Storage and Transport Technologies recommends that the federal government expand its sponsorship of research and development of appropriate energy storage technologies.

Research and development of advanced energy storage technologies requires work over a substained period of time. Clear policy statements and programs are needed. Private industry involvement particularly in the planning stages is recommended, especially to provide input on the level of risk that private industry is willing to accept and thus to guide the phasing-out of federal sponsorship.

5.2 State and Local Governments

The role of state and local governments in supporting research and development of energy storage technologies is essentially similar to the federal government's, except that they can support storage activities that have important applications within their specific regions. For example, demonstrations of appropriate energy storage technologies in a region's public works facilities can enhance general acceptance of new technologies.

5.3 Private Sector

The ASME Committee on Energy Storage recommends a greater emphasis in the private sector on development of energy storage in conjunction with energy management and conservation. The committee encourages business leaders to maintain an awareness of developments in and capabilities of energy storage. The private sector is expected to participate in all stages of the research, development, and application of these technologies—in part through government-funded research and development and in part by private funding of R&D—and to fabricate, sell, and apply the technologies in the commercial system.

Once an advanced energy storage technology has been demonstrated successfully, the private sector will produce and market the new products. Competition in the marketplace is expected to stimulate continued R&D, resulting in improved products with more cost-effective and energy-efficient features.

5.4 Technical Societies

The role of technical societies is to enhance communications, recognize contributions to the state of the art, and to provide and maintain applicable codes of standards.

6.0 ACKNOWLEDGMENTS

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