ALTERNATIVE ELECTRICAL ENERGY SOURCES FOR MAINE

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Appendix H
STORAGE OF ENERGY

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Prepared for the Central Maine Power Company.

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This appendix is one of thirteen volumes; the remaining volumes are as follows: A. Conversion of Biomass; B. Conservation; C. Geothermal Energy Conversion; D. Ocean Thermal Energy Conversion; E. Fuel Cells; F. Solar Energy Conversion; G. Conversion of Solid Wastes; I. Wave Energy Conversion; J. Ocean and Riverine Current Energy Conversion; K. Wind Energy Conversion, and L. Environmental Impacts.

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Appendix A	Conversion of Biomass - C. Glaser, M. Ruane
Appendix B	Conservation - P. Carpenter, W.J. Jones, S. Raskin, R. Tabors
Appendix C	Geothermal Energy Conversion - A. Waterflow
Appendix D	Ocean Thermal Energy Conversion - M. Ruane
Appendix E	Fuel Cells - W.J. Jones
Appendix F	Solar Energy Conversion - S. Finger, J. Geary, W.J. Jones
Appendix G	Conversion of Solid Wastes - M. Ruane
Appendix H	Storage of Energy - M. Ruane
Appendix I	Wave Energy Conversion - J. Mays
Appendix J	Ocean and Riverine Current Energy Conversion - J. Mays
Appendix K	Wind Energy Conversion - T. Labuszewski
Appendix L	Environmental Impacts - J. Gruhl

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Preface

The Energy Laboratory of the Mass. Inst. of Tech. was retained by the Central Maine Power Company to evaluate several technologies as possible alternatives to the construction of Sears Island #1 (a 600 MWe coal fired generating plant scheduled for startup in 1986). This is an appendix to Report MIT-EL 77-010 which presents the results of the study for one of the technologies.

The assessments were made for the Central Maine Power Company on the basis that a technology should be:

1) an alternative to a base-load electric power generation facility. Base-load is defined as ability to furnish up to a rated capacity output for 6570 hrs. per year.

2) not restricted to a single plant. It may be several plants within the state of Maine. The combined output, when viewed in isolation, must be a separate, "stand-alone", source of power.

3) available to deliver energy by 1985.

APPENDIX H

STORAGE OF ENERGY

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1.0 INTRODUCTION

Energy storage is used to redistribute energy in time, rather than to produce electrical energy. Therefore, it is not an alternative energy conversion technology in the same sense as are solar collectors, wind turbines, wave energy devices, etc. Storage, however, plays a major supporting role in the viability of many alternative technologies because it helps overcome the problems associated with their intermittent, unreliable energy supply. This brief appendix has been included to direct readers to more storage information than is found in the discussions of several conversion technologies.

This appendix discusses energy storage only as it affects electricity supply and the alternative technologies discussed in the other appendices. Energy storage for solar space and water heating is included, since the introduction of solar space and water heating could affect electrical demand.

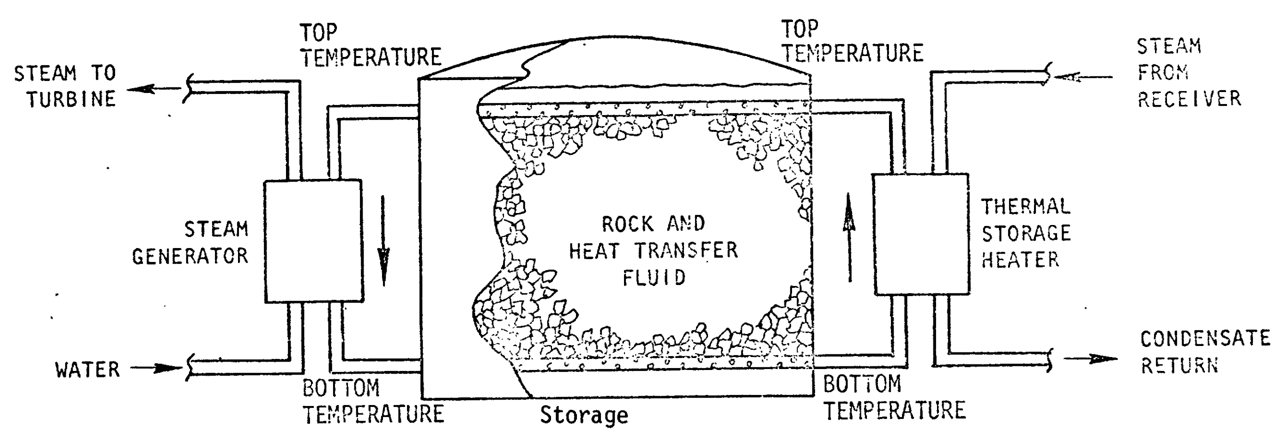
A large literature on energy storage exists, reflecting the extent of research activity in this area. Whenever possible, this appendix will rely upon two extensive comparative surveys of energy storage technologies which have recently been published (PSEG, 1976), (Bramlette, et al., 1976).

2.0 STORAGE TECHNOLOGIES

Energy conversion technologies which rely upon intermittent primary energy (e.g., solar radiation, wind, currents, waves) are unreliable (not always available) sources of electricity. Much of the current research in energy storage is directed at finding methods for economically providing reliable electrical capacity and energy levels when the primary energy supply is uncertain.

Energy can be stored at several points in the conversion process from primary energy to end use. In general, energy is stored as fuels, as thermal energy or as "electrical" energy (Figure 2.1).

Figure 2.1



Dual-Medium Thermal Storage Concept

from (Mitchell and Morgan, 1976, p. 86).

Since no fuel exists for energy sources such as solar radiation or wind (i.e., these energies must be used when available or lost forever), our discussion of storage is limited to thermal or electrical systems. Essentially the same technical parameters (Table 2.1) are used to describe both types of storage systems.

Table 2.1

STORAGE PARAMETERS

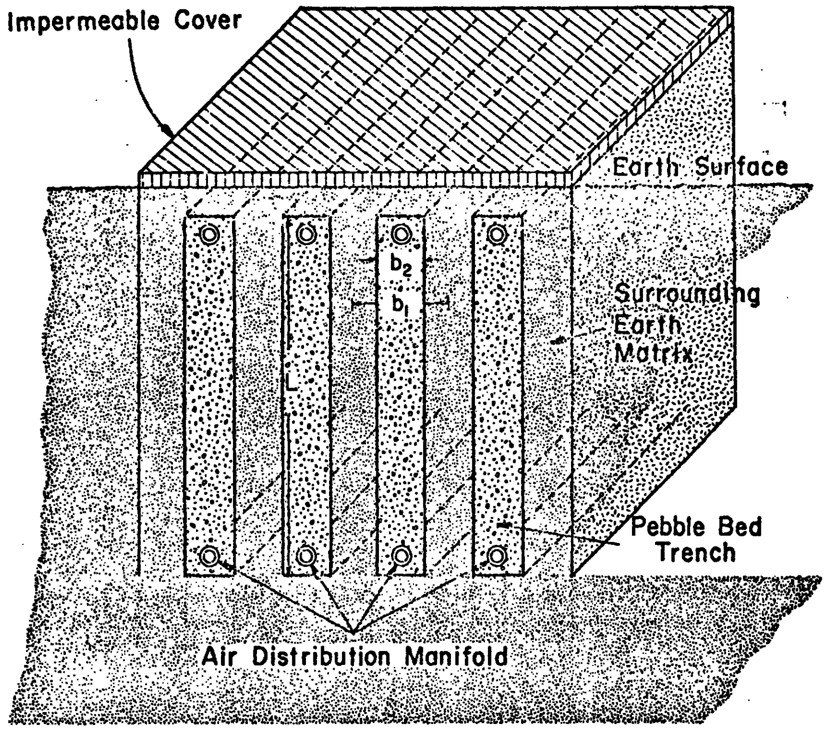
Discharge Time	- time in hrs/day spent releasing energy from storage (at rated discharge power)
Charge Time	- time in hrs/day (or hrs/week) spent storing energy (at rated charging power)
Rated Power Ratio	- ratio of rated charging power to rated discharge power
Storage Capability	- energy capacity or hours of discharge at rated discharge power
Annual Operation	- hours per year which can be spent charging (or discharging)
Efficiency	- output energy as percentage of input energy
Startup Time	- time required to reach rated discharge power
Turnaround Time	- time required to switch from charging to discharging at rated powers

2.1 Thermal Storage

Thermal energy cannot be transmitted efficiently for more than a few miles. Thermal storage devices therefore tend to be dedicated devices, i.e., directly associated with one or more specific energy conversion systems. Three storage mechanisms exist for thermal storage.

Sensible heat storage in a system is related to the system's temperature. It is charged by exposing a solid or liquid storage medium to thermal energy and allowing the medium to rise in temperature. When discharging, thermal energy is removed and the storage medium's temperature falls. For liquid storage media such as water or oil, a simple heat exchanger can be used with the storage liquid in one side and the thermal source or sink (water ,steam or other working fluids) flowing on the other. Solid storage media such as crushed stone (Riaz, et al., 1976) or steel (Turner, 1976) usually have a fluid (e.g., air, water, oil) which flows throug the solid and effects heat transfer (Figures 2.2 and 2.3).

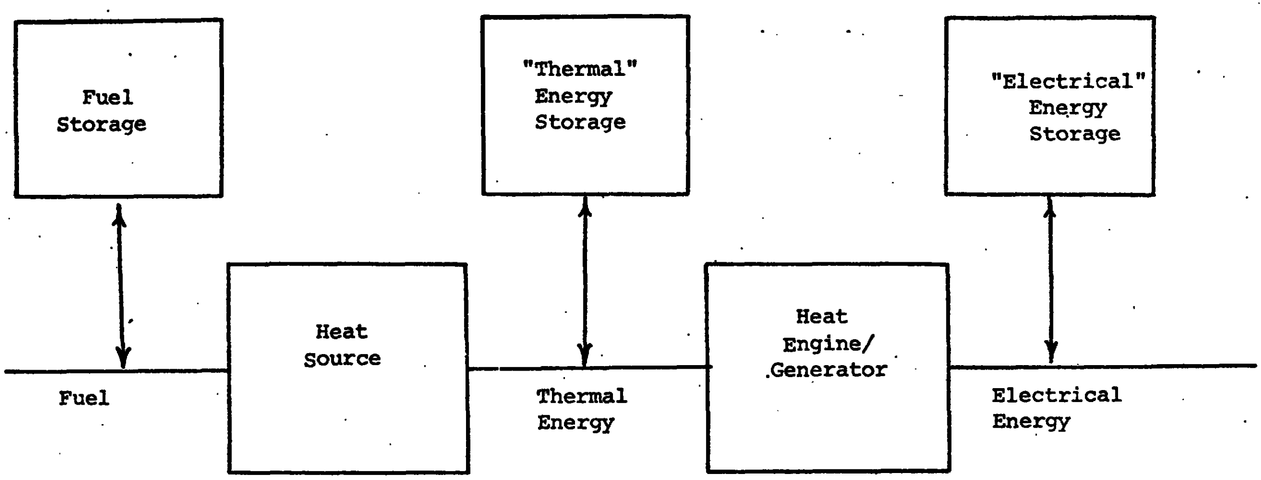
Figure 2.2



Generic configuration of pebble-bed heat accumulator

from (Riaz, et al., 1976, p. 125).

Figure 2.3



THERMAL POWER PLANT, SIMPLIFIED FLOW DIAGRAM

from (PSEG, 1976, p. 3-40)

Sensible heat storage represents the state-of-the-art for thermal storage systems (Green, et al., 1976, p. 34). For high-temperature systems, such as those required for central station uses, most thermal storage devices are not yet commercially available (Table 2.2). The most promising near-term central station systems (PSEG, 1976, p. 1-16) are pressurized water systems (Talaat, 1976), and oil systems (PSEG, 1976, p. 3-49). For low-temperature thermal storage systems, such as those needed for residential and commercial solar space heating and hot water systems, crushed rocks (with air or water as a heat transfer fluid) and water are the standard storage media. Their popularity stems from low costs, high reliability and good availability (Joy and Shelpuk, 1976, p. 2).

Table 2.2

OPERATIONAL AND CONCEPTUAL SENSIBLE HEAT STORAGE SYSTEMS

Storage Configuration	Storage Medium	Applications	Status	Temperature (°C) T_{MAX}	$T_{MAX}-T_{MIN}$	Capacity MW_t-hr	Input Rate kW_t	Output Rate kW_t	Cost $/$kW_t$-hr	Ref.
Above Ground Tank H-10m, R=0.5m	Water	Solar Central Receiver	Engineering Design	210 300	87 87	4.1 4.1		42,500 to 5640	8.0 22.0	2
Above Ground Tank H=3.15m, R=0.89m	Water, Therminol	Solar Total Energy System	Preliminary Testing	232 343	56 56	0.41	100-120	25-50	-	-
Steam Accumulator H=14.6m, R=1.83	Water	Solar Central Receiver	Engineering Design	200 300		14 37		33,300 41,800	3.0 6.0	2
Underground Tank H-30m, R=13m Depth=60m	Water	Storage for Nuclear Plant	Preliminary Design	217	141	4370		624	0.4	5,6
Acquifers	Water and Sand	Waste Heat Storage	Conceptual	170	110	42,000	19,400	19,400	0.003	8,9
Above Ground Tanks (Other Fluids)	Therminol-55 Therminol-66 Caloria-HT-43 HITEC	Solar Central Receiver	Engineering Design	315 315 302 500	55 55 83 300	226 226		452,000 452,000	62 27 11 4	11 11 12 13
Solid Storage Materials	Cast Iron	Industrial Space Heating Paint Manufacture	Operational Operational	750 700	480 430	0.75 0.64	96 80	~50 180	? ?	14,15
Packed Beds H=17.3m, R=9.7m	Granite Caloria-HT-43	Solar Central Receiver	Preliminary Design	302	84	195	42,200	30,400	5.13	12
Fluidized Bed	Sand Fly Ash	Storage for Power Plant	Conceptual	800	400	4000	500,000	500,000	?	16
Underground	Soil	Sink for Waste Heat for Underground Power Sources	Preliminary Design	100	85	500	1000		0.4-0.8	18,19
	Limestone or Granite	Solar Central Receiver	Conceptual	500	400	500,000		625,000	?	20

from (Green, et al., 1976, p. 8)

The next generation of thermal energy storage will be heat of fusion storage. In this method thermal energy is stored during a phase change of the storage medium from solid to liquid (LeFrois and Venkatasetty, 1976). These systems offer the advantages of high-temperature operation and high specific storage capacity (storage capacity per unit volume), but require specialized, expensive materials (Green, et al., 1976, p. 35). The energy stored in such systems to date has been small and only a limited number of compounds have actually been tested (Bramlette, 1976, p. 34).

An even more advanced concept is reversible chemical reactions for thermal storage (Bramlette, 1976, p. 43). These systems rely upon the reaction energies involved in chemical activity. These energies offer storage capacities an order of magnitude greater than phase change systems, operate at ambient temperatures and can be used for long-term storage. Several reactions are under study at a research level including hydrogen production, sulfuric acid-water reactions and oxidation of metal oxides (Boer, ed., 1976, pp. 163-226).

2.2 "Electrical" Storage

"Electrical" Storage occurs after primary energy sources are converted to electricity. Electrical energy is converted from electricity to another form during charging and reconverted to electricity during discharge. Electrostatic capacitors can store electricity directly. They are not feasible for utility use. Super conducting magnetic systems can. The major technologies are shown in Table 2.3.

Table 2.3

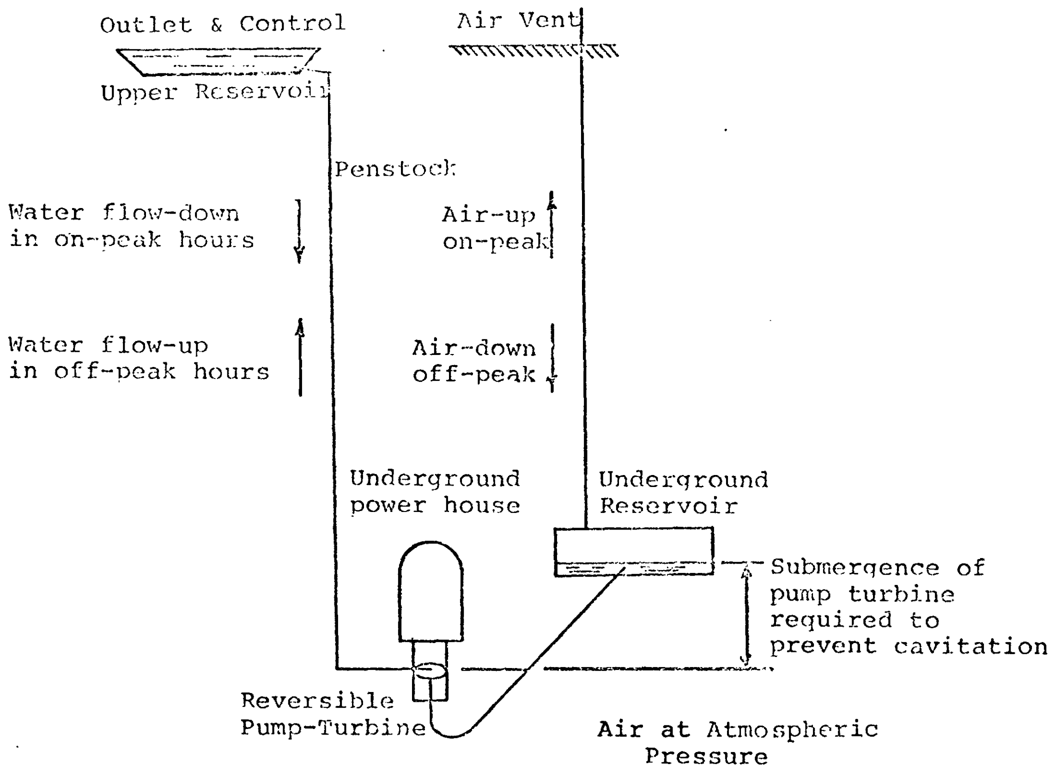
CANDIDATE TECHNOLOGIES SELECTED FOR DETAILED STUDY

"Mechanical" Storage Systems	
Hydro Pumped Storage	- Conventional - Underground Reservoir
Compressed Air Storage	- with Combustion Turbine - Storage in excavated Caverns, aquifers and salt cavities
Thermal Energy Storage	- Sensible Heat Storage - Pressurized Water in Above-ground Tanks - Hot Oil in Atmospheric Tanks
Flywheel Energy Storage	- Factory Fabricated Composite Wheels
"Chemical" Storage Systems	
Battery Energy Storage	- Lead-Acid, Lithium-Iron Sulfide, Sodium-Sulfur, Sodium-Chloride and Zinc-Chlorine
Hydrogen Storage	- Electrolyzer, Metal Hydride or Compressed Gas, and Fuel Cell or Combined Cycle
"Electromagnetic" Storage Systems	
Superconducting Magnetic Energy Storage	- Warm Reinforcement and Underground Construction

from (PSEG, 1976, p. 1-15)

Pumped hydroelectric storage is the only commonly used means of storing bulk electrical energy in the U.S.A. Electrical energy is used to energize motors that pump water to an elevated reservoir during charging (Figure 2.4). During discharge, the water falls through a turbine/generator producing electricity (IEEE, 1976; PSEG, 1976, p. 3-2). A relatively new use for this old method of storage involves underground siting of the reservoirs (PSEG, 1976, p. 3-15).

Figure 2.4

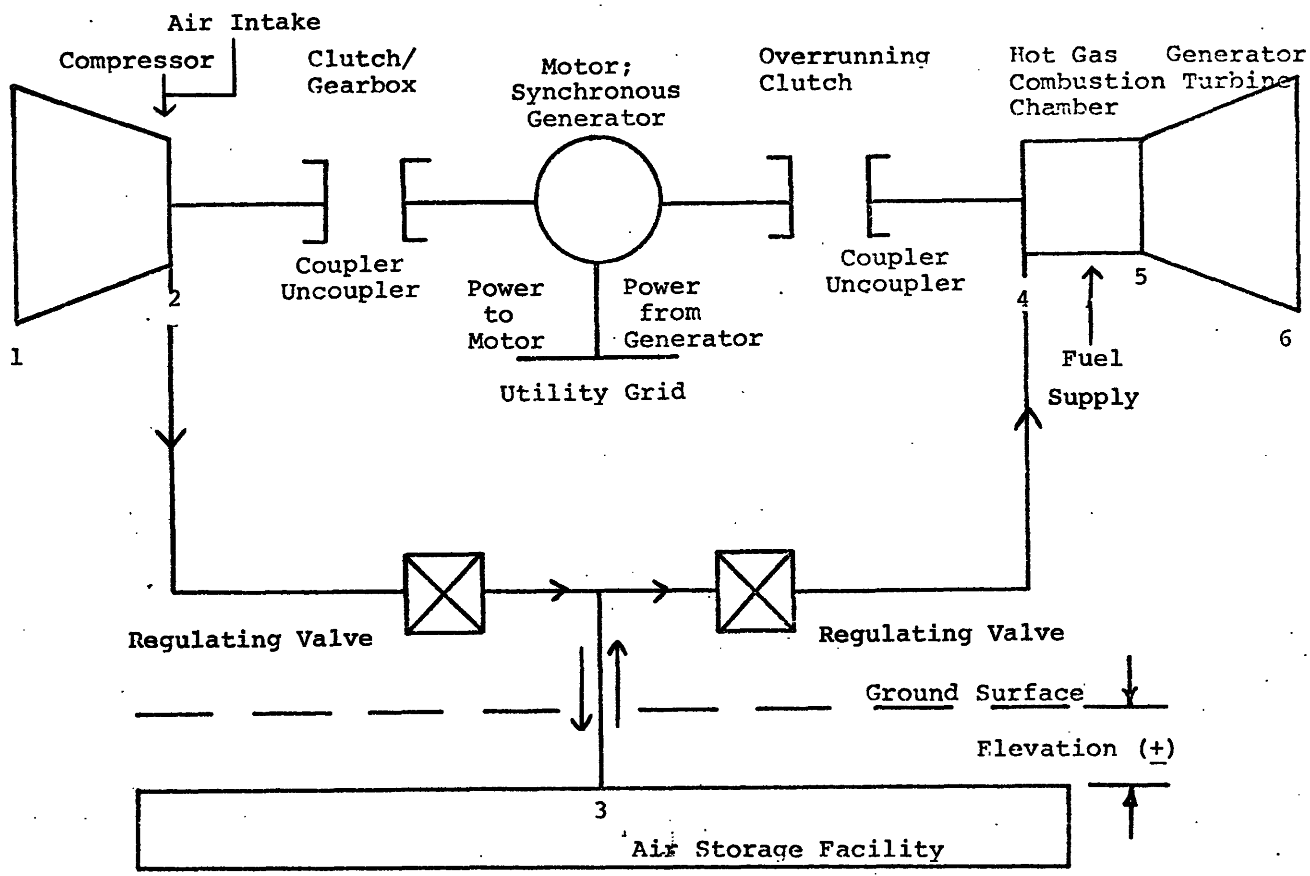


HYDRO PUMPED STORAGE

from (PSEG, 1976, p. 3-3)

Compressed air storage is used with gas turbines (Stephens, 1975). Energy is used to compress air, usually in an underground cavern or aquifer, during charging. At discharge the compressed air is used to reduce the fuel input required in a gas turbine, thereby recovering the stored energy (Figure 2.5). It is possible to use the compressed air to directly drive the turbine.

Figure 2.5



COMPRESSED AIR ENERGY STORAGE, DESIGN/OPERATING VARIABLES
from (PSEG, 1976, p. 3-25)

Thermal energy storage stores electricity as thermal energy in water, steam or refractory materials. This method is utilized as a means of shifting the demand for electricity for heating purposes by generating the heat at a convenient time (i.e., offpeak) and storing it for later use. It has had wide use in Europe (Asbury and Kouvalis, 1976), and is gaining interest in this country (EW, 1977b, p. 56).

Flywheels translate electrical energy into the rotational kinetic energy of a spinning mass during charging. Special high-speed bearings and an evacuated housing are used to reduce fricitional losses. During discharge the kinetic energy of rotation is converted back to electricity. Only simple, low-energy density systems for transportation applications have been built. No detailed design studies for electric utility use are yet available (PSEG, 1976, p. 3-89).

Battery systems (lead-acid) have long been used for low energy utility applications. Electrical energy is converted to chemical potential during charging and reconverted to electricity during discharge. Research is focusing on new battery materials in an attempt to increase energy densities and battery lifetimes (PSEG, 1976, p. 3-88). Some advanced technologies may be available by 1985 (EW, 1977a, p. 21) but considerable uncertainty exists about their reliability and costs (Science, 1976, p. 541).

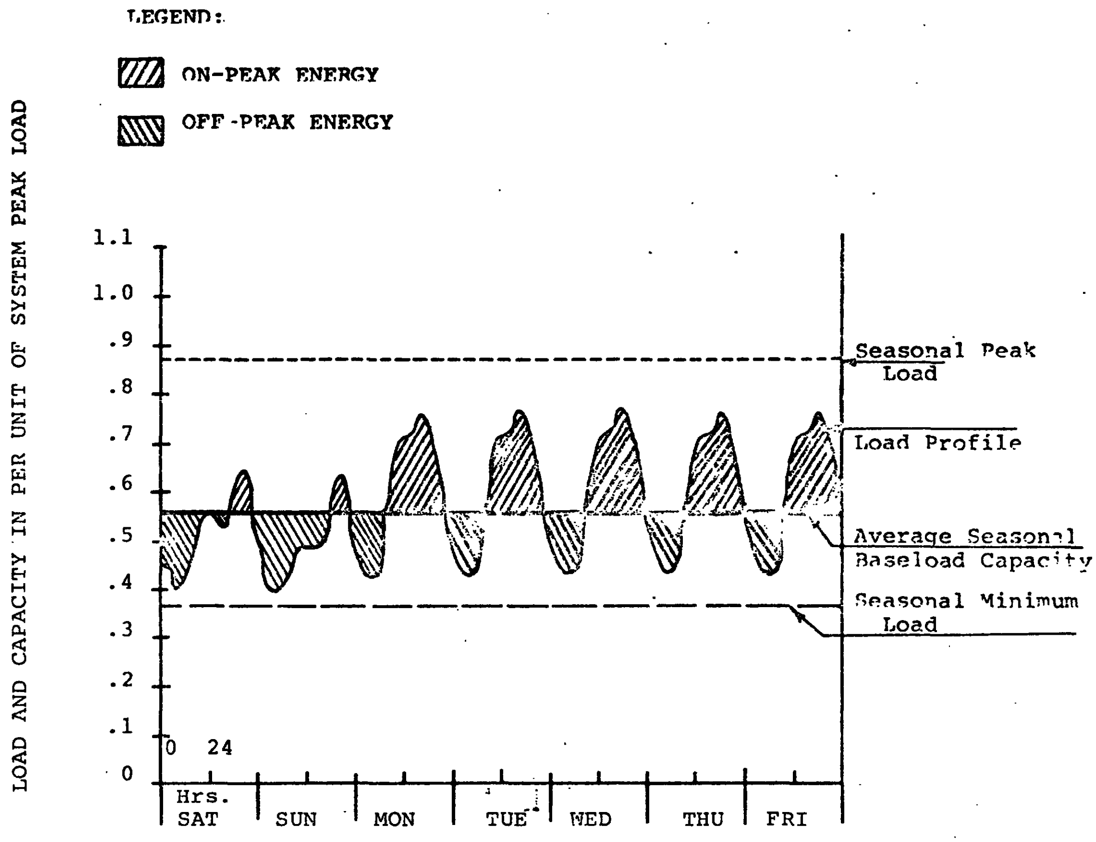
Hydrogen storage would convert electrical energy into hydrogen by hydrolysis of water. The hydrogen could be stored (as gas, cryogenically or in compounds) and then used as a supplementary turbine or fuel cell fuel to recover electrical energy. Such a system might be implemented after 1985 if efficiency improvements could be made (PSEG, 1976, p. 1-17).

Superconducting magnetic storage stores electrical energy in the magnetic field produced by a current circulating in the winding of a magnet. Superconductivity reduces resistive losses in the windings and maintains the lifetime of the charge. Research on this technology is at a basic research stage using small scale, existing technology (Boom, *et al.*, 1974) (PSEG, 1976, p. 3-121).

2.3 Applications of Storage

The basic principle of energy storage is the use of off-peak or excess energy to supply peak demands (Figure 2.6). In general, this means that storage devices serve as peaking or intermediate generating devices. Their efficient operation requires the existence of generating capacity (baseload units) which can provide off-peak power.

Figure 2.6



OFF-PEAK AND ON-PEAK ENERGY AS DEFINED BY CAPACITY LEVEL AND LOAD PROFILE

from (PSEG, 1976, p. 1-4)

This traditional definition has been expanded by the needs of alternative technologies like central solar thermal generating plants. In this case dedicated storage is used to save abundant, free energy from sunny periods for use at night or during periods of poor insolation. In effect this is still a form of off-peak power use since part of the solar energy is excess when it is available.

Both system level electrical storage and dedicated thermal and electrical storage must be matched to their system's and power plant's requirements. System daily, weekly, and seasonal load cycles, the fraction of unused capacity at various times, the incremental cost of off-peak energy and characteristics of the storage system (Tables 2.4 and 2.5) determine what storage capacity should be installed. The determination of storage sizes requires an engineering design study beyond the scope of this report. Based on an average storage efficiency of75%, it has been estimated that up to 17% of annual system peak load could be replaced by energy storage power (MW) (PSEG, 1976, p. 1-28).

Table 2.4

EXPECTED TECHNICAL AND COST CHARACTERISTICS OF SELECTED ENERGY STORAGE SYSTEMS

	NEAR TERM					INTERMEDIATE TERM			LONG TERM
Characteristics	Hydro Pumped Storage	Compressed Air	Thermal Steam	Thermal Oil	Lead Acid Batteries	Advanced Batteries	Flywheel	Hydrogen Storage	Superconducting Magnetic
Commercial Availability	Present	Present	Before 1985	Before 1985	Before 1985	1985-2000	1985-2000	1985-2000	Post 2000
Economic Plant Size (MWh or MW)	200-2000 MW	200-2000 MW	50-200 MW	50-200 MW	20-50 MWh	20-50 MWh	10-50 MWh	20-50 MW	Greater than 10,000 MWh
Power Related Costs (a) ($/kWh)	90-160	100-210	150-250	150-250	70-80	60-70	65-75	500-860	50-60
Storage Related Costs (a) ($/kWh)	2-12	4-30	30-70	10-15	65-110	20-60	100-300	6-15	30-140 (c)
Expected Life (Years)	50	20-25	25-30	25-30	5-10	10-20	20-25	10-25	20-30
Efficiency (d) (%)	70-75	(e)	65-75	65-75	60-75	70-80	70-85	40-50	70-85
Construction Lead Time (Years)	8-12	3-12	5-12 (f)	5-12 (f)	2-3	2-3	2-3	2-3	8-12

(a) Constant 1975 dollars, does not include cost of money during construction.
(b) Could be considerably higher.
(c) These numbers are very preliminary.
(d) Electric energy out to electric engery in, in percent.
(e) Heat rate of 4200-5500 Btu/kWh and compressed air pumping requirements from .58 - .80 kWh (out).
(f) Long lead time includes construction of main power plant.

from (PSEG, 1976, p. 1-19)

Table 2.5

STORAGE SYSTEM OPERATING CHARACTERISTICS

	Hydro Pumped Storage	Compressed Air with Combustion Turbine	Thermal: Separate Peaking Turbine	Thermal: Variable Extraction Turbine	Hydrogen with Fuel Cells or Batteries: Line-Commutated	Hydrogen with Fuel Cells or Batteries: Forced-Commutated	Flywheels	Superconducting Magnetic
Load Following	Yes (a)	Yes (a)	Yes	Yes	Yes	Yes (a)	Yes	Yes
Part-Load Operation	Yes (a)	Yes (a)	Yes	Yes	Yes	Yes (a)	Yes	Yes
Spinning Reserve On-Line	Yes (a)	Yes (a)	Yes	Yes	Yes	Yes	Yes	Yes
Start-Up Time	Minutes	Minutes	Minutes (b) Hours	Minutes	-Design Variable -Cycles to Minutes (c)		Few Cycles to Seconds	Few Cycles (c) to Seconds
Turnaround Time	Minutes	Minutes	Minutes (b) Hours	Minutes	-Design Variable -Cycles to Minutes		Few Cycles	Few Cycles to Seconds
Emergency Start (Black Start)	Yes	Yes	Yes	No	No	Yes (c)	Yes (d)	No (e)
Transient Stability	Normal Hydro	Normal Gas Turbines	Normal Steam Turbines		-Immune -Can Improve -Design Variable		-Immune -Can Improve -Design Variable	-Immune -Can Improve -Design Variable

(a) Yes, if sacrifice in efficiency acceptable.
(b) If turbine is at temperature.
(c) If source is at temperature.
(d) If at speed.
(e) If current-fed line-commutated converter.

from (PSEG, 1976, p. 1-21)

This would be peaking or intermediate capacity and would be dependent on the existence of adequate off-peak energy. The 17% figure includes any existing storage capabilities.

Dedicated storage can be designed to find a minimum cost storage size. Above that size collection costs and storage charges increase faster than the added energy capability, resulting in higher overall costs.

3.0 ECONOMICS

Economic analysis of storage costs is difficult to perform. There are two major cost components: equipment costs and energy costs. Except for pumped hydroelectric systems, no commercial storage units are in utility operation, so costs based on experience cannot be obtained. Table 2.4 listed te best available cost data for large electrical and thermal storage systems.

Energy costs are a function of the costs for units generating the off-peak energy of the storage efficiency and the conversion/reconversion process. While overall storage efficiencies can be estimated, off-peak energy costs will vary with time according to generation mix and fuel costs. In general, energy from storage will be more expensive than the energy used directly because of transmission losses, storage losses and conversion/reconversion and the costs of storage equipment.

4.0 ENVIRONMENTAL IMPACTS

A general impact of storage devices is their space or land requirements (Table 4.1). Quantitative assessments of environmental impacts are not yet available for most storage technologies, but qualitative issues have been collected (Table 4.2)(Figures 4.1 and 4.2).

Table 4.1

COMPARISON of STORAGE TECHNOLOGIES, LAND AREAS AND ECONOMIC SIZE

Land Requirements	Economic Size: Moderate	Economic Size: Large
Moderate	Advanced Batteries Flywheels	Thermal (Steam; Oil) Compressed Air Underground Hydro Pumped Storage Superconducting Magnets
Large	Near-Term Lead Acid Batteries Hydrogen	Conventional Hydro Pumped Storage (Low Head)

from (PSEG, 1976, p. 1-23)

Table 4.2

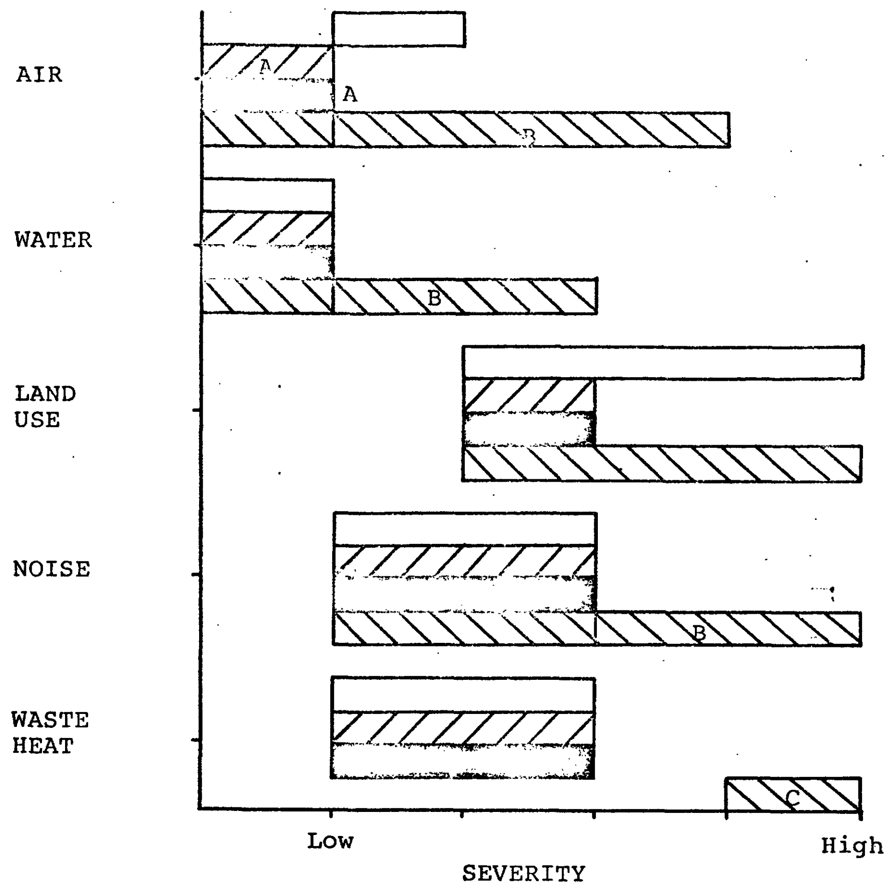
MAJOR FACTS TO BE CONSIDERED
IN ENVIRONMENT ASSESSMENT

	Air	Water	Land Use	Noise	Biological	Occupation, Safety and Health (6)
Hydro Pumped Storage	Water Vapor (8)	Heat (9)	Water Reservoirs	Pumps and Turbines	Entrainments and Impingement on Fish and Fish Larvae	Protection against flooding of Powerhouse and Against Dam or Waterway Failure
Compressed Air Storage with Combustion	Heat, NO_x, CO, CO_2 Hydrocarbons	- (4)	Combustion Turbine Water Reservoirs Compensated Storage	Compressors and Combustion Turbines	- (4)	Protection Against Oil Fires (5)
Thermal Storage	Heat	Heat	Tank Farm Power Plant Cooling Towers	Steam Turbines	- (4)	Protection Against Oil Fires (5)
Lead Acid	Heat, H_2, SO_2, Acid Mist	- (4)	Low Profile Structure	Fans, Pumps, Power Conditioning	- (4)	Personal Protection Against Acid Required. Fire and Explosion Hazards
Advanced Batteries (2)	Heat (1)	- (4)	Low Profile Outside Equipment	" "	- (4)	Various Types of Fire Hazards
Flywheels	Heat	- (4)	Subsurface	Motors and Generators Power Conditioning	- (4)	Containment of Flywheel or Fragments if Catastrophic Failures
Hydrogen	Heat, O_2	- (3) Heat	Low Profile Structures Outside Equipment and Tank Farm	Fans, Pumps, Power Conditioning Equipment	- (4)	Protection Against Fires and Explosion Hazard Required
SMES	Heat, HO_2	Heat	Low Profile Equipment Tank Farm Exclusion Arc	Refrigeration System Power Conditioning Equipment	Effects of Magnetic Fields	Protection Against Magnetic Field Required (7)

1. All Systems Should Be Designed to Meet Environmental Regulations.
2. Sealed System. No Air Emissions Anticipated.
3. If Combined Cycle Plant is Used.
4. No Special Non-Negligible Effects Identified.
5. If a Combustible Oil Used.
6. Only Unusual or Non-Standard Items Identified.
7. Exclusion Area May be Requested to Unknown Magnetic Field Effects .
8. Increase in Water Vapor in the Air Above the Reservoir.
9. Large Mass of Water May Act as a "Thermal Flywheel" and Alter Meteorology in the Vicinity.

from (PSEG, 1976, p. 6-20)

Figure 4.1



Lead Acid Batteries
Advanced Batteries
Flywheel
Hydrogen

Notes

A. Sealed System Does Not Include Heat Rejected To Air

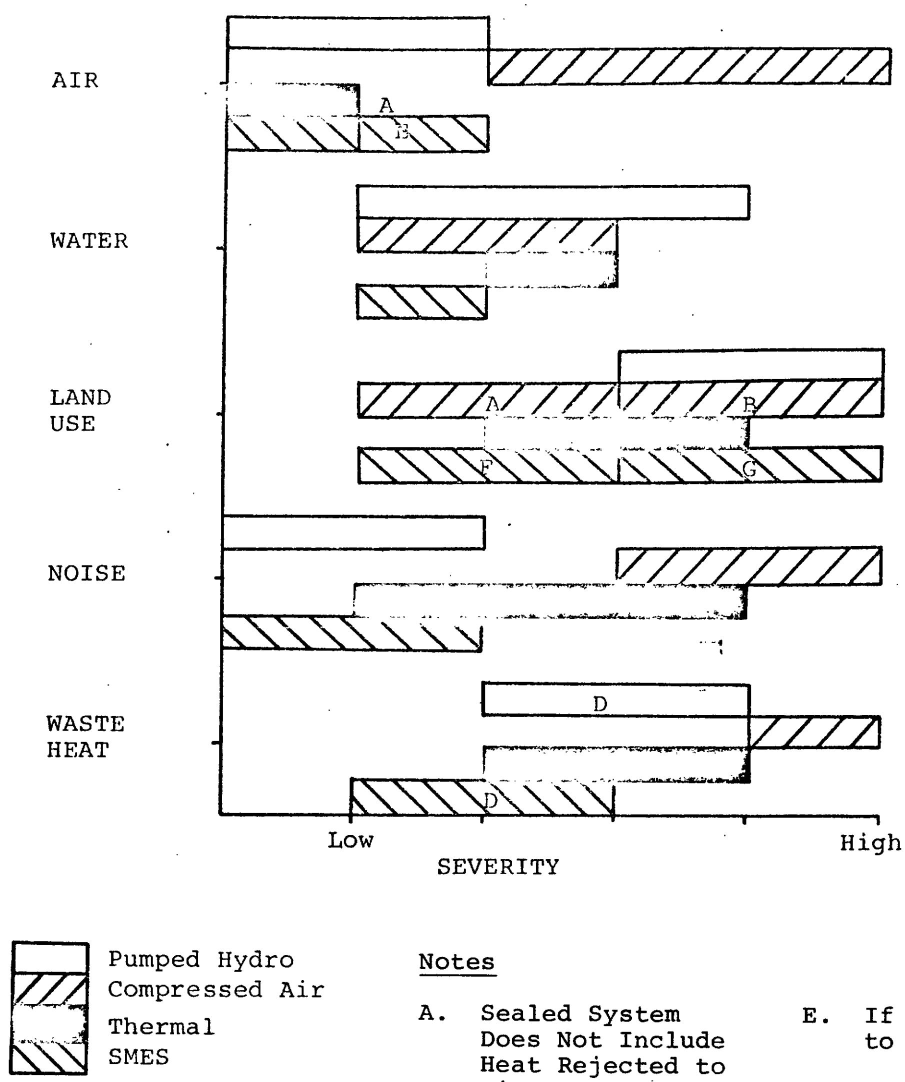
B. If Combined Cycle Plant Used for Hydrogen Combustion

C. Low Thermal Efficiency

COMPARISON OF DISPERSED STORAGE SYSTEMS BY PRINCIPAL IMPACT AREAS

from (PSEG, 1976, p. 6-21)

Figure 4.2



Notes

A. Sealed System Does Not Include Heat Rejected to Air

B. If Combined Cycle Plant Used for Hydrogen Combustion

D. Primaty Cooling With Water

E. If Helium Released to Atmosphere

F. Does Not Include Underground Space

G. Exclusion Area Required to Magnetic Field Effects

COMPARISON OF CENTRAL STATION STORAGE SYSTEMS BY PRINCIPAL IMPACT AREAS

from (PSEG, 1976, p. 6-22)

5.0 APPLICABILITY TO MAINE

Maine now participates in the pumped hydroelectric storage in the New England Power Pool. There appears to be no special requirements associated with any of the storage technologies which could not be met in Maine, with the possible exception of siting (especially pumped hydroelectric). Key technical issues delaying the use of storage devices are shown in Tables 5.1 and 5.2.

Table 5.1

Energy Storage Technologies
Technical Characteristics

Near Term (present-1985)	*Storage Density (kWh/ft^3)*	*Construction Lead Time (years)*	*Commercial Availability*	*Key Issue*
Hydro Pumped Storage	0.06	7-10	1985 (underground)	Storage Cavern
Compressed Air	0.04-0.4	4-10	1984	Storage Formation
Thermal, Steam	0.3-1.5	3-5	1983	Pressure Vessel Storage Cavern
Thermal, Oil	0.5-1.0	3-5	1983	Tankage Costs
Lead Acid Battery	1.0-1.5	2-3	1982	$/kWh
Intermediate Term (1985-2000)				
Advanced Batteries	1-5	2-3	1990	Lifetime versus Cost
Hydrogen	N.A.	2-3	1995	Electrolyzer Cost and Efficiency
Flywheels	0.5-2.0	2-3	1990	Wh/lb; $/lb
Long-Term (beyond 2000)				
Superconducting Magnetic	0.2-0.6	7-12	After 2000	Model Testing

from (Cooper, et al., 1976, p. 15)

Table 5.2

MAJOR BARRIERS TO COMMERCIAL SUCCESS

Conventional Hydro Pumped Storage	Commercial Now, Delays in Licensing
Underground Reservoir Hydro Pumped Storage	Lack of First Plant, Construction Lead Time, Construction Cost Uncertainty, Site Availability Delay in Regulatory Approval
Compressed Air Storage with Combustion Turbine	Lack of First Plant, Uncertain availability of Oil, Construction Cost Uncertainty, Site Availability Possible Need for Regulatory Approval
Thermal Storage in Water and Oil	Lack of First Modern Plant, Regulatory Hurdles, Containment Costs
Lead-Acid Batteries	Cost, Lack of First Modern Plant, Life
Advanced Batteries	Lack of Commercial Product; Life and Cost Uncertainty
Flywheels	Lack of Commercial Product, Cost
Hydrogen	Lack of Commercial Product, Cost, Efficiency
Superconducting Magnetic Energy Storage	Lack of Commercial Product; Cost Uncertainty; Site Availability; Uncertain environmental site requirements

from (PSEG, 1976, p. 7-4)

Dedicated storage will probably be developed to commercial status along with solar energy thermal electric power plants (Gutstein and Kaplan, 1976). Development of this type of storage technology will therefore not limit the introduction of that concept in Maine.

Residential and commercial storage systems are available, although generally not mass produced. They should not be a limiting factor to the use of solar space and water heating technology.

Using the estimate of Section 2.3, that as much as 17% of annual peak could possibly be served by storage (PSEG, 1976, p. 1-28), it is conjectured that up to 280 MW in 1986 could conceivably be served on the CMP system by an ideally matched storage system. Such savings are conjectural until a specific design study is done for the loads and generation to ensure that adequate off-peak energy is available. The portion of existing storage already in use must be considered in this analysis since it constitutes part of the 17% maximum figure.

6.0 CONCLUSIONS

- energy storage can play an important role in providing generating capacity for peaking and intermediate electric loads, providing sufficient economic baseload capacity is available for charging energy storage systems with off-peak energy.

- pumped hydroelectric storage is the only commercial technology and is already being used in New England.

- thermal storage, using sensible heat, is the state of the art for dedicated storage systems; small-scale systems for off-peak electricity consumption are available for residential and commercial use and large-scale systems are being designed.

- storage technologies could be applied to Maine and might supply up to 17% of peak annual load on a peaking and intermediate basis.

7.0 REFERENCES

Astury, J.G. and Kouvalis, A., "Electric Storage Heating: The Experience in England and Wales and the Federal Republic of Germany", Argonne Nat. Lab., Energy and Environmental Systems Division, Argonne, Ill., April 1976.

Boer, K.W., ed., Sharing the Sun - Solar Technology in the Seventies, Vol. 8, Joint Conference of the American Section, International Solar Energy Society and Solar Energy Society of Canada, Winnipeg, Canada, Aug. 1976.

Boom, R.W., et. al., "Wisconsin Superconductive Energy Storage Project", NSFRANN 74-065, July, 1974.

Bramlette, T.T., et. al., Survey of High Temperature Thermal Energy Storage", Saudia Laboratories, SAND-75-8063, March 1976.

Cooper, V.R., "Rationale for the EPRI Thermal Mechanical Energy Storage Program", paper presented at America Power Conference, Chicago, Ill., April 1976.

E.W.,"'Superbatteries' due on Market in Eight Years", Electrical World, Jan. 1977.

E.W., "Thermal Storage Outlook is Positive", Electrical World, March, 1977.

Green, R.M., et. al., "High Temperature Thermal Energy Storage", paper in Sharing the Sun, Vol. 8, Boer, ed., Joint Conference of the American Section, International Solar Energy Society of Canada, Winnipeg, Canada, Aug. 1976.

Gutstein, M.U. and Kaplan, G.M., "Description of Thermal Storage Sub System Designs for ERDA's 10 MWe Solar Central Receiver Pilot Plant", paper presented at ASME Winter Annual Meeting, 76-WA/HT-68, NY, NY, Dec. 1976.

IEEE, Committee Report: "Bibliography on Pumped Storage to 1975" IEEE Transactions on PAS, Vol. PAS-95, No. 3, May/June 1976.

Joy, P. and Slulpuk, B., "Solar Heating Thermal Storage Feasibility" paper 76-WA/HT-36, ASME, Winter Annual Meeting, NY, NY, Dec. 1976.

LeFrois, R.T. and Venkatasetty, H.V., "Inorganic Phase Change Materials for Energy Storage in Solar Thermal Program", paper in Sharing the Sun, Vol. 8, Boer, ed., Joint Conference of the American Section, International Solar Energy Society and Solar Energy Society of Canada, Winnipeg, Canada, Aug. 1976.

Mitchell, R.C. and Morgan, G.R., "Gravel and Liquid Storage System for Solar Thermal Power Plants", paper in Sharing the Sun, Vol. 8, Boer, ed., Joint Conference of the American Section, International Solar Energy Society and Solar Energy Society of Canada, Winnipeg, Canada, Aug. 1976.

PSEG, "An Assessment of Energy Storage Systems Suitable for Use by Electric Utilities", a report prepared by Public Service Electric and Gas Company for EPRI and ERDA, EPRI-EM-264, July 1976.

Riaz, M., et. al., "High Temperature Energy Storage in Native Rocks", paper in Sharing the Sun,Vol.8 Boer, ed., Joint Conference of the American Section, International Solar Energy Society and Solar Energy Society of Canada, Winnipeg, Canada, Aug. 1976.

Science, "Advanced Storage Batteries: Progress, but not Electrifying", Science, Vol. 192, May, 1976.

Stephens, T., "Adiabatic Compressed Air Energy Storage Systems", Working Paper, Lincoln Laboratory, MIT, Lexington, MA., Dec. 1975.

Talaat, M.E., "A Pressurized Liquid Concept for Solar-Thermal Energy Storage for the 24-Hour Continuous Operation of an Energy Conversion System", paper presented at ASME Winter Annual Meeting, 76-WA/HT-38, NY, NY, Dec. 1976.

Turner, R.H., "Thermal Energy Storage Using Large Hollow Steel Ingots", paper in Sharing the Sun, Vol. 8, Boer, ed., Joint Conference of the American Section, International Solar Energy Society and Solar Energy Society of Canada, Winnipeg, Canada, Aug. 1976.