COMPRESSED AIR ENERGY STORAGE TECHNOLOGY
PROGRAM IN THE UNITED STATES

MASTER

by

W.V. Loscutoff

Pacific Northwest Laboratory

Operated for the U.S. Department of Energy

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W.V. Loscutoff
Pacific Northwest Laboratory
Richland, Washington, U.S.A.

ABSTRACT

The development of compressed air energy storage (CAES) technology is a recognized objective of the United States Department of Energy. The specific objectives are to develop the technology to a level that will permit early commercialization of the concept and to develop advanced CAES systems that will not require any petroleum fuels for operation. This paper summarizes the CAES technology research and development program sponsored by the United States Department of Energy and provides a brief set of recommendations on the developments required for the commercialization of the concept.

INTRODUCTION

Compressed air energy storage (CAES) is a technique for supplying electric power to meet peak load requirements of electric utility systems. It incorporates a modified state-of-the-art gas turbine and an underground reservoir---an aquifer, a salt cavity or a mined hardrock cavern. The compressor and turbine sections of the gas turbine would be alternately coupled to a motor/generator for operation during different time periods. During nighttime and weekend off-peak periods, low-cost power would be used to compress air which would be stored in the underground cavern. During the subsequent daytime peak-load periods the compressed air would be withdrawn from storage, mixed with fuel, burned and expanded through the turbines to generate peak power. This concept reduces the consumption of premium fuels by more than 60 percent for conventional CAES systems when compared to simple cycle gas turbines used currently to provide peaking power. Some advanced CAES concepts do not require any premium fuels at all.

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Studies have shown that the CAES concept is technically feasible and, under certain conditions, may be economically viable. CAES systems offer several advantages over conventional systems used by utilities for meeting peak load requirements. Replacement of current gas turbines in the United States by CAES plants could result in annual savings of more than 100,000,000 barrels of oil. The net annual oil saving would be greater in the future. CAES plants are not limited to the same degree by the siting difficulties faced by conventional pumped hydro plants. Finally, a well designed CAES plant should have a smaller adverse impact on the environment compared to a conventional gas turbine peaking plant.

PRESENTATION OBJECTIVE

The objective of this presentation is to review the United States Department of Energy technology program for developing compressed air energy storage (CAES) for utility applications.

MAJOR POINTS

The objectives of the compressed air energy storage technology program are to establish the feasibility of CAES for utility application and to promote the commercialization of CAES through technology development and demonstration.

Previous and current studies point to a number of conclusions. Some of the major items are as follows.

- Low risk machinery designs for near-term CAES plants using state-of-the-art equipment with modest modifications.
- CAES plants could reduce the consumption of petroleum fuels to 30-40 percent of the amount used by conventional peaking plants.
- Long-term storage reservoir stability is a key issue to commercialization of the CAES concept.
- While near-term CAES plants can save significant amounts of petroleum fuels, they are still dependent on these fuels. It is important to minimize, or even eliminate this dependence in the near future with advanced concepts.

- Performance and economics of CAES plants could be improved with development of new equipment.
- There are no insurmountable technical barriers to prevent the implementation of CAES by the utilities.
- Economic attractiveness of CAES relative to simple cycle gas turbines needed to meet peak electric demands is marginal but is enhanced by the continuing increase in price of petroleum fuels.
- CAES systems, unlike pumped hydro storage, offer a great degree of siting flexibility.
- There are minimal institutional and environmental barriers to the construction and operation of a CAES plant.

CAES TECHNOLOGY DEVELOPMENT PROGRAM SUMMARY

The Department of Energy's CAES Technology Program was initiated in 1975 and has grown into a fairly comprehensive program in 1979 with the Pacific Northwest Laboratory as the lead laboratory. The program has two major thrusts---near-term CAES systems studies and advanced CAES concepts studies. These are a number of interrelated studies being performed by national laboratories, universities, and industry.

The near-term systems studies are directed at accelerating the implementation of the CAES concept by the utilities. These studies include a number of elements that will be discussed next.

- Reservoir design and stability criteria development.

This activity is one of the most important elements of the CAES technology program. Three types of underground air storage reservoirs are considered: salt cavities, hard rock caverns and porous rock reservoirs. Activity includes state-of-the-art surveys of literature and industry, numerical modeling of cavern behavior, laboratory studies of geochemical and material properties, and field evaluation of design and stability criteria. All of the foregoing address the response of an underground reservoir to pressure and temperature

fluctuations that would be encountered in the daily charging and discharging operations. The thermal and mechanical effects generated by daily reservoir operation could cause chemical and mechanical damage to the porous rock structures and cavern walls. Fracturing could occur leading to leakage or other damage. Certain conditions could result in rock deterioration that could lead to plugging of porous media pores or contribute to particle carryover to the turbines. In mined caverns, spalling and disintegration of walls could lead to caving, blowouts and, possibly, to total collapse. Since CAES reservoirs must have lifetimes in excess of 30 years, reservoir stability must be addressed before the concept becomes economically feasible.

- Equipment development.

Although low-risk machinery designs are feasible using state-of-the-art equipment with only modest modifications, there are a number of components that have high levels of technical uncertainty. Furthermore, technical improvements beyond current equipment could lead to reduced costs of implementing the CAES concept. In addition, identification of new CAES concepts could lead to demands for development of new equipment. All of these reasons have led to establishing a modest program that will examine heat recuperators, turbines and compressors, high temperature combustors, thermal storage systems and coal-firing equipment for CAES.

- Research on environmental concerns

The implementation of any new concept raises new potential environmental issues. A number of issues have been identified and studies are ongoing or planned to resolve some of the issues. For plants that may use porous rocks as storage reservoirs, potential issues include physical rock degradation, chemical decomposition, geochemical reactions, loss of confinement, air leakage, caprock fractures, effect on potable water, etc. For plants that may use salt cavities for storing air, potential environmental issues include brine disposal (during leaching) cavity collapse, surface

subsidence, and salt carryover. For plants that may use hard rock caverns, environmental issues include disposal of mined rock, disruption of water bearing formations, impact associated with intake and discharge to surface waters, blowouts, rock erosion, cavern collapse, etc.

A potential long term weakness of the conventional CAES concept is its reliance on petroleum fuels. The advanced concepts studies are directed at reducing and even eliminating, this dependence of the CAES concept. The approach is to develop systems that range from replacing petroleum fuels with coal, to thermal energy storage, and to integrating CAES with solar power systems. The major elements of advanced concepts studies are the following.

- Coal-fired fluidized bed combustion (FBC) integrated with CAES

A feasibility study of FBC integrated with CAES was initiated in 1978. The purpose of this study was to conduct a technical and economic assessment of CAES systems augmented by coal-fired FBC. This study will include a technology assessment of FBC, integration of FBC with CAES, preliminary screening of the major concepts, a preconceptual plant design, and a preliminary market analysis.

- Thermal energy storage systems integrated with CAES

In a conventional CAES plant, the heat of compression would be rejected into the atmosphere. It is logical to store that heat and recover it before expanding the air through a turbine. The limiting case is the adiabatic CAES concept that is a pure storage cycle requiring no injection of fuel during the power generation mode of operation. Some hybrid schemes use thermal energy storage and some fuel. Several concepts for thermal storage of compression heat have been examined. The simplest and most economic method appears to be transfer of the compression heat directly to large pebble beds contained in underground caverns. The economics of integrating thermal storage with CAES currently appear to be marginal. However, they improve as the cost of petroleum fuels rises.

- Coal Gasifiers Integrated with CAES

An alternative to using petroleum fuels is to incorporate a coal gasifier and a clean-up system. The turbomachinery for a coal gasifier/CAES concept is projected to be basically the same as petroleum-fired equipment with only minor redesigns. The cost of the gasification and clean-up system is, however, relatively high.

- Solar Energy Integrated with CAES

A number of concepts for applying CAES to solar power systems have been considered. Studies indicate that, due principally to the high cost of solar plant components, augmentation of CAES energy output by using solar thermal air heating is economically unattractive at this time.

CAES DEMONSTRATION PROGRAM

To encourage the investigation of near-term energy storage technologies by utilities, the United States Department of Energy has initiated projects on preliminary engineering design of first-of-a-kind demonstration plants. The overall goal of the program is to determine the economic and technical feasibility of deploying a demonstration CAES plant on a utility system in the 1980s. Three separate projects are currently in progress to perform preliminary design and site exploration studies, one for each type of storage reservoir---porous rock, hard rock and salt. Public Service of Indiana is the lead utility in the project to perform preliminary design of a CAES plant and site exploration using porous rock formations as the air reservoir. The Potomac Electric Power Company is leading the project for a CAES plant using hard rock caverns. Middle South Services is performing preliminary design and site exploration using salt cavities.

The underlying philosophy of the preliminary design methodology is that a utility will have the best overall picture of the economic, technical, environmental, legal, and geological factors that would affect the success of a CAES demonstration project. The preliminary design phase projects are scheduled for completion in 1980 and 1981.

RECOMMENDATIONS ON DEVELOPMENTS IN CAES

Among the unknowns that affect the viability of CAES are those related to the response of an underground reservoir to CAES conditions and the dependence of CAES on petroleum fuels. As a result, the following are recommendations on developments in CAES.

- Expand numerical and laboratory studies of the behavior of CAES reservoirs; there is currently virtually no data on material properties of rock candidates for reservoirs at non-ambient conditions.
- Initiate field studies of CAES reservoirs to provide firm empirical data on behavior of such reservoirs; other existing programs that use underground reservoirs could be used to accelerate this recommendation.
- Accelerate equipment development for CAES; this could include high temperature compressors, thermal storage beds, combustors, and reversible compressors-turbines.
- Begin detailed engineering design, site development, and construction of conventional CAES demonstration plants.
- Initiate programs directed at preliminary design of advanced CAES concepts utilizing thermal energy storage, coal-fired fluidized bed combustion, coal gasification, etc.
- Plan for demonstration of an advanced CAES concept.