Review of Environmental Studies and Issues on Compressed Air Energy Storage

Beckwith & Associates

March 1983

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**Pacific Northwest Laboratory
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REVIEW OF ENVIRONMENTAL STUDIES
AND ISSUES ON COMPRESSED AIR
ENERGY STORAGE

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FOREWORD

Compressed air energy storage is a utility scale energy storage technique that allows large scale load shifting of under utilized base load energy to meet daily peak load demands. The technology is presently undergoing commercial application in this country and an extensive data base exists to allow reliable determination of feasibility for a particular situation and to provide the basis for detail design of such a plant.

The technological readiness of compressed air energy storage has been the result of intensive study by the Department of Energy (DOE), the Electric Power Research Institute (EPRI) and by the utility industry. The Department of Energy among other efforts is sponsoring the Underground Energy Storage (UES) Program at Battelle Memorial Institute's Pacific Northwest Laboratory. Within this program are the CAES Technology Projects, which examine reservoir stability and advanced system designs. These projects are supported by the Energy Storage Technology Division. Another project is Utility Applications supported by the Electrical Energy Systems Division, which promotes feasibility investigations by small utilities on the use of energy storage on their systems.

In parallel with these technical programs, the Division of Public Safety has sponsored work examining environmental issues surrounding CAES implementation in the CAES Environmental Concerns Project. This document is a summary and assessment of available environmental work carried out in these projects and of work available from other sources. It is hoped that it will acquaint the reader with the chief environmental considerations of the technology, and also provide a basis and central reference for more detailed examination of this aspect of the commercialization of CAES by interested parties.

EXECUTIVE SUMMARY

In recent years, pressure has grown to reduce consumption of oil and natural gas in the United States, to develop alternative sources of primary energy, and to utilize these sources as efficiently and economically as possible. Large scale energy storage is a major part of this effort within the electric utility industry.

A new technology, compressed air energy storage (CAES) appears to offer the most significant near-term potential for bulk energy storage and for optimizing the efficiency of utility system generating capacity. Storing excess electrical energy available from large base load generating stations during periods of low demand in the form of compressed air in underground reservoirs allows it to be used later to generate electricity during periods of peak demand. A utility can, therefore, lessen dependence on inefficient peak load generating capacity typically fueled by petroleum or natural gas. The overall result is more efficient use of large coal or nuclear base load generating stations, reduced system-wide consumption of petroleum fuels to meet peak load demands, and ultimately, significant economic advantages.

As with most developing technologies, several environmental concerns are associated with CAES that must be thoroughly assessed and evaluated before full scale commercial development can be implemented. Not surprisingly, many of the environmental concerns are also engineering, operational, and economic concerns. If a CAES facility is constructed in a geologically unsuitable storage medium, severe perturbations to the subsurface environment may result not only in unacceptable environmental impacts, but also in an inoperable or uneconomic facility. In fact, perhaps the single most important factor in ensuring that adverse environmental impacts do not occur as a result of construction and operation of a CAES facility is careful site

selection. This consists of extensive geological characterization of subsurface conditions and thorough review of surface environmental factors combined with sound construction engineering and operational practices.

This report is a summary of the environmental and regulatory issues associated with CAES technology. It represents the culmination of the CAES Environmental Concerns Project, which is part of the Underground Energy Storage Program at the Department of Energy's Pacific Northwest Laboratory operated by Battelle Memorial Institute. This work reviews from an environmental perspective the progress and results of extensive engineering research and technology development directed at commercial development of CAES technology. It also reviews and incorporates the extensive information base prepared within several other studies sponsored individually or jointly by the U.S. Department of Energy, the Electric Power Research Institute, and private utilities. A comprehensive analysis of the legal and regulatory issues associated with CAES is also summarized in this report. Significant conclusions are:

1. The environmental impacts associated with construction and operation of CAES facilities are generally similar to or less severe than those associated with construction of conventional electrical generating facilities. They are therefore generally amenable to conventional mitigation strategies.
2. Adverse subsurface and surface environmental impacts can be largely avoided by thorough geological characterization of subsurface conditions, careful evaluation of surface environmental factors, and avoidance of unsuitable sites.
3. A large number of suitable sites exist throughout the U.S.
4. Siting flexibility for CAES facilities is much greater than for other energy storage technologies such as pumped hydroelectric storage.

5. Land use requirements are generally significantly less than for conventional (coal, nuclear, hydroelectric) generating facilities of similar generating capacity.
6. Petroleum fuel use is much less than for conventional peak power generating facilities such as combustion turbines. This results in significantly less impact on air quality.
7. CAES technology offers the potential for increased efficiency of utilization of utility system generating capacity resulting in reduced overall commitment of resources and therefore reduced environmental impacts.
8. Uncertainty still surrounds the legal and regulatory issues associated with CAES, primarily due to the recent implementation of several environmental regulatory programs and the lack of experience and precedent in implementation of this new technology.

CONTENTS

FOREWORD.	iii
EXECUTIVE SUMMARY	v
FIGURES	xiii
TABLES.	xiii
1.0 INTRODUCTION	1.1
2.0 COMPRESSED AIR ENERGY STORAGE CONCEPT FEATURES	2.1
2.1 SYSTEM DESIGN AND OPERATION	2.1
2.1.1 Compression Mode	2.2
2.1.2 Power Production Mode.	2.3
2.2 AIR STORAGE RESERVOIRS.	2.3
3.0 COMMON ENVIRONMENTAL IMPACTS OF COMPRESSED AIR ENERGY STORAGE FACILITIES	3.1
3.1 AIR POLLUTANT EMISSIONS	3.1
3.2 WATER CONSUMPTION AND DISCHARGE	3.5
3.2.1 Water Consumption.	3.6
3.2.2 Water Discharges	3.7
3.3 LAND REQUIREMENTS	3.9
3.4 FUEL REQUIREMENTS	3.10
3.5 NOISE	3.10
3.6 METEOROLOGICAL IMPACTS.	3.15
3.7 ECOLOGICAL IMPACTS.	3.17
3.7.1 Terrestrial Ecology.	3.17
3.7.2 Aquatic Ecology.	3.18
3.7.3 Cumulative Effects	3.20
3.8 GEOLOGICAL IMPACTS.	3.21

3.8.1	Surface Geology	3.21
3.8.2	Subsurface Geology	3.23
3.9	HYDROLOGIC IMPACTS.	3.26
4.0	SITE SELECTION	4.1
4.1	SITE SELECTION METHODOLOGY.	4.2
4.2	TECHNICAL CRITERIA.	4.12
4.2.1	Compressed Air Energy Storage in Hard Rock	4.12
4.2.2	Compressed Air Energy Storage in Salt Caverns. . .	4.15
4.2.3	Compressed Air Energy Storage in Confined Aquifers	4.16
5.0	REGULATORY ISSUES COMMON TO MOST COMPRESSED AIR ENERGY STORAGE FACILITIES	5.1
5.1	FUEL USE ACT EXEMPTION.	5.1
5.2	AIR EMISSION REQUIREMENTS	5.4
5.2.1	New Source Performance Standards	5.5
5.2.2	Prevention of Significant Deterioration Review . .	5.5
5.2.3	Nonattainment Review	5.8
5.3	SURFACE WATER QUALITY CONTROL	5.10
5.3.1	National Pollution Discharge Elimination Permit	5.10
5.3.2	Oil Storage.	5.11
5.3.3	Construction Activities.	5.12
5.4	WATER ACQUISITION	5.12
5.4.1	State Water Withdrawal Rights.	5.12
5.4.2	Dredge and Fill Permit	5.13
5.5	POWER PLANT CERTIFICATION AND SITING.	5.13
5.5.1	Certification	5.13
5.5.2	State Siting Legislation	5.14

5.5.3	Federal Siting Legislation	5.14
5.6	UNDERGROUND INJECTION REQUIREMENTS	5.15
5.7	WELL DRILLING AND CONSTRUCTION REQUIREMENTS	5.19
5.8	ENVIRONMENTAL IMPACT STATEMENT REQUIREMENTS	5.19
5.8.1	Federal Requirements	5.19
5.8.2	State Requirements	5.20
5.9	SAFETY AND NOISE REGULATION	5.21
REFERENCES.		R.I

FIGURES

2.1	CAES Plant Schematic	2.2
2.2	Excavated Hard Rock Cavern Section View.	2.4
4.1	Site Selection Methodology for Energy Storage Projects . . .	4.3
4.2	Determination of Study Area Within Utility Service Area. . .	4.5
4.3	Identification of Potential Siting Area.	4.6
4.4	Delineation of Candidate Siting Area	4.8

TABLES

3.1	Air Pollutant Emission Rates from a 220-MW CAES Gas Turbine Plant.	3.2
3.2	Industrial Source Complex Model Input Parameters for Sulfur Dioxide	3.3
3.3	Maximum Air Quality Impact for a 220-MW CAES Gas Turbine Plant.	3.3
3.4	Federal Prevention of Significant Deterioration Increments.	3.4
3.5	New Source Performance Standards	3.5
3.6	Raw Noise Levels by Source for a 220-MW CAES Facility in Illinois.	3.12
3.7	Sound Emitted to Class A Land During Daytime Hours in Illinois.. . . .	3.13
3.8	Sound Emitted to Class A Land During Nighttime Hours in Illinois	3.13

REVIEW OF ENVIRONMENTAL STUDIES AND ISSUES ON COMPRESSED AIR ENERGY STORAGE

1.0 INTRODUCTION

In recent years, pressure has grown to reduce consumption of oil and natural gas in the United States. This pressure is expected to increase further as petroleum prices and threatened shortages escalate. The challenge is to develop alternative sources of primary energy and to develop methods of utilizing these sources as efficiently and economically as possible; energy storage is a major factor in this effort.

The only widespread, presently available technology for bulk electrical energy storage currently is hydroelectric pumped storage. This technology employs water as the energy storage medium by pumping it to a higher reservoir using excess electrical power available during periods of low demand and later releasing it through turbines to a lower reservoir to generate electricity to meet peak demands. This concept is about 75% efficient; that is, about 75% of the energy required to "charge" the upper reservoir is recovered in meeting peak load demand. However, conventional pumped hydroelectric storage suffers from a number of disadvantages: available geographic sites are few; the sites are generally remote from load centers; and such projects are often subject to considerable opposition on environmental grounds. Therefore, research in recent years has been devoted to finding alternative energy storage technologies. Such alternatives include underground pumped hydroelectric storage (UPHS), compressed air energy storage (CAES), thermal energy storage (TES), batteries, and superconducting magnetic storage (SMES). Of these, CAES appears to offer the most significant near-term potential to electric utilities.

Compressed air energy storage (CAES) is a relatively new technology for storing and utilizing available excess electrical energy. Air is compressed, cooled and stored within underground reservoirs. Three

types of geologic reservoirs are deemed feasible: excavated hard rock caverns, solution-mined cavities in salt formations and aquifers of suitable structure and geologic properties. To generate electricity, the air is released, mixed with fuel and ignited, then expanded through modified gas turbines to drive generators. By compressing the air in advance using excess electricity, the energy of the petroleum fuel consumed by the CAES facility is devoted almost entirely to driving the electric generator. In contrast, a conventional gas turbine must drive its own compressor stage, which consumes about 60% of the turbine's power output (Kannberg and Loscutoff 1981). Therefore, a CAES power plant consumes considerably less petroleum fuel to produce a given amount of power than a conventional gas turbine power plant. Advanced CAES technology concepts may eliminate the need for petroleum fuel altogether by either storing and recovering the heat rejected during the air compression cycle or adding heat from coal fluidized bed combustion.

In view of the potential of CAES technology to reduce dependence on petroleum and to provide lower cost peaking power in the electric utility industry, the U.S. Department of Energy (DOE), in conjunction with the Electric Power Research Institute (EPRI), has undertaken a comprehensive research and development program to accelerate CAES commercialization. Among the unknowns affecting the technical, economic, and environmental feasibility of CAES technology are those related to the response and continued integrity of the underground reservoirs. Daily pressure, temperature and humidity fluctuations associated with charging and discharging over the life of the facility could conceivably cause mechanical damage to the geologic containment media, possibly causing reservoir failure and resulting in unacceptable environmental impacts or economic and operational penalties. Currently there are few suitable criteria to describe the stability of underground air storage reservoirs subjected to daily pressure, temperature and humidity fluctuations over a period of 30 years or 7,500 cycles. Development of such criteria is considered crucial to commercial

development of this promising technology. Perhaps no less crucial is the development of methodologies to accurately assess and quantify the degree of acceptable environmental risks and to determine the best possible sites for such facilities. As with many developing technologies utilizing or affecting the natural environment, technical/engineering, operational and economic concerns associated with CAES technology are also environmental concerns. Uncontrolled air leakage from an underground reservoir, for example, may not only present unacceptable environmental impacts such as disruption of heavily used, potable aquifers, but may render a very costly facility useless or, at the very least, impose severe and perhaps intolerable economic penalties on its operation.

This report presents a comprehensive summary of the environmental concerns associated with commercial development of CAES and a review of the results of studies conducted in this area to date. First, to provide necessary perspective, a general description of a CAES plant is presented in Section 2.0. Next, environmental impacts common to CAES facilities are discussed in Section 3.0. In Section 4.0, site selection criteria and methods are presented to demonstrate the relationship between siting and environmental issues. Finally, Section 5.0 reviews regulatory issues that must be considered in siting, constructing, and operating CAES facilities in the U.S.

2.0 COMPRESSED AIR ENERGY STORAGE CONCEPT FEATURES

The concept of storing and using compressed air is relatively new in North America. In contrast, many examples of the basic technology can be found in Europe, particularly in Scandinavia. Hydraulic compressors, which achieve air compression as a result of the entrainment of air bubbles in a falling column of water, have been used to supply compressed air for operating mining tools and smelter furnaces. Mining companies in Sweden have even used hydraulically compensated underground cavities to compensate for peaks in compressed air demand that occur in the course of mining operations.

The story of compressed air energy storage (CAES) employing gas turbines began in the U.S. in 1948 with a patent by F.W. Gay. This patent outlined the basic principles of supplying a gas turbine engine with compressed air from an underground air storage reservoir. However, the cost of excavating underground caverns and the shortcomings in compressor technology at that time combined to render this invention uneconomic.

2.1 SYSTEM DESIGN AND OPERATION

The main CAES design components are presented in Figure 2.1. In a conventional gas turbine peak power generation system, the gas turbine drives both the generator and the compressor stage simultaneously with approximately two-thirds of the power devoted to compressing the air necessary for turbine engine operation. In a CAES plant, a motor/generator with two disconnect couplings is located between the turbine and the compressor, thus separating the two phases of gas turbine engine operation. Air compression is accomplished by surplus electricity available at night. Peak power generation is then accomplished during the day by withdrawal and combustion of the stored air. Approximately one-third the amount of petroleum fuel produces the same amount of power as a conventional gas turbine peaking system.

FIGURE 2.1. CAES Plant Schematic

2.1.1 Compression Mode

During off-peak hours, the turbine is disengaged from the motor/generator and the compressor is engaged. The motor/generator, operating as a motor now, draws power from the electric grid to charge the air storage reservoir. Air is compressed by compressors in series which raise the pressure up to approximately 800 to 1,000 lb/in² absolute (psia). The final determination of cavern pressure is a function of the type of air storage reservoir, the subsurface geological conditions influencing reservoir operational characteristics, and the cost and efficiency of the turbomachinery employed.

The compressor train could consist of axial, low-pressure compressor stages and centrifugal high-pressure compressor stages. Heat produced during compression is rejected through a series of intercoolers and an aftercooler. Cooling the air after the last stage of compression further reduces the required reservoir volume. The waste heat is rejected to the atmosphere through cooling towers or other heat

rejection systems. Because compression usually takes place during the night, cooler nighttime temperatures further reduce the power requirements by enhancing cooling.

2.1.2 Power Production Mode

During the generating cycle, air released from the cavern passes through a recuperator and then to the gas turbines. The recuperator uses heat from the turbine exhaust to preheat the air before it enters the turbine combustion chambers. This improves the power generation performance by approximately 20%, representing a direct 20% reduction in the fuel consumed compared with CAES systems not incorporating a recuperator.

2.2 AIR STORAGE RESERVOIRS

Compressed air energy storage systems can use either a subsurface excavated cavern or a saturated, permeable geologic formation for storing compressed air. Two basic types of air storage cavern exist: 1) the uncompensated, constant-volume cavern, and 2) the water-compensated, constant-pressure cavern. In the uncompensated cavern, air must be stored at greater-than-demand pressure and released during power generation. In the compensated cavern shown in Figure 2.2, water from a surface reservoir displaces air in the cavern as it is released, maintaining a relatively constant cavern pressure because a near-constant hydraulic head is exerted on the air in the storage cavern. The volume of air stored varies with the amount of water displaced. In contrast, the amount of air stored in a constant volume, uncompensated cavern varies directly with the pressure at which the air is stored. The compensated caverns operate at a more constant storage pressure than the uncompensated caverns and can usually be constructed in equilibrium with the fluid pressure in the surrounding rock matrix (Electric Power Research Institute 1982a, Electric Power Research Institute 1981).

FIGURE 2.2. Excavated Hard Rock Cavern Sectional View

Caverns for storing compressed air can be constructed in either salt or hard rock formations. Salt domes have the necessary petrologic, structural, and rock mechanical properties to contain the compressed air and can be mined by solution rather than by excavation. A salt dome is currently being used in Germany to store compressed air as part of the Huntorf CAES facility. The Huntorf salt dome caverns were constructed using standard solution mining techniques (Allen, Doherty and Thoms 1982; Electric Power Research Institute 1982a).

Salt reservoirs are probably the least expensive air storage reservoirs. They are solution-mined in salt domes or salt evaporite beds. They most likely will not be hydraulically compensated because of the environmental risks and expense involved with surface reservoirs containing saturated brines. Solution mining technology is well

developed and has been routinely employed to create cavities for storage of hydrocarbon gases and liquids.

Rock reservoirs are more expensive than salt but offer the advantages of a greater number of suitable sites and their adaptability to hydraulic compensation (Electric Power Research Institute 1982a; Allen, Doherty and Fossum 1982). Hydraulic compensation provides for constant pressure operation and maximum air storage capacity with minimum excavated cavern volumes. For these reasons, most air storage reservoirs in hard rock will probably be water-compensated (Electric Power Research Institute 1982a; Allen, Doherty and Fossum 1982).

A third potential air storage medium consists of water-saturated aquifers with suitable geological characteristics and structure. Such a reservoir is analogous to natural gas storage reservoirs in suitable aquifers (Allen and Gutknecht 1980; Sargent & Lundy 1981a, 1981b). Suitable aquifers would have four important characteristics: 1) an anticlinal or domed shape to contain the injected air, 2) adequate pore space and permeability to permit air storage and flow, 3) a caprock over the storage zone low enough in permeability and with sufficient threshold pressure to confine the stored air, and 4) a depth such that the hydraulic pressure gradient from the water table to the storage zone confines the air at the pressure necessary to efficiently operate the turbomachinery (Allen and Gutknecht 1980). Many aquifers are suitable sites for CAES because of their relatively high availability and low development costs (as compared to excavated hard rock reservoirs). Proper site selection and adequate aquifer characterization, however, may be more important in the aquifer concept.

All three reservoir types are currently the subject of research and development sponsored by the U.S. Department of Energy and the Electric Power Research Institute. Studies by those groups and by individual utilities have considered developing reservoirs for air storage in salt domes (Middle South Services), in hard rock, (Potomac Electric Power), and in aquifers (Public Service Indiana). These studies form the basis for much of this report.

3.0 COMMON ENVIRONMENTAL IMPACTS OF COMPRESSED AIR ENERGY STORAGE FACILITIES

Environmental impacts common to all types of CAES facilities include air pollutant emissions, water consumption and discharge, land use, fuel consumption, and noise. Compressed air energy storage plants could also affect the local meteorology, terrestrial and aquatic ecology, and geology. The extent of these impacts is discussed in detail in this section.

3.1 AIR POLLUTANT EMISSIONS

A gas turbine generation system utilizing CAES will emit the same types of pollutants as a conventional gas turbine generation facility. However, because a CAES gas turbine facility consumes about two-thirds less fuel than a standard gas turbine facility, the total amount of air pollutants emitted from the CAES facility will be approximately one-third of that emitted by a standard gas turbine generator of the same power rating (Electric Power Research Institute 1982a; Environmental Science and Engineering 1981b). Increased and more continuous output from base load plants supplying the power needed to compress and store the air may result in either positive or negative shifts of air pollutant emissions between different geographical locations (Environmental Science and Engineering 1981b).

At a fuel consumption rate of 100 gpm, the emission rates by a 220 MW CAES facility for sulfur dioxide, nitrogen oxides, particulates, carbon monoxide, and limits for sulfur dioxide and nitrogen oxides defined by the U.S. Environmental protection Agency (EPA) New Source Performance Standards (NSPS) are given in Table 3.1.

The air quality impact of each pollutant emission must be evaluated to determine the significance of the emission rate for each pollutant. Such factors as height of emission release above grade (stack height), exhaust gas exit velocity, exit gas temperature, and meteorological

TABLE 3.1. Air Pollutant Emission Rates^(a) from a 220-MW CAES Gas Turbine Plant

	<u>Sulfur Dioxide</u>	<u>Nitrogen Oxides</u>	<u>Suspended Particulates</u>	<u>Carbon Monoxide</u>	<u>Hydro- carbons</u>
Predicted emission rate lb/hr	616 ^(b)	406.8	30	92.4	33.4
ppm	<140	220	--	--	--
NSPS allowable rate					
ppm	150 ^(c)	250	N.S. (d)	N.S. (d)	N.S. (d)

(a)As determined from emission factors obtained in U. S. EPA document AP-42, 1973, as updated through Supplement IX, and from standard combustion calculations.

(b)Assumes maximum sulfur content in fuel of 0.7%.

(c)0.015% by volume at 15% oxygen, dry basis.

(d)No standard has been established.

Source: Environmental Science and Engineering 1981b, p. 22.

conditions all have significant impacts on the dispersion of these air pollutants and therefore on ambient air quality.

The air quality impacts of a 220-MW CAES gas turbine facility planned by Soyland Power Cooperative were assessed by Environmental Science and Engineering of St. Louis. Dispersion modeling with the U.S. EPA-approved Industrial Source Complex (ISC) model was employed. Screening modeling, using a full year of meteorological data representative of mid-central Illinois (the proposed site of the Soyland plant), was conducted employing both the normal ISC dispersion algorithm as well as the downwash algorithm. The inputs for CAES plant ISC modeling are shown in Table 3.2. The ISC model results are given in Table 3.3. Dispersion of any pollutant can be extrapolated from the ratio of the emission rate for the desired pollutant to the rate of the pollutant that has been modelled. Only the sulfur dioxide emissions were used in the ISC model runs (Environmental Science and Engineering 1981b).

TABLE 3.2. Industrial Source Complex Model Input Parameters for Sulfur Dioxide

Emission Rate (grams/sec)	Stack Height (m)	Exit Velocity (m/sec)	Stack Diameter (m)	Exit Temp (°K)	Building		
					Height (m)	Length (m)	Width (m)
77.68	28.69	13.40	6.10	449.8	26	85	28

Source: Environmental Science and Engineering 1981b, p. 24.

TABLE 3.3. Maximum Air Quality Impact for a 220-MW CAES Gas Turbine Plant

Concentration Period	Highest-2nd High SO ₂ Concentrations		AAQS		PSD
	(μg/m ³)	Downwind Distance (m)	Primary (μg/m ³)	Secondary (μg/m ³)	Significance Level (μg/m ³)
Without downwash					
3 hr	16.6	1.3	N/A ^(a)	1300 ^(b)	25
24 hr	2.45	1.3	365	N/A	25
With downwash					
3 hr	21.0	2.3	N/A ^(a)	1300 ^(b)	25
24 hr	5.7	2.3	365	N/A	25

(a) N/A = no standard exists.

(b) Maximum concentration not to be exceeded more than one per year.

Source: Environmental Science and Engineering 1981b, p. 27.

The ISC model results predict the highest and second highest concentrations of sulfur dioxide emissions to be below Prevention of Significant Deterioration (PSD) significance levels for both the 3-hr and 24-hr averaging periods when normal dispersion conditions are considered (Tables 3.3 and 3.4). The emissions are also below the 3-hr and only slightly above the 24-hr averaging periods when downwash is considered. These predicted values are below the levels established as Ambient Air Quality Standards (AAQS), which are also shown in Table 3.3.

TABLE 3.4. Federal Prevention of Significant Deterioration Increments
($\mu\text{g}/\text{m}^3$)

<u>Pollutant/Averaging Time</u>	<u>Class</u>		
	<u>I</u>	<u>II</u>	<u>III</u>
Particulate matter			
Annual geometric mean ^(a)	5	19	37
24-hr maximum ^(a)	10	37	75
Sulfur dioxide			
Annual arithmetic mean ^(a)	2	20	40
24-hr maximum ^(a)	5	91	182
3-hr maximum ^(a)	25	512	700

*Increment can be exceeded once per year for each class

Sources: Public Law 95-95, Clean Air Amendments of 1977. Federal Register, Vol. 43, No. 118, June 19, 1978; Environmental Science and Engineering 1981b, p. 27.

The heat input to the 220-MW CAES plant (846×10^6 Btu/hr) qualifies this facility as a major new source as defined by the U.S. EPA Regulations for the Prevention of Significant Deterioration (Table 3.4) and subject to New Source Performance Standards as presented in Table 3.5. Under these regulations, no major new source or major modification can exceed these emissions limits or "utilize" more than a specified incremental level of available air quality as measured in terms of pollutant concentration for sulfur dioxide and particulate matter.

The maximum allowable increase (increment consumption) in the air concentrations of sulfur dioxide and particulate matter by area classification is also given in Table 3.4. Most areas of the country are designated as Class II air quality areas, whereas national parks and national wilderness areas are designated as Class I. As may be observed from this table and the modeling results given in Table 3.3, the proposed Soyland CAES facility will consume a small fraction of the available PSD increment in Class II areas. It should be easy to locate a typical CAES facility far enough from any Class I area to effect minimal PSD increment consumption (Environmental Science and Engineering 1981a, 1981b).

TABLE 3.5. New Source Performance Standards

<u>Emission Limits for Gas Turbines</u>	
SO ₂	150 ppm ^(a)
NO _x	75 ppm
Particulates	No standard

-
- (a) Alternate SO₂ emission standard fulfilled by a limit of 0.8% on the sulfur content of the fuel.
 (b) Applies to stationary gas turbines with heat input at peak load greater than 100 million Btu/hr.
 (c) Contingencies allow regenerative design for the proposed CAES facility to increase emission limits to 250 ppm

Source: Electric Power Research Institute 1982b, p. 2-10.

In summary, the impacts of air pollutant emissions from a 220-MW CAES power generating plant on ambient air quality are well within Ambient Air Quality Standards (AAQS) or allowable PSD increments (Environmental Science and Engineering 1981a, 1981b; Electric Power Research Institute 1981, 1982a, 1982b; Sargent & Lundy 1981a, 1981b). Similar conclusions were reached in an environmental assessment of a similar size CAES plant proposed by Middle South Services, Inc. in a salt dome in central Mississippi using the CRSTER model developed by the U. S. EPA Meteorology Laboratory.

3.2 WATER CONSUMPTION AND DISCHARGE

Relatively large volumes of water will be consumed and discharged during the various phases of CAES plant construction and operation. The effects of both types of water use are discussed in the next two subsections.

3.2.1 Water Consumption

Compressed air energy storage facilities require water for cavern construction to cool the compressed air before storage, cool lubricating oils and electrical equipment, supply a water compensation system, control air quality, and for human consumption as well as other miscellaneous uses.

The primary use of water during operations will be for cooling (Environmental Science and Engineering 1981a, 1981b; Electric Power Research Institute 1982a). The amount of water needed will vary depending upon the cooling method chosen and, in the case of cooling towers, the quality of the water source. Water compensation system requirements will consist of an initial filling of the reservoir and evaporation makeup of the reservoir (Electric Power Research Institute 1981). The need for makeup water will depend on the balance between rainfall and evaporation and seepage loss from the reservoir (Environmental Science and Engineering 1981b; Electric Power Research Institute 1981, 1982a). Water may be required for nitrogen dioxide control in the gas turbine exhaust; however, such emission control systems are not anticipated to be required (Environmental Science and Engineering 1981a, 1981b; Electric Power Research Institute 1981, 1982a, 1982b). The need for nitrogen dioxide control will depend mainly upon the size of the facility (Electric Power Research Institute 1981, 1982a). Water will also be required for filter backwash and water treatment resin rinse. These needs will be based upon design water quality requirements and the quality of the water source. Sanitary water for drinking, washing, waste removal, and for other miscellaneous uses will be required in small quantities due to the limited manpower needed to operate a CAES facility (Electric Power Research Institute 1982b).

The 220-MW CAES facility planned by Soyland will use mechanical cooling towers. The maximum flow rate through the cooling system will be approximately 50,000 gpm with rates averaging about 35,000 gpm and 10,000 gpm for compression and power generation phases, respectively (Environmental Science and Engineering 1981b). The maximum drift and

evaporation losses from the cooling system will be on the order of 1,100 to 1,200 gpm (Environmental Science and Engineering 1981b). Blowdown from the system, based upon keeping the dissolved solids in the circulating water at four times the incoming concentration, will be about 300 to 350 gpm. Therefore, the maximum amount of makeup water required by the cooling system will be approximately 1,400 to 1,550 gpm and this need will occur during the compression phase when heat rejection requirements are greatest (Environmental Science and Engineering 1981b). Average daily consumption is projected to be approximately 750 gpm or 1.08 million gallons per day (Environmental Science and Engineering 1981b; Electric Power Research Institute 1982a).

Other water needs will probably amount to less than 10 gpm. Water for treatment needs such as filter backwash and water softener resin regeneration will vary depending on source water quality, but likely will average less than 10 gpm. Sanitary and miscellaneous water needs will be minimal. Consumptive water use will also occur temporarily in solution mining operations (Electric Power Research Institute 1982b). For solutioning two 3.3-million barrel caverns for a CAES facility proposed for the Middle South Services system, a flow rate of 1750 gpm of fresh water will be required for 33 months (Electric Power Research Institute 1982b).

3.2.2 Water Discharges

Possible sources of water discharge from a CAES facility include:

1. blowdown from cooling systems--This could be blowdown from cooling towers, overflow from cooling ponds, or once-through cooling, depending on the system used in a given facility.
2. overflow and/or blowdown from the compensating water reservoir-- Overflow will occur periodically in areas where rainfall is greater than evaporation and seepage, and will occur if the reservoir must be emptied for maintenance.

3. discharge from water treatment operations--This could include filter backwash water, softener/demineralized resin rinse water, and sludge dewatering
4. sewage discharges
5. oily wastes from fuel storage and plant service drains.

The 220-MW CAES facility planned by Soyland will have water discharges averaging 350 to 400 gpm (Environmental Science and Engineering 1981a, 1981b). The major discharge, blowdown from the cooling towers, will be approximately 300 to 350 gpm. Likely pollutants requiring treatment are the dissolved solids, sulfates, chlorides, chemicals for biological control (probably chlorine), and thermal discharge (Environmental Science and Engineering 1981a, 1981b).

Overflow from the water-compensating reservoir of this proposed facility may be an occasional discharge depending on local hydrologic conditions. Rainfall exceeds lake evaporation in Illinois by 0 to 10 in. Discharges from the compensating reservoir at a site in Illinois will probably average less than 5 gpm annually and will have little potential for carrying pollutants (Environmental Science and Engineering 1981a, 1981b).

Discharge from a demineralizer will vary depending on water source and water quality requirements and will likely average less than 10 gpm. This discharge will contain salts removed during demineralization and regeneration of water softening resin columns (Environmental Science and Engineering 1981a, 1981b).

Sewage discharges will be extremely small because of the limited manpower present at the site during operation. Oil and grease from fuel storage and plant service drains will also be minimal.

Another type of wastewater discharge which must be considered results from solution mining operations. Although this discharge is temporary and limited to the construction phase of CAES systems in salt,

it is of relatively large magnitude (Electric Power Research Institute 1982b). Approximately 8 to 10 volumes of saturated brine are produced for every one volume of storage volume (1600 gal/yd^3) created. For solutioning the two 3.3-million barrel caverns for a 220-MW CAES facility proposed for the Middle South Services utility system, approximately 66 million barrels of brine will be produced (Electric Power Research Institute 1982b). For disposal, the brine may be injected into deep saline aquifers (Electric Power Research Institute 1982b). However, ocean disposal of brine may be a viable option for other sites (Hendrickson 1981). Brine disposal, whether by deep well injection or ocean dumping, is associated with several environmental concerns and is heavily regulated by state and federal agencies (Hendrickson 1981).

3.3 LAND REQUIREMENTS

Land requirements for CAES facilities are expected to be minimal. Systems utilizing salt or compensated hard rock caverns will require 100 to 200 acres of land (Electric Power Research Institute 1982a). Only 25 to 35 acres will actually be occupied by buildings, fuel storage facilities, switchyard equipment, and roads (Environmental Science and Engineering 1981a, 1981b; Electric Power Research Institute 1982a; Sargent & Lundy 1981a, 1981b). Compensated systems will require a surface reservoir of another 25 to 30 acres and perhaps more for placement of excavated rock if an offsite disposal site is unavailable or uneconomical (Environmental Science and Engineering 1981a, 1981b; Electric Power Research Institute 1981, 1982a). Aquifer-based systems will require considerably more land area (Electric Power Research Institute 1982a, Sargent & Lundy 1981a, 1981b). A 1000-MW CAES facility utilizing aquifer storage at a site in Illinois investigated by Public Service of Indiana was projected to disturb about 200 acres of land for surface facilities. However a field of 40 air injection/withdrawal wells would be dispersed over about 1080 acres (Sargent & Lundy 1981a, 1981b). Although it is anticipated that much of the well field acreage will remain available for its original use, access will be restricted by surface piping and well heads (Sargent & Lundy 1981b).

3.4 FUEL REQUIREMENTS

In a 220-MW net capacity CAES generating plant, fuel consumption during full power electrical generation is approximately 100 gallons of No. 2 fuel oil per minute or about 6,000 to 7,000 gallons per hour (Environmental Science and Engineering 1981b; Electric Power Research Institute 1982a). Because projects of higher output capacity are currently planned as modular facilities made up of units with output capacities of 200 to 250 MW, this fuel consumption rate can be used for the purpose of extrapolation.

3.5 NOISE

The ambient noise levels in the vicinity of a CAES facility would be increased by construction and operation activities (Electric Power Research Institute 1982a). Actual noise levels at the site boundary and at residences and other noise-sensitive areas will be dependent on several site-specific factors; the size of the site, the location of the noise sources within the site, surrounding topography, vegetation, and the location of noise-sensitive areas relative to the site.

The major sources of noise are numerous:

1. construction equipment (temporary)
2. air intake (for the compressor)
3. compressor
4. blow-off valve
5. turbine exhaust (stack)
6. gas turbine
7. cooling tower(s).

Each of these sources generates a different noise intensity and frequency pattern, which singly or in combination can create a high level if left unabated. By incorporating appropriate design features, the intensity of generated noise can be reduced to an acceptable level (Electric Power Research Institute 1982a).

Noise levels of plant operation vary according to the operating phase and load (Electric Power Research Institute 1982a). Operation can be subdivided into three basic phases; each is characterized by a set of noise sources:

1. Turbine operation noise sources include turbine exhaust, step-up transformers and possibly switchyard equipment.
2. Compressor startup sequence noise sources include turbine exhaust (approximately 50% of normal operational noise level), compressor air inlet, blow-off stack, cooling towers, and possibly switchyard equipment. This phase would be expected to last for about 15 minutes.
3. Compressor operation sources include compressor air inlet, rotating or reciprocating components, cooling towers, and possibly switchyard equipment.

Table 3.6 shows the noise levels by source predicted for a 220-MW CAES facility proposed by Soyland Power Cooperative at a site in Illinois. As observed from Table 3.6, the most significant sources of noise emissions are the air intake (suction pipe) to the compressor and the blow-off valves. The blow-off valves can produce a maximum level of 155 db measured 3 ft from the source. Some attenuation would normally be realized by increased distance from the source. Because compliance with allowable sound levels mandated by the Illinois EPA (Tables 3.7 and 3.8) is determined at a distance of no greater than 25 ft from the source property line, the location of each separate source with respect to the property line can significantly reduce noise levels at the measurement point. However, unless distances are great, meeting the desired sound pressure levels at the property line (or up to 25 ft out past property line) may be difficult without special design consideration (Environmental Science and Engineering 1981a, 1981b).

TABLE 3.6. Raw Noise Levels by Source for a 220-MW CAES Facility in Illinois

SUCTION NOISE, SUCTION OPENING, COMPRESSOR OPERATION										
(Hz)	32	64	125	250	500	1k	2k	4k	8k	db-A
(db)	120	120	120	128	135	140	140	135	130	145
BLOW-OFF VALVES										
(Hz)	125	250	500	1000	2000	4000	8000	16000		
(db)	145	150	155	155	155	147	138	130		
GAS EXHAUST NOISE, STACK (TURBINE OPERATION)										
(Hz)	32	64	125	250	500	1k	2k	4k	8k	db-A
(db)	103	105	107	103	102	100	90	80	65	107
NOISE RADIATION OF THE BUILDING (INCLUDING TURBINE, VALVES, PIPING AND COMPRESSION)										
(Hz)	32	64	125	250	500	1k	2k	4k	8k	
(db)	90	95	100	100	100	100	105	100	95	
COOLING PLANT										
(Hz)	32	64	125	250	500	1k	2k	4k	8k	db-A
(db)	110	110	110	102	102	102	102	100	97	110

Source: Environmental Science and Engineering 1981b, p. 44.

Various measures can be taken to attenuate the noise level reaching the property-line measurement point and, more importantly, reaching sensitive receptors such as dwellings (Class A land) or places of business (Class B land). These measures include dampers, insulations, silencers, baffles, design features such as air inlet structure size and shape, orientation of air inlet structure and blow-off valve exhaust, deflecting earth berms, and noise-absorbing vegetation cover. None of these measures will totally eliminate noise from an operating CAES facility, but they may aid in the attenuation to an acceptable level of the noise emitted (Electric Power Research Institute 1982a).

The limits on both broadband noise and discrete tones generally apply to measurements made at any point near the property line of the

TABLE 3.7. Sound Emitted to Class A Land During Daytime Hours in Illinois

Octave Band Center Frequency (Hertz)	Allowable Octave Band Sound Pressure Levels (db) of Sound Emitted to any Receiving Class C Land (a)	Class B Land (a)	Class A Land from (a)
31.5	75	72	72
63	74	71	71
125	69	65	65
250	64	57	57
500	58	51	51
1000	52	45	45
2000	47	39	39
4000	43	34	34
8000	40	32	32

(a) Land class designations based on Standard Land Use Classification Manual (SLUCM) (1969), U. S. Department of Transportation, Federal Highway Administration.

Source: Environmental Science and Engineering 1981b, p. 41.

TABLE 3.8. Sound Emitted to Class A Land During Nighttime Hours in Illinois

Octave Band Center Frequency (Hertz)	Allowable Octave Band Sound Pressure Levels (db) of Sound Emitted to any Receiving Class C Land (a)	Class B Land (a)	Class A Land from (a)
31.5	69	63	63
63	67	61	61
125	62	55	55
250	54	47	47
500	47	40	40
1000	41	35	35
2000	36	30	30
4000	32	25	25
8000	32	25	25

(a) Land class designations based on Standard Land Use Coding Manual (SLUCM) (1969), U. S. Department of Transportation, Federal Highway Administration.

Source: Environmental Science and Engineering 1981b, p. 42.

receiving land. The actual limitations on noise depend on the land use classifications of the property-line noise source and the adjacent receiving land. For applying the provisions of the regulations, land use is generally categorized in one of three classes:

- Class A - residential (including individual houses on other land categories), forest preserves, and other noise-sensitive uses
- Class B - commercial and recreational
- Class C - industrial and agricultural

The following conclusions were drawn from the analysis of noise due to the operation of a 1000-MW CAES plant at a site in northwestern Illinois proposed by Public Service of Indiana (Sargent & Lundy 1981a, 1981b):

1. Sound levels along the site property lines are expected to meet plant noise objectives based on the Illinois Pollution Control Board Rules and Regulations.
2. Because background sound levels at the proposed site are expected to be low, plant sound emissions are likely to be audible and identifiable near the portions of the property line closest to the plant structures.
3. The acoustical impact on the closest residents not adjacent to site property lines should be slight to mild depending on actual existing background sound levels. Plant noise emissions will be generally noticeable and will include primarily low-frequency noise from the compressor/turbomachinery sets.

During construction, noise will be generated by the equipment used for clearing, excavation, construction, and drilling. Noise sources will include equipment such as scrapers, crawler tractors, backhoes, graders, crawler cranes, trucks, compressors, and drilling rigs. Except for construction of the makeup water and blowdown pipelines, most of

this equipment will be located at the cooling tower, turbomachinery building, and oil storage areas. The highest construction noise levels will probably occur during site clearing, excavation, and foundation work (Electric Power Research Institute 1982a; Sargent & Lundy 1981b).

Noise during construction can be controlled by confining construction activity to daytime hours and less sensitive parts of the site and using construction equipment meeting U.S. EPA standards (Electric Power Research Institute 1982a). Construction noise will also be reduced naturally through wave divergence, atmospheric absorption, and anomalous attenuation. For example, wave divergence alone decreases sound levels at 1000 ft by more than 25 db from their values at 50 ft. Air absorption will provide another 10 db of attenuation at this distance at high frequencies. A more accurate assessment of construction noise impact can be completed when more information becomes available on the number of pieces of equipment anticipated onsite along with their associated usage factors (Electric Power Research Institute 1982a).

A detailed assessment of noise impacts produced by a CAES facility necessarily involves a case-by-case and source-by-source study of available alternative noise abatement methods. Such factors as plant site elevation with respect to neighboring land areas, surrounding topographical relief, and occurrence of other naturally-occurring noise deflecting or attenuating features either singly or in combination, can have a dramatic effect on the level of noise attenuation required to meet both property-line and receiving land sound pressure levels (Environmental Science and Engineering 1981a, 1981b).

3.6 METEROLOGICAL IMPACTS

Only those CAES facilities employing a surface compensating reservoir in temperate climes are expected to produce local meteorological impacts of fogging and icing (Electric Power Research

Institute 1982a). Steam fog forms when relatively cold, moisture-saturated air overlies warm water. The intensity of such steam fog is dependent upon the ambient air temperature, relative humidity, and the difference between the water and ambient air temperature. Fogging and associated icing would be expected to occur predominantly in winter (Electric Power Research Institute 1982a).

The surface reservoir for a 1000-MW CAES facility investigated for the PEPCO system covers only 35 acres (Electric Power Research Institute 1981); the reservoir for the 220-MW system proposed by Soyland is expected to be less than 35 acres (Environmental Science and Engineering 1981b). The difference between the reservoir water and ambient air temperatures is expected to be about 5°F (Electric Power Research Institute 1981). The average frequency of fog in the winter at the PEPCO site is less than 5%. Even for the potentially severe conditions often occurring in February, the maximum fog frequency was calculated to be less than 10%. Therefore, the CAES system is not expected to produce any significant fogging and icing impacts (Electric Power Research Institute 1981). It is also expected that the increase in relative humidity will be of little significance (Electric Power Research Institute 1981).

One other aspect of CAES system operation having the potential for creating meteorological impacts of fogging, icing and increases in relative humidity is cooling tower operation (Electric Power Research Institute 1982a). It is anticipated that CAES facilities will employ evaporative (wet) cooling towers to reject heat to the atmosphere during the compression phase. Because of the evaporative nature of operation, such systems have the potential to create visible fog plumes under certain conditions. Such effects would not be expected to differ from those associated with cooling tower operation of conventional coal or nuclear power plants, except for the cyclical operation of the CAES cooling systems. Assessment of fogging and icing aspects associated with CAES facility operation must consider site-specific topographical,

meteorological, and demographic factors, as well as the operational and design characteristics of the proposed facility (Electric Power Research Institute 1982a).

3.7 ECOLOGICAL IMPACTS

As with most fossil fuel electric generation facilities, CAES systems will impact or potentially impact terrestrial ecosystems more than aquatic ecosystems (Environmental Science and Engineering 1981a; Electric Power Research Institute 1981, 1982a). The likely effects on both ecosystems are presented in the next two subsections.

3.7.1 Terrestrial Ecology

To estimate impacts on terrestrial ecosystems it is necessary to evaluate

1. habitat alteration and disturbance
2. effects of air emissions on terrestrial biota
3. effects of waste and raw material storage and handling
4. noise/activity impacts.

A CAES facility can be constructed on less than 100 acres of land; therefore, loss of significant habitat for terrestrial organisms is not a major impact. When such a small land area is required, important habitats can be avoided through careful siting (Electric Power Research Institute 1982a). Only when the entire region being considered for siting is composed of relatively undisturbed land (e.g., in some portions of the western United States) will habitat loss be a likely major impact.

Air emissions from the 220-MW Soyland CAES facility should not have measurable effects upon terrestrial organisms (Environmental Science and Engineering 1981a, 1981b). Because a distillate fuel oil will be burned, sulfur dioxide emissions will be low. Ambient air quality standards can be met so long as the plant is located outside designated

nonattainment areas (i.e., localities that currently have significant air pollution problems). Systems burning natural gas will have even less impact, and probably none at all (Environmental Science and Engineering 1981a, 1981b).

Because CAES plants will be highly automated, they will require little human activity (Electric Power Research Institute 1982a, 1982b). Subsequently, little disturbance to adjacent wildlife will occur. The noise associated with the compression of air and operation of turbines may, however, be great enough to affect animals in the nearby vicinity of the plant. Delivery of fuel and other materials may also create potential disturbances. The creatures most susceptible to noise would be those dependent upon sound to find prey, to attract mates, or to avoid predators (Environmental Science and Engineering 1981a, 1981b; Electric Power Research Institute 1981, 1982a). Animals that are particularly wary of man would also likely be disturbed by noise at the CAES plant.

3.7.2 Aquatic Ecology

Aquatic ecosystems may be impacted by any of four CAES facility effects:

1. sedimentation and siltation during construction
2. entrainment/impingement of aquatic organisms during water withdrawal
3. discharges of blowdown and other wastes
4. leachates and runoff from waste and raw material storage areas.

The degree of impact associated with each of these effects is largely determined by the facility size and capacity, techniques utilized in facility construction, and the design and operation of waste-handling or treatment facilities and water intake structures (Electric Power Research Institute 1982a). Impact is also determined by characteristics of the aquatic systems on or near the site.

During construction of any power generation facility, a certain amount of land must be disturbed. This can result in erosion, producing turbidity and sedimentation in watershed streams, and can influence the hydrology of those streams. Impact of land disturbance depends primarily on:

1. amount of land disturbed
2. soil and topographic characteristics
3. soil erosion control techniques used during construction
4. size and characteristics of watershed streams.

Withdrawals made from a surface body of water to meet CAES system water requirements will also contain aquatic organisms. The number of organisms entrained or impinged by a CAES facility depends on the intake volume and velocity, the intake screen system, and characteristics of the aquatic habitat used as a water source. A well-designed intake structure located in a non-prime biological area generally minimizes entrainment/impingement losses (Environmental Science and Engineering 1981a, 1981b; Electric Power Research Institute 1982a).

The major wastes that may be generated by CAES systems are blowdown from the cooling system and compensation reservoir, oily wastes, and demineralizer sludge (Electric Power Research Institute 1982a). Discharges from cooling systems may periodically contain residual biocides (e.g., chlorine) used to control biofouling. Most wastes can be stored or treated onsite with little discharge to surface waters. Often blowdown is discharged into surface waters, and once-through cooling systems return significant quantities of water at higher temperatures to surface waters. Thermal and chemical discharges can significantly impact aquatic biota depending on quantities and constituents of the discharges, the dilution potential of the receiving water, and the sensitivity of biota present (Environmental Science and Engineering 1981a, 1981b).

Compressed air energy storage systems may generate some solid wastes that may be stored or treated onsite. Those wastes associated with fuel and lubrication oils often have a toxic potential for aquatic organisms. In most cases, the wastes can be disposed of onsite. Depending on the material excavated, waste rock spoil piles may produce toxic leachate or runoff. If the excavated rock contains easily weathered sulfide minerals, and the site is in an area of heavy rainfall, a situation similar to acid mine drainage may occur, producing acid runoff high in dissolved heavy metals. Evaluation of the mineralogic characteristics of the excavated rock, proper location of spoil piles, and adequate drainage systems should prevent such adverse impacts (Environmental Science and Engineering 1981a, 1981b).

3.7.3 Cumulative Effects

The severity of potential impacts associated with a CAES plant will be determined by the sensitivity of the local environment to disturbances and the measures taken to mitigate impacts. None of the predicted CAES impacts is considered to have critical or severe effects upon ecological systems (Electric Power Research Institute 1982a). However, the cumulative effect of the impacts might be significant, depending on the site. Impacts can be reduced by properly selecting the site and designing the facility in accordance with site characteristics (Environmental Science and Engineering 1981b; Electric Power Research Institute 1982a).

Electrical power is required by CAES generating plants during the compression phase of operation. This power will most likely come directly from the utility grid system. Because of the additional load demand imposed by the CAES facilities during their compression cycle, the output of base load facilities continuously supplying power to the utility grid is likely to be increased somewhat, with the overall effect being to shift (or distribute) the impacts of electrical energy generation from one geographical location to another. Therefore, the

impacts associated with higher levels of base load facility operation must be assessed at the same time as the direct effects of the CAES plant(s) if the cumulative effects of a given CAES project are to be accurately determined.

3.8 GEOLOGICAL IMPACTS

Construction and operation of CAES facilities will undoubtedly have some impact on site geology. The significance of such impacts will be site-specific, varying considerably from site to site. Such impacts will range from topographic changes generally associated with large construction projects to potential seismic effects. This section briefly discusses geologic impacts associated with CAES facilities in generic terms (Electric Power Research Institute 1982a).

3.8.1 Surface Geology

Topographic impacts include changes in elevation and the addition of structures and large manmade landforms resulting from construction, and the existence during operation (in some CAES projects) of compensating reservoirs, fuel storage areas, and containment dikes, as well as excavated soil and rock spoil piles. These landforms could cover a considerable area of the site and could increase site elevation in some places.

Both spoil piles and reservoir and fuel storage area dikes can be expected to have an unnatural form with round to flat tops, angular to round shapes, and highly regular sloping sides that would be in contrast with most natural terrain. The reservoir dikes would be permanent, but it is possible that the soil and rock spoil piles could be removed or at least reduced in size if an alternative disposal option is available (e.g., onsite use or sale of earth materials for construction purposes). Depending on site characteristics, it may be possible to blend spoil piles into the natural terrain to minimize contrast.

Other impacts on topography include small increases and decreases in elevation and alteration of natural landforms by site grading and construction of plant facilities. Plant facilities will include the switchyard, turbomachinery buildings, and cooling water system. Stockpiles of topsoil and of fill and construction materials would have unnatural shapes similar to soil and rock spoil piles.

Erosion impacts due to construction activities include initiation and acceleration of erosion processes. Because site plans should include an erosion and sedimentation control plan, erosion would be minimized by the implementation of various mitigative procedures. Erosion and sedimentation control measures are extremely important in site areas that drain directly into local waterways, lakes, marshes, reservoirs, or other water bodies. No impacts on surface erosion are expected from facility operation.

Potential soils impacts might include changes to or loss of established soil horizons, and changes to or loss of special interest soils, if they exist on a site. Special interest soils are high quality and potentially productive soils which have been assigned a high level of value by the U.S. Soil Conservation Service (SCS). Special interest soils include Prime Farmland and Farmland of Statewide Importance.

Impacts on special interest soils due to construction activities include altering and/or destroying soil designated as Prime Farmland and Farmland of Statewide Importance. Activities associated with facility operation are not expected to further impact soils. Disturbances would vary depending on the type of construction activity. In general, topsoils will be stripped after clearing and grubbing and stockpiled for subsequent use. Likewise, fill materials will be excavated from borrow pits and stockpiled, resulting in mixing of horizons and/or compaction. Unsuitable soils and bedrock will be excavated and placed in spoil piles (Electric Power Research Institute 1982a).

3.8.2 Subsurface Geology

Mining-type activities associated with the development of subsurface reservoirs will affect the geologic subsurface environment, as will the cyclic injection to and withdrawal of fluid from the reservoir during facility operations (Electric Power Research Institute 1982a). Effects from both of these activities will generally be confined to subsurface formations. However, they may cause instabilities in reservoir rock that may propagate upward and impact surface conditions.

Potential impacts to the subsurface geologic environment include (Electric Power Research Institute 1982a):

- creation of manmade cavities and related "workings," or drilled wells
- thermal alteration of subsurface energy storage zone, i.e., rock and ground water
- cavity closure by altering stress fields, rock strengths, and/or removal or redistribution of material, which may lead to surface subsidence
- subsurface erosion and weathering, which may lead to cavity failure and subsequent surface subsidence, increases of porosity/permeability, carryover of subsurface materials in the air stream, and geochemical reactions that could change the physical character of aquifers.

Increased pore pressures across a fault zone as a result of air injection can decrease the effective normal stress and, in some cases, cause an increase in seismicity along the fault zone. An example of increased seismicity due to pore pressure changes occurred at the Rocky Mountain Arsenal near Denver, Colorado. Waste material was injected into a Precambrian gneiss at a depth of approximately 12,000 ft over a period of 3 years. Waste injection at the arsenal well was stopped in 1966 pending investigation of a theory that there may be a direct

relationship between Denver-area earthquakes and the injection of waste when it was noted that a close correlation existed between the number and magnitude of earthquakes and the volume of fluid and injection pressure at the waste injection well (Electric Power Research Institute 1982a).

The seismicity of the site area could potentially be increased as the result of surface and underground water storage associated with compensating reservoirs. Water storage may increase the stress distribution in rock and/or increase the effective pore pressure and hence decrease the effective normal stress. These effects could enhance brittle fault displacement and cause minor earthquakes. Water reservoir-induced seismicity associated with hydroelectric and other storage reservoirs is a common phenomenon. The magnitude of potential seismic impacts is estimated to be much less significant for CAES reservoirs and systems generally as they operate very near the prior geologic equilibrium by design.

Water and air cycling through the energy storage reservoir system will be at different temperatures than the surrounding rock and ground water, causing thermal alterations. Thus, subsurface "weathering" and erosion may occur. Silicate and carbonate hydrolysis are among the most common mineral weathering reactions that may take place. Effects of such reactions include pH increases, production of potentially swellable clay minerals and residual solids, and cations and silicic acid in solution. Other important potential reactions are silicate, carbonate, and sulfide oxidations. Typical effects include precipitation of insoluble oxides and hydroxides; production of weak silicic, carbonic, and/or sulfuric acid; and additional pH decrease from subsequent hydrolysis of metal ions. Erosion and weathering of subsurface rock would likely include: a) grain and cement disintegration and microfracturing; b) solutioning and redistribution of mineral components; c) reduction in elastic moduli and compressive strength; and d) thermal and cyclic fatigue of reservoir rock (Electric Power Research Institute 1982a).

The stress history of salt domes is such that the lateral stress can be expected to be larger than the vertical stress. Accommodation of this ratio may be difficult in the design of the mined energy storage cavity. Thus, gradual viscoplastic cavity closure may be anticipated. Cycling of hot compressed air may accelerate closure (Electric Power Research Institute 1982a, 1982b, 1982c; Fenix & Scisson 1978). Cavity closure may ultimately cause surface subsidence.

Because salt has very low permeability, the stored compressed air is unlikely to affect ground water temperature; neither is it likely to affect pore pressures in the rock, and hence local seismicity. However, brine disposal by injection wells in the faulted strata typically associated with salt domes might induce seismic activity. The magnitude and significance of this impact can be assessed with respect to the experience of the oil storage industry in such injection (Electric Power Research Institute 1982a, 1982b).

Subsurface erosion and weathering of the reservoir rock are apt to be important in aquifer CAES facilities. Elevated temperatures and pressures will have some impact on the physical and chemical conditions within the aquifer system. Hydrolytic and oxidation reactions, mineral solutioning transport and reprecipitation, degradation of cement bonds, transport of fine grains, swelling of clay minerals, and alteration of packing geometry and general reduction in elastic moduli and compressive strength are possible reactions (Stottlemire, Erikson and Smith 1979). The result of these processes may modify the porosity and permeability within the zone of air storage (Stottlemire, Erikson and Smith 1979).

Thermal-mechanical and thermal-chemical stresses may also affect the integrity of the confining strata (caprock), the injection well casing and the completion cement (Electric Power Research Institute 1982a). Casing/cement failures are possible if care is not exercised. The casing may be pretensioned during installation and installed using geothermal completion practice. Excessive thermal shock during operation is to be avoided. Blowout phenomena due to poor completion

practice can occur around well casings. This is documented by the natural gas and geothermal industries.

Inappropriate reservoir operation may cause formation water to move to the wellbore, thus reducing well efficiency. Water movement could be caused by failure to control encroachment of bottom water, and by failure to prevent water coning and buildup of excess connate water (Sargent & Lundy 1981a, 1981b).

Research currently underway at the Pacific Northwest Laboratory is aimed at establishing stability criteria for the three types of underground storage reservoirs. To date, guidelines have been formulated for reservoirs in hard rock (Allen, Doherty and Fossum 1982) and in salt cavities (Allen, Doherty and Thoms 1982). Engineering guidelines for reservoirs in porous media (aquifers) are under development.

3.9 HYDROLOGIC IMPACTS

Construction and operation of CAES facilities can also impact local hydrologic conditions, both surface and subsurface. As with geological impacts such effects will undoubtedly depend on site specific factors. In general, hydrologic impacts range from alteration of surface hydrologic conditions due to construction of compensating reservoir dikes and building foundations to alteration of ground water aquifers due to construction and operation of subsurface air storage reservoirs. Much of the following discussion is drawn from EPRI's Integrated Environmental and Safety Assessment of Selected Mechanical Energy Storage Systems (1982a).

The failure of the compensating reservoir likely to be used by some CAES facilities may create flooding, causing significant damage to life and property immediately downstream of the reservoir (Electric Power Research Institute 1982a). The flood hydrograph will depend on the reservoir characteristics and the failure mode. The extent of flooding

will depend on downstream topography. The damage to life and property will depend on the demography of the flooded area, and can vary from very low to high. Although modification of the site so that all precipitation appears as runoff may increase flooding on or near the site, the impact on downstream flood flows is not expected to be significant (Electric Power Research Institute 1982a).

The major site-generated pollutant during construction will probably be suspended sediment resulting from land-disturbing operations and hydrological modification of streams. Other site-generated pollutants may be comprised of construction chemicals, including heavy metals derived from construction wastes; refractory organics such as pesticides and herbicides; salinity derived from dust control chemical and petroleum products; leachate from spoil piles; and seepage from compensating reservoirs highly mineralized due to evaporation during operation (Electric Power Research Institute 1982a). Engineering practices implemented in response to federal and local laws controlling nonpoint source pollution should minimize the impact of site-generated pollutants. Runoff of site-generated pollutants to streams is not expected to significantly affect surface water quality.

During operation, the water in onsite compensating reservoirs will probably become highly mineralized, due primarily to evaporation (Electric Power Research Institute 1982a). Failure of reservoir containment may not only create flooding conditions but may also cause downstream degradation of water quality.

Construction at a site can decrease the permeability of the surface, thus decreasing the rate of infiltration to local aquifers and the amount of ground water in storage. A reduction in aquifer recharge zone is not expected to significantly decrease the amount of ground water in storage if the site area is small in comparison to the area of the total recharge zone. This is expected to be the case in most CAES projects.

Dewatering during shaft construction will remove some ground water from storage and may locally decrease ground-water levels. However, shafts will be lined and cemented as excavation proceeds, thereby minimizing ground-water inflow that can deplete local aquifers. Because of the extremely low permeability of the rock required for a CAES reservoir, very little ground water is expected to flow into the caverns at that level (Electric Power Research Institute 1981, 1982a). Therefore, although shaft construction may cause some dewatering of near-surface aquifers and may lower ground-water levels at or near the site, the regional impact on ground-water aquifers is not expected to be significant (Electric Power Research Institute 1981, 1982a).

Excavation of shafts can breach the confining strata of aquifers, forming a pathway for ground-water flow between deep and shallow aquifers with subsequent depletion of, or alteration in quality. However, adequate casing and cementing of the shaft should prevent a flow pathway from forming. The integrity of the cement bond between the shaft casing and the host rock must be maintained. Shaft excavation can also disrupt the aquifer, altering its configuration and flow dynamics. The shafts can change the flow patterns because the flow path will diverge around the shafts, thereby altering ground water down-gradient from the shaft. However, it is anticipated that such impacts will be extremely localized and that the flow patterns in regional aquifers will not be altered (Electric Power Research Institute 1981, 1982a).

Ground-water quality may also be degraded if it is infiltrated by site-generated pollutants such as construction chemicals, spoil pile leachate, reservoir seepage, and sanitary waste. As with surface water impacts, these impacts will be low if proper engineering and collection procedures are followed (Electric Power Research Institute 1982a).

Because CAES in a confined aquifer does not have a significant water requirement and will not have a compensating surface reservoir, there will be minimal impacts due to consumptive uses. However, the air storage in the porous aquifer storage matrix can change the

ground-water flow patterns because the flow paths will diverge around the air "bubble", and may decrease the yields of down gradient wells (Electric Power Research Institute 1982a, Sargent & Lundy 1981b). The magnitude of the impact of aquifer disruption on ground water availability is expected to be very low, if the experience of the natural gas storage industry is any indication and if proper site selection is ensured.

The cyclic introduction of hot air into the porous media storage matrix can lead to geological changes (oxidation and hydrolytic reactions) that may degrade ground-water quality (Stottlemyre, Erikson and Smith 1979). The magnitude of the impact of ground water quality degradation is expected to vary from low to moderate, depending on the site. This is an area of intense research, because water quality degradation resulting from geochemical reactions is likely to be accompanied by degradation in operational reservoir characteristics as well.

Injection and disposal of solutioning brine produced by construction of CAES cavities in salt into saline aquifers can cause a breach in the confining strata as a result of hydraulic fracturing. The rate and pressure of injection must depend on receiving aquifer porosity, permeability and discovery pressure. The injection rate and pressure must be controlled so as not to exceed the confining pressure of caprock and thus minimize the impact of hydraulic fracturing. The magnitude of the impact on ground-water quality due to breaching the confining strata is expected to be low if the injection zone is adequately characterized and the injection operation properly engineered and controlled (Electric Power Research Institute 1982b).

4.0 SITE SELECTION

As with almost all large construction projects, the magnitude and acceptability of environmental impacts is largely a function of the site chosen. In the case of CAES facilities, the primary environmental concerns are associated with the impact on the subsurface environment of construction and operation of underground air storage reservoirs. Surface environmental impacts of power plant operation are well known, generally tolerable and amenable to proven mitigation and control measures. Uncertainty, however, surrounds many environmental concerns associated with underground storage reservoirs and facilities. In fact, the nature and magnitude of such impacts are largely determined by the characteristics of the site and the system proposed for a particular site. Matching site characteristics to system characteristics is thus crucial in minimizing adverse environmental impacts.

Safe, efficient and economical construction and operation of subsurface CAES reservoirs is dependent almost entirely on geological suitability and integrity (Electric Power Research Institute 1981; Environmental Science and Engineering 1981a, 1981b). In this sense, environmental concerns are also engineering, operational and economic concerns. Construction of a CAES reservoir in unsuitable geologic media may not only cause unacceptable environmental impacts but may also result in an inoperable or, at the very least, an uneconomical facility. Therefore, siting studies for CAES facilities usually begin with defining the subsurface geology required by a proposed system and then searching for a site or sites meeting such criteria (Electric Power Research Institute 1982a). Surface environmental factors as well as economic and social concerns play a large part, of course, in selecting a site for a CAES facility, but successful construction and operation depends primarily on subsurface geological conditions (Environmental Science and Engineering 1981a, 1981b).

This section first presents the general methodology used to select sites for CAES facilities. The procedures used to formulate and rank

specific selection criteria are explained. The information presented is based on siting studies performed as part of DOE or EPRI research aimed toward commercializing CAES technology in the U. S.

Specific studies include an analysis of energy storage in reservoirs mined from hard rock performed for the Potomac Electric Power Company by NUS Corporation and Acres American, Inc., and a salt dome siting study performed for Middle South Services by United Engineers & Constructors and Fenix & Scisson. Other studies performed to date include an assessment of CAES in aquifers performed by Sargent & Lundy for Public Service of Indiana. These studies are summarized in EPRI's Integrated Environmental and Safety Assessment of Selected Mechanical Energy Storage Systems (1982a). A study of a CAES facility proposed by Soyland Power Cooperative for a site in Illinois performed by Environmental Science and Engineering (1981a) is also described. Most of the following discussion is based on these two studies. For more thorough discussions of specific CAES facility site selection studies, the reader is referred to Acres American, Inc., (1978), EPRI (1981a), Fenix & Scisson, Inc. (1978), and Sargent & Lundy (1981a).

4.1 SITE SELECTION METHODOLOGY

The site selection procedures for CAES facilities consist of methods developed by NUS Corporation, Acres American, Inc., Fenix & Scisson, Inc., and Environmental Science and Engineering for previous energy storage projects. Selection criteria are formulated and assigned a rank or value. Candidate sites are then evaluated systematically and consistently according to their cumulative "scores" across the range of criteria.

The site selection methodology is applied in a series of five steps, graphically portrayed in Figure 4.1 :

- define study region
- determine potential siting area

FIGURE 4.1. Site Selection Methodology for Energy Storage Projects

- define plant characteristics
- exclude unsuitable areas
- delineate sites in suitable area and evaluate.

The first step is to define the study region based on projected energy demand considerations, including the utility's service area and the load center within that area. The load centers are those geographic portions of the service area with the highest projected demand for electricity. It may be decided, for example, that an energy facility should be located within a certain distance of these centers to minimize costs of transmitting power to them. The availability of competing alternative energy sources within this area will also affect the definition of the study region. Certain sections of the service area may be very suitable for mine-mouth coal plants, conventional hydropower, dispersed solar power, and other forms of energy generation. Such sections would be excluded from the study area, but only if their suitability for alternative sources is indisputable. Figure 4.2 presents a hypothetical service area, the load center and conventional energy sections within it, and the study area (Electric Power Research Institute 1982a, p. 3-3).

The second step in the methodology is to determine the potential siting area--those portions of the study area having the appropriate geological characteristics for the type of storage facility under consideration. This step, which can be conducted concurrently with Step 1, involves examining the literature describing the geological history of the region to delineate the areas possessing the general rock properties for hard rock facilities, salt features for dissolved salt facilities, or porous media for confined aquifer facilities. The shaded area in Figure 4.3 represents the potential siting area, which is the intersection of a suitable geological region with the study area (Electric Power Research Institute 1982a, p. 3-4).

The third step is to select the energy storage method and to define the plant characteristics. This includes determining the type of plant,

FIGURE 4.2. Determination of Study Area Within Utility Service Area

FIGURE 4.3. Identification of Potential Siting Area

the power and energy storage capacities desired, and the approximate area required for surface facilities. Other factors which would be included are the depths of potential storage areas, and the water and fuel requirements (Electric Power Research Institute 1982a).

The next step is to eliminate all areas from the study area that are technically, socially, or environmentally unsuitable for the energy storage facility. Technically unsuitable areas include those near formation contacts and faults, those possessing very rugged terrain or volcanic features, or those without nearby water. An area would be excluded for social reasons if it were a population center; national forest; national, state, or local park or monument; or a recreational center. It would also be excluded if it would severely conflict with local plans or zoning laws. Environmentally unsuitable areas include important wetlands, critical habitats for endangered species, and conservation and wilderness areas. After these exclusions have been made, the candidate siting area remains. This step is depicted in Figure 4.4 (Electric Power Research Institute 1982a, p. 3-6).

Finally, sites in the candidate area are selected for detailed evaluation. The number of sites selected depends on the size of the potential siting region and the time and resources available for applying the site selection criteria described below. A review of these criteria can help in determining which sites are selected. For example, sites located close to transmission lines and roads might be included in the selection. Current ownership would also influence the selection. For example, it may be more difficult to negotiate for a site consisting of parcels with many different owners than for one owned by a single entity.

An index ranking system was developed by Acres American during the PEPOO study (Electric Power Research Institute 1981) for those technical factors considered to be site-specific and having the greatest economic impact on plant construction costs. The index system is based on a hypothetical "ideal" plant with departures from the "ideal" conditions

FIGURE 4.4. Delineation of Candidate Siting Area

reflected in additional plant construction costs. Thus, an "ideal" condition is equated as a "0" dollar increase in overall plant costs while a less than "ideal" condition would have some penalty cost expressed in units of dollars per kilowatt (\$/kW) as determined by the costs of the penalty divided by the plant generating capacity. The \$/kW for the "worst" condition is calculated to provide the index range from "ideal" to "worst" for a particular factor. The index values may be approximate and may not reflect absolute cost figures; however, they will provide a consistent basis for relative ranking of the sites. This system combines the weighting and ranking into one cost penalty; the best site has the lowest total cost penalty. The weight that is applied to each technical factor is equal to the worst-case penalties. The ranking is obtained by converting the cost penalty to a somewhat subjective scale of 10 to 0.

In the site selection methodology for various underground energy storage concepts presented in EPRI (1982a), the site selection criteria fall into ten categories. These consist of a technical (including economic) category, and nine social, environmental, and safety categories. Each category is assigned a total weight of 100 units. The 100 units are divided among the separate impacts in a given category according to their importance relative to one another. The weights of each impact were assigned by the individual who assessed the specific impacts in a given impact category. For example, in the social category, the cultural impact of the loss of historic resources was assigned a weight of 7 units, while the infrastructure impacts were assigned a weight of 20 units.

Each individual impact is ranked on a scale of 0 to 10 for a specific site. The rank is 0 if the site characteristics are such that the impact would be severe, and 10 if there would be minimal impact. For example, the historic resources ranking would be 0 if there were an historically significant resource on the site and 10 if there were none.

A specific site would be ranked somewhere between 0 and 10 if its characteristics were such that the impact would be between the two extremes.

A similar weighting and ranking technique is applied for the technical category included in the site evaluation. The weights in this case are based on a percentage of total cost attributable to each technical factor, and the ranking is based on the site characteristics affecting that technical factor.

The weight and rank of each item are then multiplied to provide a numerical value of the quality of the site with respect to that item. For instance, in the example cited above where the historical resource criterion was assigned a weight of 7 units, if a particular site were located in an area where there would be a minimum impact on historic resources, the rank would be 10, and the numerical measure for that impact within that impact category would be $7 \times 10 = 70$. The maximum rating a site can receive for each category is 1000 (Electric Power Research Institute 1982a).

To assess the importance of one category relative to another, a weight has also been assigned to each of the ten impact categories. The weights are assigned on a scale of 0 to 1. The sum of the ten category weights is 1. The weights are presented as suggested values. For a specific region the weight could be adjusted for local conditions, existing legislation, or other relevant factors.

The site rating is obtained by multiplying the category weight and the numerical values for each impact in that category, and adding the results. In mathematical terms, the site rating is:

$$\sum_{i=1}^{10} W_i \times (\sum_j W_{ij} \times r_{ij})$$

where

i = the category

$$\begin{aligned} \sum_{i=1}^{10} &= \text{the sum over all ten categories} \\ w_i &= \text{the weight assigned} \\ w_{ij} &= \text{the weight for the } j\text{th element of the } i\text{th category} \\ r_{ij} &= \text{the rank for the } j\text{th element of the } i\text{th category} \\ \sum_j &= \text{the sum over all the elements within a category.} \end{aligned}$$

Using this method, the maximum rating a site can receive is 1000 (Electric Power Research Institute 1982a).

Although this methodology can be applied manually, **it** would be simplified **if it** were automated. A spread sheet computer program can be used to accomplish this, and this would have the advantage that the component weights could easily be modified to perform sensitivity analysis. **It** is advisable that the criteria be examined in order of decreasing significance. Thus a small number of sites may be selected even before all the criteria have been examined, and even under the most extreme conditions the remaining criteria would not change the order of these sites. The computer program could be written to test when this is the case and to signal that no further site examination is necessary.

A similar approach was used by Environmental Science and Engineering in its site selection study for the Soyland facility (Environmental Science and Engineering 1981a). **It** employed fewer information elements and a somewhat "coarser" gradation of weights assigned to both individual impacts and impact categories. At first glance, **it** appears simpler than the methodology described by EPRI and perhaps less able to discriminate among sites having similar characteristics. On the other hand, the Environmental Science and Engineering methodology may identify preferred sites more clearly because of its fewer "subjective" value judgments of individual impacts and greater (coarser) range of individual impact and impact category weights.

4.2 TECHNICAL CRITERIA

After defining a general study region, the next step in the siting methodology is to examine the region's geology to delineate areas that are generally suitable. Previously specified technical criteria for each reservoir type are then used in defining general suitability.

4.2.1 Compressed Air Energy Storage in Hard Rock

For CAES caverns in hard rock, available geologic information about the study region is reviewed, leading to the selection of potentially suitable host rock types (Electric Power Research Institute 1982a).

The hard rock CAES concept is based on the creation of subsurface storage volume by excavating a series of interconnected tunnel systems at substantial depths below the surface. The cost of reservoir excavation is a significant proportion (approximately 20%) of the total project cost. The costs involved with the excavation and structural support augmentation of a poor quality rock would be prohibitive. Thus, a primary factor in siting a CAES plant is the selection of an acceptable rock body in which the large underground cavern can be excavated at the least cost. The host rock should have:

- uniformity and properties that will assure long-term integrity of the mined chambers with minimal roof and wall support
- a composition that will not be degraded by contact with air and/or water or temperature fluctuations
- low permeability.

Based on considerations of rock mechanics, cavern design, and construction methods, the rock bodies selected as candidate siting areas should have the following general physical and mechanical properties:

- compressive strength - 10,000 lb/in²
- modulus of elasticity - 400 to 500^(a)

^(a)As defined on the basis of Modulus Ratio ($E/(u/t)$) where E = tangent modulus at 50% ultimate strength and (u/t) = ultimate uniaxial compressive strength.

- rock quality - good to excellent (75 to 100% RQD^(a))
- joint spacing - wide to excellent (greater than 3 ft)
- in-situ stresses - horizontal < 2 lithostatic
- permeability - low (10^{-6} cm/s).

These rock properties should be available for a major rock unit within a study area. Certain generalizations regarding the rock's properties can be made based on rock type and the geologic history of the region. A potential host rock must also have sufficient lateral and vertical dimensions to provide enough space for the underground structures. Regional and site geology should therefore be evaluated to ensure rock mass continuance with depth.

Technically unsuitable areas should be eliminated. Rock bodies that may otherwise be suited for a CAES site should be eliminated if they fail to provide the degree of confidence needed to assure sufficient dimensions. In areas where there is insufficient subsurface data for interpretation, only the larger and more homogeneous rock units, as mapped on the surface, should be selected as candidate siting areas. Areas having potential geologic hazards such as faults or zones of intense jointing or shearing that may seriously affect the integrity of the air storage reservoir should be identified and eliminated from further siting consideration.

The technical factors considered to have the greatest site-specific economic impact on plant construction, as identified in the PEPCO study (Electric Power Research Institute 1981), are:

<u>Factor</u>	<u>Influence Reflected in Index</u>
Geotechnical	
Watertightness	Measures or designs necessary to minimize leakage into the reservoir

^(a)RQD (rock quality designation) is obtained by summing the total length of sound rock core (greater than 4-in. lengths) recovered from a core run and expressing it as percentage (Electric Power Research Institute 1982a).

Condition of shafts	Potential problems associated with the sinking and equipping of shafts to the required depths
Rock structure	Design and cost of the arrangement and support requirements of the reservoir caverns
Rock structure and in situ stress	Design and cost associated with the general arrangement and dimensions of the reservoir caverns
Permeability of rock	Airtightness of CAES caverns
Seismicity	Cost of earthquake design for surface plant
Topography	Site relief, which affects compensating water (surface) reservoir dike height (where used)
Locational	
Filling water	Proximity of the site to a suitable source of initial surface reservoir filling water
Site access	Length and cost of access roads to site from nearest major highway or railroad
Transmission line	Interconnection of plant facilities with power system
Property acquisition	Cost of purchasing property for construction of the facility
Fuel supply (CAES) (Electric Power Research Institute 1982a)	Cost of fuel supply line or other transportation system

Other technical factors considered to have an impact on plant construction costs can be added to this list, depending on the degree of detail desired for this step in the siting methodology. The number of

factors considered at this step, however, is largely dependent on the type of the project, cost, and availability of adequate information for assessing cost penalty impacts.

4.2.2 Compressed Air Energy Storage in Salt Caverns

The technical criteria for CAES in salt caverns are based on the site-selection methodology developed by Fenix & Scisson for comparing 47 salt domes in Louisiana and Mississippi (Fenix & Scisson 1978). In this methodology, the cost of all the items required to develop and operate a CAES facility in a salt dome are estimated. Seventeen site characteristics are then identified and their contributions to each of the costs are estimated. For each of the site characteristics, the sum of its contributions to cost is then obtained. The weight assigned to a particular characteristic is equal to its percentage of the total costs attributed to all site characteristics.

The major difference between this and the cost-penalty methodology used by Acres American for the PEPCO hard rock system is that the total site-related cost is used in the weighting, whereas the marginal cost above that of an ideal site is used in the cost-penalty (Acres American) method.

The weights for the locational criteria are based on a comparison between the best and worst sites and are therefore variables that are determined after all sites have been evaluated. In the Fenix & Scisson study, 47 sites were examined and numerical weights were obtained for all criteria. It was necessary to modify these results to reflect the generic nature of the analysis as presented in EPRI (1982a). The transmission and site access weights, expressed in variable terms in the EPRI report, were used in place of the actual cost estimates presented by Fenix & Scisson (to Middle South Services). The other three locational factors examined for CAES in hard rock were distance to filling water, site acquisition, and fuel lines. The first is not relevant to CAES in dissolved salt and the latter two were incorporated into other categories in the Fenix & Scisson report.

Fourteen criteria are presented in the EPRI analysis. Of the seventeen presented in the Fenix & Scisson report, three related to transmission factors were replaced by an overall transmission factor. High wind, an additional factor, was eliminated because it is specifically related to Gulf Coast hurricanes and is not relevant to a general methodology. The resulting 14 criteria are:

1. depth to salt
2. surface of land over dome (topography)
3. current use of dome
4. flood hazard
5. seismic risk
6. distance to surface facilities
7. distance from existing transportation facilities (rail, highway, water)
8. availability of and distance to leaching water supply
9. availability of and distance to brine disposal site
10. land use at site
11. requirement for seismic survey
12. future plant expansion possible
13. transmission line access
14. site access.

4.2.3 Compressed Air Energy Storage in Confined Aquifers

The technical criteria for CAES in confined aquifers presented in EPRI (1982a) were adapted from those developed by Acres American for a study performed for the California Energy Commission (1978) and studies performed by Sargent & Lundy (1981a) for Public Service Indiana. As with CAES in hard rock, the technical requirements for a site are compared with those of an ideal site and a cost penalty is derived for each requirement. Both geological and locational factors are included and the weightings and rankings are based on the cost penalties.

Geologically, the ideal porous media site is one that possesses the following characteristics (Allen and Gutknecht 1980):

- geologic structure - simple dome or anticlinal structure, with little or no faulting
- structural closure - closure of 200 ft or more, with an impermeable caprock and isolation from other producing fields or potable aquifers
- reservoir rock quality - generally a massive sandstone with good porosity (20 to 35%), and permeability (500 to 1000 millidarcies)
- reservoir rock thickness - generally 200 ft or more
- depth to the storage reservoir - 1500 to 3500 ft; optimum depth is approximately 2000 to 2500 ft
- discovery pressure - 1000 psig or higher
- geologic hazards - free of known geologic hazards and in an area of low to moderate seismicity.

The geologic characteristics of study areas are compared with the ideal; those sections similar to this ideal are selected as the potential site areas. After eliminating unsuitable areas, the site-specific geological ranking is performed. The factors included in this ranking are described in the following paragraphs:

4.2.3.1 Permeability

The permeability of the porous media under consideration determines the number of air injection wells because pressure losses in the formation are higher when the permeability is low. Therefore, the number of wells required increases as the permeability decreases below the ideal level of one darcy (Sargent & Lundy 1981a, 1981b).

4.2.3.2 Porosity and Water Saturation of the Medium

The porosity of the storage medium determines the volume of the rock mass required to store the volume of air for the specific plant capacity considered. This volume is further affected by existing connate water, which takes up part of the available pore space at least

during the initial operation of the plant. "Effective porosity" is the volume of void space available for containment of compressed air. It does not include isolated pores or capillary openings that may be filled with either connate or secondary ground water.

4.2.3.3 Depth

Depth below the water table determines both the operating pressure and the volume of storage required for a plant module. Higher storage pressures resulting from storage in a deeper medium increase plant equipment costs.

4.2.3.4 Formation Thickness

The formation thickness of the medium limits the storage volume. Greater formation thickness allows for larger storage volumes, provided that closure exists.

4.2.3.5 Seismicity

Proximity to regions of high seismic activity may have an economic effect on the design of the above-ground facilities for a CAES plant. In underground structures, however, the additional reinforcement and structural stiffness offered by the surrounding rock mass provide strong resistance to potential earthquake damage. It is anticipated, that the design of the underground structures will require only minimal allowance for seismic design (Electric Power Research Institute 1982a).

The index values are chosen to reflect the additional cost of seismic design and construction of the above-ground facilities. Seismicity values are assigned based on the estimated maximum acceleration that could occur at the site. These calculations are based on the distance to the closest active or potentially active fault, and estimated maximum credible earthquake magnitudes. Acceleration ranges were assigned ranking values as follows:

<u>Acceleration</u>	<u>Ranking Value</u>
0 to 0.3g	0
0.3g to 0.4g	1
0.4g to 0.5g	2
0.5g to 0.6g	3
0.6g to 0.7g	4

4.2.3.6 Ideal Project Characteristics

The technical ranking is based on the additional cost of developing a feasible site above the cost at an ideal site. An ideal 250-MW plant has the following characteristics (Robertson 1975; Sargent & Lundy 1981a):

- 4-hr storage capacity with a volume cushion of 10:1
- storage reservoir depth of 2300 ft and thickness of 200 ft
- permeability of 1000 millidarcies
- effective porosity of 24% (porosity reduced by nondisplaceable connate or secondary water saturation = effective porosity)
- total of 40 wells with a surface well spacing of 150 ft
- total surface acreage of 20 acres for plant site.

The ideal number of wells, well size, and well spacing are determined as described in the following paragraphs.

4.2.3.6.1 Number of wells. The design flow for a 250-MW plant module is 40 MMscf per hr. To limit the pressure losses in the system to within the plant design criteria, the maximum flow per well was established as 1.0 MMscf per hr. This dictated a minimum plant design of 40 wells (Robertson 1975; Sargent & Lundy 1981a).

4.2.3.6.2 Well size. Previous studies by General Electric Company (1976) have shown that a detailed study can be made of the relative economics of well size as a function of porosity. The General Electric study concluded that, for a permeability of 1000 millidarcies, the most

economic well diameter was 7 in. (casing diameter). This size is therefore generally utilized in comparing various sites for CAES with aquifer storage.

4.2.3.6.3 Well spacing. The minimum number of wells and the geometric configuration of the formation determine the spacing of the wells. To determine this spacing, the pressure drop in the aquifer investigated by Public Service Indiana was estimated. At a depth of 2300 ft, a volume of voids (900% cushion included) of at least $27 \times 10^6 \text{ ft}^3$ is required for storage. For a formation with assumed characteristics of 20% porosity, 30% connate water saturation, and 20-ft formation thickness, the well spacing must be 150 ft to accommodate the minimum required 40 wells (Robertson 1975; Sargent & Lundy 1981a). If the porosity of the formation is 30%, the thickness of the medium can be as low as 140 ft and still have the required volume.

4.2.3.7 Development of Cost Penalties for Geologic Factors

Three items are affected by the geologic properties of the reservoir: the number and depth of wells, the amount of surface piping, and the cost variations of turbomachinery designed to operate at different and variable reservoir (input) pressures. To develop index values that represent a \$/kW value of incremental cost over the ideal situation, the following procedure was used:

- A determination was made of the various volume requirements with depth.
- The ideal base conditions were established to be a permeability of 1.0 darcy in 200-ft sandstone thickness of 20% porosity.
- Well spacing of 150 ft to maintain a minimum pressure drop of 10 psia.
- The required number of wells is inversely related to permeability.
- The costs for well and surface piping were established; the layout and size of surface piping were determined for various numbers of wells; and the thickness was assessed for varying pressure.

- A table was prepared giving the cost of wells versus depth for various numbers of wells. This was then converted to an index value in \$/kW and plotted to show index values versus number of wells for varying depths.
- A table was prepared giving actual surface piping cost against depth and number of wells. This was also converted to an index value in \$/kW and plotted.
- Seismic design costs were estimated and assigned index values in accordance with the ranges of maximum lateral acceleration ranging from 0.30 to 0.70g. Because seismic design affects only the surface plant, the costs in \$/kW reflect only the increased cost for the surface plant.
- Index values reflecting the increased cost of plant machinery resulting from operating pressures associated with a given depth were also plotted.

Based on these considerations, the worst-case cost penalties resulting from the four technical factors affected by the site geological characteristics were estimated to be.

5.0 REGULATORY ISSUES COMMON TO MOST COMPRESSED AIR ENERGY STORAGE FACILITIES

This section discusses regulatory considerations potentially applicable to CAES systems. The focus is on federal regulatory considerations with secondary attention given to state and local requirements. The principal regulatory areas of concern are likely to be requirements under the Powerplant and Industrial Fuel Use Act (FUA) related to the combustion of oil or gas, air emissions, Underground Injection Control Program requirements, power plant siting legislation, and environmental impact statement (EIS) requirements. The following discussion is drawn from Hendrickson (1981) of the Pacific Northwest Laboratory. It is the only comprehensive study to date on the regulatory issues surrounding CAES.

5.1 FUEL USE ACT EXEMPTION^(a)

Under Section 201 of the Fuel Use Act, (42 USCA 8311, 10 CFR 502.3) no new electric power plant may use natural gas or petroleum as a primary energy source unless exempted. For a conventional CAES facility, this restriction presents a potential regulatory problem because natural gas or petroleum will be the fuel of choice to reheat the stored compressed air prior to expansion through the turbine. The problem may not be burdensome because the Soyland Power Cooperative, Inc. has received a permanent fuel mixture exemption from the act (46 Fed. Reg. 38302 June 6, 1980). This exemption will most likely provide a precedent for future CAES applications requiring an exemption from the Act. The question of a fuel use exemption may even be moot because under the Reagan Administration little emphasis has been placed on enforcement. In fact, the Economic Regulatory Administration, the entity within DOE responsible for enforcement of FUA, has all but been disbanded.

^(a)DOE published a notice of proposed rule making on June 12, 1981, 46 Federal Register 31216, that will significantly simplify exemption procedures under FUA if the proposed changes are made final.

The term "primary energy source" is defined in section 1.3(b)(15) of the FUA simply as the fuel or fuels used by any new electric power plant. The primary fuel to produce the peak load power in a CAES facility (in terms of percentage of Btu energy required to generate electricity) is the surplus power from the grid that operates the compressors during the compression phase of operation. This surplus generally will come from coal or nuclear base-load plants. However, according to the definition in the FUA, it is entirely possible that the natural gas or petroleum used in the CAES installation will be interpreted to be the primary fuel because it is the fuel used at the plant during actual production of peak load power. Fortunately, certain exemptions to the Section 201 prohibition are provided for in Sections 211-214 of the FUA. Final regulations relating to the exemptions were issued by the Economic Regulatory Administration (ERA) within DOE in June 1980 and became effective August 5, 1980 (45 Fed. Reg. 38302 June 6, 1980).

Section 212 of the FUA provides for several categories of permanent exemptions from the Section 201 prohibition. The exemptions most likely to be suitable for a CAES facility are the exemption in Section 212 (d) for certain fuel mixtures that include gas or petroleum and the exemption in Section 212(g) for peak-load power plants.

The fuel mixture exemption is available when an alternate fuel is used in combination with natural gas or petroleum to produce electricity. The electricity used to compress the air will have been generated at a coal or nuclear power plant. If one of these base-load fuels (or the electricity produced by them) is considered part of the fuel mixture used to produce power at the CAES facility, and this fact can be demonstrated on a system-wide basis, the fuel mixture exemption probably applies (10 CFR 503.386). Additionally, the Btu energy input from the natural gas or petroleum cannot exceed the minimum Btu energy input supplied by the utility grid. Compliance with this requirement should not be difficult for a typical CAES installation because the

ratio of energy from the grid required to run the compressors to that of the additional fuel required to produce electricity is typically 2 or 3 to 1.

Several informational requirements must be submitted to EPA in support of a fuel mixture exemption (10 CFR 503.38(6)). The requirements are extensive and include a complete description and engineering assessment of the fuel mixture, design specifications, a demonstration that no reasonable alternative source of electric power exists, a description of conservation measures designed to minimize oil or gas use, and an environmental impact analysis of the proposed and reasonable alternative sites. A demonstration that alternative fuels cannot be used is also required (10 CFR 503.11 ; 10 CFR 503.16).

The other most probable exemption category applies to peak-load power plants. To qualify for this exemption a petitioner must certify to EPA that the power plant will be operated solely as a peak-load plant for the life of the facility, as defined by FUA. If natural gas is to be used as the fuel source, the cognizant air pollution control agency must determine that the use of any alternative fuel would contribute to a condition in which a national air quality standard would be exceeded. As with the fuel mixture exemption, several informational studies must be conducted to qualify for the peak-load power exemption. The required studies are similar to, but not identical to, those required for the fuel mixture exemption. The several requirements include:

- a demonstration that alternative fuels cannot be used at the proposed site and at reasonable alternative sites (10 CFR 503.11 , 503.16)
- documentation of fuel conservation measures (10 CFR 503.13)
- information on oil and gas consumption (10 CFR 503.14)
- an environmental impact analysis (10 CFR 503.15).

5.2 AIR EMISSION REQUIREMENTS

The source of air pollutants from a CAES facility is the combustion of natural gas or oil to heat the compressed air for subsequent expansion through the turbine. Compliance with ambient air quality standards and emission limitation requirements is a potentially complex process.

At a minimum, the EPA New Source Performance Standard (NSPS) for stationary gas turbines and any applicable state requirements issued pursuant to a state implementation plan will have to be met. Also, a permit under the EPA Prevention of Significant Deterioration (PSD) regulations will most likely be required or special requirements will be imposed if a proposed CAES facility is to be located in an area where any ambient air quality standard is being violated.

The basis for air pollution regulation is the Clean Air Act of 1970 (CAA), as amended. Section 109 of the CAA (42 USCA 7409) directs EPA to promulgate primary national ambient air quality standards for individual air pollutants that cannot be exceeded without causing a threatening situation to human health. Secondary standards are designed to prevent adverse effects on the public welfare (e.g., vegetation and scenic values). To date EPA had promulgated primary national ambient air quality standards for sulfur dioxide, particulates, carbon monoxide, nitrogen oxide, lead, hydrocarbons, and ozone (40 CFR 50); these are frequently referred to as the "criteria pollutants". The standards for ozone and hydrocarbons are enforced in conjunction with each other because hydrocarbons are considered to have adverse effect only as they contribute to the formation of ozone (40 CFR 50.10). Secondary standards have been designated for sulfur dioxide and particulates. Section 110 of the CAA directs states to develop and adopt state implementation plans (SIPs) that set forth all necessary control efforts to achieve compliance with the national ambient air quality standards. The state implementation plans establish specific emission limits for various categories of air pollution sources, or in some cases, limits

for individual sources, or emission limits by geographic area. To facilitate compliance with the national standards, EPA and the states have divided the country into 247 air quality control regions according to the direction provided in Section 107 of the CAA.

5.2.1 New Source Performance Standards

Overlying the state implementation plans are the new source performance standards (NSPS) that Section 111 of the CAA directs EPA to promulgate. These standards apply to specified categories of new or modified stationary air pollution sources. New source performance standards have been issued for about 30 source categories, including stationary gas turbines. The EPA denied a petition to revise the gas turbine standard on December 11, 1980 (Fed. Reg. 81653). The stationary gas turbine standard applies to units with heat input at peak load equal to or greater than 10.7 gigajoules per hr, which corresponds to a peak power output of about 2.5 MWe. Essentially all first-generation CAES facilities will exceed this level and therefore be subject to the standard. Implementation and enforcement of the standards has generally been delegated to the states. Under its implementation plan, a state has the option of applying the new source performance standard as promulgated by EPA or adopting a more restrictive standard. In virtually all cases then, a CAES operator will require a permit from the cognizant state or local air pollution control authority authorizing operation of the turbine in conformity with the EPA new source performance standard for gas turbines or a more restrictive state standard if one exists.

5.2.2 Prevention of Significant Deterioration Review

In addition to the new source performance standard, a CAES facility will most likely have to comply with EPA regulations for prevention of significant deterioration and/or regulations for operation in nonattainment areas (i.e., areas where an ambient air quality standard is being violated). These regulations are complex and compliance can be a time-consuming and costly process. Their potential application can only be summarized here.

New EPA PSD regulations were issued August 7, 1980. Generally, any major new or modified stationary source is subject to the PSD regulations if the area is in compliance (attainment) or is unclassifiable with respect to at least one of the national ambient air quality standards. If applicable, the PSD regulations will require application of the "best available control technology" and preparation of pollutant-specific impact analyses.

A key element of the PSD requirements is the definition of a major air pollution source. According to the regulations (10 CFR 52.21), a major source is a source that emits or has the potential to emit, after application of appropriate pollution control technology, 250 tons per year (tpy) or more of any pollutant subject to the CAA. A large CAES installation may emit or have the potential to emit 250 tpy or more of a criteria pollutant. An illustration is provided by the CAES installation being investigated by Potomac Electric Power Company. The conceptual plant will have four units, a total capacity of 1000 MWe, and will use number 2 fuel oil. The estimated total emissions for the four turbines in tpy, assuming 10 hr/day and 365 days/yr operation are:

sulfur dioxide	329
particulates	77
carbon monoxide	219
■ hydrocarbons	77
● nitrogen oxides	612 ^(a) .

Under these conditions, PSD review would most likely apply to sulfur dioxide and nitrogen oxide emissions.

If a CAES facility is determined to be subject to PSD review, several important requirements apply. First, the facility must have the "best available control technology" installed to control the emission of each pollutant with the potential to emit 250 tpy or more. What

(a) NUS Corporation, Rockville, MD, Preliminary Design Study of Underground Pumped Hydro and Compressed Air Energy Storage in Hard Rock, prepared for Acres American, Inc., Buffalo, NY, and Potomac Electric Power Co., Washington, D.C., Table 5-5, March 1980.

constitutes this technology is generally negotiated with the cognizant regulatory authority (40 CFR 52.21 (b)(12)). In any case, the new source performance standard must be met.

A second requirement of PSD review is that the impact on ambient air quality of each criteria pollutant emitted that is subject to PSD review must be assessed (40 CFR 52.21 (i)(b)(k)). This requirement may involve monitoring the air quality of criteria pollutants for up to a year preceeding the PSD permit application if such data are not otherwise available. Modeling of air quality impacts on noncriteria pollutants subject to the CAA will also be required. Additionally, applicants will have to demonstrate how much of the available PSD increment the facility will consume. The PSD increment is the amount of additional pollution that may be allowed in a particular area. The amount of available increment is determined by baseline air quality, the national ambient standards and the classification of the area. Geographic areas are classified in decreasing order of desired air quality as Class I, II, or III. Areas are generally classified by the states, except that certain areas such as parks are permanently designated in Section 162(a) of the CAA as Class I. Available increments for sulfur dioxide and for particulates are designated in Section 163 of the CAA.

A third requirement of PSD review is that the applicant must conduct an air quality analysis for all pollutants that are regulated under the CAA which the proposed CAES facility has the potential to emit in "significant" amounts. This requirement applies to all pollutants regulated under the CAA, not simply to criteria pollutants with the potential to emit 250 tpy or more. Significant amounts are defined to be rates of emission (in tpy) that equal or exceed the following (40 CFR 51.24 (b)(23)):

carbon monoxide	100
nitrogen oxides	40
sulfur dioxide	40

particulates	25
ozone	40
lead	0.6
asbestos	0.007
beryllium	0.0004
mercury	0.1
vinyl chlorides	1
fluorides	3
sulfuric acid mist	7
hydrogen sulfide	10
total reduced sulfur	10
reduced sulfur compounds	10.

A fourth requirement of PSD review is analysis of the impairment to visibility, solids, and vegetation that would occur as a result of the facility and associated commercial and residential growth in the surrounding area. Finally, the PSD permit application calls for a variety of information relating to the proposed facility including its location, operating specifications, construction schedule, emissions, and emission controls.

One way to avoid PSD review is to keep all criteria pollutant emissions below the 250 tpy cut-off. A second possibility is to limit the breadth of PSD review by limiting the number of criteria pollutants that have the potential to exceed 250 tpy. Serious attention should be devoted to these options during design.

5.2.3 Nonattainment Review

If a proposed CAES facility is to be located in a geographic area where the existing concentration of a criteria pollutant exceeds the national ambient air quality standard (i.e., the area is nonattainment with respect to the pollutant), the nonattainment permit and review procedures must be followed. These procedures apply only to sources with the potential to emit 100 tpy of a criteria pollutant in geographic areas where the same pollutant exceeds ambient standards. Each

individual pollutant must be analyzed. For example, one pollutant from a particular CAES facility could be subject to the nonattainment review procedures, a second pollutant could be subject to both PSD and nonattainment review, while a third pollutant from the same facility could be subject only to the PSD review process if the ambient concentration of this pollutant is within the applicable air quality standard.

If nonattainment review applies to a particular criteria pollutant, several important requirements must be met. In nonattainment areas, a plan for reaching attainment status must be in effect. If the state plan to reach attainment is inadequate or is not being carried out, a construction moratorium on all new air pollution sources may be in effect. Second, the lowest achievable emission rate (LAER) must be achieved for the nonattainment pollutant. This level of emission cannot be higher than the new source performance standard and will be subject to negotiation with the appropriate regulatory agency. Third, the applicant must demonstrate that all other air pollution sources owned by it within the state are in compliance with air pollution regulations or are on a compliance schedule. A final requirement is that the applicant must comply with the emissions offset rule. If an area is in nonattainment for any criteria pollutant, that area can permit new sources only by effecting reductions in emissions for the nonattainment pollutant from existing sources sufficient to create a margin of air quality within ambient standards necessary to accommodate new sources. Or the state can require a new applicant to achieve sufficient offsets (i.e., reductions in emissions from other sources) to more than make up for the emissions to be generated by the new source.

The nonattainment review requirements can potentially be as burdensome as the PSD permit requirements. The potential CAES operator may want to seriously investigate whether the emission of criteria pollutants in nonattainment status for the specific geographic area can be kept below 100 tpy to avoid this review (Hendrickson 1981).

5.3 SURFACE WATER QUALITY CONTROL

The discharge of water pollutants into surface water bodies will most likely require a National Pollution Discharge Elimination Permit (NPDES). Permits required under Section 401 of the Clean Water Act (CWA) (33 USCA 1342), can be obtained from either the Regional EPA Administrator or the state water quality agency, whichever operates the program. At least 33 states have now received EPA authority to operate the NPDES system within their borders. Discharges without a permit are illegal. The only exception to this requirement is through a sewer to a treatment works with its own NPDES permit.

5.3.1 National Pollution Discharge Elimination Permit

Any discharge of pollutants to navigable waters will require an NPDES permit. Navigable waters are defined in the CWA as the waters of the United States including the territorial seas. Waters of the U.S. are defined at 40 CFR 122.3 to include virtually all surface water bodies. NPDES permits include interim and final effluent limitations, a compliance schedule to achieve final effluent limitations and self-monitoring and reporting requirements. The final effluent standard in the NPDES permit will require the more stringent of the following:

1. Limitations necessary to meet the water quality standards of the receiving waters under Sections 301(b)(1)(C), 302, or 304 of the CWA, or any more stringent state standard, or
2. (a) the best conventional pollutant control technology must be applied to conventional pollutants (biochemical oxygen demand, total suspended solids, pH, fecal coliform, and oil and grease).
(b) the best available technology for all nonconventional pollutants.

These requirements must be met by July 1, 1984, and consequently would effectively apply to any new CAES facility in the U.S. Interim effluent requirements prior to July 1, 1984, require the application of the best

practicable control technology currently available. The necessary equipment and control technologies to meet these standards will ultimately be determined by negotiation with the cognizant authority.

A potentially useful point regarding thermal discharges for the CAES operator is Section 316 of the CWA. This section authorizes the state or EPA, as appropriate, to set the thermal component of any discharge permit at a level that "will assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on" the water body. Protection beyond this level is not required.

In addition to the effluent requirements described above, any cooling water intake structure in navigable waters will require a permit from the U.S. Army Corps of Engineers. The EPA requires that the structure reflect "the best technology available for minimizing adverse environmental impact".

5.3.2 Oil Storage

A conventional CAES facility using oil will have oil storage tanks. If the oil could possibly pollute a surface water body after an accidental spill, special regulatory requirements may have to be met.

Section 311(b)(3) of the CWA prohibits discharge of oil or hazardous substances in harmful quantities into the navigable waters of the U.S., adjoining shorelines, or the contiguous zone. A harmful quantity is any discharge that will violate applicable water quality standards or cause a film or sheen upon the water surface or adjoining shoreline. Even a very small discharge will produce a film and hence be a harmful quantity. The scope of protection extends to essentially all surface water bodies.

The EPA regulations applicable to oil pollution prevention are found at 40 CFR 112. They apply to all oil consuming activities unless: 1) the geographic location of the facility is such that an accidental oil spill could not reach a surface water body, or 2) the underground

buried storage capacity of the facility is 42,000 gallons of oil or less, or 3) the surface storage capacity does not exceed 1320 gallons and no single oil container has a capacity exceeding 660 gallons. If the above exemptions are not applicable, a variety of precautionary design and operating steps must be taken. These precautions include appropriate containment and diversionary structures and provisions for inspection of equipment and record keeping. The precautionary steps must be documented in a spill prevention control and countermeasure plan that has been certified by a professional engineer. The plan must be available for EPA review during business hours.

5.3.3 Construction Activities

Water pollution from construction activities related to a CAES facility may be subject to regulation under local or state law. Section 208 of the CWA provides a procedure for area-wide waste management and treatment. The geographic area and a planning/regulatory agency is to be designated by the state governor. Any plan prepared under this process must include provisions to control construction activity sources of pollution, and the disposal of pollutants on land or in subsurface excavations. Investigation into whether such an agency has been designated and its regulatory requirements should precede any construction activity.

5.4 WATER ACQUISITION

5.4.1 State Water Withdrawal Rights

In nearly all western states and many eastern states, a permit from the state water resources agency will be required to obtain water for cooling or other purposes. This requirement applies to either surface water or ground water. In addition, separate permits will most likely be needed if any water body is dammed, has its course altered, or is otherwise affected.

Western states generally follow the appropriation system for acquiring surface and ground-water rights. A permit to withdraw water

will usually be granted **if** the state agency determines that the proposed use will not interfere with the rights of existing users of waters drawn from the water body, that unappropriated water is available, and that the project is not otherwise contrary to the public interest.

Eastern states generally follow the riparian system of water law. Under this system an owner of land contiguous with a surface water body may ordinarily use a reasonable amount of the water in a beneficial way. Many eastern states (e.g. Delaware, Florida, Iowa, Kentucky, Maryland, Mississippi, New Jersey, North Carolina, and Wisconsin) specifically require a permit to utilize surface water. A lesser number of eastern states require a permit for ground-water withdrawals.

5.4.2 Dredge and Fill Permit

In addition to a state permit to withdraw water, a permit from the U.S. Army Corps of Engineers may be required **if** any dredging or filling activities in a wetland area or surface water body are needed for placement of a water intake structure or **otherwise**. The authority for the permit requirement is Section 404 of the CWA. Applicable regulations are at 33 CFR 323.

5.5 POWER PLANT CERTIFICATION AND SITING

5.5.1 Certification

A CAES facility will probably require a certification of convenience and necessity prior to construction **if** the facility is to be located in a state that normally requires such a certificate for new power generating stations. Certificates are required for new generating facilities added by investor-owned utilities in approximately 35 states and for publicly-owned utilities in approximately 16 states. Certificates are required for major transmission line additions by investor-owned and public utilities in approximately 37 and 18 states, respectively.

5.5.2 State Siting Legislation

A proposed CAES facility may have to meet siting requirements at both the local and state level of government. At a local level, zoning requirements must be met. Preemption of local requirements by a state siting agency is unusual, and local requirements must normally be met in addition to state requirements.

Forty-two states now have some form of state role in power plant siting. The siting legislation follows a general pattern, but details differ from state to state. The general thrust of the legislation is to coordinate state regulatory efforts and designate a single agency to play the lead role in issuing whatever construction permit and/or certificate of convenience and necessity is needed for final state approval.

5.5.3 Federal Siting Legislation

Although the federal government does not directly participate in the power plant siting decision process, several federal laws are indirectly applicable. The National Environmental Policy Act (NEPA) is most likely to have impact in nearly all CAES siting decisions. The Fish and Wildlife Coordination Act requires consultation with the Fish and Wildlife Service whenever any body of water is to be impounded, directed, or modified in any manner. Any CAES facility needing a federal permit that is to be located in a coastal zone must furnish certification to the permitting agency that the facility will comply with the state's coastal zone management program. These programs generally were formulated in response to the Coastal Zone Management Act of 1972. A list of other federal legislation that can potentially affect the siting process is in the Tenth Annual Report of the Council on Environmental Quality (Council on Environmental Quality 1979). Licensing by the Federal Energy Regulatory Commission could conceivably be required for a CAES facility with a compensating reservoir; however, this seems unlikely.

5.6 UNDERGROUND INJECTION REQUIREMENTS

Most likely every CAES facility will require an underground injection control (UIC) permit issued by the U.S. EPA or the state water quality control agency authorized by EPA to operate a UIC program. The authority for the UIC program is Part C of the Safe Drinking Water Act of 1974 (SDWA) (42 USCA 300 et seq., Public Law 93-325). The SDWA directs EPA to promulgate regulations limiting the underground emplacement of fluids by well injection that may contaminate any underground water that supplies, or can reasonably be expected to supply any public water system. Regulatory programs will be administered by the states under procedures established by EPA. The EPA has broadly interpreted its Congressional mandate and has prohibited any underground injection unless authorized by permit or rule by the cognizant regulatory authority. The UIC program is only recently being implemented. Final regulations for the program were issued by EPA on May 19, 1980, (45 Fed. Reg. 33436) and are found at 40 CFR 122.31 -122.45 and 40 CFR 146. State requirements applicable to establishing acceptable UIC programs are found at 40 CFR 123, **Subparts A and C**. In addition to requirements under UIC program, certain states also have existing underground injection requirements. These requirements may eventually merge with or be superseded by regulations under the SDWA as the state UIC programs are implemented.

The EPA has utilized the discretion provided **it** in the SDWA and determined that all states will be subject to the UIC regulations. All states must submit an approvable UIC program to EPA; **otherwise**, EPA will establish a program for the state.

Underground injection is defined in Section 1421(d)(1) of the SDWA to be the subsurface emplacement of fluids by well injection. The definitions of "fluid" and "well injection" are important in determining application of the SDWA to CAES. Although the SDWA does not define the term "fluid", the EPA regulations define **it** to include any gas. Well injection is defined to be "the subsurface emplacement of fluids through

a bored, drilled, driven or a dug well where the depth of the well is larger than the largest surface dimension". Under these definitions, any CAES facility presumably will be subject to the UIC regulations.

In the criteria and standards that EPA has promulgated at 40 CFR 146 implementing the UIC program, five injection well classifications are established and injection practices included within Classes I- IV are defined. All wells not included within these classes are lumped into Class V. The air injection portion of a CAES facility will almost certainly be a Class V injection well. This classification includes wells that inject nonhazardous fluids into or above formations that contain underground sources of drinking water. The examples for Class V wells given in the regulations do not include air or gas injection; however, the list is stated to be illustrative only.

The UIC regulations provide for four separate types of underground injection authorization: authorization by rule, individual permits, area-wide permits, and emergency permits. Injection into Class V wells may be authorized by rule indefinitely, provided that applicable existing and future regulatory requirements are met. Authorization by permit is regulated under the requirements at 40 CFR 122.38. A CAES injection well authorized by rule must still obtain a permit unless authorization by rule was for the life of the well. A permit for a Class V well may be issued for a fixed term not to exceed 10 years. An area-wide permit for multiple wells in a limited geographic area is authorized under 40 CFR 122.39. This provision is especially applicable to aquifer-based CAES systems that may require as many as a hundred wells in a single well field. Emergency permits are authorized at 40 CFR 122.4, although this provision would probably not be applicable to a CAES project.

The technical requirements applicable to Class V wells are found at 40 CFR 146 Subpart F. The regulations direct owner/operators of these wells to submit a description of any existing well and its status to the state within one year of the effective date of a state UIC program.

Within three years of the effective date, the state must submit to EPA information on the construction features of Class V wells and the nature and volume of injected fluids, an assessment of their contamination potential, available corrective actions and their economic and environmental consequences, and recommendations for regulatory action. Final construction requirements for underground injection through Class V wells thus will probably not be issued for three to four years.

Although Subpart F does not impose construction requirements on Class V wells at this time, certain regulations are applicable. These requirements are effective when a state UIC program is approved by EPA or when EPA establishes a UIC program for the state. General conditions applicable to all UIC and NPDES permits are found at 40 CFR 122.7. These conditions establish certain duties, such as the duty to mitigate environmental damage and to allow inspections by regulatory officials. Another limitation is that no Class V injection well shall be authorized by rule or permit if the well will allow the movement of any fluid containing any contaminant into underground sources of drinking water (defined as an aquifer which supplies drinking water or contains water with less than 10,000 mg/l TDS) if the presence of the contaminant may cause a violation of any primary drinking water regulation under 40 CFR 142 or may adversely affect public health. Various sanctions can be applied if a violation from an operating Class V well is detected. The following requirements, found at 40 CFR 122.41, are also applicable to any injection well authorized by permit:

1. All records concerning the nature and composition of the injected fluid must be retained
2. The cognizant UIC regulatory official must be notified
 - a. whenever any contaminant may endanger an underground source of drinking water or may cause fluid migration into or between underground sources of drinking water
 - b. 180 days prior to conversion or abandonment of the injection well.

3. Injection may not begin until construction is complete and the cognizant UIC regulatory agency has been notified and given an opportunity to inspect the well.

Under 40 CFR 142.42(f), a permit for a Class V well may include conditions to ensure that plugging and abandonment of the well will not allow the movement of fluids that will adversely affect drinking water supplies. Finally, under 40 CFR 122.41 (g) a performance bond or other form of financial guarantee may be required by the cognizant regulatory authority to assure proper abandonment of the well. From the CAES facility owner's standpoint, the most desirable authorization thus appears to be authorization by rule for the life of the project. A regulatory authority obviously may or may not want to confer this type of authorization.

Certain states also have their own permit requirements related to underground injection. Eventually these requirements may merge into the requirements under the SDWA; however, in the interim they must be identified and complied with. For example, any injection well in Illinois, the site of a field test of CAES in aquifers conducted by DOE's Pacific Northwest Laboratory, must be approved by the State Environmental Protection Agency until its UIC program is approved by the U.S. Environmental Protection Agency. Changes are expected to be minimal but must be observed. A permit from a cognizant state or local health authority may be needed in any state if any possibility exists that public drinking water supplies will be affected by a CAES project. Also, a CAES facility possibly will be regulated at the state level similarly to an oil or natural gas well. Such things as an engineering and geology study and an injection plan could be required.

Finally, an NPDES permit for the air injection portion of the CAES operation should not be required because only discharges of pollutants without a permit are prohibited by the CWA and air is not within the scope of pollutants as defined in the Act.

5.7 WELL DRILLING AND CONSTRUCTION REQUIREMENTS

All CAES facilities will require the construction of at least one air injection/withdrawal shaft. A CAES facility with a pressure-compensating reservoir will require at least two shafts. A CAES system utilizing aquifer storage may require up to a hundred wells or even more for a large system through which to inject and withdraw, sample, and monitor the aquifer. Many states have well drilling, construction, and abandonment regulations; compliance with these regulations most likely will be necessary. In addition, some state requirements go into considerable detail and may cover such areas as information needed for a permit, well location, well design and construction, well drilling equipment and materials, pumps and related equipment, testing, maintenance, and abandonment. Most states license well drillers. Some states have inspection requirements and require that log data and/or well completion reports be filed. Chemical and bacteriological analyses may also be required.

5.8 ENVIRONMENTAL IMPACT STATEMENT REQUIREMENTS

An environmental impact statement (EIS) most likely will need to be prepared prior to construction of a commercial CAES facility. The EIS may be required by NEPA, by a state environmental policy act (SEPA), or both. The NEPA requires federal agencies to prepare a detailed EIS for each major federal action significantly affecting the quality of the human environment (42 USCA 4322 (2) (6)).

5.8.1 Federal Requirements

Two questions must be answered before determining whether an EIS under NEPA would be required for a particular CAES project. The first question is whether a major federal action is involved. A typical CAES facility will require an exemption from the FUA by DOE-ERA. The facility may require a permit from EPA for air or water discharges or underground injection if the respective programs are not being operated by the state. A permit from the Corps of Engineers may be needed if a

cooling water intake structure is placed in a surface water body or in a wetland area. Also, a CAES facility possibly could be located on land leased, exchanged, or purchased from a federal agency, or federal funds or loan guarantees could be utilized in financing the CAES facility. Any of these federal actions could possibly trigger the NEPA requirement for an EIS. The second question is whether the environmental impacts of the CAES project are significant. Impacts may be significant even if, on balance, there is a positive environmental impact. Given the extent of environmental impacts that will arise during the construction and operation of a CAES facility, and that CAES is a new technology, a CAES project will probably be construed to have significant impacts.

A federal agency may decide to prepare an environmental assessment if it is unclear whether an EIS should be prepared; to facilitate preparation of an EIS; or to aid an agency's compliance with NEPA when no EIS is necessary. When more than one federal agency will be involved in the NEPA process, the agencies must determine which one will be the lead agency and which will be cooperating agencies. A state agency involved in the NEPA process because of the existence of a SEPA may act as a joint lead agency with a federal agency. The Council on Environmental Quality will appoint a lead agency if agreement cannot be reached. It is difficult to predict in advance which federal agency would be the most likely lead agency if a CAES facility is determined to require preparation of an EIS.

5.8.2 State Requirements

A SEPA EIS possibly could be required for a CAES facility because more than half of the states now have some type of state EIS requirement. A variety of permit requirements, including an air or water discharge permit, a certificate of convenience and necessity to construct the facility, a UIC permit, or a request for a zone change, could potentially trigger the need for a SEPA EIS.

Both a NEPA and a SEPA EIS would probably not be required because federal agencies are directed to cooperate with state and local

governments to coordinate EIS preparation and eliminate duplication. Moreover, many states specify that an otherwise necessary SEPA EIS will not be required if an adequate NEPA EIS has been prepared.

If either a NEPA or a SEPA EIS is prepared, the CAES plant owner will most likely have to prepare either a comprehensive environmental analysis and report or a draft EIS, either of which will be used by the regulatory agency to issue the final EIS.

5.9 SAFETY AND NOISE REGULATION

The construction and operation of a CAES facility will be subject to the safety regulations of the Occupational Safety and Health Administration (OSHA). Regulations applicable to construction activities are found at 29 CFR 1926, whereas regulations applicable to operation of a CAES facility are found at 29 CFR 1910. The OSHA regulations are enforced either by OSHA or by a state health and safety agency that has been delegated enforcement responsibility by OSHA.

The OSHA regulations applicable to noise control are of particular concern. An operating CAES facility will generate noise from several sources, the most important of which include turbine operation, the air inlet to the compressor, and cooling tower operation if a tower is used.

The OSHA noise regulations are applicable to the work environment. Many states and local governments also have noise regulations applicable to the general environment. These regulations vary in scope and detail, but their potential applicability should be determined prior to construction.

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