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SELECTION OF ALTERNATIVE CENTRAL-STATION TECHNOLOGIES FOR THE SATELLITE POWER SYSTEM (SPS) COMPARATIVE ASSESSMENT

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SATELLITE POWER SYSTEM
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ABSTRACT

An important effort in the Satellite Power System (SPS) Comparative Assessment is the selection and characterization of alternative technologies to be compared with the SPS concept. This report summarizes the ground rules, criteria, and screening procedure applied in the selection of those alternative technologies. The final set of central-station alternatives selected for comparison with the SPS concept includes: (1) light water reactor with improved fuel utilization, (2) conventional coal combustion with improved environmental controls, (3) open-cycle gas turbine with integral low-Btu gasifier, (4) terrestrial photovoltaic, (5) liquid metal fast breeder reactor, and (6) magnetic-confinement fusion.

1 INTRODUCTION AND BACKGROUND

The Satellite Power System (SPS) Concept Development and Evaluation Program was established within the Department of Energy to provide information from which a rational decision could be made in regard to the direction of the satellite power system program after fiscal 1980. The Concept Development and Evaluation Program is divided into five functional activities:

1. systems definition,
2. evaluation of environmental and health and safety issues,
3. evaluation of societal issues,
4. comparative assessment of alternative energy systems, and
5. planning and analysis.

The systems definition activity produces a reference SPS concept to be used as a basis for evaluation. In the environmental assessment and societal assessment activities, key issues related to the SPS technology are addressed. The comparative assessment activity characterizes terrestrial alternatives to the SPS and compares the advantages and disadvantages of each. Finally,

planning and analysis provides input to the overall program plan and ensures proper direction for the program and subsequent efforts.

An important part of the comparative assessment is the selection and characterization of reference alternative technologies to be compared with the SPS concept. This report summarizes the selection process and documents the rationale and criteria applied in screening more than thirty central-station electric generation technologies to a representative and manageable subset. Ground rules applied to this first selection phase omitted consideration of the more than 20 decentralized generating technologies and nonelectric energy systems, such as coal-derived synfuels in nonelectric applications. An effort to select one or more decentralized systems to be included in the final comparative assessment report is underway and will be documented separately.

2 DESCRIPTION OF GROUND RULES AND SCREENING PROCESS

The objective is to compare the SPS with a representative sample of baseload electric power technologies. This will provide the decision maker with a set of reference points from which he can compare SPS with other technologies on a consistent and traceable basis. Thus it was necessary to design and apply a screening process to select a representative subset of technologies that are potential competitors with the SPS concept in the year 2000 and beyond.

A set of three ground rules was established prior to preparing the list of technologies to be subjected to the screening process. The ground rules included:

1. The candidate system must be suitable for baseload electric generation service.
2. The candidate system must not use fuels or energy sources projected to be unavailable for electric utility use in 2000 and beyond, and
3. The candidate system must be suitable for central-station application.

The first ground rule eliminates consideration of gas peaking turbines and pure storage technologies, since these systems do not provide baseload service. The second ground rule eliminates consideration of oil and natural gas combustion, new baseload hydroelectric, and new dry-steam geothermal technologies. The final ground rule restricts consideration to large centralized power systems, eliminating all decentralized options such as integrated community energy systems and industrial cogeneration.

The rationale underlying the ground rules was to restrict consideration to those technologies that could compete for market positions in the post-2000 era in applications most similar to that envisioned for the SPS, i.e., baseload electric generation. However, because of the possible role of decentralized energy systems in the nation's energy future, effort is currently underway to select one or more small-scale, distributed systems to be included in the comparative assessment, such as distributed photovoltaics or small fossil-fuel cogeneration facilities.

Subject to the constraints imposed by the ground rules, 31 candidate technologies were identified and categorized by primary energy source. Each energy source category was then further subdivided into conventional and advanced technologies. Table 2.1 lists the technologies that were identified.

A preliminary and final screening was applied in the process of selecting the final subset of generation systems to be included in the SPS comparative assessment. In the preliminary screen, two methods and sets of criteria were applied to reduce the original list of 31 systems. These systems were then briefly characterized and preliminary investigation was made into the research and development status of and technical data base available for each. Subsequently, the technologies were subjected to the final screening criteria, and six were selected for inclusion in the comparative assessment.

The following sections discuss the methods and criteria applied in the preliminary and final screening processes.

Table 2.1 Candidate Generation Systems for the Year 2000

Conventional Systems	Advanced Systems
	PRIMARY ENERGY SOURCE: COAL
Coal Steam Plants with Flue Gas Desulfurization	Coal Steam Plants with Improved Environmental Controls
	Atmospheric Fluidized Bed
	Pressurized Fluidized Bed
	Low-Btu Gasifier/Open-Cycle Gas Turbine Combined Cycle
	Closed-Cycle Gas Turbine
	Metal Vapor Topping Cycle
	Open-Cycle Magnetohydrodynamics
	Closed-Cycle Magnetohydrodynamics
	Molten Carbonate Fuel Cell/Gasifier
	Synthetic Fuels for Advanced Power Cycles
	PRIMARY ENERGY SOURCE: FISSION
Light Water Reactors with Once-Through Fuel Cycle	Light Water Reactors with Improved Fuel Utilization Efficiency
	Light Water Reactors with Mixed-Oxide Fuels
	High Temperature Gas-Cooled Reactors
	Advanced High Temperature Reactors
	Liquid Metal Fast Breeder Reactors
	Gas-Cooled Fast Breeder Reactors
	Light Water Breeder Reactors
	Electronuclear Breeders
	Fusion-Fission Systems
	PRIMARY ENERGY SOURCE: FUSION
—	Magnetic-Confinement Fusion
	Inertial-Confinement Fusion
	PRIMARY ENERGY SOURCE: SOLAR
—	Solar Thermal Electric with Storage
	Solar Photovoltaic with Storage
	Ocean Thermal Energy Conversion
	Wind Energy Conversion with Storage
	Biomass Fuels
	PRIMARY ENERGY SOURCE: GEOTHERMAL
—	Liquid-Dominated Hydrothermal
	Geopressured
	Hot Dry Rock

3 PRELIMINARY SCREENING

The objective of the preliminary screening was to reduce the initial list of 31 technologies to a subset of systems considered representative of central-station technologies that would be viable alternatives to the SPS in 2000 and beyond. Two different approaches and screening criteria were applied. These can best be described as a "qualitative" screening approach and a "quantitative" screening approach.

For the preliminary qualitative screening, a small team of energy technology experts was assembled and asked to nominate those technologies listed in Table 2.1 that best fit the following criteria:

A representative list of year-2000 electric generation systems should:

A. Include improved conventional systems

B. Represent the following classes of advanced systems:

   1. Advanced Coal Combustion and/or Synthetic Fuels
   2. Nuclear Fission
   3. Fusion
   4. Solar
   5. Geothermal

C. Include the principle systems that are most suitable for large central-station baseload generation and represent very long-term or inexhaustible energy sources for each class in criterion B.

D. Reflect consensus judgement as to what systems are most likely to be technologically viable in the year 2000.

The team of experts was asked to consider the level of development of each technology, and in general, the economics and resource bases applicable to each. Table 3.1 shows the team's recommended options and the major criteria (from the list above) on which the recommendations were based.

The preliminary quantitative screening was more rigorous in that it explicitly recognized five major criteria and numerous subcriteria, in the form of potential restrictions on the feasibility of a technology, as shown in Table 3.2. In this screening, the technology experts were asked to assign

Table 3.1 Recommended Options Based on Qualitative Screening

Option	Major Criteria Used
Coal-Steam Improved Environmental Controls Atmospheric Fluidized-Bed Boiler	Include Improved Conventional Systems
Light Water Reactors Improved Fuel Utilization Mixed-Oxide Fuels	Include Improved Conventional Systems
Open-Cycle Gas Turbine Combined Cycle Integral Low-Btu Gasifier Synthetic Liquid Fuel	Represent Advanced Coal Systems Represent Synthetic Fuels Reflect Consensus Judgment
Molten Carbonate Fuel Cell/ Gasifier	Represent Advanced Coal Systems Reflect Consensus Judgment
Liquid Metal Fast Breeder Reactor	Represent Advanced Fission Include Principal Inexhaustibles
Solar Photovoltaic with Storage	Represent Solar Include Principal Inexhaustibles
Solar Thermal with Storage	Represent Solar Include Principal Inexhaustibles
Open-Cycle Magnetohydrodynamic	Represent Advanced Coal Systems Reflect Consensus Judgment
Magnetic-Confinement Fusion	Represent Fusion Reflect Consensus Judgment
Hot Dry Rock	Represent Geothermal Include Principal Inexhaustibles

numeric values ranging from 1 (most restrictive) to 5 (least restrictive) to each of the five criteria for all the technologies listed in Table 2.1. Each criterion was weighted equally and the process was applied separately to each technological option.

After each participant had independently scored the technologies, the team met to disclose their rankings, discuss their differences, and arrive at a consensus with respect to scoring and ranking of each system. The team consensus scorings, by technology and major criteria, are displayed in Table 3.3. The total score shown for each system is the sum of the individual criteria scores, each weighted equally.

Table 3.2. Criteria for Preliminary Quantitative Evaluation

Criterion	Subcriteria
Technology Availability	Technology Feasibility Fuel or Energy Resource Availability Regional Limitations Status of Development
Economic Attractiveness	Research, Development, and Demonstration Costs Capital and Operation and Maintenance Costs Fuel Costs Plant Availability and Reliability Capacity Factor Compatibility with Utility Grid System
Environmental Impacts	Air and Water Pollution Disruption of Land Areas Public Health and Safety Reversible and Irreversible Impacts
Critical Resource Requirements	Energy Water Material Land Capital Manpower
Socioeconomic Factors	Economic Impacts Industrial Infrastructure Impacts Social Impacts International Impacts

Since the criteria were applied separately to each major group of technologies, the recommended list of options was determined by selecting the one or two systems from each major group that received the highest total score. This procedure was followed to ensure that a representative set of options was selected. The ten technologies chosen as recommended options are also indicated in Table 3.3.

Of the conventional and improved systems, light water reactors with improved fuel utilization received the highest total score and were thus recommended as an option. Conventional coal/steam and coal/steam with improved environmental controls each received a score of 20 points. Since the technology with improved environmental controls is considered more viable for the twenty-first century, it was selected as a representative option.

Table 3.3. Scores of Alternative Systems in Quantitative Screening

System Type	Criterion: Availability	Economic	Environmental	Critical Resource	Socioeconomic	Total Score	Recommended: QN[a]	QL[a]
CONVENTIONAL AND IMPROVED SYSTEMS								
Coal-Steam, Conventional	5	4	3	4	4	20		
with Improved Environmental Controls	4	3	5	4	4	20	X	X
with Atmospheric Fluidized Bed	3	4	4	4	4	19		X
Light Water Reactor, Conventional	5	5	4	3	3	20		
with Improved Fuel Utilization	4	5	4	4	4	21	X	X
with Mixed-Oxide Fuel	4	5	3	5	2	19		X
ADVANCED COAL SYSTEMS								
Pressurized Fluidized Bed	2	3	4	3	3	15		
Gas Turbine, Closed-Cycle	3	1	4	3	3	14		
Open-Cycle, Low-Btu Gasifier	2	4	4	4	3	17	X	X
Open-Cycle, Synthetic Liquid Fuel	2	4	3	3	3	15		X
Metal Vapor Topping Cycle	3	2	2	3	3	13		
Molten Carbonate Fuel Cell	3	5	5	4	3	20	X	X
Magnetohydrodynamic, Open-Cycle	1	4	4	4	3	16		X
Closed-Cycle	1	2	3	4	3	13		
ADVANCED FISSION SYSTEMS								
High Temperature Gas-Cooled Reactor	3	2	3	3	3	14		
Advanced High Temperature Reactor	2	3	3	3	3	14		
Liquid-Metal Fast Breeder Reactor	4	4	3	4	4	19	X	X
Gas-Cooled Fast Breeder Reactor	3	3	3	4	3	16		
Light Water Breeder Reactor	3	4	3	3	4	17	X	
Electronuclear Breeder	1	2	4	4	3	14		
Fusion-Fission System	1	2	3	4	3	13		
FUSION SYSTEMS								
Magnetic Confinement	1	2	3	3	3	12	X	X
Inertial Confinement	1	2	3	3	2	11		
SOLAR ENERGY SYSTEMS								
Terrestrial Thermal	4	3	4	3	3	17	X	X
Terrestrial Photovoltaic	3	2	5	3	3	18	X	X
Ocean Thermal Energy	2	2	3	2	2	11		
Wind Energy	2	2	3	3	3	13		
Biomass Fuels	4	2	3	2	2	13		
GEOTHERMAL SYSTEMS								
Hydrothermal	2	2	3	3	2	12		
Geopressured	2	3	2	3	3	13	X	
Hot Dry Rock	2	2	2	2	2	10		X

[a]QN = Recommended in quantitative screening; QL = Recommended in qualitative screening.

In the advanced coal/synfuels group, the molten carbonate fuel cell and open-cycle gas turbine with integral low-Btu gasifier received the highest team rankings and were thus recommended as options. Similarly, the liquid metal fast breeder technology and light water breeder received the highest rankings in the advanced fission systems group and were thus recommended. Magnetic-confinement fusion scored one point higher than inertial-confinement fusion and was recommended on this basis.

Of the solar and geothermal technologies, solar thermal, solar photovoltaic and geopressured geothermal received the highest overall rankings and were included to complete the set of ten technologies recommended for further consideration. These technologies are identified in Table 3.3, along with the recommendations that resulted from the qualitative screening.

In the final phase of the preliminary screening process, these results were reviewed by another panel of persons familiar with a wide range of issues related to future electric generation technologies. The review panel was composed of energy and cost engineers, an economist, a sociologist, and specialists in environmental control and health and safety, primarily from the Argonne staff and its subcontractors; the DOE SPS Program Manager was also included in the panel. Each of the preliminary screening methods and criteria, and the decision rationale leading to the preliminary recommendations, was presented for panel review.

In general, the review panel concurred with the recommendations from both the qualitative and quantitative screenings, which included the following technologies:

- Coal/Steam with Improved Environmental Controls
- Light Water Reactor with Improved Fuel Utilization
- Molten Carbonate Fuel Cell
- Open-Cycle Gas Turbine with Low-Btu Gasifier
- Liquid Metal Fast Breeder Reactor
- Magnetic-Confinement Fusion
- Solar Thermal
- Solar Photovoltaic

The review panel recommended that further consideration be given to the open-cycle magnetohydrodynamic system as a third technology representative of advanced coal systems. This recommendation was based on the status of its development, level of technical interest, and overall ranking relative to the other technologies in the advanced coal group.

Although light water breeders were identified in the quantitative screen, the panel recommended that this system not be included because of the much more advanced state of the liquid metal breeder and the large political uncertainties surrounding breeder technology.

It was also recommended that hot dry rock geothermal be included as the tenth preliminary option. Each of the other geothermal technologies have

limited regional availability. Hot rock geothermal is the only option in that group considered to have an extensive and nearly inexhaustible resource base. Although not as highly rated in the quantitative screening as the geopressured option, it was the general consensus that hot rock geothermal represents a more extensive and longer term potential for geothermal energy.

Each of these ten systems was then briefly investigated to determine as quantitatively as possible the research and development status of and technical data base available for each. This information formed part of the basis for the final screening of central-station options for the comparative assessment.

4 FINAL SCREENING

The final screening process was based on a review of information pertaining to development status and availability of technical and cost data for each of the ten preliminary options. DOE programmatic considerations were also factored into the final selection of technologies for comparison with the SPS concept. That is, where major R&D policy questions concerning SPS versus alternative technologies could be anticipated, respective criteria were made part of the final selection scheme. The resulting final selection criteria are listed in Table 4.1. Table 4.2 shows the decision matrix as applied in the final selection of major central-station alternatives to the SPS concept. The matrix shows how the list of ten technologies ranked on each of the seven final selection criteria. However, it is not immediately apparent which are the dominant technologies.

Clearly, the LWR and coal technologies best satisfy the applicable criteria and should be included among technologies to be compared with SPS. Only one technology, terrestrial photovoltaic (TPV) meets the special criterion established to provide for a direct comparison of photovoltaics in space versus nonspace applications.

Three of the remaining seven technologies are advanced coal-based systems (molten carbonate fuel cell, open-cycle gas turbine/low-Btu gasifier, and magnetohydrodynamic). The selection of only one of these three as representative of advanced coal systems was considered appropriate for the limited objectives of the SPS comparative assessment project. The open-cycle gas-turbine/low-Btu gasifier system has the highest ranking of the three, and thus was selected.

Of the four remaining technologies, the liquid metal fast breeder reactor has the highest ranking. Although presently controversial, this technology has received worldwide backing and should be included in the comparative assessment.

The final three technologies (solar thermal, hot dry rock geothermal, and fusion) represent extensive sources of energy. Fusion is very heavily funded by DOE and represents a technology of high scientific interest and potential. For this reason, it was selected for comparison as an alternative to SPS, even though commercial application may be one to several decades after the year 2000.

Table 4.1. Criteria for Final Selection of Alternative Technologies

1. Technical data available in sufficient detail to allow adequate technical characterization and comparison.
2. Cost data defined and available in sufficient detail to allow adequate cost characterization and comparison.
3. Projected technology available by year 2000 for commercial application.
4. Improved current baseload technologies.
5. Include representative advanced technologies currently being engineered.
6. Include alternative (nonspace) application of photovoltaic solar energy technology.
7. Include one technology alternative that shows potential as a long-term energy source in the post-2000 era and which receives heavy development funding.

Table 4.2. Final Decision Matrix for Selection of Technologies[a]

	Criterion (from Table 4.1)						
Technology	1	2	3	4	5	6	7
Light Water Reactor, Improved Fuel Use	VH	VH	Y	Y	-	-	-
Conventional Coal-Steam, Improved Environmental Controls	VH	VH	Y	Y	-	-	-
Molten Carbonate Fuel Cell	A	A	P	-	Y	-	-
Open-Cycle Gas Turbine/Combined Cycle with Low-Btu Gasifier	H	H	Y	-	Y	-	-
Terrestrial Photovoltaic	A	A	P	-	-	Y	-
Terrestrial Solar Thermal	A	A	P	-	-	-	-
Liquid Metal Fast Breeder Reactor	H	H	P	-	Y	-	Y
Magnetic-Confinement Fusion	L	L	N	-	-	-	Y
Magnetohydrodynamic	A	A	P	-	Y	-	-
Hot Dry Rock Geothermal	L	L	N	-	-	-	-

[a]Key to criterion values: VH = Very High, H = High, A = Adequate, L = Low, Y = Yes, P = Possible, N = No, - = Not Applicable.

The final central station technologies to be included in the comparative assessment are:

- Light Water Reactor with Improved Fuel Utilization
- Conventional Coal with Improved Environmental Controls
- Open-Cycle Gas Turbine with Integral Low-Btu Gasifier (Combined Cycle)
- Terrestrial Photovoltaic (Central Station)
- Liquid Metal Fast Breeder
- Magnetic-Confinement Fusion.

At least one decentralized technology will also be included in the final SPS comparative assessment. Effort is currently underway to select one or more such systems. This effort will be documented separately.

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