A Preliminary Analysis of Patent Trends for Sodium/Sulfur Battery Technology

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July 1985

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
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PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

NTIS Price Codes
Microfiche A01

Printed Copy	Price
Pages	Codes
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
201-225	A010
226-250	A011
251-275	A012
276-300	A013

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FOR SODIUM/SULFUR BATTERY TECHNOLOGY

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ACKNOWLEDGMENTS

The authors of this document would like to acknowledge the important contributions of several individuals who made this study possible. First, we appreciate the valuable support of Ms. Terry M. Levinson, Office of Energy Systems Research, U.S. Department of Energy. Terry's willingness to promote development of innovative methods to help understand technology change was the basis for conducting this research. Also, Dr. Albert R. Landgrebe and Mr. James E. Quinn of the Energy Storage Technologies Division, U.S. Department of Energy, provided excellent technical guidance and personal support throughout the entire study.

This study would not have been completed without the technical assistance of Dr. Ralph J. Brodd of the Amoco Research Laboratory. His knowledge of advanced battery technology was an invaluable aspect of the research. We also appreciate the support and technical review provided by Mr. Jonathon W. Hurwitch of the Battelle-Columbus Laboratories. Finally, we want to acknowledge the editorial assistance provided by Ms. Judy Danko.

EXECUTIVE SUMMARY

This document summarizes development trends in sodium/sulfur battery technology based on data from U.S. patents. The purpose of the study was to use the activity, timing and ownership of 285 U.S. patents to identify and describe broad patterns of change in sodium/sulfur battery technology. The analysis was conducted using newly developed statistical and computer graphic techniques for describing technology development trends from patent data. This analysis suggests that for some technologies trends in patent data provide useful information for public and private R&D planning.

BACKGROUND AND OBJECTIVES

Sodium/sulfur batteries are an attractive advanced battery concept with favorable characteristics for application in electric vehicles and utility load-leveling systems. Since its invention by Ford Motor Company in 1965, the technology has undergone significant public and private effort to develop reliable, long-life operational systems. However, even with significant federal support since 1974, sodium/sulfur batteries are still several years away from commercial applications. Important technical problems in system design and engineering remain and are being vigorously addressed. New developments are being patented both in this country and overseas.

Analysis of patent data is one of several ways to detect and measure the technological progress of R&D programs. Patent data can indicate the level and nature of inventive technical efforts undertaken by firms and countries. In this study sodium/sulfur patent activity and ownership characteristics are used to describe certain aspects of development trends for the technology. More specifically, the objectives of this report are:

- to identify U.S. and foreign leaders in sodium/sulfur battery technology and their areas of technical emphasis
- to describe emerging trends in areas of important sodium/sulfur battery development activity.

RESEARCH APPROACH AND PRELIMINARY FINDINGS

After defining the aspects of sodium/sulfur battery R&D to be studied, a systematic patent search and review by experts was undertaken to identify a complete set of relevant patents. Four key components (called "technology types") of sodium/sulfur battery systems were then defined to permit comparisons of research progress in important technical areas. A total of 285 patents issued through April 1, 1984, was identified during the patent search. The distribution of these patents in several categories is shown below:

<u>Assignee Sector</u>			<u>Assignee Region</u>		
Government and Government Supported	42	(14.8%)	U.S.	165	(57.9%)
Government Contractor Not Supported	36	(12.6%)	Non-U.S.	<u>120</u>	<u>(42.1%)</u>
Other U.S. Firms	87	(30.5%)	Total	285	100%
Non-U.S.	<u>120</u>	<u>(42.1%)</u>			
Total	285	100%			

<u>Assignee Country</u>			<u>Technology Type</u>		
United States	165	(57.9%)	Electrodes	63	(22%)
United Kingdom	55	(19.3%)	Electrolytes	92	(32%)
West Germany	28	(9.8%)	Seals/Containers	67	(24%)
France	19	(6.7%)	General Design	<u>63</u>	<u>(22%)</u>
Japan	17	(6.0%)	Total	285	100%
South Africa	<u>1</u>	<u>(0.3%)</u>			
Total	285	100%			

A total of 51 assignees (29 U.S. and 22 foreign) held U.S. patents.

Patents selected in the search were analyzed by computer and several results were developed in light of the research objectives. The principal findings of this preliminary research are summarized below:

1. After Ford's patent in 1965, patent activity was fairly low (about 5 to 10 patents filed per year) until 1975 when it rose dramatically.

Activity reached a peak in 1976 and 1977 (41 and 40 patents filed, respectively), but has declined steadily since 1977.

2. The early U.S. dominance in development of sodium/sulfur batteries has declined substantially since 1974. While U.S. firms hold 58% of all patents, foreign activity has outpaced that of the U.S. in recent years. Several viable international development efforts [e.g., United Kingdom (19% of the patent set), West Germany (10%), France (7%)] are under way and appear to be stable. Notably, Japan's early patent effort has almost disappeared since the mid-1970s.
3. Typically, the development effort in foreign countries is concentrated in only one or two firms, whereas in the U.S. there have been several new entrants each year in addition to previously active firms.
4. U.S. and foreign countries are both active in the four technology areas studied in this research (electrodes, electrolytes, seals/containers, and general design). U.S. patents tend to emphasize electrolytes and seals/containers. Non-U.S. development focuses on electrodes and general design, and the electrolyte category to a lesser degree.
5. Although Ford still has a leading technological position overall, its historical predominance in this technology relative to other firms has recently diminished. Chloride Silent Power of the United Kingdom is generally well positioned alongside Ford and appears to have a stronger overall position relative to Brown Boveri^(a) of West Germany. Since 1974, Chloride Silent Power has had a balanced emphasis in the four technical areas, while Ford has very small output in electrolytes. Chloride Silent Power's post-1974 patents are more highly cited than Ford's patents of the same period.

(a) Although incorporated in Switzerland, Brown Boveri was considered as West German for this study since all sodium/sulfur development occurred at a West German facility and was substantially funded by the West German government.

6. The pattern of citations among the patents studied suggests that sodium/sulfur battery technology is a very closely knit area of activity. Outside technologies are rarely referred to, with ceramic forming methods being the most commonly referenced area. The age of the references given in sodium/sulfur patents is quite low relative to other patent sets that have been studied.
7. Experts in sodium/sulfur technology have indicated that these results confirm important development trends which are known through other sources (e.g. contact between professionals in the field and scientific literature). This suggests that patent trend analysis provides useful empirical information for some technologies in public and private R&D programs. Patent data can provide insights into the state of technical progress, inventions undergoing further development, technical approaches used and the areas emphasized by various assignees for emerging technologies.

The findings and the data in this document are limited to a preliminary review of U.S. patents issued before April 1, 1984. Significant events occurring after that date, such as the decision by General Electric Company to discontinue development of sodium/sulfur technology, are not reflected in these results. Moreover, other potentially informative patent sources (especially foreign patent systems such as those in Japan, Great Britain or West Germany) were not considered in this study. These other sources could provide more comprehensive findings in future patent-based studies.

GLOSSARY

Knowledge of a number of technical terms that are rooted in patent law and the practices of the U.S. Patent Office is important for a full understanding of research involving patent information. Also, a number of special terms to describe various aspects of patent trend analysis are used in this study. A brief glossary of terms is included below:

Activity	- a patent indicator that reflects the amount of effort being expended to solve a particular technical problem.
Assignee	- the legal owner of a patent.
Basic Patent	- an early, core patent on the fundamental principles or configurations of a key invention in an area that receives numerous citations from later patents.
Citation	- the receipt by an earlier patent of a reference from a subsequent patent document whose inventive scope is legally limited by the claims in the earlier patent. The earlier patent receives a <u>citation</u> from the later patent, whereas the later patent document contains a <u>reference</u> to the earlier patent. See reference.
Concentration	- a patent indicator measuring the number of assignees, inventors, countries, etc., active in a particular technology and the relative amounts of their inventive output.
Corporate Inventor	- an inventor listed on a patent assigned to a private firm or corporation at the patent's date of issue.
Dominance	- a patent indicator that reflects the relative strength of patent positions among assignees, inventors, countries, etc., based on the distribution of citations received.

Immediacy	- a patent indicator that reflects the age of the prior art being referenced by a set of patents.
Independent Inventor	- an inventor listed on a patent that is either unassigned or was assigned to an individual at its date of issue.
Indicator	- one of a family of measures used to characterize some aspect of technology change based on patent data.
In-set Patent	- a patent included in a specifically defined group or set of patents under study (see patent study set).
Involution	- a patent indicator that reflects the relative proportion of references given to patents within the defined set of patents (in-set) versus those references given to patents outside the set (out-of-set).
Novelty	- a legal requirement for receiving a patent, i.e., an invention must be new or not previously known or used.
Out-Of-Set Patent	- a patent outside of a specifically defined group or set of patents (see patent study set).
Patent Study Set	- a group or set of patents that is being studied for information on technology trends in a particular technology or business area of interest.
Prior Art	- the body of previous patents that determines the scope of a given patent applicant's claims.
Problem Domain	- some aspect of a technology's functional performance that can be addressed by certain technical developments or solutions and that may be the focus of patent activity.
Reference	- the identification on a patent document of an earlier patent whose claims relate to the scope of the later patent which mentions it. See Citation.

- Sector - a description of the type of assignee, e.g., corporate, government agency, independent inventor.
- Self-Citation - the number or proportion of citations received from an assignee's own patents relative to citations received from other assignee's patents.

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1.0 INTRODUCTION

This document presents a data summary and preliminary findings to describe development trends in sodium/sulfur battery technology based on data from U.S. patents. The study was sponsored by the Office of Energy Systems Research, U.S. Department of Energy. The study focuses on identifying and describing broad patterns of change in sodium/sulfur technology as indicated by 285 U.S. patents. This analysis suggests that patent studies of some technologies provide useful empirical information for public and private R&D planning.

1.1 BACKGROUND

Sodium/sulfur battery technology was invented by the Ford Motor Company in 1965. Because of their high energy storage density and favorable charge and discharge characteristics, sodium/sulfur batteries have been promoted for use in electric vehicles and in load-leveling for electric utilities. Following the oil embargo in the early 1970s, development effort was boosted by federal funding that has continued to the present. Federal funding has fallen off recently and some firms have relied on internal funds as the technology continues to mature.

Patent data provide a unique view of the process of technology development for areas of high long-term interest such as the sodium/sulfur battery. Information contained in patents can indicate who is active in developing the technology, the level of inventive effort, and the direction of inventive activity. It is often difficult to describe the relative technological positions of firms who are developing new and emerging technologies such as sodium/sulfur batteries. Instead of competing within a marketplace, firms compete to produce potentially marketable ideas in the form of patents. These patents, and the ideas that they represent, provide the basis for future technology developments and commercial market positions.

Patent data analysis is a relatively new technique for analyzing technology change (Campbell 1983). Although useful for studying the positions of private firms in technological markets, its value for planning and evaluating large public sector R&D programs has not been established. This study

describes development trends for sodium/sulfur batteries in an effort to clarify the potential role of patent information in federal research. Several planning and policy questions important in research in the sodium/sulfur battery provided the background for this study:

- What is the United States' patent position relative to that of other countries? How does the level of effort or the technological emphasis differ?
- What has been the impact of federal funding on sodium/sulfur battery technology? To what extent has the technology been transferred to the private sector or have means been established for development of its commercial potential?
- What are the relative patent positions of firms within this technological area?

Patent data provide one useful input to an analysis of these issues.

1.2 RESEARCH OBJECTIVES AND SCOPE

This study presents a preliminary analysis of the nature and sources of developments in sodium/sulfur battery technology based on U.S. patent data. The research will be limited to a description of the general characteristics of patent activity and assignees for the major sodium/sulfur technology areas. The specific objectives of the research in this volume are as follows:

- to identify U.S. and foreign leaders in sodium/sulfur battery technology and their areas of technical emphasis
- to describe emerging trends in areas of important sodium/sulfur battery development activity.

This research is not intended to be an exhaustive analysis of sodium/sulfur patent data. The study focuses on assembling patent data pertinent to the issues above and cataloging it into a form useful for both preliminary findings and further detailed review.

1.3 RESEARCH APPROACH

In this analysis certain key information is extracted from U.S. patents and analyzed using statistical and computer graphics techniques. The patent data are distilled into several aggregate measures called patent trend indicators which are used to identify and understand the nature of changes represented by patent activity. Identification of trends in the data over time--including patent relationships between firms and technology areas--are an important part of the study. The analysis follows the general research approach outlined below:

1. After the research objectives for the study were formulated, the specific technical areas to be covered were defined. This process included specifying the particular technical problem domain of the sodium/sulfur technology being studied. A problem domain is some aspect of a technology's functional performance that can be addressed by certain technical developments or solutions and that may be the focus of important patent activity.
2. The sodium/sulfur technology was then categorized into technical subgroups or system components relevant to the overall problem domain. The resulting classification helps to identify relevant patents and allows comparative analyses of development activity, technical linkages, and assignees for patent subgroups or technical areas of interest. For this study, individual patents were also categorized according to particular groups of assignees, such as government, universities, government-supported private firms, etc., to permit comparisons of the roles various organizations played in developing the technology.
3. The patent search activity was conducted next; its purpose is to identify those patents which pertain to the analysis and to construct the patent study data set. Information on each relevant patent is then entered into a computerized data base management system for subsequent editing and analysis. The information included on each patent in this study is shown below:

- Patent Number
- Issue Date
- Filing Date
- Title
- Assignee Name
- Assignee Sector^(a)
- Assignee Country
- Technology or Application Category
- Inventor Name
- Patent Reference

4. After the patent data base was constructed, computer analysis and interpretation of the patent data were completed.

1.4 REPORT ORGANIZATION

Section 2.0 briefly summarizes sodium/sulfur technology and the federal role in supporting its development. In addition, the basis for defining the patent set is established in terms of the rules for determining which patents were relevant to the study and the manner in which patents have been categorized. Section 3.0 describes several features of the major assignee groups and their roles in technical developments to date. Section 4.0 presents the general characteristics of the technology and its development over time as seen through patent data. Section 5.0 focuses more specifically on a comparison of U.S. and foreign activity. Section 6.0 compares the patent positions of specific firms involved in the development of this technology. Finally, several additional data tables and a list of patents analyzed in this study are presented in the appendices.

(a) Sector refers to a descriptive categorization of assignees as corporate, government agency, or independent inventor.

2.0 DEFINITION OF THE SODIUM/SULFUR PATENT DATA SET

The foundation for conducting patent trend studies is the identification of an accurate set of relevant patents. This section presents the steps taken to identify a relevant patent data set and describes the patent categories used to distinguish among technical areas of emphasis and types of assignees.

2.1 SODIUM/SULFUR BATTERY TECHNOLOGY

Sodium/sulfur batteries contain electrodes composed of molten sodium and sulfur separated by a solid electrolyte material, either a ceramic or glass. The technology is attractive for use in electric vehicles and in load leveling for electric utilities. Its advantages relative to other battery technologies follow chiefly from a combination of the following characteristics:

- high specific energy (watt-hours/kg)
- high utilization efficiency (ratio of discharge/charge)
- relatively flat power level throughout discharge.

Recent research has focused on obtaining low-cost electrolyte materials with suitable operating characteristics and on designing containers and seals so as to have cells with long-life characteristics. Some development aimed at obtaining reliable battery systems has also dealt with the problems of cell interconnection methods. Many innovations resulting from each of these lines of activity have been protected through patents.

2.2 SODIUM/SULFUR PROBLEM DOMAIN

A problem domain is considered to be some aspect of a technology's functional performance that can be addressed by certain types of technical developments or solutions and that may be the focus of important patent activity. Usually a problem domain represents technical issues or difficulties that must be overcome before a technology can become commercially viable. These issues may include cost or operating performance (e.g. reliability, ease of use), key technical barriers to commercialization, or system design characteristics. In any case, a problem domain specifies areas that are the focus of inventive

activity. Thus, definition of the appropriate problem domain is an important aspect of identifying patents relevant to a particular study.

Given the objectives of this study, the problem domain was defined as the major technical barriers to future development of commercial battery systems. Thus, patents that address important engineering and cost problems were selected for analysis. The technical development problems selected for analysis were as follows:

- preventing fracture of the electrolyte materials
- containing the corrosive battery components for time periods needed in commercial applications
- producing low-cost, long-life materials.

Many patents that were relevant to the technology but not to current development problems were excluded from the research (e.g., "technology base" patents in ceramics, electrolytes, or design).

2.2.1 Patent Technology Categories

To organize the problem domain for this analysis, the technology breakdown shown in Figure 2.1 was developed. This categorization was used to identify relevant patents and to place them into groups for comparison. Each group

FIGURE 2.1. Technology Categories for Sodium/Sulfur Battery Patents

represents a major area of research being undertaken to overcome technical problems that prevent development of a commercial battery. The four principal technology categories are described below:

- (ED) Electrode materials, both anode (sodium) and cathode (sulfur), designs and fabrication methods. Innovations that address flow restrictions in the event of electrolyte failure were included.
- (EY) Electrolyte materials and fabrication methods, both ceramics (beta alumina) and glasses, as well as coatings for these electrolytes. These innovations focused on producing long-lived and low-cost materials.
- (SC) Seals/Containers and matters related to development of reliable and long-lived containers to withstand the high temperature and corrosive environment. Some innovations also focused on current collection methods.
- (DS) General Design patents for overall cell designs, interconnection strategies for battery systems, and other issues related to overall battery operations such as temperature control.

2.2.2 Patent Assignee Categories

To better understand the contributions of federal funding to development of the sodium/sulfur technology, U.S. patent assignees were broken into categories. The categories were designed to allow comparisons of patent characteristics between government and private developments, where possible. The three major U.S. assignee groups are described below:

1. U.S. government-held or sponsored: these include patents held by the U.S. government, of which there are only 4, and patents held by government contractors who acknowledge government support [e.g., the National Science Foundation (NSF), Energy Research and Development Administration (ERDA), U.S. Department of Energy (DOE), or the U.S. Army].

2. DOE (or NSF) contractor, not government-sponsored: these include patents filed before 1974 by Ford, Dow and others, as well as some later patents that did not acknowledge government support.^(a)
3. Other U.S. assignees: General Electric, Electric Power Research Institute, Corning, Dupont, etc.

2.3 PATENT SEARCH STRATEGY

Relevant sodium/sulfur technology patents issued through April 1, 1984, were identified through a combination of search techniques and expert technical review of each patent. The specific search procedure consisted of the following four steps:

1. Keyword Search - A keyword search of patent Class 429--Chemistry, Electrical Current Producing Apparatus, Product, and Process--identified two subclasses that contained most of the patents: 429/104--Active material in molten state with solid-state electrolyte; 429/193--Include electrolyte composition chemically specified...Solid...Metal Oxide Component. All patents from these two subclasses were ordered.
2. Technical Patent Review - The 330 patents (issued between 1971^(b) and early 1984) from these two subclasses were reviewed for their technical relevance and 233 were selected. These patents formed the basis for the remaining search steps.
3. Out-of-Set Reference Screening - Patents frequently cited by the patents in step 2, many of which were issued prior to 1971, were identified. From this additional set, any patent not already

(a) While Category 1 patents acknowledge government support, some Category 2 patents may still have been partially supported by government funds. At the present time, there is no legal obligation for assignees to acknowledge even partial government support for patented work.

(b) The data base selected for this step of the search did not include information on patents issued before 1971.

identified but having four or more citations was selected and screened for relevance. These sets overlapped substantially; however, 18 new patents were added.

4. Out-of-Set Citation Screenings - An additional set of candidate patents was identified from those which cited the patents in steps 2 and 3. After a technical screening, 34 patents had been added, many of them fairly recent.

Relevant patents were found in several additional patent subclasses within Class 429 and in other patent classes as well. Among the most common classes were the following:

- 204/195S - Chemistry, Electrical and Wave Energy--Solid Electrolyte Apparatus
- 429/103 - With fused electrolyte
- 29/623.2 - Metal Working--Electric Battery Cell...including Sealing
- 264 - Plastic and Non-Metallic Article Shaping or Treating...Pore forming in situ...including vitrification or firing
- 106 - Composition, Coating or Plastics.

The relevance of each patent to the problem domain of the study had to be established; this was not always a clear-cut decision. Some patents, especially those related to electrolyte materials, might emphasize technologies outside the immediate field of sodium/sulfur battery technology. Other patents might relate primarily to other battery technologies, but have enough relevance to sodium/sulfur technology to be included in the set. Many of the patents that were rejected dealt with solid electrolyte systems for other battery types and solid electrolyte systems for instrumentation devices such as oxygen sensors.

2.4 PATENT SEARCH RESULTS AND DATA SET SUMMARY

The patent search and screening process resulted in a final total of 285 patents for analysis. The patent search identified U.S. patents that issued up through April 1, 1984. Since most U.S. patent applications take approximately

24 months to issue, this means that patent activity results for 1981-1984 probably do not include all patents filed during those years. The overall composition of the study data set (number of patents) for several categories of interest is shown below:

<u>Technology Type</u>			<u>Assignee Region</u>		
Electrodes	63	(22.1%)	United States	165	(57.9%)
Electrolytes	92	(32.2%)	Non-U.S.	<u>120</u>	<u>(42.1%)</u>
Seals/Containers	67	(23.5%)	Total	285	100%
General Design	<u>63</u>	<u>(22.1%)</u>			
Total	285	100%			
<u>Assignee Sector</u>			<u>Assignee Country</u>		
Government and Government Supported	42	(14.8%)	United States	165	(57.9%)
Government Contractor Not Supported	36	(12.6%)	United Kingdom	55	(19.3%)
Other U.S. Firms	87	(30.5%)	West Germany	28	(9.8%)
Non-U.S.	<u>120</u>	<u>(42.1%)</u>	France	19	(6.7%)
Total	285	100%	Japan	17	(6.0%)
			South Africa	<u>1</u>	<u>(0.3%)</u>
			Total	285	100%

A total of 51 individual assignees (29 U.S. and 22 foreign) held U.S. patents. They are listed along with several of their patent characteristics in Appendix A. The 285 patents, grouped alphabetically by assignee, are listed in Appendix B.

3.0 AN OVERVIEW OF PATENT ASSIGNEE CHARACTERISTICS

This section presents a general comparison of several assignee groups for the sodium/sulfur technology types defined in this research. The data include only aggregate tabulations. More detailed comparisons by assignee and by year are presented in Sections 4.0, 5.0 and 6.0.

3.1 ASSIGNEE REGION

Table 3.1 shows a breakdown of patent activity by assignee region (U.S. vs. non-U.S.) and by technology type. For the most part, foreign patent activity closely parallels that of the U.S. One significant difference, however, appears in the relative emphasis placed upon the technical areas of the sodium/sulfur technology. U.S. activity is much more heavily concentrated in electrolytes and seals and containers; foreign activity is more concentrated in electrodes and general design. The U.S. activity seems to emphasize the development of: 1) reliable, low-cost electrolyte materials and 2) long-lived, corrosion-resistant containers.

3.2 ASSIGNEE COUNTRY

Table 3.2 presents a breakdown of patent activity by assignee country and technology type. Major foreign patent positions are held by firms in the

TABLE 3.1. Patent Activity by Assignee Region/Technology Type

Assignee Region	Technology Type				Total	%
	Electrodes	Electrolytes	Seals/ Containers	General Design		
United States	29 (18%)	61 (37%)	49 (30%)	26 (15%)	165	57.9
Non-U.S.	34 (28%)	31 (26%)	18 (15%)	37 (31%)	120	42.1
	63	92	67	63	285	100

Note: Table entries in parentheses are row percentages.

TABLE 3.2. Patent Activity by Assignee Country/Technology Type

Assignee Country	Technology Type				Total	%
	Electrodes	Electrolytes	Seals/ Containers	General Design		
United States	29	61	49	26	165	57.9
United Kingdom	20	12	9	14	55	19.3
West Germany	8	3	7	10	28	9.8
France	1	8	1	9	19	6.7
Japan	5	8	-	4	17	6.0
South Africa	-	-	1	-	1	0.3
Total	63	92	67	63	285	100

United Kingdom, West Germany, and France. This is especially true for electrode and general design patents. The U.S. has a dominant position in terms of total patent production, with very strong holdings in electrolytes and in seals/containers. Each major assignee country has some activity in each technology area, with the exception of France in electrodes and seals/containers, and Japan in seals/containers.

3.3 ASSIGNEE SECTOR

Table 3.3 contains a breakdown of patent activity by assignee sector. About half of the 165 patents held by U.S. assignees are held by firms other than government contractors. While the patents referred to as government supported explicitly acknowledge government support in the main body of the

TABLE 3.3. Patent Activity by Assignee Sector/Technology Type

Assignee Sector	Technology Type				Total	%
	Electrodes	Electrolytes	Seals/ Containers	General Design		
Government and Government Supported	11	12	10	9	42	14.8
Government Contractor Not Supported	4	15	7	10	36	12.6
Other U.S. Firms	14	34	32	7	87	30.5
All Foreign	<u>34</u>	<u>31</u>	<u>18</u>	<u>37</u>	<u>120</u>	<u>42.1</u>
Total	63	92	67	63	285	100

patent, there may still be patents in the "government contractor not supported" group that were funded in part, or even in total, by government funds. Under present patent regulations assignees are not required to acknowledge government support. Although the estimate of government support may not be completely accurate, it does provide some indication of the status of government supported work in the overall evolution of sodium/sulfur battery technology.

For the third category, the Electric Power Research Institute (EPRI) has supported sodium/sulfur battery development principally through General Electric and indirectly through Chloride Silent Power in the United Kingdom (U.K.). A separate accounting of these patents has not been made; however, the EPRI and General Electric patents taken together should give a fair view of the level of effort and direction for EPRI funding.

Foreign governments, chiefly the U.K. and West Germany, have supported the development of this technology through private firms, much as the U.S. government has done. Because there is no way to easily trace the source of funding for foreign-held patents, a separate breakdown was not made for patents supported by foreign governments.

4.0 AGGREGATE CHARACTERISTICS OF TECHNOLOGY CHANGE

A series of indicators to describe technological change over time have been constructed from patent data (Campbell 1983, Campbell and Levine 1984). These indicators can be used to describe a particular patented technological area in terms of the overall level of inventive effort, the nature of the inventions (or technology) being developed, and the nature of the assignees (or inventors). This section summarizes the following key indicators for describing overall sodium/sulfur technology characteristics: 1) patent activity and the relative emphasis on the four technology types; 2) the degree to which sodium/sulfur battery technology draws upon work in other fields (known as involution); and 3) the age of the technology base from which sodium/sulfur technology is evolving.

4.1 PATENT ACTIVITY

The level of inventive effort depends upon the collective expectations of the individuals and firms working in a particular technological area. Inventors have expectations relative to the potential payoffs that are likely to accrue from inventive effort. Patent data on the number of patents filed over time provide insight into changes in the level of effort being expended. Inventive effort can also be measured by the number of inventors and the number of firms who are active at any given time.

Figure 4.1 shows the number of patents filed in each year since the original sodium/sulfur battery patent was filed by Ford Motor Company in 1965. Activity remained low, about 5-10 patents per year, until 1975. Patent filings surged during the oil embargo and the ensuing interest in alternative energy sources and utilization methods.

Total activity peaked in 1976 and 1977 with 41 and 40 patents filed, respectively. Since 1977, however, patent filings have declined. The data for the final two years probably understate the true number of patent filings since some patents filed in that period are still pending. (In the U.S. patent system no information is publicly available on pending patent applications.)

FIGURE 4.1. Sodium/Sulfur Patent Activity

Consequently, it is likely that more than eight patents were actually filed in 1982. This effect is shown in all patent time series illustrations by a dashed line in the 1981 position.

Figure 4.2 shows total patent activity and its makeup by technology type. Before 1974, activity was greatest in electrolyte materials. The peak in activity in 1976 and 1977 was associated with a rise in each of the four technology areas. Only the seals/containers category peaked after 1976, reaching its maximum in 1978.

4.2 THE SODIUM/SULFUR TECHNOLOGY BASE

Inventive activity usually builds upon prior work in an area. In the patent system, strict standards of novelty for work are maintained to ensure that any invention represents a significant new advance over prior developments. To establish its relationship with the prior art, each patent must reference other patents that are closely related. These references provide useful information for determining what technical areas inventive activity is drawing upon. Involution, a patent-based technology indicator, measures the percentage of "in-set" references, i.e., references made by patents in the

FIGURE 4.2. Patent Activity by Technology Type

study set to other patents in the same patent set. ("Out-of-set" references are those references made to patents not included in the study set). In general, the higher the involution, the more self-contained the technology (since a high involution measure implies a high percentage of in-set references). Lower values of involution show a technology that draws heavily upon technical areas outside the patent study set.

Figure 4.3 shows involution over time for the sodium/sulfur patent set. As is typical in many developing technologies, involution is low early in the study period before the field has coalesced. Involution increases as development problems become more well-defined and the alternative approaches are specified. Later patents build upon or offer improvements to the existing art. For this set of 285 patents, 63.4% of the references were in-set references. This figure is very high relative to other technologies studied with patent analysis methods (Campbell and Levine 1984), and suggests that sodium/sulfur technology is more closely knit than those other technologies.

Involution has also been calculated for the patents in each of the four technology areas as shown in Table 4.1. The electrolyte patents have the

FIGURE 4.3. Involution: Percent of In-set References

TABLE 4.1. Involution by Technology Type

<u>Technology Type</u>	<u>Involution Level</u>
Electrodes	76.7%
Electrolytes	54.1%
Seals/Containers	62.8%
General Design	65.5%
Overall	63.4%

lowest involution, meaning that developments draw more heavily on technologies (inventions) outside the area of study. Electrolyte materials are made from either ceramic or glass. Electrolyte patents for both ceramic and glass have referenced patents for fabrication methods that have been applied in completely different fields (outside the patent study set). For example, many of General Electric's early electrolyte patents reference earlier work on ceramic fabrication methods applied to turbine blades.

4.3 THE AGE OF THE SODIUM/SULFUR TECHNOLOGY BASE

The patent indicator immediacy shows the age of the technology that is being developed and the pace of its progress. Immediacy is computed as the

average age of the patent references for all patents filed in each year under study. In general, for technologies that refer to relatively older patents, we say that the pace of change is slower (or that the rate of obsolescence is less) than for technologies that reference very recent patents.

Figure 4.4 shows a time series plot of immediacy for the total patent set, references given to in-set patents, and references given to out-of-set patents. In-set and out-of-set references follow different patterns over time. Over most of the study period, the average age of in-set references has remained steady at about two years although it has risen to approximately four years recently. The average age of reference in the patent set for sodium/sulfur batteries is lower than that for most other emerging technologies studied with patent analysis (Campbell and Levine 1984). This low average age of in-set references implies that the technology is developing rapidly. Such a high rate of change suggests that organizations must continually invest R&D resources to keep up with the state-of-the-art.

FIGURE 4.4. Immediacy: Average Age of References

5.0 COMPARISON OF U.S. AND FOREIGN PATENT ACTIVITY

Several of the broad trends in foreign and U.S. patent activity have been very similar. The growth in patent activity occurred in parallel, as did the activity peak and more recent decline in total output. Nevertheless, important differences between U.S. and foreign activity have emerged, e.g., important differences in the respective sodium/sulfur development strategies. In this section trends in patent activity and characteristics of the technology and its inventors are explored to highlight similarities and differences in the U.S. and foreign approach to technology development.

5.1 TIME SERIES OF FOREIGN AND U.S. ACTIVITY

Figure 5.1 shows the level of overall sodium/sulfur patent activity and its breakdown by U.S. and foreign assignees. Before 1970 almost all patents were held by U.S. firms with activity averaging about 5 patents per year. In

FIGURE 5.1. Activity: Foreign Versus United States

1975 and 1976 patent filings increased sharply with foreign activity matching or slightly exceeding that of U.S. assignees. U.S. activity peaked with 26 patents in 1977 and 1978 before activity declined steadily. Foreign activity peaked in 1976, dropped somewhat in 1977, and has remained fairly constant since then at about 12 patents per year.

No U.S. patents filed in 1982 had issued by April 1984, while eight foreign patents filed in 1982 had issued. It is too soon to tell if foreign activity will actually surpass U.S. activity when all filed patents have issued. (Statistics are not available on patents awaiting issue in the U.S. patent system.)

5.2 ACTIVITY BY COUNTRY

Only six countries hold sodium/sulfur battery patents. Table 5.1 displays the patent filings by country in each of the three-year periods following the invention of the sodium/sulfur battery in 1965. In addition, both the total number of assignees and the number of new assignees active in each period are shown as a measure of the concentration of activity within each country.

The United States has dominated patent activity throughout the course of the technology's development. Through 1970, U.S. assignees accounted for 21 of the 24 sodium/sulfur patents that had been filed and subsequently issued. Japanese assignees accounted for the remaining three patents. The U.S. dominance of this technology declined in the last three years of the study period. While the data in this final period are incomplete because of the delay in patent issuance, the U.S. accounts for less than half of the total patents filed. Together West Germany and the United Kingdom account for 23 patents in this period, which nearly equals the U.S. total of 24.

Table 5.1 also reveals important information regarding the number of assignees involved in sodium/sulfur development in each country. Typically, when an area shows commercial potential, as sodium/sulfur technology first did in the mid-1960s and later following the oil embargo, more firms become active

TABLE 5.1. Patent and Assignee Activity by Country

	Total 1965-82	Issue Year					
		65-67	68-70	71-73	74-76	77-79	80-82
United States							
Patents	165	11	10	15	36	69	24
Active Assignees		3	4	7	13	15	9
New Assignees	29	3	1	4	9	9	3
Japan							
Patents	17	--	3	5	6	1	2
Active Assignees		--	2	3	3	1	2
New Assignees	7	--	2	2	1	1	1
United Kingdom							
Patents	55	--	--	4	23	16	12
Active Assignees		--	--	2	5	2	2
New Assignees	5	--	--	2	3	--	--
West Germany							
Patents	28	--	--	--	3	14	11
Active Assignees		--	--	--	2	3	2
New Assignees	5	--	--	--	2	2	1
France							
Patents	19	--	--	2	9	6	2
Active Assignees		--	--	1	2	4	1
New Assignees	4	--	--	1	1	2	--

(South Africa holds one patent)

in its development. As development proceeds, the potential returns to inventive activity decline and some of the initial participants drop out. Thus, the development becomes more concentrated in fewer firms, particularly those that are well positioned to capture the commercial potential of the technology. Several measures of assignee concentration have been used in the past (see Campbell and Levine 1984). One measure of concentration can be obtained simply by taking a ratio of the number of patents to the number of assignees active in any given period. Dow Chemical, Ford Motor Company, General Electric, and EPRI hold most of the U.S. patents (122 out of 165). Twenty-five firms and agencies hold the remaining 43 patents. This shows fairly concentrated activity among a few major developers.

The United Kingdom and, more recently, West Germany have shown the most concentrated activity among foreign assignees. British activity has been very strong since 1974. Initially, British activity was shared among several organizations--the British Railways Board, The Electric Council, and the Secretary of State for Industry. From 1977 on, however, British activity has been concentrated in Chloride Silent Power, Ltd. The focus for technical development has shifted from the government and utility organizations to the private sector.

West Germany holds 28 patents, all of which were filed after 1974. Brown Boveri & Cie holds 22 patents, which shows a high degree of concentration of effort within a single firm. No German patents are held by government agencies or utility research organizations. France holds 19 patents, 17 of which were filed after 1973. Compagnie Generale d'Electricite holds 13 patents, 11 of which were filed after 1975. As with the United Kingdom and West Germany, French activity is very highly concentrated within a single firm.

Japanese activity differs markedly from that of the other countries. While 17 patents are held, 8 were filed prior to 1974 and only 3 were filed after 1976. In the early stages, both Toyota and Yuasa Battery Corp., Ltd., were active. NKG Spark Plug Company has been the most recent assignee. The Agency of Industrial Science and Technology was active (4 patents) between 1973 and 1976. Thus, Japanese activity has been less concentrated than that of the European countries and declined sharply in a period when the general level of activity was increasing or stable.

5.3 AREAS OF TECHNOLOGY EMPHASIS

An interesting difference in emphasis between U.S. and foreign patent positions can be seen in Table 3.1. Foreign patents appear to focus on electrodes and general design, whereas U.S. work emphasizes patents in electrolyte and seals/containers. Some indication as to the relative significance of the respective patent positions in these technology areas can be obtained by counting patent citations (Campbell and Nieves 1979). A patent is said to be "cited" if it is listed in the references of a later patent. Later patents usually represent improvements or extensions of the patents they are citing.

Thus, highly cited patents are likely to be more technically significant than patents with low citation counts.

Table 5.2 displays data on U.S. and foreign citation counts by technology type; pre- and post-1974 performance is separated. When the number of patents receiving 10 or more citations is compared with patent activity, foreign patents appear to have an edge. Overall, the highly cited foreign patents number 11 out of 120 patents, while the same measures for U.S. patents are 10 out of 165. Citation of foreign patents is even more dramatic after 1973. In that case, 6 out of 106 foreign patents are highly cited and 2 out of 129 U.S. patents are highly cited.

Table 5.2 also indicates that the areas of dominance for highly cited patents are generally consistent with activity data. The U.S. has more highly cited patents in the electrolyte and seals/container areas; foreign patents are more highly cited in the electrode and general design categories.

TABLE 5.2. Highly Cited Patents^(a) Versus Overall Patent Activity by Technology Type^(b)

	U.S.					Foreign					Total				
	ED	EY	SC	DS	Total	ED	EY	SC	DS	Total	ED	EY	SC	DS	Total
Pre-1974															
Highly Cited Patents	1	2	1	4	8	2	--	--	3	5	3	2	1	7	13
Overall Activity	7	18	2	9	36	2	7	--	5	14	9	25	2	14	50
Post-1973															
Highly Cited Patents	--	--	2	--	2	2	--	2	2	6	2	--	4	2	8
Overall Activity	22	43	47	17	129	32	24	18	32	106	54	67	65	49	235
1965-1982															
Highly Cited Patents	1	2	3	4	10	4	--	2	5	11	5	2	5	9	21
Overall Activity	29	61	49	26	165	34	31	18	37	120	63	92	67	63	285

(a) Highly cited patents are defined as those with at least 10 citations.

(b) ED = Electrodes
 EY = Electrolytes
 SC = Seals/containers
 DS = General design.

6.0 COMPARISON OF U.S. AND FOREIGN ASSIGNEES

Patent data provide insight into the level of inventive effort and the focus of that effort within the most active firms in a technology. This section summarizes patent data on the major U.S. and foreign assignees especially in terms of the level of inventive effort and the development linkages between patents for different assignees.

6.1 OVERALL ASSIGNEE CHARACTERISTICS

The 285 sodium/sulfur battery patents included in the patent set are distributed among 51 U.S. and foreign assignees. Domestic assignees began their patent activity in the mid-1960s. Japanese firms were the first foreign assignees to file for U.S. patents in the late 1960s; they were followed by British and French firms in the early 1970s and by West German assignees a few years later.

As a basis for the comparisons that follow, patent characteristics for the major assignees (those holding five or more patents) in the patent set are shown in Table 6.1. Some assignees with fewer patents are shown because of the significance of their patents or their participation in sodium/sulfur battery research.

6.1.1 Activity

The simplest indication of an assignee's patent activity in sodium/sulfur battery technology is the total number of patents. According to this indicator, four American firms (Ford, General Electric^(a), EPRI and Dow Chemical) and three foreign firms (England's Chloride Silent Power, the West German firm Brown Boveri & Cie, and the Compagnie Generale d'Electricite of France) were the most active. The highest number of patents for a Japanese assignee (6) is held by Toyota.

(a) General Electric announced a termination of its sodium/sulfur battery development program after the date of the latest patents studied in this research. Accordingly, these results do not reflect that significant event.

TABLE 6.1. Patent Characteristics of Major Assignees

	Total Number of Patents	Total Number of Depreciated Patents	Number of Inventors	Number of Patents, 1974 on	Number of Patents by Technology Type				Number of In-set Citations	Number of Self Citations	Percent In-set References	Cites/ Patent (Total)	Cites/ Patent 1974 on
					ED	EY	SC	DS					
Ford	45	23.3	23	33	11	6	16	12	223	57	70.0	5.0	2.1
U-Utah/Ceramatee	5	3.6	9	5	1	3	0	1	6	0	71.4	1.2	1.2
U.S. DOE	3	2.7	5	3	0	3	0	0	1	0	70.4	0.3	0.3
Dow	17	9.1	12	9	3	8	1	5	85	26	56.8	5.0	1.4
DuPont	5	3.7	3	5	0	5	0	0	4	0	52.2	0.8	0.8
Corning	5	4.5	2	5	0	1	2	2	0	0	87.5	0.0	0.0
General Electric	38	22.7	24	27	4	17	15	2	97	24	41.4	2.6	2.1
EPRI	22	16.0	10	22	7	0	12	3	36	14	67.6	1.6	1.6
Toyota	6	2.5	5	2	2	4	0	0	32	2	44.1	5.3	3.5
Agency Ind. Sci/Tech	4	2.2	3	3	2	0	0	2	16	1	68.4	4.0	1.0
Yuasa Battery	2	0.8	2	0	1	0	0	1	31	1	80.0	15.5	0.0
Chloride Silent Power	31	23.7	26	31	10	7	8	6	75	20	68.2	2.4	2.4
Electric Council	9	5.1	4	7	5	3	0	1	51	4	86.0	5.7	4.9
Sec./State Industry	8	4.6	10	8	4	1	0	3	35	2	82.9	4.4	4.4
British Railways Board	5	2.6	3	3	1	1	1	2	24	0	66.7	4.8	7.0
Brown Boveri & Cie	23	18.8	21	23	7	1	7	8	15	6	60.5	0.7	0.7
Generale d'Electricite	13	8.2	12	11	1	5	0	7	44	1	67.2	3.4	2.1
Others	44	--	--	38	4	27	5	8	80	--	--	1.8	--
Total	285	--	--	235	63	92	67	63	855	--	63.4	3.0	--

The number of depreciated patents held by an assignee is a relative indication of how recently the assignee's set of patents was issued. This figure is calculated by summing the years remaining for all patents, then dividing the total by 17 (the term of a single patent). The result is the cumulative number of full patent terms remaining for all of an assignee's patents. When firms are ranked by the Total Number of Patents held, Ford and General Electric are the most active assignees, followed by Chloride Silent Power. But when assignees are ranked by the Number of Depreciated Patents held, Chloride Silent Power comes out ahead of Ford and General Electric. Chloride's patent activity has been concentrated in the past ten years, so its patents have more cumulative years remaining than those of either Ford or General Electric.

Another way of gauging how current an assignee's patents are is to list patent activity from 1974 onward. (Since it marked the beginning of major U.S. government funding, as well as the start of the sharp rise in overall patent activity, 1974 was chosen to divide patent activity.) From 1974 on Ford continued to be the most active assignee, but General Electric fell to third most active behind Chloride Silent Power.

6.1.2 Number of Inventors

Table 6.1 also shows the number of inventors listed in the patents held by each assignee. The overall number of inventors is a measure of the relative levels of effort made by assignees. Chloride Silent Power, General Electric, Ford, and Brown Boveri & Cie have each listed more than twenty inventors on the patents they hold. One can also consider the ratio of the assignee's inventors to the number of patents it holds (not shown in Table 6.1). This ratio varies widely for assignees with fewer than ten patents. For the seven assignees with more than ten patents, American firms have a lower ratio of inventors to patents (ranging from 0.45 to 0.71) than do foreign assignees (0.84 to 0.92).

6.1.3 Areas of Emphasis

The number of patents by technology type indicates the focus of an assignee's research. Some assignees (for instance, General Electric, EPRI, Dow Chemical and Dupont) have concentrated their patenting in one or two of the

four technology areas. Others (such as Ford, Chloride Silent Power, and Brown Boveri & Cie) have patented in three or all four technology areas.

6.1.4 Patent Citations

The remaining measures in Table 6.1 deal with the citations received and references given by the assignees' patents. Data on citations provide a measure of the technical importance of the patents held by assignees. The number of in-set citations is the broadest indicator of the significance of an assignee's patents. Several factors influence the overall number of citations: the number of patents held by an assignee, the technical significance of the patents, and the age of the patents (older patents are likely to have received more citations than newer patents). The number of citations per patent and the number of citations per patent from 1974 on have also been calculated to control for the overall level of activity and the effect of citations on early basic patents.

The number of citations per patent for all patents shows the importance of Japanese inventions. Yuasa Battery and Toyota have high citation rates, although each holds relatively few patents. A ranking of assignees by the citations they have received per patent from 1974 on shows the importance of three British assignees holding relatively few patents (the British Railways Board, The Electric Council, and Britain's Secretary of State for Industry).

The high overall activity of some major assignees becomes less important when their citations are considered. Brown Boveri & Cie's patents have been infrequently cited; General Electric shows a low number of citations per patent, and the number of citations per patent that Dow Chemical has received falls sharply when only its later patents are considered (from 5 citations per patent to 1.44 per patent for the newer patents).

6.1.5 Patent References

The final measure shown in Table 6.1 is the percent of in-set references, or involution (which is described in Section 4.2). Most major assignees are near the average of 63.4% for the patent set. A lower figure may indicate an attempt by the assignee to draw on technologies outside the patent set in solving research problems addressed by its patents. Of the four technology

types, electrolyte research seems to have the largest potential for synthesis of other technologies. Also, assignees active early in the study period when there were few in-set patents to reference will tend to show a lower involution measure. General Electric and Toyota, two assignees with below-average involution figures, were both active fairly early and both hold patents in the electrolyte technology area.

6.2 PATENT CITATION ANALYSIS

The relationships between patent assignees in a technology can be shown by analyzing the citations and references passed between the major assignees in a patent set. The patterns of citations and references can illuminate several trends in the technology. Assignees who produce technically important patents will receive a large number of citations. Those assignees who draw on technology developed within the patent set will reference a greater proportion of in-set patents. Those assignees who attempt to draw on other technologies will reference a greater proportion of out-of-set patents.

The distinction between a citation and a reference is important in this discussion. A patent may make references to other patents; in turn, the same patent may receive citations from later patents. References to earlier patents are listed on the front page and in the text of a patent; the citations a patent accumulates after its issue can only be counted by looking at the references of a later patent. References are made to the most relevant prior art. By implication, patents receiving many citations are in some sense more significant than other patents because they are at the center of much follow-up activity.

In-set citations and references will be examined in two ways. First, the patterns of citations and references between assignees will be discussed with the help of an intercitation matrix of assignees. Then, individual patents that been highly cited will be covered.

6.2.1 Intercitation Matrix

Figure 6.1 shows an intercitation matrix for the major assignees in the sodium/sulfur battery patent set. In this matrix, the name of each assignee is

CITATIONS RECEIVED	REFERENCES GIVEN	Ford Motor Co.	U. Utah/Ceramatec	U.S. DOE	Dow Chemical	Dupont	Corning Glass	General Electric	EPRI	Toyota	Ind. Science - Tech. (a)	Yuasa Battery	Chloride Silent Power	Electric Council	Sec./State Industry (b)	British Railways Board	Brown Boveri DeCie	Generale d'Electricite	Other In-set	Total
Ford Motor Co.	57	4	1	19	2			22	6	9	7	4	12	15	10	6	14	18	17	223
U. Utah/Ceramatec			2					2											2	6
U.S. DOE																		1		1
Dow Chemical	3			26	8	14		2	4	1	2	1	4		2	3	7	1	7	85
Dupont						1													3	4
Corning Glass																				
General Electric	18		2					24	16	1		1	5	1	1	3	6	10	9	97
EPRI	8		1					1	14				4				5	1	2	36
Toyota	1		4	1					2	2	1		5	5	1		1	1	8	32
Ind. Science - Tech. (a)	2							1			1		3	2	2		3	1	1	16
Yuasa Battery	3								1	1		1	5	5	4	2	3	1	3	31
Chloride Silent Power	12	1	3			1	5	14					20				9		10	75
Electric Council	8	4	2	2				1	3				17	4	4	1	2	2	1	51
Sec./State Industry (b)	5								7				7	1	2	2	1	4	6	35
British Railways Board	12							2	2				4	1			1		2	24
Brown Boveri DeCie	2												1				6		6	15
Generale d'Electricite	7			1				11	2		2	1	6	3		1	4	1	5	44
Other In-set	4	6	4	1	2	5	4	4	1				10		3		5		31	78
Out-of-Set	61	6	8	38	11	3	109	36	15	6	2	48	6	6	9	28	20	81		493
Total	203	21	27	88	23	24	186	111	30	19	10	151	43	35	27	95	61	194		1348

(a) Agency of Industrial Science and Technology, Japan

(b) Secretary of State for Industry, United Kingdom

FIGURE 6.1. Intercitation Matrix for Sodium-Sulfur Battery Technology

listed both as a row heading and as a column heading because an assignee's patents may both give references and receive citations. To find out whose patents an assignee references, find the column heading naming that assignee and follow the column down. To find out who has cited a particular assignee's patents, locate the row heading naming the assignee and follow the row across. The diagonal crossing the matrix from upper left to lower right shows self-citations (references made by an assignee to its own patents).

The size of the numbers in Figure 6.1 makes the patterns of citations and references easy to discern; the largest indicate assignees whose patents have been cited most by others. In this patent set, we can see that Ford, Dow Chemical and General Electric have been the most widely cited American assignees. EPRI, the other major American assignee, has been cited by fewer other assignees. In the United Kingdom, Chloride Silent Power has received 50% more citations than The Electric Council, but these have been received from fewer assignees. Even though Chloride's patents are more highly cited, their patents have been less widely cited than those of The Electric Council.

The rows in the intercitation matrix also show assignees whose patents have not been highly cited. Among American assignees, Corning's patents have not been cited at all; the University of Utah/Ceramatec, U.S. Department of Energy, and Dupont have received only a few citations from other patents. The patents of all the Japanese and British assignees shown here have been cited by others. Also the difference between the Compagnie Generale d'Electricite and Brown Boveri & Cie is noteworthy. Although the Compagnie Generale holds only 13 patents to Brown Boveri's 23, its patents have received three times as many citations as Brown Boveri's and have been cited by many more assignees.

The columns in Figure 6.1 indicate whose patents an assignee references in its own patents. As with the rows, assignees can be seen to reference the patents of many other assignees, or of only a few other assignees. Among American assignees, Ford has most widely referenced the patents of other firms, drawing particularly on the patents of General Electric, Chloride Silent Power and the British Railways Board. General Electric and EPRI have also referenced the patents of many other assignees, Dow Chemical less so. The U.S. Department of Energy's pattern of references is interesting in that, even though they hold

only three patents, they have referenced the patents of seven other assignees, including Japanese and British assignees.

Foreign assignees also show some patterns of referencing diverse assignees. Japanese patents mostly reference those of Ford, Dow Chemical and General Electric. Patents held by the six European assignees in the matrix show a more marked attempt to synthesize other's results by referencing U.S. patents, Japanese patents, and those of the other European assignees (except, as noted earlier, Brown Boveri & Cie patents).

When combined with what we have shown about overall patterns of activity, information on citations and references can begin to show how assignees draw on other's technology. Many of the citations received by the large American assignees in the patent set are references given to their early basic patents. These basic patents were referenced by the Japanese in the late 1960s and early 1970s. The resulting Japanese patents, as well as the early American patents, were referenced by the European assignees when they began patenting a few years later. Patents assigned to the British organizations, to Japanese assignees, and to the Compagnie Generale d'Electricite are now being cited by newer American patents. This illustrates how one group of assignees can draw upon the work of others, with their advances, in turn, serving as further inspiration to those that began the work in the field.

6.2.2 Highly Cited Patents

The patterns of citations and references between assignees over time can be discerned by identifying individual patents receiving a high number of citations. A list of those patents in the set that have received ten or more in-set citations is shown in Table 6.2. Ten of the 21 patents in this list are held by U.S. assignees; the other eleven are held by foreign assignees.

The top portion of Table 6.2 is dominated by the early basic patents held by Ford and Dow Chemical. These basic patents have been cited many times since their issue (the older a patent is, the more citations it is likely to have received). Other Ford and Dow Chemical patents in the highly cited list are

TABLE 6.2. Patents Receiving Ten or More Citations

Patent Number	Assignee	Patent Title	Filing Date	Number of Citations
3413150	Ford Motor	Battery Having a Molten Alkali Metal Anode and a Molten Sulfur Cathode	9/28/66	31
3404035	Ford Motor	Secondary Battery Employing Molten Alkali Metal Reactant	10/22/65	28
3811943	Ford Motor	Mass Transportation Electrode for Energy Conversion Device	2/16/71	24
3679480	Dow Chemical	Electrical Cell Assembly	5/8/69	23
4048391	Chloride Silent Power (UK)	Alkali Metal-Sulfur Cells	4/23/76	22
3404036	Ford Motor	Energy Conversion Device Comprising a Solid Crystalline Electrolyte and	5/2/66	21
3982957	Electric Council (UK)	Sodium/Sulfur Cells	2/14/75	19
3476602	Dow Chemical	Battery Cell	7/25/66	18
3770502	Yuasa Battery (Japan)	Sodium/Sulfur Storage Battery	8/11/72	17
3959013	General Electric	Cathode Cell Casing Portion, a Cell Casing, and a Hermetically Sealed SO	6/11/75	16
3758337	Gen. d'Electricite (France)	Sodium/Sulfur Accumulator with Temperature Controlling Means	12/21/71	16
3946751	General Electric	Cell Casing with a Hermetic Mechanical Seal and a Hermetically Sealed SO	2/18/75	15
3841912	Yuasa Battery (Japan)	Sodium/Sulfur Storage Battery	4/2/73	14
3883367	Toyota (Japan)	Sodium/Sulfur Storage Battery	10/17/73	13
3939007	British Railway Board (UK)	Sodium/Sulfur Cells	1/16/74	12
3837918	Ind. Science/Tech. (Japan)	Sodium/Sulfur Storage Battery	3/14/73	12
4024320	Chloride Silent Power (UK)	Galvanic Cells	12/15/75	11
3829331	Dow Chemical	Sodium Borate Glass Compositions and Batteries Containing Same	12/30/71	11
4037027	Gen. d'Electricite (France)	Sodium/Sulfur Electric Cell and Method of Forming Same	11/4/76	10
3932195	Sec./State Industry (UK)	Electric Cells	4/29/75	10
3756856	Ford Motor	Flexible Sealing Material for Energy Conversion Devices	11/2/71	10

also earlier patents (all filed before 1972). Of American assignees, only General Electric holds newer highly cited patents. The two General Electric patents in Table 6.2 were filed in 1975.

Four of the 17 patents issued to Japanese assignees have received ten or more citations and are included in Table 6.2. These patents were all filed in the early 1970s, so have had less time to be cited than the Ford/Dow patents. Most notable are the two Yuasa Battery patents in the list. The two patents held by Yuasa have received 17 and 14 citations. Patents held by Toyota and the Agency of Industrial Science and Technology have also been highly cited.

Some of the patents in Table 6.2 held by British and French assignees are even newer than the Japanese patents. The highest foreign patent on the list, from Chloride Silent Power, received 22 citations in the eight years since it was filed. (The most highly cited patent overall received 31 citations, but those citations were received over the 18 years since the patent was filed in 1966.) Chloride Silent Power is joined in Table 6.2 by three other British assignees: The Electric Council, the British Railways Board and the Secretary of State for Industry. The earliest British-assigned patent in this list was filed in 1971.

Other foreign activity is represented in Table 6.2 by two patents held by the French firm Compagnie Generale d'Electricite, both filed in the 1970s. No Brown Boveri & Cie patents have been highly cited, which is consistent with their patents receiving few citations overall (shown in Figure 6.1).

The patents in Table 6.2 were re-ordered chronologically and are shown in Table 6.3. This table reveals a more pronounced pattern of American patents at the top of the list (oldest), Japanese patents clustered in the middle and British assignees represented at the bottom of the list (most recent). The arrangement of highly cited patents over time parallels the patterns found in the intercitation matrix: early work by American assignees has been highly cited by Japanese and British assignees in their patents, which in turn are now being cited by newer American patents.

TABLE 6.3. Patents Receiving Ten or More In-set Citations,
Ranked Chronologically

<u>Patent Number</u>	<u>Assignee</u>	<u>Filing Date</u>	<u>Number of Citations</u>
3404035	Ford Motor	10/22/65	28
3404036	Ford Motor	5/2/66	21
3476602	Dow Chemical	7/25/66	18
3413150	Ford Motor	9/28/66	31
3679480	Dow Chemical	5/8/69	23
3811943	Ford Motor	2/16/71	24
3756856	Ford Motor	11/2/71	10
3758337	Gen. d'Electricite (France)	12/21/71	16
3829331	Dow Chemical	12/30/71	11
3770502	Yuasa Battery (Japan)	8/11/72	17
3837918	Ind. Science/Tech. (Japan)	3/14/73	12
3841912	Yuasa Battery (Japan)	4/2/73	14
3883367	Toyota (Japan)	10/17/73	13
3939007	British Railways Board (UK)	1/16/74	12
3982957	Electric Council (UK)	2/14/75	19
3946751	General Electric	2/18/75	15
3932195	Sec./State Industry (UK)	4/29/75	10
3959013	General Electric	6/11/75	16
4024320	Chloride Silent Power (UK)	12/15/75	11
4048391	Chloride Silent Power (UK)	4/23/76	22
4037027	Gen. d'Electricite (France)	11/4/76	10

6.3 PROFILES OF MAJOR ASSIGNEES

The major domestic organizations patenting in the sodium/sulfur battery technology can be divided into two groups. Research undertaken by the first group, which includes the Department of Energy, Ford Motor Company, and Dow Chemical Company, was supported by the National Science Foundation and the Department of Energy. The other major domestic group contains the Electric Power Research Institute (EPRI) and General Electric, which has been supported by EPRI in recent years.

6.3.1 Department of Energy/Ford/Dow Chemical

Since 1973 the U.S. government has made a significant investment in sodium/sulfur battery research. The National Science Foundation provided early funding; in 1976 the program was transferred to ERDA/DOE.

Ford, the most active assignee in the patents under study, has benefited from government funding. Their independent work in the area resulted in 12 patents filed between 1965 and 1971; these patents concentrated in the electrolyte and design technology areas. Five of these patents are highly cited, basic patents. Early government-funded work (1975-76) concentrated in electrodes; more recently, Ford has been patenting in the seals/containers and general design areas. However, the patents resulting from their later, government-funded research have not been highly cited by others.

The University of Utah and its spin-off firm Ceramatec have received funding from DOE through Ford for sodium/sulfur research and have received five patents. They began filing patents in 1975 and have done most of their work in electrolytes. They hold no highly cited patents.

Dow Chemical has also participated in the NSF/DOE research program. Dow is a major assignee, holding seventeen patents filed between 1966 and 1978. While they have patented in all four technology areas, their work is concentrated in glass electrolytes. Three of Dow's patents have been highly cited. Like Ford, Dow's highly cited patents were issued early in the study period, with patents resulting from government-funded research not being highly cited.

Dupont and Corning Glassworks each hold five patents that heavily reference Dow patents. Dupont patented in the electrolyte area and only patented in the late 1970s. Corning, a recent entry in the field, does not seem to have concentrated in any one technology area. None of the Dupont or Corning patents have been cited much, at least partially because of their newness.

6.3.2 General Electric/Electric Power Research Institute

The second group of major U.S. patent assignees includes General Electric and the Electric Power Research Institute (EPRI). EPRI has funded some of General Electric's later work in the area.

General Electric is the second most active assignee in the study, claiming 38 patents filed between 1967 and 1981. They have filed patents in all four technology areas, but have concentrated their efforts in electrolytes and containers. General Electric's level of activity has been fairly steady. Two of their container patents, both issued in 1976, have been highly cited, however, their earlier work has not been cited often, their later patents even less.

EPRI did not file its first patent until 1976 and has had 22 patents issued since then. They filed several patents a year through 1979. If they have filed any patent applications more recently than 1980, the patents have not yet been issued. EPRI patents are concentrated in containers and electrodes. None of their patents have been highly cited (a 1978 container patent is the most highly cited with eight citations). Again, this is partly because their patents are relatively new.

6.3.3 Other U.S. Assignees

In addition to the eight assignees discussed above, 21 other U.S. assignees are listed in the sodium/sulfur patent set. None of these firms or organizations have been assigned more than three patents. There are a few interesting points about these less active assignees. For instance, several petroleum companies (Exxon, Shell, Phillips) have made brief efforts in the area; each holds only one patent. The U.S. Army has also done some sodium/sulfur research and has funded Westinghouse Electric Corporation for two of Westinghouse's three patents, all of which have issued since 1980. Among research and academic organizations, MIT holds two patents, the Cornell Research Foundation and Bell Labs each hold one patent.

6.3.4 Japanese Assignees

Japanese patenting in sodium/sulfur batteries is mostly limited to the early and mid-1970s. Several Japanese assignees received patents during these years. While research in the technology continues, recent funding by the Japanese government has not led to new U.S. patent activity by Japanese assignees. Several highly cited patents are included in those held by Japanese assignees. For instance, Toyota holds six patents, which were filed from 1969 through 1975; one of their electrode patents, which was issued in 1975, has

already received 13 citations. Yuasa Battery holds only two patents, but they have received 17 and 14 citations since their issue (1973 and 1974). In general, the Japanese patents cite earlier Ford patents; their patents, in turn, are being cited heavily by British assignees' patents.

Other Japanese assignees are the Agency of Industrial Science and Technology (associated with MITI), NKG Spark Plug, Nichicon Capacitor, Seiko and Hitachi.

6.3.5 British Assignees

British patenting in sodium/sulfur batteries began in 1971, rose sharply in 1975, and has remained fairly steady since then. Research done by British assignees is divided into all technology areas--none seem to have concentrated in only one area.

The earliest patented work was done by The Electric Council (nine filings from 1971 through 1977) and the British Railways Board (five filings, 1971 through 1976). In 1975 and 1976 Britain's Secretary of State for Industry filed for eight patents, all of which were issued. Each of these assignees holds one patent receiving ten or more citations (all issued in 1976).

Recent British patenting has been done almost exclusively by Chloride Silent Power, Ltd., the third most active assignee in the patent set with 31 sodium/sulfur patents listed in its name. Chloride Silent did not file any patents before 1975, but has been patenting heavily since then, as activity by the other British assignees has fallen off. Chloride Silent's patents are in all technology areas; their first electrode patent, issued in 1977, has already received 22 citations.

Early British work cites the basic Ford and General Electric patents, as well as Japanese patents. Chloride Silent's patents cite earlier British patents. In turn, Chloride Silent is now being cited by Ford and EPRI, among others.

6.3.6 Brown Boveri & Cie (West Germany)

An assignee whose pattern of activity is similar to that of Chloride Silent Power is West Germany's^(a) Brown Boveri & Cie, A.G. Brown Boveri filed its first patent application in 1975, and has been issued 23 patents since then (fourth largest in the patent set). Their earlier work was concentrated in the electrode technology area; more recently, they have been patenting in seals/containers and general design technologies. Brown Boveri patents cite Ford and Chloride Silent Power patents. Their own patents, however, have been infrequently cited, in marked contrast to those of the Japanese and British assignees.

6.3.7 Compagnie Generale d'Electricite (France)

The last major assignee is the Compagnie Generale d'Electricite of France. This firm has received 13 patents between 1971 and 1981. Seven of these patents were filed in 1976; their activity has been low since then. Their 1976 burst of filings was concentrated in the design area; recently, they have been filing electrolyte patents. They primarily cite Ford and General Electric patents, including both the basic and newer patents. Two of the Compagnie Generale's design patents have received 16 and 10 citations. Their patents have been most cited by General Electric, Ford and Chloride Silent Power.

(a) Although incorporated in Switzerland, Brown Boveri was considered to be a West German firm for this study since all sodium/sulfur technology development occurred at a West German facility and was substantially funded by the West German government.

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APPENDIX A

SODIUM/SULFUR PATENT ANALYSIS DATA

TABLE A.1. Assignee Patent Activity Over Time

Filing Year	Number of Patents	Assignee Sector ^(a)				Technology Type ^(b)			
		GV	GC	OD	FO	ED	EY	SC	DS
65	1	0	1	0	0	0	0	0	1
66	6	0	6	0	0	0	4	0	2
67	4	0	3	1	0	0	0	0	4
68	1	1	0	0	0	0	0	0	1
69	9	0	3	5	1	2	6	0	1
70	3	0	1	0	2	1	2	0	0
71	13	0	4	3	6	3	6	1	3
72	5	0	2	1	2	2	3	0	0
73	8	0	1	4	3	1	4	1	2
74	9	1	0	3	5	2	3	3	1
75	27	8	0	5	14	10	6	4	7
76	41	4	4	11	22	12	15	5	9
77	40	12	2	12	14	12	7	15	6
78	36	5	3	18	10	7	8	17	4
79	31	5	4	8	14	6	8	8	9
80	19	3	0	9	7	1	7	7	4
81 ^(c)	24	3	2	7	12	3	11	4	6
82 ^(c)	8	<u>0</u>	<u>0</u>	<u>0</u>	<u>8</u>	<u>1</u>	<u>2</u>	<u>2</u>	<u>3</u>
TOTAL		42	36	87	120	63	92	67	63
PERCENT		(0.15)	(0.13)	(0.31)	(0.42)	(0.22)	(0.32)	(0.24)	(0.22)

(a) GV = Government-held or sponsored.

GC = Government Contractor (e.g. Ford, Utah, Dow, etc.)

OD = Other U.S. assignee (GE, EPRI, Corning, etc.)

FO = Foreign assignee

(b) ED = Electrode design

EY = Electrolyte/Separator

SC = Seal/Container

DS = General design

(c) Probably understates true activity since some patents filed have yet to issue. We have all patents issuing through 4/1/84.

TABLE A.2. U.S. Versus Foreign Activity by Technology Type Over Time

Filing Year	Electrodes			Electrolytes			Seals/ Containers			General Design			Total		
	US	FN	Total	US	FN	Total	US	FN	Total	US	FN	Total	US	FN	Total
1965	--	--	--	--	--	--	--	--	--	1	--	1	1	--	1
1966	--	--	--	4	--	4	--	--	--	2	--	2	6	--	6
1967	--	--	--	--	--	--	--	--	--	4	--	4	4	--	4
1968	--	--	--	--	--	--	--	--	--	1	--	1	1	--	1
1969	2	--	2	5	1	6	--	--	--	1	--	1	8	1	9
1970	1	--	1	--	2	2	--	--	--	--	--	--	1	2	3
1971	3	--	3	3	3	6	1	--	1	--	3	3	7	6	13
1972	1	1	2	2	1	3	--	--	--	--	--	--	3	2	5
1973	--	1	1	4	--	4	1	--	1	--	2	2	5	3	8
1974	--	2	2	2	1	3	2	1	3	--	1	1	4	5	9
1975	5	5	10	4	2	6	2	2	4	2	5	7	13	14	27
1976	4	8	12	9	6	15	4	1	5	2	7	9	19	22	41
1977	5	7	12	4	3	7	13	2	15	4	2	6	26	14	40
1978	4	3	7	7	1	8	13	4	17	2	2	4	26	10	36
1979	2	4	6	5	3	8	6	2	8	4	5	9	17	14	31
1980	1	--	1	4	3	7	5	2	7	2	2	4	12	7	19
1981	1	2	3	8	3	11	2	2	4	1	5	6	12	12	24
1982	--	1	1	--	2	2	--	2	2	--	3	3	--	8	8
Total	29	34	63	61	31	92	49	18	67	26	37	63	165	120	285

TABLE A.3. Patent Characteristics Over Time by Technology Type

Filing Years	Number of Patents				Distinct Inventors				Total Inventors				Distinct Organizations			
	ED	EY	SC	DS	ED	EY	SC	DS	ED	EY	SC	DS	ED	EY	SC	DS
1965	0	0	0	1	0	0	0	2	0	0	0	2	0	0	0	1
1966	0	4	0	2	0	4	0	2	0	6	0	4	0	2	0	1
1967	0	0	0	4	0	0	0	4	0	0	0	4	0	0	0	2
1968	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1
1969	2	6	0	1	1	10	0	3	2	15	0	3	1	4	0	1
1970	1	2	0	0	2	3	0	0	2	3	0	0	1	2	0	0
1971	3	6	1	3	5	9	1	6	5	9	1	6	3	6	1	2
1972	2	3	0	0	3	4	0	0	3	4	0	0	2	3	0	0
1973	1	4	1	2	1	4	1	2	1	6	1	2	1	2	1	2
1974	2	3	3	1	4	8	5	3	4	8	5	3	2	3	2	1
1975	10	6	4	7	16	16	9	10	22	16	10	13	4	5	3	3
1976	12	15	5	9	19	22	6	11	26	27	7	19	8	14	3	5
1977	12	7	15	6	14	11	16	9	23	14	25	9	7	5	5	4
1978	7	8	17	4	11	9	26	7	12	10	38	7	5	7	7	4
1979	6	8	8	9	8	15	12	13	10	15	12	16	3	6	6	6
1980	1	7	7	4	2	11	15	5	2	14	16	5	1	5	5	4
1981	3	11	4	6	4	15	7	8	4	17	8	9	2	8	3	5
1982	1	2	2	3	3	4	6	3	3	4	6	4	1	2	1	1
TOTAL	63	92	67	63	93	145	104	89	119	168	129	107	41	74	37	43

TABLE A.4. Involution Over Time

<u>Filing Year</u>	<u>Number of Patents</u>	<u>Number of References</u>	<u>Number of In-set References</u>	<u>Number of Out-of-Set References</u>	<u>Involution: Percentage of In-set References</u>
1965	1	3	-	3	-
1966	6	15	3	12	20.0
1967	4	16	8	8	50.0
1968	1	2	-	2	-
1969	9	34	14	20	41.2
1970	3	8	4	4	50.0
1971	13	79	43	36	54.4
1972	5	20	11	9	55.0
1973	8	40	22	18	55.0
1974	9	44	24	20	54.5
1975	27	116	92	24	79.3
1976	41	144	95	49	66.0
1977	40	159	111	48	69.8
1978	36	243	157	86	64.6
1979	31	183	115	68	62.8
1980	19	98	58	40	59.2
1981	24	111	69	42	62.2
1982	<u>8</u>	<u>33</u>	<u>29</u>	<u>4</u>	<u>87.9</u>
Total	285	1348	855	493	63.4

TABLE A.5. Immediacy Over Time

<u>Filing Year</u>	<u>Mean Age of References (in years)</u>		
	<u>All References</u>	<u>In-Set References</u>	<u>Out-of-Set References</u>
1965	15.7	-	15.7
1966	3.9	0	4.8
1967	6.1	0	12.1
1968	17.5	-	17.5
1969	0.9	0.6	1.1
1970	0.9	1.5	0.3
1971	4.3	1.9	7.1
1972	5.5	1.9	9.8
1973	4.1	2.2	6.4
1974	2.5	2.2	2.9
1975	2.6	2.3	3.8
1976	3.0	2.0	4.9
1977	2.7	1.6	5.1
1978	5.3	2.0	11.3
1979	8.4	3.0	17.5
1980	5.1	2.7	8.7
1981	4.6	3.8	6.0
1982	4.2	3.6	8.8
Overall	4.5	2.3	8.4

TABLE A.6. Patent Characteristics of Sodium/Sulfur Assignees

Assignee	Total Number of Patents	Number of Inventors	Number of Patents by Technology Type				Number of In-set Citations	Number of Self Citations	Citations Per Patent
			ED	EY	SC	DS			
Agence Nationale de Valorisation de La Recherche (France)	2	4	--	2	--	--	3	--	1.5
Agency of Industrial Science & Technol- ogy (Japan)	4	3	2	--	--	2	16	1	4.0
Aluminum Company of America	1	2	--	1	--	--	3	--	3.0
Bell Telephone Laboratories	1	1	1	--	--	--	--	--	0.0
British Railways Board (UK)	5	3	1	1	1	2	24	--	4.8
Brown Boveri & Cie AG (WG)	23	21	7	1	7	8	15	6	0.7
Chloride Silent Power Ltd. (UK)	31	26	10	7	8	6	75	20	2.4
Compagnie Generale d'Electricite (France)	13	12	1	5	--	7	44	1	3.4
Compagnie Generale des Etablissements Michelin (France)	2	3	--	--	1	1	--	--	0.0

TABLE A.6. (contd)

Assignee	Total Number of Patents	Number of Inventors	Number of Patents by Technology Type				Number of In-set Citations	Number of Self Citations	Citations Per Patent
			ED	EY	SC	DS			
Cornell Research Foundation Inc.	1	2	--	1	--	--	7	--	7.0
Corning Glassworks	5	2	--	1	2	2	--	--	0.0
Deutsche Automobilge- sellschaft (WG)	2	5	--	1	--	1	3	--	1.5
Dow Chemical Company	17	12	3	8	1	5	85	26	5.0
E. I. Dupont De Mours & Company	5	3	--	5	--	--	4	--	0.8
Eastman Kodak Company	1	1	--	1	--	--	2	--	2.0
Electric Council (UK)	9	4	5	3	--	1	51	4	5.7
Electric Power Research Institute Inc.	22	10	7	--	12	3	36	14	1.6
Engelhard Minerals & Chemical Corp.	1	1	--	1	--	--	1	--	1.0
ESB Inc.	1	1	--	1	--	--	1	--	1.0
Exxon Research & Engineering Company	1	1	--	1	--	--	7	--	7.0
Ford Motor/Aerospace	45	24	11	6	16	12	223	57	5.0

TABLE A.6. (contd)

Assignee	Total Number of Patents	Number of Inventors	Number of Patents by Technology Type				Number of In-set Citations	Number of Self Citations	Citations Per Patent
			ED	EY	SC	DS			
General Electric Company	38	24	4	17	15	2	97	24	2.6
General Motors	1	2	--	1	--	--	3	--	3.0
Great Lakes Carbon Corp.	2	2	2	--	--	--	1	--	0.5
Hitachi, Ltd. (Japan)	1	3	--	1	--	--	--	--	0.0
Institute of Gas Technology	1	1	--	--	1	--	--	--	0.0
International Busi- ness Machines Corp.	1	2	--	1	--	--	1	--	1.0
Kabushiki Kaisha Seikosha (Japan)	1	2	--	1	--	--	1	--	1.0
Kabushiki Kaisha Toyota (Japan)	6	5	2	4	--	--	32	2	5.3
MIT	2	3	--	2	--	--	5	1	2.5
Monsanto Company	1	1	--	1	--	--	--	--	0.0
Nichicon Capacitor Ltd. (Japan)	1	1	--	1	--	--	1	--	1.0
NKG Spark Plug Ltd. (Japan)	2	2	--	1	--	1	6	1	3.0

TABLE A.6. (contd)

Assignee	Total Number of Patents	Number of Inventors	Number of Patents by Technology Type				Number of In-set Citations	Number of Self Citations	Citations Per Patent
			ED	EY	SC	DS			
Owens-Illinois Glass Inc.	1	3	--	1	--	--	2	--	2.0
Phillips Petroleum Co.	1	1	--	--	1	--	--	--	0.0
Rockwell Interna- tional Corp.	1	1	--	1	--	--	--	--	0.0
Secretary of State for Industry (UK)	8	10	4	1	--	3	35	2	4.4
Shell Oil Company	1	2	--	1	--	--	6	--	6.0
Societe Anonyme de Vehicules Industriels (France)	1	1	--	--	--	1	1	--	1.0
South African Inven- tions Development Corp. (South Africa)	1	1	--	--	1	--	--	--	0.0
TRW Inc.	1	3	--	1	--	--	6	--	6.0
U.S. Department of Energy	3	5	--	3	--	--	1	--	0.3
U.S. Secretary of the Army	1	1	--	--	--	1	3	--	3.0

TABLE A.6. (contd)

Assignee	Total Number of Patents	Number of Inventors	Number of Patents by Technology Type				Number of In-set Citations	Number of Self Citations	Citations Per Patent
			ED	EY	SC	DS			
Unassigned or Individually Owned (one U.S., two WG)	3	10	1	--	1	1	11	--	3.7
United Kingdom Atomic Energy Authority (UK)	2	5	--	1	--	1	5	--	2.5
University of Utah/ Ceramatec	5	9	1	3	--	1	6	--	1.2
Varta Aktiengesell- schaft (WG)	2	4	--	1	--	1	--	--	0.0
Westinghouse Electric Corp.	3	4	--	3	--	--	1	1	0.3
Yuasa Battery Ltd. (Japan)	2	2	1	--	--	1	31	1	15.5

APPENDIX B

PROFILE OF SODIUM/SULFUR BATTERY PATENTS

APPENDIX B

PROFILE OF SODIUM/SULFUR BATTERY PATENTS

The following pages contain a list of sodium/sulfur battery patents analyzed in this study. The patent set is organized alphabetically by assignee and, within assignees, by patent number. Codes used in this appendix are shown below.

<u>Column Heading</u>	<u>Item</u>	<u>Code</u>	<u>Explanation</u>
Sector	Assignee Sector	1	Government
		2	Government Supported Contractor
		3	Government Contractor Not Supported
		4	Other U.S.
		5	Foreign
Country	Assignee Country	US	United States
		UK	United Kingdom
		JP	Japan
		FR	France
		WG	West Germany
		SA	South Africa
Tech Type	Technology Type	ED	Electrodes
		EY	Electrolytes
		SC	Seals/Containers
		DS	General Design

ASSIGNEE PATENT NUMBER	PATENT TITLE	FILING DATE	ISSUE DATE	SEC TOR	COUN -TRY	TECH TYPE	CITA- TIONS
AGENCE NATIONALE DE VALORISATION DE LA RECHERCHE FRANCE							
4070529	SOLID ELECTROLYTE	7/ 7/76	1/24/78	5	FR	EY	2
4237201	IONIC CONDUCTIVITY MATERIALS SUITABLE FOR CONSTITUTING SOLID ELECTROLYTE	2/ 2/79	12/ 2/80	5	FR	EY	1
AGENCY OF INDUSTRIAL SCIENCE & TECHNOLOGY JAPAN							
3837918	SODIUM SULFUR STORAGE BATTERY	3/14/73	9/24/74	5	JP	DS	12
4024319	SODIUM SULFUR STORAGE BATTERY	9/15/75	5/17/77	5	JP	DS	0
4027075	SODIUM SULFUR STORAGE BATTERY	1/29/75	5/31/77	5	JP	ED	1
4076902	SODIUM-SULFUR STORAGE BATTERY	10/15/76	2/28/78	5	JP	ED	3
ALUMINUM COMPANY OF AMERICA							
3859427	PRODUCTION OF BETA ALUMINA	11/ 4/71	1/ 7/75	4	US	EY	3
BELL TELEPHONE LABORATORIES							
4054728	SODIUM-SULFUR BATTERIES	2/ 9/77	10/18/77	4	US	ED	0
BRITISH RAILWAYS BOARD ENGLAND							
3765945	ELECTRIC CELL AND BATTERIES	11/29/71	10/16/73	5	UK	DS	2
3783024	ELECTRIC CELLS AND BATTERIES	11/23/71	1/ 1/74	5	UK	DS	1
3939007	SODIUM SULFUR CELLS	1/16/74	2/17/76	5	UK	SC	12
4076903	ALKALI METAL SULFUR CELLS	7/22/76	2/28/78	5	UK	EY	3
4104448	ALKALI METAL-SULFUR CELLS	10/ 8/76	8/ 1/78	5	UK	ED	6
BROWN, BOVERI AND CIE AG. GERMANY							
4018969	ELECTROCHEMICAL STORAGE CELL	3/26/76	4/19/77	5	WG	ED	3
4029857	ELECTROCHEMICAL STORAGE CELL OR BATTERY	12/ 5/75	6/14/77	5	WG	SC	0
4038462	SOLID-ELECTROLYTE BATTERY PARTICULARLY FOR THE STORAGE OF ELECTRICAL EN	3/29/76	7/26/77	5	UK	DS	3
4127705	ELECTROCHEMICAL STROAGE CELL	7/20/77	11/28/78	5	WG	ED	1
4184013	ELECTROCHEMICAL STROAGE CELL	12/22/78	1/15/80	5	WG	ED	0
4206272	ELECTROCHEMICAL STORAGE CELL	4/27/79	6/ 3/80	5	WG	DS	1
4207386	ELECTROCHEMICAL STROAGE CELL	5/ 1/79	6/10/80	5	WG	DS	0
4216275	ELECTROCHEMICAL STORAGE CELL OF BATTERY	6/13/78	8/ 5/80	5	WG	SC	2
4216276	ELECTROCHEMICAL STORAGE CELL	6/22/79	8/ 5/80	5	WG	ED	1
4221848	ELECTROCHEMICAL STARGE CELL OR BATTERY OF THE ALKALI METAL AND SULFUR T	11/22/77	9/ 9/80	5	WG	ED	0
4235956	ELECTROCHEMICAL STORAGE BATTERY	4/27/79	11/25/80	5	WG	DS	2
4237200	ELECTROCHEMICAL STORAGE CELL	12/ 4/78	12/ 2/80	5	WG	ED	2
4238553	ELECTROCHEMICAL STORAGE CELL	6/22/79	12/ 9/80	5	WG	ED	0
4239837	ELECTROCHEMICAL STORAGE CELL	4/ 3/79	12/16/80	5	WG	SC	0
4388381	ELECTROCHEMICAL STORAGE CELL	6/24/81	6/14/83	5	WG	EY	0
4401731	ELECTROCHEMICAL STORAGE CELL	8/18/81	8/30/83	5	WG	SC	0
4403023	THERMAL INSULATION	10/ 6/81	9/ 6/83	5	WG	DS	0
4405696	ELECTROCHEMICAL STORAGE CELL	4/22/82	9/20/83	5	WG	DS	0
4413043	ELECTROCHEMICAL STARGE CELL	8/18/81	11/ 1/83	5	WG	SC	0
4414296	ELECTROCHEMICAL STARGE CELL OR BATTERY	4/23/82	11/ 8/83	5	WG	SC	0
4414297	SHUNT ELEMENT	4/23/82	11/ 8/83	5	WG	DS	0
4419418	INDIVIDUAL RECHARGEABLE ELECTRIC CELL	3/26/82	12/ 6/83	5	WG	SC	0
4419419	RECHARGEABLE ELECTRIC STARGE BATTERY	4/23/82	12/ 6/83	5	WG	DS	0
CERAMATEC, INC.							
4407912	ELECTROCHEMICAL CELL UTILIZING MOLTEN ALKALI METAL ELECTRODE-REACTANT	10/13/81	10/ 4/83	2	US	ED	0

ASSIGNEE PATENT NUMBER	PATENT TITLE	FILING DATE	ISSUE DATE	SEC TOR	COUN -TRY	TECH TYPE	CITA- TIONS
CHLORIDE SILENT POWER LIMITED GB.							
4024320	GALVANIC CELLS	12/15/75	5/17/77	5	UK	SC	11
4024321	ALDALI METAL-SULFUR CELLS	6/28/76	5/17/77	5	UK	SC	7
4048391	ALKALI METAL-SULFUR CELLS	4/23/76	9/13/77	5	UK	ED	22
4052535	SODIUM SULFUR CELLS	8/19/76	10/ 4/77	5	UK	ED	4
4055710	ELECTROCHEMICAL CELLS HAVING SOLID ELECTROLYTE FO TUBULAR FORM	10/ 1/76	10/25/77	5	UK	EY	2
4074026	SEALING OF ELECTROCHEMICAL DEVICES UTILIZING LIQUID SODIUM AND A SOLID C	2/ 4/77	2/14/78	5	UK	SC	1
4117056	PRODUCTION OF BETA-ALUMINA CERAMIC ARTICLES	3/ 9/77	9/26/78	5	UK	EY	2
4117209	ELECTTOCHEMICAL CELLS	11/21/77	9/26/78	5	UK	SC	4
4118545	SODIUM SULPHUR CELLS	2/15/77	10/ 3/78	5	UK	ED	3
4123596	CATHODE STRUCTURE FOR SODIUM SULPHUR CELLS	9/ 2/77	10/31/78	5	UK	ED	2
4124739	ALKALI METAL SULFUR CELLS	6/20/77	11/ 7/78	5	UK	DS	2
4137376	SODIUM SULPHUR BATTERIES COMPRISING A PLURALITY OF SEPARATE CELLS WITHIN	10/31/77	1/30/79	5	UK	DS	4
4151235	PRODUCTION OF BETA-ALUMINA	8/ 4/77	4/24/79	5	UK	EY	2
4167550	METHODS OF MANUFACTURE OF BETA-ALUMINA	1/18/78	9/11/79	5	UK	EY	0
4167807	IMPROVEMENT IN MAKING ELECTROCHEMICAL CELLS IMPLYING AN ALKALI METAL AN	5/15/78	9/18/79	5	UK	DS	1
4173686	SODIUM SULPHUR CELLS	9/14/78	11/ 6/79	5	UK	ED	2
4212933	CURRENT COLLECTOR FOR ELECTROCHEMICAL CELLS AND METHOD OF MAKING	5/22/78	7/15/80	5	UK	SC	1
4215466	METHOD OF SEALING CERAMIC ELECTRLOYTE MATERIAL IN ELECTROCHEMICAL CELLS	5/ 3/78	8/ 5/80	5	UK	SC	1
4243733	ELECTRODE STRUCTURES	8/27/79	1/ 6/81	5	UK	ED	0
4291107	GLASS SEALS FOR SEALING BETA-ALUMINA IN ELECTROCHEMICAL CELL OF OTHER EN	4/15/80	9/22/81	5	UK	SC	1
4294005	METHOD OF FORMING CATHODIC ELECTRODE STRUCTURE FOR A SODIUM SULFUR CELL	5/23/79	10/13/81	5	UK	ED	1
4294897	SEALING OF CERAMIC ELECTROLYTE TUBES IN ELECTROCHEMICAL CELLS	3/25/80	10/13/81	5	UK	SC	2
4348467	ELECTROCHEMICAL CELLS CONTAINING LIQUID SODIUM AND THE ANODIC MATERIAL	7/ 7/81	9/ 7/82	5	UK	ED	0
4348468	BETA ALUMINA SOLID ELECTROLYTE MATERIAL AND ITS MANUFACTURE AND ELECTROC	12/17/80	9/ 7/82	5	UK	EY	0
4356241	SODIUM SULPHUR CELLS	7/ 7/81	10/26/82	5	UK	EY	0
4365409	METHOD AND APPARATUS FOR FILLING SODIUM INTO SODIUM SULFUR CELLS	10/ 2/80	12/28/82	5	UK	DS	0
4376809	SODIUM SULPHUR BATTERIES AND CELL MODULES THEREFOR	7/14/81	3/15/83	5	UK	DS	0
4383013	HIGH TEMPERATURE MULTICELL ELECTROCHEMICAL STORAGE BATTERIES	7/14/81	5/10/83	5	UK	DS	0
4396688	ELECTROCHEMICAL CELLS CONTAINING LIQUID SODIUM AS THE ANODIC MATERIAL	12/11/81	8/ 2/83	5	UK	ED	0
4414299	ELECTROCHEMICAL CELLS WITH BETA ALUMINA CERAMIC ELETROLYTE MATERIAL	6/ 9/82	11/ 8/83	5	UK	EY	0
4415637	CATHOD ELECTRODE STRUCTURES FOR SODIUM SULPHUR CELLS AND THEIR MANUFACTU	3/15/82	11/15/83	5	UK	ED	0
COMPAGNIE GENERALE D'ELECTRICITE FRANCE							
3748178	ELECTROCHEMICAL GENERATOR OF THE SODIUM-SULFUR TYPE	10/22/71	7/24/73	5	FR	EY	5
3758337	SODIUM SULFUR ACCUMULATOR WITH TEMPERATURE CONTROLLING MEANS	12/21/71	9/11/73	5	FR	DS	16
4037027	SODIUM SULFUR ELECTRIC CELL AND METHOD OF FORMING SAME	11/ 4/76	7/19/77	5	FR	DS	10
4037028	SODIUM SULFUR TYPE ELECTRIC CELL	11/ 4/76	7/19/77	5	FR	DS	4
4041216	SODIUM-SULFUR BATTERY MORE PARTICULARLY FOR ELECTROCAL DRIVE	3/ 2/76	8/ 9/77	5	FR	DS	1
4049884	SOCIU-SULFUR ELECTRIC CELL	4/ 8/76	9/20/77	5	FR	DS	1
4064209	METHOD OF CONNECTING AN ALKALI BETA ALUMINA PART TO AN ALPHA ALUMINA PAR	7/ 1/76	12/20/77	5	FR	EY	1
4076900	SODIUM-SULFUR TYPE ELECTRIC CELL	11/ 4/76	2/28/78	5	FR	DS	1
4125682	SODIUM-SULFUR ELECTRIC CELL	10/11/77	11/14/78	5	FR	ED	4
4137287	METHOD OF PREPARING BETA ALKALINE ALUMINA PARTS	11/11/76	1/30/79	5	FR	EY	0
4211570	METHOD OF MANUFACTURING BETA ALKALINE ALUMINA PARTS	3/22/79	7/ 8/80	5	FR	EY	0
4330496	METHOD OF STINTERING TUBULAR CERAMIC PARTS	7/28/80	5/18/82	5	FR	EY	0
4332866	METHOD OF TEMPERATURE REGULATION	1/21/81	6/ 1/82	5	FR	DS	1
COMPAGNIE GENERALE DES ETABLISSEMENTS MICHELIN, SOCIALE MICHELIN-CIE FRAN							
4212931	ARRANGEMENT COMPRISING A COMPARTMENT AND A CONDUIT	7/19/78	7/15/80	5	FR	SC	0
4216273	ELECTROCHEMICAL DEVICE WITH SOLID SEPARATOR AND SOLID ELECTROLYTE	12/ 4/78	8/ 5/80	5	FR	DS	0

ASSIGNEE PATENT NUMBER	PATENT TITLE	FILING DATE	ISSUE DATE	SEC TOR	COUN -TRY	TECH TYPE	CITA- TIONS
CORNELL RESEARCH FOUNDATION INC. 3959022	METHOD FOR PRODUCING SODIUM-BETA-ALUMINA SOLID ELECTROLYTES	7/ 9/75	5/25/76	4	US	EY	7
CORNING GLASSWORKS 4310607	BATTERY CELL CONSTRUCTION	7/11/80	1/12/82	4	US	DS	0
4311772	SEALING GLASSES FOR ELECTROCHEMICAL, ELECTRICAL, ELECTRONIC AND OPTICLA	10/ 9/80	1/19/82	4	US	SC	0
4347295	SEALING GLASSES FOR ELECTROCHEMICAL,ELECTRICAL,ELECTRONIC AND OPTICAL AP	8/20/81	8/31/82	4	US	SC	0
4375503	SODIUM ION CONDUCTING GLASSES AND BATTERIES EMBODYING GLASSES	11/ 4/81	3/ 1/83	4	US	EY	0
4387505	METHOD OF FORMING A BATTERY CELL	8/17/81	6/14/83	4	US	DS	0
DEUTSCHE AUTOMOBILGESELLSCHAFT GMBH GERMANY 4230778	SODIUM-SULFUR BATTERY WITH GLASS ELECTROLYTE	3/16/79	10/28/80	5	WG	DS	2
4237196	SODIUM ION-CONDUCTING GLASS ELECTROLYTE FOR SODIUM SULFUR BATTERIES	3/19/79	12/ 2/80	5	WG	EY	1
DOW CHEMICAL COMPANY 3476602	BATTERY CELL	7/25/66	11/ 4/69	3	US	EY	18
3663294	BATTERY EMPLOYING AN ALKALI METAL POLYSULFIDE HAVING A LOW ALKALI METAL	7/ 1/70	5/16/72	3	US	ED	5
3672995	SOLID ELECTROLYTE FOR ELECTROCAL CELLS	5/ 8/69	6/27/72	3	US	EY	2
3679480	ELECTRICAL CELL ASSEMBLY	5/ 8/69	7/25/72	3	US	DS	23
3749603	ALKALI METAL-SULFUR BATTERY HAVING A CATHODIC CURRENT COLLECTOR COATED W	4/17/72	7/31/73	3	US	ED	9
3765944	BATTERY HAVING A MOLTEM ALKALI METAL POLYSULFIDE CATHODE AND CORBON COAT	11/26/71	10/16/73	3	US	ED	2
3829331	SODIUM BORATE GLASS COMPOSITIONS AND BATTERIES CONTAINING SAME	12/30/71	8/13/74	3	US	EY	11
3877995	POTASSIUM BORATE GLASS COMPOSITIONS	12/ 3/73	5/15/75	3	US	EY	2
3917490	METHOD OF GRINDING SOLDER GLASSES	12/23/74	11/ 4/75	2	US	EY	1
4050915	FERRULE AND USE THEREOF FOR COOLING A MELT SPUM HOLLOW GLASS FIBER AS IT	10/ 4/76	9/27/77	2	US	EY	1
4112203	ALKALI METAL/SULFUR BATTERY	4/21/77	9/ 5/78	2	US	DS	6
4170695	SELECTIVE PLUGGING OF BROKEN FIBERS IN TUBESHEET-HOLLOW FIBER ASSEMBLIES	9/22/77	10/ 9/79	3	US	SC	1
4219613	HELIUM FIBER TYPE TUBESHEET FOR HOLLOW FIBER TYPE BATTERY CELLS AND METH	2/16/79	8/26/80	3	US	EY	2
4224386	TUBESHEET FOR HOLLOW FIBER TYPE, HIGH TEMPERATURE BATTERY CELLS	7/18/79	9/23/80	3	US	EY	1
4226921	SELECTIVE PLUGGING OF BROKEN FIBERS IN TUBESHEET-HOLLOW FIBER ASSEMBLIES	7/16/79	10/ 7/80	3	US	DS	0
4252869	BY PASS FOR INTERNALLY OPEN-CIRCUITED CELLS	8/13/79	2/24/81	3	US	DS	1
4332868	HIGH TEMPERATURE BATTERY CELL COMPRISING STRESS-FREE HOLLOW FIBER BUNDL	9/ 1/78	6/ 1/82	3	US	DS	0
E.I. DUPONT DE NEMOURS AND COMPANY 4097345	NA5GOSI4012 AND RELATED RARE EARTH SODIUM ION CONDUCTORS AND ELECTROLYTI	10/15/76	6/27/78	4	US	EY	1
4181579	SODIUM ION CONDUCTING SODIUM ALUMINUM PHOSPHATE GLASSES	6/19/78	1/ 1/80	4	US	EY	0
4190500	SODIUM ION CONDUCTING SODIUM ALUMINUM BORATE GLASSES	6/19/78	2/26/80	4	US	EY	2
4206016	SODIUM ION CONDUCTING SODIUM BOROPHOSPHATE GLASS	4/ 6/79	6/ 3/80	4	US	EY	1
4223077	NA+ CONDUCTING GLASS. GLASS CERAMIC AND CRYSTALLINE CUBIC COMPOSITION	7/ 2/79	9/16/80	4	US	EY	0
EASTMAN KODAK COMPANY 4083919	BETA-ALUMINA COMPOSITES AND METHODS FOR PRODUCING THEM	4/ 4/76	4/11/78	4	US	EY	2
ELECTRIC COUNCIL ENGLAND 3903225	PRODUCTION OF BETA ALUMINA CERAMIC	12/28/71	9/ 2/75	5	UK	EY	9
3922176	ELECTROCHEMICAL CELLS HAVING A LIQUID ALKALI METAL ELECTRODE	1/ 2/74	11/25/75	5	UK	ED	5
3950463	PRODUCTION OF BETA-ALUMINA CERAMIC TUBER	5/ 9/72	4/13/76	5	UK	EY	8
3953227	ELECTROCHEMICL CELLS HAVING A LIQUID ALKALI METAL ELECTRODE AND SOLID EL	9/20/74	4/27/76	5	UK	DS	3
3982957	SODIUM SULFUR CELLS	2/14/75	9/28/76	5	UK	ED	19
4059663	PRODUCTION OF BETA-ALUMINA CERAMIC ARTICLES AND FURNACE THERFOR	12/ 8/75	11/22/77	5	UK	EY	1
4061840	SODIUM SULFUR CELLS	9/ 9/76	12/ 6/77	5	UK	ED	4

ASSIGNEE PATENT NUMBER	PATENT TITLE	FILING DATE	ISSUE DATE	SEC TOR	COUN -TRY	TECH TYPE	CITA- TIONS
ELECTRIC COUNCIL ENGLAND							
4066826	SODIUM SULPHUR CELLS	9/ 8/76	1/ 3/78	5	UK	ED	2
4129690	SODIUM SULPHUR CELLS	10/13/77	12/12/78	5	UK	ED	0
ELECTRIC POWER RESEARCH INSTITUTE, INC.							
4048390	NA/S CELL REACTANT CONTAINER WITH METAL ALUMINIDE COATING	12/20/76	9/13/77	4	US	SC	2
4049885	CONSTRUCTION FOR SOLID ELECTROLYTE IN SODIUM/SULFUR BATTERY	10/12/76	9/20/77	4	US	DS	3
4053689	CONTACT BETWEEN METAL CAN AND CARBON/GRAPHITE FIBERS IN SODIUM/SULFUR CE	12/20/76	10/11/77	4	US	ED	3
4070527	EFFICIENT SODIUM-SULFUR BATTERY	8/13/76	1/24/78	4	US	ED	4
4110516	SOCIUM SULFUR CELL CASING	6/15/77	8/29/78	4	US	SC	8
4123566	NA/S CELL REACTANT CONTAINER WITH METAL ALUMINIDE COATING	6/23/77	10/31/78	4	US	SC	0
4124740	SODIUM SULFUR BATTERY	12/27/77	11/ 7/78	4	US	SC	1
4131226	SULFUR ELECTRODE CONTAINER CONSTRUCTION AND METHOD OF MANUFACTURE	9/28/77	12/26/78	4	US	SC	6
4146683	SULFUR CELL CONSTRUCTION AND METHOD	11/ 4/77	3/27/79	4	US	ED	0
4188463	SODIUM-SULFUR BATTERY AND METHOD OF MAKING A DOUBLE CARBON MAT-COMPOSITE	2/ 1/79	2/12/80	4	US	ED	0
4189530	SODIUM INSERT CONTAINER FOR A SODIUM-SULFUR CELL AND METHOD	9/25/78	2/19/80	4	US	SC	1
4189531	NA/S REACTANT CONTAINER WITH PROTECTIVE RESIN COATING	10/26/78	2/19/80	4	US	SC	0
4204035	SODIUM INSERT CONTAINER FOR A SODIUM-SULFUR CELL AND ITS METHOD OF USE	9/25/78	5/20/80	4	US	DS	0
4218524	IN-SITU PREPARATION OF THE SULFUR ELECTRODE FOR SODIUM-SULFUR BATTERIES	4/ 9/79	8/19/80	4	US	ED	0
4219128	SULFUR ELECTRODE CONTAINER CONSTRUCTION AND METHOD OF MANUFACTURE	10/10/78	8/26/80	4	US	SC	0
4220691	SODIUM SULFUR CELL	9/25/78	9/ 2/80	4	US	ED	1
4232098	CODIUM SULFUR CELL COMPONENT PROTECTED BY A HIGH CHROMIUM ALLOY AND MEHT	3/22/78	11/ 4/80	4	US	SC	2
4234668	SOMPOSITE SULFUR ELECTRODE CONTAINER AND METHOD OF MANUFACTURE	4/20/78	11/18/80	4	US	SC	2
4246325	SODIUM SULFUR BATTERY INCLUDING THERMALLY RESPONSIVE VALVE AND METHOD	7/ 3/79	1/20/81	4	US	DS	1
4266712	METHOD OF MAKING A SULFUR ELECTRODE CONTAINER	3/31/80	5/12/81	4	US	SC	0
4269909	SODIUM-SULFUR CELL WITH METHOD OF CONSTRUCTING THE SULFUR ELECTRODE	1/18/80	3/16/81	4	US	ED	1
4287664	SULFUR ELECTRODE CONTAINER AND METHODS OF MANUFACTURE	10/22/79	9/ 8/81	4	US	SC	1
ENGELHARD MINERALS AND CHEMICAL CORP.							
4193954	BETA ALUMINA MANUFACTURE	3/27/78	3/18/80	4	US	EY	1
ESB INCORPORATED							
3718505	SODIUM-SULFUR BATTEWRY HAVING ALUMINUM SULFIDE OR ALUMINUM POLYSULFIED I	12/ 7/71	2/27/73	4	US	EY	1
EXXON RESEARCH AND ENGINEERING COMPANY							
3895963	PROCESS FOR THE FORMATION OF BETA ALUMINA-TYPE CERAMICA	12/20/72	7/22/75	3	US	EY	7
FORD AEROSPACE & COMMUNICATIONS CORP.							
4170694	HERMATECALLY SEALED ALKALI METAL BATTERY CONTAINER	12/ 4/78	10/ 9/79	3	US	SC	3
FORD MOTOR COMPANY							
3404035	SECONDARY BATTERY EMPLOYING MOLTEN ALKALI METAL REACTANT	10/22/65	10/ 1/68	3	US	DS	28
3404036	ENERGY CONVERSION DEVICE COMPRISING A SOLID CRYSTALLINE ELECTROLYTE AND	5/ 2/66	10/ 1/68	3	US	DS	21
3413150	BATTERY HAVING A MOLTEN ALKALI METAL ANODE AND A MOLTEN SULFUR CATHODE	9/28/66	11/26/68	3	US	DS	31
3446677	METHOD OF MAKING A SOLID IONIC CONDUCTOR	11/21/66	5/27/69	3	US	EY	7
3468709	SECONDARY BATTERY EMPLOYING AN ELECTRONICALLY-INSULATIVE CATIONCALLY-CON	4/ 3/67	9/23/69	3	US	DS	7
3468719	SOLID STATE IONIC CONDUCTOR AND METHOD OF MAKING	11/21/66	9/23/69	3	US	EY	6
3475220	SECONDARY BATTERY	6/22/67	10/28/69	3	US	DS	4
3475225	METHOD FOR PREPARING SOLID STATE IONIC CONDUCTOR	11/21/66	10/28/69	3	US	EY	4
3514332	SECONDARY BATTERY WITH ALKALI SULFUR ELECTRODES AND MOVABLE SOLID ELECTR	4/ 3/67	5/26/70	3	US	DS	8
3719531	CATIONICALLY CONDUCTIVE CERAMICS, THEIR PREPARATION AND USE	12/22/69	3/ 6/73	3	US	EY	3

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FORD MOTOR COMPANY							
3756856	FLEXABLE SEALING MATERIAL FOR ENERGY CONVERSIN DEVICES	11/ 2/71	9/ 4/73	3	US	SC	10
3811943	MASS TRANSPORTATION ELECTRODE FOR ENERGY CONVERSION DEVICE	2/16/71	5/21/74	3	US	ED	24
3951689	ALKALI METAL-SULFUR CEL WITH GAS FUEL CELL ELECTRODE	8/20/75	4/20/76	2	US	DS	0
3966492	SODIUM SULFUR BATTERY OR CELL WITH IMPROVED WMPERE-HOUR CAPACITY	8/20/75	6/29/76	2	US	ED	0
3976503	PROCESS FOR RECHARGING SECONDARY BATTERIES	4/14/75	8/24/76	2	US	ED	2
3980496	ENERGY CONVERSION DEVICES WITH IMPROVED ELECTRODE SHAPES	1/29/75	9/14/76	2	US	ED	9
3985576	SEAL FOR ENERGY CONVERSION DEVICES	2/18/76	10/12/76	3	US	SC	6
3993503	SECONDARY BATTERY OR CELL WITH COMPOSITE ELECTRODE	1/30/76	11/23/76	2	US	ED	7
3994745	SECONDARY BATTERY WITH SEPARATE CHARGE AND DISCHARGE ZONES	1/30/76	11/30/76	2	US	ED	3
4002806	SECONDARY BATTERY OR CELL	8/20/75	1/11/77	2	US	ED	2
4002807	ALKALI METAL SULFUR BATTERY OR CELL WITH SINGLE PHASE SULFUR ELECTRODE	9/30/75	1/11/77	2	US	ED	4
4038465	SODIUM SULFUR BATTERY OR CELL WITH EXTERNAL STORAGE	11/11/75	7/26/77	2	US	DS	3
4048393	ALKALI METAL BATTERY STRUCTURE	9/ 3/76	9/13/77	3	US	SC	2
4048394	SECONDARY BATTERY OR CELL WITH VITEOUS CARBON COATED GRAPHITE CURRENT CO	2/28/77	9/13/77	2	US	DS	1
4049889	HERMETICALLY SEALED ALKALI METAL BATTERY CONTAINER	9/ 1/76	9/20/77	3	US	SC	7
4056589	METHOD FOR SINTERING CERAMICS	2/18/76	11/ 1/77	3	US	EY	2
4084041	SECONDARY BATTERY OR CELL WITH POYSULFIDE WETTABLE ELECTRODE	2/22/77	4/11/78	2	US	ED	0
4084042	SECONDARY BATTERY OR CELL WITH POYSULFIDE WETTABLE ELECTRODE #1	3/22/77	4/11/78	2	US	ED	2
4091151	SECONDARY BATTERY OR CELL WITH IMPROVED RECHARGEABILITY	9/15/77	5/23/78	2	US	EY	1
4091190	HERMETICALLY SEALED ALKALI METAL BATTERY CONTAINER	5/23/77	5/23/78	2	US	SC	2
4102042	MEHTOD FOR PREPARING A SODIUM/SULFUR CELL	3/11/77	7/25/78	2	US	DS	3
4110515	METHOD OF PREPARING COMPOSITE BODY AND SECONDARY BATTERY OF CELL INCORP	2/28/77	8/29/78	2	US	ED	2
4117208	ELECTRICAL CONVERSION DEVICE WITH CERAMIC ELECTRODE	9/15/77	9/26/78	3	US	SC	2
4166156	SECONDARY BATTERY OR CELL WITH PYROLYTIC GRAPHITE COATED GRAPHITE CURREN	2/28/77	8/28/79	2	US	SC	0
4169919	DOUBLE SEAL FOR SODIUM SULFUR BATTERY	10/26/78	10/ 2/79	2	US	SC	2
4192911	SODIUM SULFUR BATTERY SEAL	11/ 1/78	3/11/80	2	US	SC	1
4197363	SEAL FOR SODIUM SULFUR BATTERY	10/26/78	4/ 8/80	2	US	SC	1
4226923	VOLUME EFFICIENT SODIUM SULFUR BATTERY	10/29/79	10/ 7/80	2	US	DS	1
4239838	ENERGY CONVERSION DEVICE WITH IMPROVED SEAL	12/ 5/79	12/16/80	2	US	SC	0
4245012	SODIUM SULFUR BATTERY CELL	8/28/79	1/13/81	2	US	SC	1
4247605	METHOD OF FORMING AND STARTING A SODIUM SULFUR BATTERY	4/ 7/80	1/27/81	2	US	DS	0
4248943	SODIUM SULFUR CONTIANER WITH CHROMIUM/CHROMIUM OXIDE COATING	4/21/80	2/ 3/81	2	US	SC	1
4290192	METHOD OF MAKING A SODIUM SULFUR BATTERY	12/20/79	9/22/81	2	US	SC	0
4375127	METHOD OF ASSEMBLING AND SEALING AN ALKALI METAL BATTERY	9/ 5/80	3/ 1/83	2	US	SC	0
GENERAL ELECTRIC COMPANY							
3533848	SODIUM-SULFUR FUEL CELL UNITS	4/20/67	10/13/70	4	US	DS	9
3579382	SEALED CONTAINER FOR ELEMENTAL SODIUM	3/27/69	5/18/71	4	US	ED	1
3607405	SEALED CONTAINER FOR ELEMENTAL SODIUM	2/27/69	9/21/71	4	US	ED	0
3607435	METHOD OF MAKING SINTERED BETA-ALUMINA BODIES	12/17/69	9/21/71	4	US	EY	3
3607436	SINTERED BETA-ALUMINA BODIES AND METHOD	12/17/69	9/21/71	4	US	EY	4
3625773	METHOD OF PRODUCING BETA-ALUMINA ELECTROLYTES	12/17/69	12/ 7/71	4	US	EY	4
3672994	SODIUM-SULFUR CELL WITH THIRO ELECTRODE	1/ 4/71	6/27/72	4	US	ED	4
3852114	CELL CASING AND HERMETICALLY SEALED PRIMARY SODIUM-SULFUR CELL	12/28/73	12/ 3/74	4	US	SC	3
3896018	METHOD OF FORMING BETA-ALUMINA ARTICLES	9/24/73	7/22/75	4	US	EY	2
3896019	METHOD OF FORMING BETA-ALUMINA ARTICLES	10/ 4/73	7/22/75	4	US	EY	2
3900381	METHOD OF FORMING BETA-ALUMINA ARTICLES	9/24/73	8/19/75	4	US	EY	2
3928071	HERMETICALLY SEALED PRIMARY BATTERY	10/ 4/74	12/23/75	4	US	SC	6
3933523	SOLID SODIUM ION-CONDUCTIVE ELECTROLYTE WITH LIQUID METALLIC LAYER	2/24/75	1/20/76	4	US	EY	4
3946751	CELL CASING WITH A HERMETIC MECHANICAL SEAL AND A HERMETICALLY SEALED SO	2/18/75	3/30/76	4	US	SC	15

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GENERAL ELECTRIC COMPANY							
3959013	CATHODE CELL CASING PORTION, A CELL CASING, AND A HERMETICALLY SEALED SO	6/11/75	5/25/76	4	US	SC	16
3960596	BATTERY CASING AND HERMETICALLY SEALED SODIUM-SULFUR BATTERY	3/ 4/74	6/ 1/76	4	US	SC	7
3976554	METHOD OF FORMING BETA-ALUMINA ARTICLES	12/31/75	8/24/76	4	US	EY	0
4012563	SEALED LITHIUM-SODIUM ELECTROCHEMICAL CELL WITH SODIUM BETA-ALUMINA ELEC	3/ 1/76	3/15/77	4	US	DS	2
4073711	METHOD OF PRODUCING LITHIATED BETA ALUMINA ARTICLES	11/22/76	2/14/78	4	US	EY	0
4084040	CELL CASING AND A HERMETICALLY SEALED SODIUM-SULFUR CELL	2/28/77	4/11/78	4	US	SC	7
4109063	COMPOSITE BODY	6/17/77	8/22/78	4	US	SC	1
4124744	COMPOSITE SOLID ELECTROLYTE BODY	11/17/77	11/ 7/78	4	US	SC	0
4134694	COMPOSITE BODY AND METHOD OF FORMING	3/20/78	12/26/78	4	US	SC	0
4135040	SOLID ION-CONDUCTIVE ELECTROLYTE BODY AND METHOD OF FORMING	12/20/77	1/16/79	4	US	EY	0
4140841	SULFUR ELECTRODE, SULFUR ELECTRODE CONTAINER AND METHODS OF MANUFACTURE	5/11/78	2/20/79	4	US	ED	2
4142945	METHOD OF FORMING A COMPOSITE BODY AND METHOD OF BONDING	6/22/77	3/ 6/79	4	US	SC	0
4197171	SOLID ELECTROLYTE MATERIAL COMPOSITE BODY, AND METHOD OF BONDING	10/24/78	4/ 8/80	4	US	EY	1
4209573	SULFUR ELECTRODE CONTAINER AND METHODS OF MANUFACTURE	4/10/78	6/24/80	4	US	SC	1
4230256	METHOD OF BONDING A COMPOSITE BODY TO A METALLIC ELEMENT	11/ 6/78	10/28/80	4	US	SC	0
4236661	THERMOCOMPRESSSION METHODS OF FORMING SODIU-SULFUR CELL CASINGS	1/17/79	12/ 2/80	4	US	SC	0
4268313	SODIUM RESISTANT SEALING GLASSES	4/21/80	5/19/81	4	US	SC	0
4291108	PRODUCTION OF BETA-ALUMINA CERAMIC TUBES	8/25/80	9/22/81	4	US	EY	0
4302519	PRODUCTION OF B-ALUMINA CERAMIC TUBES	8/25/80	11/24/81	4	US	EY	0
4307138	SINTERED ION-CONDUCTIVE COMPOSITE ELECTROLYTE OF BETA-ALUMINA AND B"-ALU	5/23/80	12/22/81	4	US	EY	0
4341849	SODIUM RESISTANT SEALING GLASSES AND SODIUM-SULFUR CELLS SEALED EITH SAI	3/ 2/81	7/27/82	4	US	SC	1
4374701	CHEMICALLY POLISHED CERAMIC BODY	8/ 3/81	2/22/83	4	US	EY	0
4381216	METHOD OF ETCHING TO FORM CATIONICALLY-CONDUCTIVE CERAMIC BODY	8/ 3/81	4/26/83	4	US	EY	0
4381968	ETCHED BETA"-ALUMINA CERAMIC ELECTROLYTE	8/ 3/81	5/ 3/83	4	US	EY	0
GENERAL MOTORS							
4052538	METHOD OF MAKING SODIUM BETA-ALUMINA POWDER AND SINTERED ARTICLES	4/19/76	10/ 4/77	4	US	EY	3
GREAT LAKES CARBON CORP.							
4127634	SULFUR GRAPHITE FIBER ELECTRODE FOR SODIUM-SULFUR BATTERIES	1/ 4/78	11/28/78	4	US	ED	0
4169120	SULFUR ELECTRODE FOR SODIUM-SULFUR BATTERIES	5/15/78	9/25/79	4	US	ED	1
HITACHI, LTD. JAPAN							
4390460	LITHIUM OXIDE BASED AMORPHOUS MATERIAL AND PROCESS FOR PREPARATION THERE	9/28/81	6/28/83	5	JP	EY	0
INSTITUTE OF GAS TECHNOLOGY							
4226922	SODIUM SULFUR ELECTROCHEMICAL CELL OR BATTERY	8/ 9/79	10/ 7/80	4	US	SC	0
INTERNATIONAL BUSINESS MACHINES CORP							
4024214	METHOD OF PREPARING BETA AL2O3	2/17/76	5/17/77	4	US	EY	1
KABUSHIKI KAISHA DAINI SEIKOSHA JAPAN							
3963522	METHOD OF IMPROVED TREATMENT RELATING TO THE SURFACE OF THE ELECTROLYTE	11/13/74	6/15/76	5	JP	EY	1
KABUSHIKI KAISHA TOYOTA CHUO KENKYUSHO JAPAN							
3655845	HEATING A SINTERES ALUMINA ARTICLE IN ATMOSPHERE CONTAINING SODIUM OR PO	7/29/69	4/11/72	5	JP	EY	5
3707589	REHEATING A BETA-ALUMINA ARTICLE IN AN ALDALI METAL ATMOSPHERE TO IMPROV	4/13/71	12/26/72	5	JP	EY	5
3743543	SEPARATOR FOR CONTROLLING ALKALI METAL ION FLOW IN AN ELECTRODE ACTIVE M	9/29/70	7/ 3/73	5	JP	EY	2
3883367	SODIUM SULFUR STORGE BATTERY	10/17/73	5/13/75	5	JP	ED	13
3915741	SODIUM-SULFER CELL WITH IMPROVED SEPARATOR	7/17/74	10/28/75	5	JP	ED	6

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KABUSHIKI KAISHA TOYOTA CHUO KENKYUSHO JAPAN 4021255	SINTERED BETA-ALUMINA ARTICLE PERMEABLE TO SODIUM AND POTASSIUM IONS AND	2/14/75	5/ 3/77	5	JP	EY	1
MIT 4049891	COMPOSITION FOR FAST ALKALI-METAL-ION TRANSPORT	6/21/76	9/20/77	2	US	EY	3
4166159	PROCESS FOR FORMING FAST SODIUM-ION TRANSPORT COMPOSITIONS	8/ 2/78	8/28/79	3	US	EY	2
MONSANTO COMPANY 4348458	COILED INORGANIC MONOLITHIC HOLLOW FIBERS	9/ 8/80	9/ 7/82	4	US	EY	0
NICHICON CAPACITOR LIMITED JAPAN 3687735	METHOD OF MANUFACTURING A SOLID ION CONDUCTIVE COMPOSITION	1/ 5/70	8/29/72	5	JP	EY	1
NKG SPARK PLUG CO., LTD. JAPAN 4082826	PROCESS FOR PRODUCING HIGHLY ION-CONDUCTIVE PORCELAIN	5/19/77	4/ 4/78	5	JP	EY	5
4279974	SOLID ELECTROLYTE MATERIAL AND USE THEREOF	3/19/80	7/21/81	5	JP	DS	1
OWENS-ILLINOIS GLASS INC 4041215	METHOD FOR FORMING SOLID ELECTROLYTE COMPOSITE	4/ 5/76	8/ 9/77	4	US	EY	2
PHILLIPS PETROLEUM COMPANY 4172182	ENERGY CONVERSION DEVICES	3/21/78	10/23/79	4	US	SC	0
ROCKWELL INTERNATIONAL CORP. 4358516	SODIUM ION CONDUCTOR SOLID ELECTROLYTE STRENGTHENED WITH ZIRCONIA	10/16/81	11/ 9/82	3	US	EY	0
SECRETARY OF STATE FOR INDUSTRY ENGLAND 3932195	ELECTRIC CELLS	4/29/75	1/13/76	5	UK	DS	10
3982959	SODIUM SULFUR BATTERY CELLS	3/ 7/75	9/28/76	5	UK	DS	8
4006281	ELECTRIC CELLS	6/30/75	2/ 1/77	5	UK	ED	4
4029858	ELECTRIC CELLS	11/17/75	6/14/77	5	UK	ED	7
4035553	SODIUM-SULFUR ELECTRIC BATTERIES WITH CERAMIC SPACER IN SULFUR COMPARTME	7/ 6/76	7/12/77	5	UK	ED	1
4044191	ELECTRIC CELLS	11/17/75	9/23/77	5	UK	ED	0
4044194	ELECTRID BATTERIES	6/30/75	9/23/77	5	UK	DS	2
4068048	METHOD FOR PREPARING ALKAILINE BETA ALUMINA PARTS	3/22/76	1/10/78	5	FR	EY	3
SHELL OIL COMPANY 3795723	BETA ALUMINA PRODUCTION	3/29/72	3/ 5/74	4	US	EY	6
SOCIETE ANONYME DE VEHICULES INDUSTRIELS ET D'EQUIPMENTS MACHANIQUES SAV 4230780	SODIUM SULFUR ELECTRIC CELL	10/22/79	10/28/80	5	FR	DS	1
SOUTH AFRICAN INVENTIONS DEVELOPMENT CORP. 4269905	ELECTROCHEMICAL CELL AND THE PROTECTION OF AN ELECTROCHEMICAL CELL	11/28/79	5/26/81	5		SC	0
TRW INC. 3901733	THIN FILM SOLID ELECTROLYTE STRUCTURES AND PROCESS OF MAKING SAME	10/ 7/74	8/26/75	4	US	EY	6

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U. S. DEPT. OF ENERGY							
4263381	SINTERING OF BETA-TYPE ALUMINA BODIES USING ALPHA-ALUMINA ELCAPSULATION	10/27/78	4/21/81	1	US	EY	1
4339511	PREPARATION OF POWDERS SUITABLE FOR CONVERSION TO USEFUL B-ALUMINAS	4/16/81	7/13/82	1	US	EY	0
4393124	SOLID ELECTROLYTES STRENGTHENED BY METAL DISPERSIONS	10/ 5/81	7/12/83	1	US	EY	0
U.S.A. SECRETARY OF THE ARMY							
3449165	BATTERY	2/ 9/68	6/10/69	1	US	DS	3
UNASSIGNED OR INDIVIDUALLY OWNED							
4038464	SODIUM-SULFUR BATTERY AND PROCESS FOR ITS PRODUCTION	11/26/75	7/26/77	5	WG	DS	3
4105834	ELECTRIC CELLS	10/ 3/77	8/ 8/78	4	US	SC	3
4146684	ELECTROCHEMICAL STORAGE CELL	7/20/77	3/27/79	5	WG	ED	5
UNITED KINGDOM ATOMIC ENERGY AUTHORITY ENGLAND							
4011366	ELECTRIC CELLS	5/11/76	3/ 8/77	5	UK	DS	4
4322485	PREPARATION OF MATERIALS	6/ 5/80	3/30/82	5	UK	EY	1
UNIVERSITY OF UTAH							
4013477	METHOD FOR PREPARING DENSE BETA-ALUMINA CERAMIC BODIES	7/30/75	3/22/77	2	US	EY	3
4113928	METHOD OF PREPARING DENSE, HIGH STRENGTH AND ELECTRICALLY CONDUCTIVE CER	4/18/77	9/12/78	2	US	EY	1
4138455	METHOD FOR PREPARING DENSE, BETA-ALUMINA CERAMIC BODIES BY LIQUID PHASE	4/15/77	2/ 6/79	2	US	EY	1
4160069	ELECTRICALLY CONDUCTIVE AND CORROSION RESISTANT CURRENT COLLECTOR AND/OR	2/18/77	7/ 3/79	2	US	DS	1
VARTA AKTIENGESSELLSCHAFT GERMANY							
4394280	ION CONDUCTIVE MIXED CRYSTAL	4/19/82	7/19/83	5	WG	EY	0
4424262	ELECTROCHEMICAL STORAGE CELL	10/21/81	1/ 3/84	5	WG	DS	0
WESTINGHOUSE ELECTRIC CORP.							
4208475	METHOD OF FORMING SODIUM BETA-AL2O3 SOLID MATERIALS	12/28/78	6/17/80	2	US	EY	0
4244986	METHOD OF FORMING SODIUM BETA-AL2O3 FILMS AND COATINGS	4/24/79	1/13/81	2	US	EY	1
4395432	BETA-ALUMINA COATING	12/16/81	7/26/83	3	US	EY	0
YUASA BATTERY CORPORATION LTD. JAPAN							
3770502	SODIUM-SULFUR STORAGE BATTERY	8/11/72	11/ 6/73	5	JP	ED	17
3841912	SODIUM SULFUR STORAGE BATTERY	4/ 2/73	10/15/74	5	JP	DS	14

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