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Environmental, Health, and Safety Issues of Sodium-Sulfur Batteries for Electric and Hybrid Vehicles

Volume II: Battery Recycling and Disposal

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Preface

This report is the second of four volumes to identify and assess the environmental, health, and safety issues involved in using sodium-sulfur (Na/S) battery technology as the energy source in electric and hybrid vehicles. These reports are intended to help the Electric and Hybrid Propulsion Division of the Office of Transportation Technologies in the U.S. Department of Energy (DOE/EHP) determine the direction of its research, development, and demonstration program for Na/S battery technology.

These reports were prepared by the Analytic Studies Division of the National Renewable Energy Laboratory and are one part of DOE/EHP's RD&D program to work with industry to commercialize Na/S batteries. For example, data and information obtained through these reports will assist the DOE/EHP implement recommendations made by participants at government-industry meetings on sodium-beta batteries sponsored by the DOE/EHP. The reports may also assist the DOE/EHP and the Ad Hoc Electric Vehicle Battery Readiness Working Group coordinate the RD&D needed to commercialize Na/S and sodium metal chloride battery technologies.[1]

This volume covers battery recycling and disposal. Regulations affecting Na/S battery disposal are reviewed and discussed, and their impacts on potential recycling processes are analyzed. The report is based on a review of the literature and on discussions with experts at DOE, national laboratories and agencies, universities, and private industry. Subsequent volumes will address environmental, health, and safety issues involved in cell and battery safety, shipping cells and batteries, and in-vehicle safety.

I am indebted to many people who helped me obtain information for this report and reviewed its contents. I am especially indebted to Rudy Jungst of Sandia National Laboratories who helped me understand some of the different recycling processes being studied for Na/S batteries and who reviewed this report. I would also like to thank David Topping of the United States Environmental Protection Agency for reviewing a draft of this report and offering helpful suggestions. Finally, I would like to thank Dana O'Hara of the Department of Energy's Electric and Hybrid Propulsion Division for his leadership and support in directing and sponsoring the Environment, Health, and Safety program and this work.

[1]The Ad Hoc Electric Vehicle Battery Readiness Working Group consists of leading scientists and program managers from government agencies, battery developers, automobile manufactures, and the chemical processing industry.

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Introduction

Recycling and disposal of spent sodium-sulfur (Na/S) batteries are important issues that must be addressed as part of the commercialization process of Na/S battery-powered electric vehicles. The use of Na/S batteries in electric vehicles will result in significant environmental benefits, and the disposal of spent batteries should not detract from those benefits. In the United States, waste disposal is regulated under the Resource Conservation and Recovery Act (RCRA). Understanding these regulations will help in selecting recycling and disposal processes for Na/S batteries that are environmentally acceptable and cost effective.

Treatment processes for spent Na/S battery wastes are in the beginning stages of development, so a final evaluation of the impact of RCRA regulations on these treatment processes is not possible. The objectives of this report on battery recycling and disposal are as follows:

- Provide an overview of RCRA regulations and requirements as they apply to Na/S battery recycling and disposal so that battery developers can understand what is required of them to comply with these regulations;

- Analyze existing RCRA regulations for recycling and disposal and anticipated trends in these regulations and perform a preliminary regulatory analysis for potential battery disposal and recycling processes.

This report assumes that long-term Na/S battery disposal processes will be capable of handling large quantities of spent batteries. The term disposal, as further used in this report, includes treatment processes that may incorporate recycling of battery constituents. The environmental regulations analyzed in this report are limited to U.S. regulations. Part 1 of this report gives an overview of RCRA and discusses RCRA regulations governing Na/S battery disposal (readers familiar with RCRA regulations may skip part 1 if they wish). Part 2 of this report contains a preliminary regulatory analysis for Na/S battery disposal.

Part 1 - Overview of Resource Conservation and Recovery Act Regulations Governing Na/S Battery Disposal

Background

Solid waste in the United States is regulated under the Resource Conservation and Recovery Act (RCRA). RCRA was passed in 1976 as an amendment to the Solid Waste Disposal Act. The primary objectives of RCRA are to protect human health and the environment and to conserve valuable material and resources [1]. The requirements contained in Subtitle C of RCRA cover the management of hazardous wastes. Spent Na/S batteries contain wastes that are considered hazardous under Subtitle C of RCRA, so the storage and disposal of spent Na/S batteries are subject to this subtitle. RCRA regulations, as further discussed in this report, refer to the hazardous waste regulations contained in Subtitle C of RCRA.

It is the responsibility of the U. S. Environmental Protection Agency (EPA) to develop regulations to carry out and enforce RCRA. Hazardous waste regulations enforcing RCRA can be found in *Code of Federal Regulations (40 CFR), Parts 260-281*. *Code of Federal Regulations* is updated once a year to reflect new rulings. Most states have the authority from the federal EPA to operate their own hazardous waste programs. States that have this authority may adopt their own hazardous waste regulations, which must be at least as stringent as the EPA regulations. RCRA regulations would apply to Na/S batteries after they were designated as a hazardous waste, hence the issue of when (and if) a spent Na/S battery becomes a regulated waste under RCRA will need to be examined as the regulatory process for Na/S battery disposal becomes further defined. The Appendix contains an overview of RCRA, with explanations of the major provisions and definitions of important terms and concepts.

RCRA Regulations Impacting Na/S Battery Storage and Disposal

RCRA regulations that affect Na/S battery disposal are discussed below. This is not a comprehensive list of all the RCRA requirements that will affect Na/S battery disposal, but an overview of some of the more important requirements and provisions.

Listed and Characteristic Wastes

A solid waste is considered a hazardous waste (and therefore subject to RCRA requirements) if it is either a "listed " waste under *40 CFR Part 261 Subpart D*, or a "characteristic" waste [1]. A waste is listed as a hazardous waste based on the process from which the waste was generated and/or the constituents found in the waste [1]. A characteristic waste exhibits any one or more of the following hazardous characteristics: ignitability, corrosivity, reactivity, or toxicity. The Appendix gives definitions for each type of hazardous characteristic.

Waste Manifesting and Treatment, Storage, and Disposal Facilities

RCRA regulations require that a hazardous waste be tracked from its generation to its final disposal. Final disposal takes place at a licensed treatment, storage, and disposal (TSD) facility. This "cradle-to-grave" approach incorporates a tracking system whereby the waste is accompanied by a manifest as it exchanges hands from generators to transporters through to its disposal at a TSD facility. The manifest system assigns responsibility for the hazardous waste to someone at each stage of its handling, with the TSD facility being the last link in a manifest system under RCRA. The recordkeeping and reporting requirements associated with the manifest system are burdensome.

TSD facilities are defined in *40 CFR Part 260.1* and explained in depth in Part 264. A TSD facility encompasses three different functions:

- Treatment: Any method, technique, or process, including neutralization, designed to change the physical, chemical or biological character or composition of any hazardous waste so as to neutralize such waste, or so as to recover energy or material resources from the waste, or so as to render such waste nonhazardous, or less hazardous; safer to transport, store, or dispose of; or amenable for recovery, storage or reduced in volume.

- Storage: The holding of hazardous waste for a temporary period, at the end of which the hazardous waste is treated, disposed of, or stored elsewhere.

- Disposal: The discharge, deposit, injection, dumping, spilling, leaking or placing of any solid waste or hazardous waste into or on any land or water so that any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including ground waters (*40 CFR 260.1*).

RCRA regulations require that owners and operators of TSD facilities obtain a permit from the EPA. A TSD permit, often referred to as a *Part B permit*, is required if a facility performs any one of the three processes of treating, storing, or disposing of a hazardous waste. The TSD permitting process is typically a very long process requiring very detailed information that is site-specific and technology-specific. The approximate time required to obtain a TSD permit to treat and dispose of hazardous wastes is hard to predict and depends on the specific waste being treated and the treatment technology proposed, as well as the state environmental agency where the permit is required. Permit approvals may take up to 5 years in certain cases. Permits for storing hazardous wastes are usually much easier to obtain than those for treating hazardous wastes.

Some of the requirements for a TSD permit for treating and disposing of hazardous wastes are: waste analysis, security requirements, preparedness and prevention plans, training requirements, contingency plans and emergency procedures, and a manifest including recordkeeping and reporting. A public hearing is also a requirement for a TSD permit, although the public hearing may be waived in cases in which there is no public interest.

Federal Versus State Authorization

EPA may delegate authority to individual states to operate a state hazardous waste program in lieu of part or all of the federal hazardous waste program, yet EPA still retains certain oversight authority in states with EPA-authorized hazardous waste programs. State regulations must be as stringent as the federal regulations and may be more stringent if the state desires. Most states have been granted authority to administer their own state hazardous waste programs, and these programs may vary significantly from state to state. Although the EPA requires that state regulations be as stringent as the federal regulations, in many cases state hazardous waste requirements are less stringent than the federal requirements because of the procedures by which the regulations are interpreted and enforced. Differences in state hazardous waste programs may have an effect on where companies choose to locate their TSD facilities.

Hazardous Waste Export Requirements

40 CFR Part 262.51 contains regulations for the export of hazardous waste. Exporters of hazardous waste must comply with stringent notification, recordkeeping, and manifesting requirements. New regulations may be adopted in the future that further restrict hazardous waste exports.

Future Regulations

RCRA and its 1984 amendments are up for reauthorization, and Congress is currently in the process of passing new RCRA legislation, with a number of bills being discussed, revised, and evaluated. Most of the new legislation would extend RCRA's regulatory authority. For example, legislation expanding the definition of a hazardous waste and tightening existing regulations is being considered [1]. RCRA reauthorization may include provisions for exempting more recycling processes from RCRA permitting, which could make recycling easier for these processes. This could have a direct impact on Na/S battery recycling processes by redefining their status under RCRA. Politics will play a role in the RCRA reauthorization process. RCRA reauthorization would be a good opportunity to make regulatory changes for electric vehicle (EV) battery disposal, if they were needed.

Both lead-acid and nickel-cadmium batteries have been the subject of increased regulatory action lately. In the Congress, at least eight pending bills may have a major impact on the lead-acid and nickel-cadmium industries [2]. Legislation to promote lead-acid battery recycling has been passed in 37 states. Several states have placed a tax on the sale of lead-acid batteries to raise revenue for environmental funds [2]. It is important to be aware of how these existing regulatory trends could affect the disposal process for Na/S and other EV batteries.

Exclusion from RCRA Requirements

Certain waste treatment processes may be excluded from all or parts of the RCRA regulatory requirements. RCRA exclusions that may be applicable to the treatment, storage, and disposal of spent Na/S batteries are discussed below.

Recycling of Hazardous Wastes

Hazardous wastes that are recycled (known in RCRA as *recyclable materials*) may be exempt from all or parts of the RCRA regulations. RCRA regulations for recycling of hazardous wastes are complex and are subject to interpretation by the EPA or state environmental agencies. EPA is also changing the recycling regulations, which may make recycling for certain materials easier in the future. It is usually necessary to know the specifics of the treatment process and how the recycled products are to be reused or disposed of to determine whether RCRA regulations apply for a specific waste. Recycling via use and/or reuse involves the return of a waste material either to the originating process as a substitute for an input material or to another process as an input material. "A material is 'reclaimed' if it is processed to recover a useful product or if it is regenerated. Examples include the recovery of lead values from spent batteries and the regeneration of spent solvents" (*40 CFR Part 261.1[c][4]*). In general, recycling by use and/or reuse is exempt from RCRA, while recycling by reclamation is often subject to RCRA. Materials are not regulated under RCRA when they can be shown to be recycled by being: "1) Used or reused as ingredients in an industrial process to make a product, provided the materials are not being reclaimed; or 2) used or reused as effective substitutes for commercial products; or 3) returned to the original process from which they are generated, without first being reclaimed" (*40 CFR Part 261.2 [e][1][i-iii]*).

The regulatory interpretation of recycling is sometimes difficult to understand. EPA encourages recycling, yet it is very sensitive to treatments that are merely called recycling in order to evade regulation. From an EPA perspective, the issue of whether an activity is considered legitimate recycling involves assessing whether the secondary material is "commodity-like" [3]. The main environmental considerations are (1) whether the secondary material truly has value as a raw material/product (i.e., is it likely to be abandoned or mismanaged prior to recycling rather than being recycled), and (2) whether the recycling process (including ancillary storage) is likely to release hazardous constituents (or otherwise pose risks to human health and the environment) that are different from or greater than the processing of an analogous raw material/product [3]. The decision of whether a Na/S battery disposal process would qualify as recycling would probably be made by the environmental agency in the state where the recycling takes place. Different states may have different interpretations of recycling for a given treatment process. Listed below are some of the criteria that EPA uses to determine if a treatment process is classified as recycling [3].

1. Is the secondary material similar to an analogous raw material or product?

    - Does it exhibit hazardous characteristics that the analogous raw material/product would not?
    - Does it contain levels of recoverable material similar to the analogous raw material/product?
    - Is the secondary material as effective as the raw material it replaces?

2. What degree of processing is required to produce a finished product?

    - Can the secondary material be fed directly into the process (i.e. direct use) or is reclamation (or pretreatment) required?
    - How much value does final reclamation add?

3. What is the value of the secondary material?

   - Does the secondary material have economic value comparable to the raw material that normally enters the process?

4. Is there a guaranteed market for the end product?

   - Is there a contract in place to purchase the "product" produced from the hazardous secondary materials?
   - If the type of recycling is reclamation, is the product used by the reclaimer? The generator?

5. Is the secondary material handled in a manner consistent with the raw material/product it replaces?

   - Is the secondary material stored in a similar manner as the analogous raw material (i.e. to prevent loss)?
   - Are adequate records regarding the recycling transactions kept?

6. Other relevant factors.

   - What are the economics of the recycling process? Does most of the revenue come from charging generators for managing their wastes or from the sale of the product?

Exemption from RCRA, based on recycling of hazardous battery disposal materials, would benefit the Na/S battery commercialization process by eliminating costs for hazardous waste disposal and other costs associated with RCRA permitting.

State Research and Development (R&D) Permits

Some state hazardous waste programs have provisions for R&D permits for treating and storing hazardous waste. State R&D permits allow research and development for hazardous waste treatment processes to take place without a RCRA permit. The requirements for R&D permits vary from state to state. For example, some state R&D permit requirements limit on-site storage of untreated waste to 1 year and 1000 kg at any one time. Appropriate recordkeeping is required as part of a state R&D permit. Application requirements for R&D permits are usually very simple and quick, and a permit can be acquired within 2 weeks in some cases.

RCRA Exemptions for Small Quantity Generators

Generators producing between 100 and 1000 kg of hazardous waste per calendar month are considered small quantity generators (SQGs) and may be exempt from a RCRA permit provided they meet specific requirements. SQGs are required to properly label their hazardous waste and use the manifest system to ensure that waste is sent to an EPA or state-approved facility [1]. SQGs must use only authorized hazardous waste TSD facilities and may be exempt from manifest requirements provided the waste is reclaimed under a contractual agreement that specifies the type of waste and the frequency of shipments [1]. Several states have more stringent requirements for SQGs, and three states (California, Louisiana and Rhode Island) have no exemption for SQGs [1].

Spent Lead-Acid Batteries

The storage and disposal of spent lead-acid batteries are exempt from some of the RCRA regulations. Reclamation of spent lead-acid batteries is regulated under *40 CFR Part 266 Subpart G*. These regulations were passed to specifically address spent lead-acid battery disposal. Subpart G states that "generators, transporters, and collectors of spent batteries (or people who store them but do not reclaim them) are exempt from 40 CFR Parts 262-266, 270, or 124, and Section 3010 of RCRA" (this is a exemption from most of the RCRA requirements including a RCRA permit). Owners and operators who *reclaim* spent batteries are subject to the following: Notification requirements under Section 3010, and Part 264, Subparts A, B (not 264.13), C, D, E (not 264.71 or 264.72 dealing with manifests), F and L. (Part 264 covers TSD facilities.) In summary, the transport and storage of spent lead-acid batteries are mostly exempt from RCRA regulations, whereas the reclamation (treatment) process for spent lead-acid batteries is subject to the majority of the regulations for a TSD facility (Part 264 requirements), with the exception of the manifest requirements. It should be noted that the transport of spent lead-acid batteries is regulated under Department of Transportation (DOT) regulations and the transport of Na/S batteries would also be regulated by the DOT.

Secondary lead smelters, where lead is reclaimed from lead-acid batteries, are currently only required to have a RCRA permit for the storage of hazardous wastes (when stored over 90 days) and not for their treatment. This is an important distinction because a RCRA storage permit is much easier to obtain than a RCRA treatment and disposal permit.

Part 2 - Preliminary Regulatory Analysis for Sodium-Sulfur Battery Disposal

Regulatory Strategies for Na/S Battery Disposal

Regulatory strategies for Na/S battery disposal were divided into two categories: short-term disposal and long-term disposal. Research and development is creating an immediate need for a short-term disposal process for spent Na/S batteries. This will be replaced by a long-term disposal process after the appropriate research and development work is performed. Although the majority of Na/S batteries used in the United States would initially be manufactured overseas, the disposal of these batteries in the United States would probably be easier because of the stringent RCRA regulations for the export of hazardous wastes.

Short-Term Disposal of Na/S Batteries

Preliminary short-term estimates for Na/S battery disposal are approximately 200 batteries per year for 1993 and approximately 350 batteries per year for 1994 to 1996 [4]. A typical spent 50 kWh Na/S battery used for EVs could contain approximately 100 kg of sodium polysulfides. These materials are considered a hazardous waste by the EPA. A disposal rate of 200 batteries per year would result in an annual hazardous waste generation of about 20,000 kg of polysulfides, or approximately 1670 kg per month. A state R&D permit might allow for 1670 kg per month of hazardous waste to be treated, provided it could be shown that the treatment process was in the research and development stage. A process operating under a state R&D permit would not be subject to RCRA permitting. Obtaining a state R&D permit appears to be the best short-term regulatory method for disposal of Na/S battery wastes. Once the Na/S battery disposal process was out of the R&D phase, the R&D permit would not be valid.

Regulations for SQGs' limit hazardous waste storage to 6000 kg and less than 180 days. Hazardous waste generation from the R&D phase of Na/S battery development might meet the SQG requirements, resulting in an exemption from a RCRA permit but still requiring the process to meet strict disposal regulations. This could be a beneficial approach should a state R&D permit not be obtainable.

The EPA and state environmental agencies are very strict regarding hazardous waste storage and disposal, and they will not grant an interim variance (for longer than a year) for the storage of hazardous wastes from spent Na/S batteries, even if a long-term methodology for Na/S battery disposal was developed that met with EPA approval. Storing hazardous wastes for more than a year is not an approved practice for any hazardous waste. The development of a long-term method for Na/S battery disposal is extremely important because a state R&D permit would be limited to the R&D phase, and if hazardous wastes could not be disposed of after the R&D phase, then their generation (and hence the further use of Na/S batteries) could be limited.

Regulatory Strategies for Long-Term Na/S Battery Disposal

Estimates of the amount of Na/S batteries for long-term disposal vary. The amount of Na/S batteries for long-term disposal will increase as more states pass regulations requiring zero emission vehicles.

(California was the first state to adopt regulations requiring 2% of all new cars sold in 1998 to emit zero emissions. Twelve northeastern states are considering adopting these same regulations.) The regulatory trend towards requiring EVs on the road by 1998 will result in a large number of Na/S batteries for disposal at that time, so the development of an acceptable long-term disposal process for Na/S batteries is crucial.

The preferred method for long-term Na/S battery disposal is recycling. The main reasons for recycling spent Na/S batteries are waste reduction, environmental protection, and reduction in permitting and disposal costs. Basic conditions must be met in order for recycling to be economical, environmentally safe, and practical. These conditions include (1) sufficient quantity of spent batteries for recycling, (2) high enough concentration of recyclable materials so they can be reused/reclaimed, (3) availability of a treatment process with justifiable energy requirements and low environmental impacts (e.g., low emissions and process residues), and (4) a market for the recovered materials [5]. It will be important to evaluate the developing Na/S battery treatment processes according to the above conditions.

It would be beneficial for any long-term recycling process for Na/S batteries to be exempt from RCRA. Exemption from RCRA would require that the treatment process meet the EPA requirements for recycling that were outlined in part 1 of this report. Exemption from RCRA based on recycling would benefit both battery developers and the EPA: battery developers would benefit by not having to pay for disposal of hazardous wastes from spent Na/S batteries and by not having to comply with burdensome RCRA regulations and permits, and the EPA would benefit because their emphasis on waste minimization would be achieved (recycling is a form of waste minimization). If Na/S battery recycling was not exempt from RCRA, then a potential regulatory strategy for long-term disposal could be one similar to lead-acid battery regulations.

Changes in the RCRA regulations may be needed to facilitate the treatment, storage, and disposal of EV batteries taken as a group and including technologies other than Na/S, such as lithium-polymer and advanced lead-acid battery technologies. Examples of these potential RCRA changes include exemption of EV batteries from RCRA transport and storage requirements (similar to existing lead-acid battery regulations) and exemption from a RCRA storage permit for EV battery recycling facilities. If specific changes to RCRA regulations are needed for the disposal of EV batteries, then the RCRA reauthorization process would be a good opportunity to try to make these changes.

Adding a RCRA exemption for recycling spent EV batteries to the RCRA reauthorization bill could be the best method for enacting regulatory change for EV battery recycling. A total exemption from RCRA for EV battery recycling would eliminate the need for the Environmental Protection Agency (EPA) to pass regulations for EV battery disposal. Because of the long time period it usually takes for the EPA to adopt new regulations, waiting for the EPA to pass regulations for EV battery recycling could severely impede the commercialization process for EVs.

Disposal Methods

Potential disposal methods for Na/S batteries can be divided into three basic categories: (1) treatment and disposal (such as incineration), (2) reclamation/recycle (i.e., chemical conversion to usable products), and (3) direct recycling/reuse of materials (i.e., no intermediate processing of hazardous materials). Although incineration is an environmentally acceptable method of disposing of spent Na/S batteries, it was excluded from further consideration because of the high costs associated with it. The one U.S. company licensed to dispose of batteries charges approximately $30-$35 per kg for disposal [6]. (Incineration may be reconsidered if incineration costs for Na/S batteries can be lowered significantly and if recycling costs for Na/S batteries end up being higher than those reduced incineration costs.) Incineration also has a bad image with the general public and hence could potentially detract from public acceptance of Na/S batteries. In June of 1990, an international Na/S battery workshop sponsored by the U.S. Department of Energy and the Electric Power Research Institute (EPRI) was held. Members of the workshop strongly favored developing treatment processes for Na/S battery disposal based on recycling and reclamation [6].

There are a number of chemical treatment processes being examined for Na/S battery disposal that include reclamation/recycle of spent battery materials; although from an environmental/regulatory standpoint, the closer a process is to direct recycling/reuse the better it is. However, direct recycling processes may not produce products that are as marketable as reclamation/recycle products, and this is a key factor in selecting a treatment process. For example, the approximate market value for sodium tetrasulfides is $760 per metric ton, and the annual production rate is less than 1000 metric tons [7]. Sodium tetrasulfides could be produced from a *direct recycling* process for Na/S batteries. In comparison, the approximate market value for sodium dithionite is $1370 per metric ton and the annual production is about 50,000 metric tons [7]. Sodium dithionite could potentially be produced from a *reclamation/recycle* process for Na/S batteries. Given the small market size for sodium tetrasulfides, any direct recycling process for sodium tetrasulfides would likely overwhelm the market and greatly reduce the market value of the product. However, a reclamation/recycle process that produced sodium dithionite would have a much greater market. In addition, the existing market value is nearly twice that of sodium tetrasulfide. The above example exemplifies the two main factors that affect the economics of a reclamation/recycle product: cost and production.

It will be important to evaluate a number of different parameters, including product costs and markets, environmental impacts of the disposal process, chemical feasibility (e.g., chemical reaction rates), and permitting requirements, when making a final selection of a disposal process for Na/S battery recycling. This report is primarily concerned with evaluating the environmental permitting requirements, but it is important to examine how this fits in with the other criteria for selecting a Na/S battery disposal process.

RCRA Hazardous Waste Standards

General

Standards for specific types of hazardous wastes are outlined in RCRA. "Best Demonstrated Available Technology" (BDAT) refers to the methodology for developing standards for *toxic* hazardous wastes. Standards are developed by selecting the BDAT for a treatability group (i.e., specific pollutant) and using this technology as a basis for developing concentration-based standards [8]. Compliance with a concentration-based standard requires only that the concentration level be achieved; once achieved, the waste may be landfilled. The waste does not have to be treated by the BDAT methodology. The concentration-based standard provides flexibility in the choice of treatment technology because any treatment, including recycling or any combination of treatment technologies, unless prohibited (e.g., impermissible dilution) or unless defined as land disposal, can be used to achieve the standards [8].

RCRA definitions characterizing ignitable, corrosive, and reactive wastes are given in *40 CFR 261.* Some of the definitions include EPA test methods for determining hazardous waste characteristics. There are no available analytical techniques to quantify ignitability, corrosiveness, and reactivity for many types of hazardous wastes. For these wastes, the EPA has developed the concept of "deactivation." Deactivation is a required method of treatment for specific wastes [8]. The standard for most ignitable, corrosive, or reactive wastes is listed in *40 CFR Part 268.42* as simply "Deactivation to remove the characteristics of ignitablity, corrosivity and reactivity." EPA has determined that many technologies, when used alone or in combination, can achieve this standard [8].

Hazardous Classification of Na/S Battery Disposal Products

Solid sodium is considered as a hazardous waste because of its reactive characteristics [9]. Sodium sulfides are classified as reactive and are listed in *40 CFR Part 261.23(a)(5).* Sodium polysulfides may also be classified as a hazardous waste due to their corrosive characteristics [10]. *Liquid* (i.e., high temperature) sodium and sulfur have hazardous characteristics that are not considered here because these materials will be disposed of as solids at ambient temperature, although certain treatment processing steps may occur in the liquid phase. Chromium and chromium compounds could be considered hazardous based on toxicity. Table 1 lists the materials contained in a Na/S battery and classifies them as either nonhazardous, capable of being neutralized to nonhazardous, or subject to testing for toxicity. (See the Appendix for a description of the toxicity characteristic leaching procedure [TCLP]. This test is used to determine if a waste is hazardous based on toxicity.)

Specific RCRA Treatment Standards for Na/S Battery Products

The EPA standard for total chromium is 5.0 milligrams per liter (mg/L). No differentiation between trivalent and hexavalent chromium is made in the standard [8]. The EPA realizes that trivalent chromium is less toxic than hexavalent chromium, yet it still regulates total chromium because of the potential for trivalent chromium to oxidize to hexavalent chromium in certain environmental situations (e.g. in certain soils) [11]. However, the regulations do provide for an *exclusion* for wastes testing toxic for total chromium but not containing hexavalent chromium. This exclusion requires a demonstration (i.e., a petition) to the EPA that the waste meets three specified conditions stated in the regulations. To this date, no one has filed for a petition. Testing for chromium is conducted by using the TCLP method, and the maximum concentration must not exceed 5.0 mg/L [8]. The chromium standard is the only concentration-based standard applicable to Na/S battery disposal.

Table 1. Classification of Materials in Na/S Battery Disposal

	Nonhazardous[a]	Neutralize	Recycle
Low carbon steel	X	--	?
Aluminum	X	--	?
Stainless steel	X	--	?
Copper	X	--	?
Ceramic insulation	X	--	--
Sodium	--	X	X
Sodium polysulfides	--	X	X
Chromium compounds	--	EPA Toxic?[b]	?
Sulfur	X	--	X
Alumina	X	--	--
Graphite	X	--	--

[a] Processing methods for breaking down batteries may make it unfeasible (i.e. either uneconomical or environmentally unacceptable) to recycle non-hazardous battery materials such as aluminum, steel, and copper.

[b] Compare to EPA standard of 5.0 mg/liter using toxic characteristic leachate procedure (TCLP) test method.

The other standard for hazardous Na/S battery disposal products is deactivation. Deactivation applies to wastes that are classified as hazardous because of ignitable, corrosive, or reactive characteristics. For Na/S batteries, this includes sodium and sodium polysulfides. Deactivation for sodium and sodium polysulfides requires that they be converted to nonreactive substances. EPA test methods for determining whether a waste is a reactive sulfide are given in *EPA Test Methods for Evaluating Solid Waste* [12]. Sodium polysulfides may also be considered corrosive, and EPA test methods for this determination are referenced in the defmition for corrosive wastes given in *40 CFR Part 261.22*; although this determination may not be necessary because any method of deactivation for reactivity would probably deactivate the waste for its potential corrosive characteristic as well.

Battery disposal products that are characterized as either corrosive or reactive, and Table A-2 in the Appendix lists the suggested EPA treatment technologies for these EPA waste categories. Use of these specific technologies is not mandatory and does not preclude direct *reuse, recovery*, and/or the use of other pretreatment technologies provided deactivation is achieved [8].

Preliminary Regulatory Analysis of Potential Treatment Methods

Background

A preliminary analysis was conducted to characterize potential Na/S battery treatment processes in terms of their recycling status under RCRA. This analysis was not intended to be a definitive assessment of the regulatory requirements for potential treatment processes; rather, it was intended to point out regulatory issues that could be discussed further by those involved in Na/S battery commercialization and development and to identify areas where additional information would be needed for a detailed environmental and regulatory analysis.

A preliminary evaluation procedure was developed to characterize potential treatment processes in terms of their environmental and regulatory impacts. The procedure is shown in Figure 1. (Additional information other than that listed in Figure 1 will be needed for a *detailed* environmental and regulatory analysis of the treatment processes.) Based on the procedure in Figure 1, potential treatment processes will be ranked in terms of their environmental and regulatory impacts. Most of the information needed for the evaluation procedure in Figure 1 is not available because the treatment processes are in the early stages of development. Treatment processes for Na/S battery disposal can be evaluated in detail when the information in Figure 1 is available.

In order to help understand how specific treatment processes will be characterized, general treatment process descriptions for Na/S battery disposal were developed based on the procedure outlined in Figure 1. The general treatment process descriptions allow for an understanding of the key environmental and regulatory issues associated with Na/S battery disposal. Table 2 lists the general treatment process descriptions for Na/S battery disposal and ranks them according to their environmental and regulatory impacts. *Specific* treatment processes for Na/S battery disposal can be categorized in terms of the general treatment processes when the information in Figure 1 is determined. Processes with an *A* in Table 2 have chromium concentrations below the EPA standard, whereas those with a *B* have chromium concentrations above the EPA standard (no differentiation is made between trivalent and hexavalent chromium).

1. Determine hazardous characteristics of battery constituents *before* recycling/reclamation procedure.
   a. Ignitability, corrosivity, reactivity, and toxicity (per RCRA definitions). Includes performing the TCLP to determine chromium concentrations.
2. Determine hazardous characteristics of battery constituents *after* recycling/reclamation procedure.
   a. Ignitability, corrosivity, reactivity and toxicity (per RCRA definitions). Includes performing the TCLP to determine chromium concentrations.
3. Estimate the amount of recycled products for a high and low Na/S battery usage scenario.
4. Determine if there is a potential market for the recycled products so that classification as a recycling process under RCRA can be justified.
5. Conduct preliminary estimate of the economics for the recycling process so that classification as a recycling process under RCRA can be justified.
6. Evaluate any potential environmental impacts of the recycling process(e.g. hazardous air emissions or process residues).
7. If the final products are a hazardous waste, determine the following:
   a. Can the products be directly reused?
      1. In the manufacturing process of Na/S batteries.
      2. In other manufacturing processes.
   b. Is reclamation required before reuse (e.g. to remove chromium)?
8. If the final products are not a hazardous waste, will they
   a. Be disposed of on land (i.e. landfilled)
   b. Reused in a manufacturing process.

Figure 1. Regulatory evaluation procedure for potential Na/S battery treatment processes

Table 2. Characterization of Disposal Processes for Na/S Batteries [a]

Number/ Ranking[b]	General Description of Process	RCRA Permit for Treatment and Disposal Required?[c]
1	Recycling through direct reuse (no processing or reclamation of hazardous materials required). Market for recycled materials exists.[d] There are no significant environmental impacts from the recycling process (e.g., air emissions).	No
2A	Sodium, sulfur, and sodium polysulfides are processed to form recyclable materials. *No reclamation* of chromium is required for the recyclable materials.[d] Market for recycled materials exists.[e] There are no significant environmental impacts from the recycling process.	Maybe[f]
2B	Sodium, sulfur, and sodium polysulfides are processed to form recyclable materials. *Reclamation* of chromium is required for the recyclable materials[d]. (Chromium must be manifested and disposed through a hazardous waste contractor or reused in a commercial process.) Market for recycled materials exists.[e] There are no significant environmental impacts from the recycling process.	Maybe[f]
3A	Sodium, sulfur, and sodium polysulfides are processed to form nonhazardous materials and disposed of as solid waste (i.e., landfilled or incinerated). (Chromium concentrations are *below* EPA standards and hence do not characterize waste as hazardous).[d]	Yes
3B	Sodium, sulfur, and sodium polysulfides are processed to form nonhazardous materials and disposed of as solid waste (i.e., landfilled or incinerated). (Chromium concentrations are above EPA standards and so chromium must be removed from the materials prior to their disposal. (Chromium must be manifested and disposed through a hazardous waste contractor or reused in a commercial process.)	Yes
4	All hazardous materials are shipped off-site via a hazardous waste contractor (at a high cost). Materials must be manifested prior to off-site shipment. (Note: Hazardous materials would probably be disposed of in a hazardous waste incinerator.)	No

(footnotes on next page)

Table 2. Characterization of Disposal Processes for Na/S Batteries [a] (concluded)

[a] Descriptions apply only to processing of hazardous Na/S battery materials (i.e., sodium, intermediate sulfur compounds, sodium polysulfides, and chromium compounds).

[b] Processes are listed in order of their preference from an environmental/regulatory standpoint. Processes with an *A* (e.g. 2A) assume that chromium concentrations are below the EPA standard, and processes with a *B* assume that chromium concentrations are above the EPA standard.

[c] A RCRA permit for hazardous waste *storage* would probably be required for all of the process descriptions. EPA may change this rule in the future and not require storage permits for certain recycling facilities.

[d] Although the EPA is aware that trivalent chromium(Cr [III]) is less toxic than hexavalent chromium (Cr [VI]), it still regulates *total* chromium concentrations. The reason for this is that the Cr [III] may convert to Cr [VI] in a number of environmental situations (e.g., Cr [III] has been found to oxidize to Cr [VI] under conditions found in many field soils [8].)

[e] The EPA may require a RCRA permit if there is no demand for the recycled products. (In addition, a recycling process that has no demand for the recycled products will probably not be economical.)

[f] Recycling processes that *reclaim* materials (i.e., "processed to recover a useful product or regenerated" - *40 CFR261.1*) usually require a RCRA storage permit but usually do not require a RCRA treatment and disposal permit, although this may depend on the regulatory interpretation given by a specific state environmental agency.

Four potential treatment processes currently being evaluated by Sandia National Laboratories for Na/S battery disposal are: recovery of sodium polysulfides; oxidation to sodium sulfate, sodium chloride and sulfur; recovery of sodium and sulfur; and acidic oxidation and Claus process to form sulfur and sodium sulfate [13]. Table 3 lists the four potential treatment processes with a brief description of each one [13]. The processes are in the beginning stages of development. (It should be noted that other recycling and disposal processes are being investigated by Sandia Laboratories in addition to the four listed here.)

It was assumed that each Na/S battery would be disassembled into individual cells before processing. The battery would be discharged prior to cooling and disassembly, except for the process consisting of recovery of sodium and sulfur, in which case the battery would be fully charged before cooling and disassembly [13]. The four potential treatment processes are discussed below and compared with the general treatment process descriptions outlined in Table 2.

Recovery of Polysulfides

Sodium tetrasulfide (Na_2S_4) is the only polysulfide produced in significant quantities in the United States [10]. The amount of Na_2S_4 produced is not very great, and preliminary estimates show that the amount of Na_2S_4 produced from a 10,000 battery/year plant would be far in excess of the demands of the Na_2S_4 market [13]. It appears that a significant market for Na_2S_4 does not exist, although additional information still needs to be obtained on the Na_2S_4 market. It would be difficult to justify reuse of Na_2S_4 because of the apparent lack of a market for it. Since the Na_2S_4 would be classified as a hazardous waste, it would be prohibited from being landfilled. Hence, it appears that this treatment process would be subject to RCRA and that the Na_2S_4 product would have to be disposed of as a hazardous waste (at a significant cost). If a market were identified for Na_2S_4, then the recycling status of this treatment process could change. For comparison, this treatment process would be characterized best by general process description 4 in Table 2, which was ranked last in terms of environmental and regulatory criteria. If a market were identified for Na_2S_4, then this process would be characterized best by general process description 2A or 2B in Table 2, depending on the chromium concentration in the recycled products. General process descriptions 2A and 2B were ranked second in Table 2.

Recovery of Sodium and Sulfur

This process would consist of direct recovery of sodium (i.e. extraction of the sodium directly from 2the cells) and reclamation of the sulfur from the cells. Sulfur reclamation would consist of extraction of the sulfur from the battery matrix followed by treatment to produce elemental sulfur. Recovery of sodium and sulfur from charged cells is characterized best by general process description 1 or 2B in Table 2. General process description 1 is exempt from RCRA because the hazardous battery products can be directly reused by battery manufacturers or used in other industrial processes, and no processing of hazardous materials is required before reuse. This is the best type of process from an environmental and regulatory viewpoint. If chromium removal were required prior to reuse of the sodium and sulfur, then this process would be characterized best by general process description 2B in Table 2. Reclamation of chromium would probably require a RCRA permit, although it could depend on a specific state environmental agency's interpretation of recycling. Future EPA changes to recycling regulations could also affect the permitting status of this process by allowing certain reclamation processes to be exempt from RCRA. Since sodium is considered a hazardous waste, it could not be landfilled after being extracted.

Table 3. Description of Four Potential Treatment Processes
(Compiled by Sandia National Laboratories)

Treatment Process	Description
Recovery of Polysulfides	The sodium polysulfide is recovered by crushing the cells. Excess sulfur is added to oxidize any Na_2S_3 to Na_2S_4, followed by dissolving the sodium polysulfide in water. The aqueous solution is dried to a powder product and drummed for shipment. An alternative process would be to add excess sodium to the sodium polysulfide to reduce the Na_2S_3 to Na_2S. [The preliminary regulatory ranking of this process is second or fourth, depending on whether a market exists for the product — see text for discussion.]
Recovery of Sodium and Sulfur	The battery is charged prior to disassembly of the cells. Although as many as 10% of the cells cannot be recharged, 90% of the cells will be charged. The individual cells are heated to 100° C and the sodium is removed. After removal of the sodium, the outer cell can is removed and the sulfur is hydrotreated to form H_2S. The hydrogen sulfide is oxidized to elemental sulfur via the Claus process. (The preliminary regulatory ranking of this process is first or second, but see text for discussion of possible shortcomings.)
Oxidation to Form Sodium Sulfate, Sodium Chloride, Sulfur	The battery is fully discharged to form Na_2S_3. (Battery discharge will not give 100% Na_2S_3 for all cells — some cells will be electrically and isolated and this will have to be addressed.) The cell cases are breached and sodium hypochlorite (bleach) is added to oxidize the polysulfide to sodium sulfate and sulfur. After filtering, a solution of sodium sulfate and sodium chloride is produced. (The preliminary regulatory ranking of this process is second or third — see text.)
Acidic Oxidation and Claus Process to Form Sodium Sulphate	The battery is fully discharged to form Na_2S_3 (see comment on battery discharge in above process). The cell cases are breached, and sulfuric acid is added to the Na_2S_3 to form hydrogen sulfide and elemental sulfur. The hydrogen sulfide is oxidized to elemental sulfur via the Claus process. (The preliminary regulatory ranking of this process is second or fourth — see text.)

Source: Ref. 13 (Lott).

The disadvantage to this process is that it requires the cells to be charged prior to treatment. Some cells are not functional at the end of a battery's life and hence would not charge. Uncharged cells would require special treatment (because they would contain significant amounts of sodium polysulfides). This could create problems for their processing. Therefore, although this process appears favorable from an environmental and regulatory viewpoint, it may be unfavorable because of engineering and processing constraints.

Oxidation to Form Sodium Sulfate, Sodium Chloride, and Sulfur

Although the price for the products is low, there appears to be a market for the sodium sulfate/sodium chloride product (sodium sulfate is the primary product from a cost standpoint) [13]. Since neither of the end products are classified as a hazardous waste, they could be landfilled if they were not marketed. If the products are recycled, then this process would be characterized best by general process description 2A or 2B in Table 2. If the products are disposed of as a solid waste, then the process would be characterized best by general process description 3A or 3B in Table 2.

Acidic Oxidation and Claus Process to Form Sulfur and Sodium Sulfate

This process is characterized best by general process description 2A or 2B in Table 2. It appears that the sodium sulfate and sulfur could be reused in an industrial process. There appears to be a market for sodium sulfate and sulfur, although it needs to be determined whether the materials would have to be refined before reuse. Sodium sulfate is not a hazardous waste so it could be landfilled if it was not reused.

Additional Information Needed

Additional information is still needed in order to further define the regulatory status of potential disposal treatment processes. This information includes the following:

- The concentration of chromium in the recycled products needs to be estimated so that a determination can be made as to whether spent Na/S batteries are hazardous based on toxicity. This can be determined by performing two separate TCLP tests: one test to determine chromium concentrations in the polysulfides from spent Na/S battery cells and the second test to determine chromium concentrations in spent Na/S battery casings (this last test would consist of performing the TCLP test on crushed battery cells).

- Information on product markets for all potential recyclables is required for a regulatory analysis.

- Information on *all* wastes involved in potential treatment processes is required for a complete regulatory analysis. For example, intermediate processing steps in a recycle/reclamation process could produce hazardous wastes that are not part of the recycled product. These wastes could still affect the regulatory status of a treatment process.

- Estimates of any potential air and water emissions for potential treatment processes are needed for an environmental analysis.

Environmental Ranking of Na/S Disposal Processes

Regulatory impact requirements, as described in this paper, comprise one criteria that will contribute to an overall environmental ranking for Na/S battery disposal processes. The other three criteria that will make up the environmental ranking are disposal requirements, environmental impacts of the process, and perceived public acceptance of the process. These four criteria are briefly summarized below. The four environmental criteria will not necessarily contribute equally to the final environmental ranking for a given process.

Regulatory Impact

This is an assessment of the regulatory burden under RCRA regulations as described in this report. It reflects the estimated permitting requirements under RCRA. For example, processes that are estimated to require a full blown RCRA TSD permit will be given a low ranking. Low ranking processes may include new processes that are not widely proven because they typically require more stringent permitting requirements.

Processes that result in conversion of the hazardous battery products to reclaimable wastes that are still considered hazardous under RCRA are given an intermediate ranking. Processes that produce reclaimable products with a high market value and large market are preferred because these processes are more likely to be classified as recycling under existing EPA regulations and therefore may only require a RCRA storage permit or no permit at all. The highest regulatory impact ranking is reserved for direct recycling processes because they require no processing or reclamation before reuse (other than extraction from the batteries) and hence do not require a RCRA permit. An example of this is the recovery of sodium and sodium polysulfides for reuse.

Disposal Requirements

The disposal requirement criteria assesses the environmental impact of disposing of the waste products that will not be reclaimed or reused. It also takes into consideration, to a lesser extent, whether the reclaimed or reused materials will have to be transported via a waste manifest to the end-user (under RCRA, hazardous wastes require a manifest for transport and disposal). For example, the process consisting of oxidation with bleach to sodium sulfate, sodium chloride, and sulfur is given a high ranking because the end products are not considered hazardous, and the process does not produce hazardous intermediate products that would require special disposal.

Environmental Impacts of Process

This criterion assesses the potential for environmental impacts from the actual process itself. It takes into consideration the potential for air and water emissions from the process as well as Occupational Safety and Health Administration (OSHA) requirements for handling toxic materials.

Public Acceptance

This criterion reflects the following: potential for a disposal processes to create a not in my backyard syndrome (NIMBY) and hence drive up permitting and siting costs, and the potential for the disposal process to create a negative impression with the environmental community. This last situation could result in the battery technology receiving no support (and potential criticism) from active environmental organizations who might favor other battery technologies based on the environmental analysis of the Na/S battery disposal process. Recycling processes will receive a high ranking under this criterion.

Future Work Goals

The single most important task that needs to be performed is to determine whether spent Na/S batteries are a hazardous waste based on toxicity. Once this is accomplished, a more detailed regulatory assessment can be conducted. As the treatment technologies for Na/S battery disposal continue to develop, it will be important to perform an environmental and regulatory analysis for each of them. This will include identifying the impacts of the regulations and performing a regulatory cost analysis for each treatment alternative. Disposal costs for Na/S battery disposal products will be influenced by their hazardous classification under RCRA, and these costs should be estimated. RCRA permitting costs should also be estimated. Disposal and recycling considerations should be included in future cell designs and material selections. The development of a clearly defined regulatory strategy for long-term Na/S battery disposal should be pursued by all parties involved with the commercialization process of Na/S batteries and with input from the EPA.

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Appendix A
Regulatory Overview of RCRA

The RCRA statute is divided into 10 subtitles:
Subtitle A - General Provisions
Subtitle B - Office of Solid Waste; Authorities of the Administrator
Subtitle C - Hazardous Waste Management
Subtitle D - State or Regional Solid Waste Plans
Subtitle E - Duties of the Secretary of Commerce in Resource Recovery
Subtitle F - Federal Responsibilities
Subtitle G - Miscellaneous Provision
Subtitle H - Research Development, Demonstration, and Information
Subtitle I - Regulation of Underground Storage Tanks
Subtitle J - Demonstration Medical Waste Tracking Program.

Subtitle C establishes a comprehensive management program to regulate hazardous waste from generation to disposal. Subtitle C contains the majority of the requirements for RCRA permitting, operations, cleanup, closure; and it includes EPA criteria for identifying hazardous waste. Subtitle C contains the regulations that will govern the disposal of any hazardous materials from spent Na/S batteries.

Under Subtitle C, one must determine whether the solid waste generated is a hazardous waste not excluded from regulation. If the waste is a hazardous waste subject to regulation, then the volume of the waste generated must be calculated. Calculating the volume of the hazardous waste allows one to properly classify the process as either a conditionally exempt small quantity generator (CESQG - generates less than 100 kg per month of hazardous waste), a small quantity generator (SQG - generates less than 1000 kg per month of hazardous waste), or a fully regulated generator. Each type of hazardous waste generator is subject to a different level of RCRA notification and operational requirements.

Listed below are definitions of selected terms from Subtitle C of the RCRA regulations that may be applicable to Na/S battery disposal (Definitions from *RCRA Handbook*, see source [2]).

Characteristic Waste - A solid waste that is a hazardous waste because it exhibits one or more of the following hazardous characteristics: ignitability, corrosivity, reactivity, or toxicity.

Container - Any portable device in which a material is stored, transported, treated, disposed of, or otherwise handled.

Contingency Plan - A document setting out an organized, planned, and coordinated course of action to be followed in case of fire, explosion, or release of hazardous constituents which could threaten human health or the environment.

Delisting - Exclusion (or petitioning for exclusion) of a solid waste from the definition of "hazardous waste" even though that waste is listed as hazardous under RCRA. To have a specific waste delisted, the owner/operator of a facility must petition for a regulatory amendment. The application must satisfy EPA and/or state authorities that the waste does not meet any of the criteria under which the waste was listed as "hazardous," and does not have other harmful constituents or properties.

Designated Facility - An authorized hazardous waste treatment, storage, or disposal facility that has been designated on the manifest of the generator to receive a shipment of waste.

Disposal - The discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including groundwater.

EPA Hazardous Waste Number - A number assigned by EPA to waste that is hazardous by definition; to each hazardous waste listed in 40 CFR 261 Subpart D from specific and nonspecific sources identified by EPA (F,K,P,U); and to each characteristic waste identified in 40 CFR 261 Subpart C, including wastes with ignitable (D001), reactive (D002), corrosive (D003), and EP toxic (D004-D0017) characteristics.

Facility Management Plan - Detailed plan, including technical studies which are required of TSD facilities. The plan must address waste analysis; security; inspections; personal training; and ignitable, reactive, or incompatible wastes.

Hazardous Waste - Includes those solid wastes that (1) have not been excluded from the definition of hazardous waste, (2) have been listed as hazardous wastes by EPA, (3) exhibit one or more of the characteristics of hazardous waste (see also *characteristic waste),* or (4) have been mixed or derived from a listed hazardous waste.

Land Disposal - Includes, but is not limited to, placement in a landfill, surface impoundment, wastepile, injection well, land treatment facility or salt dome formation intended for disposal purposes. Land disposal facilities are a subset of TSD facilities.

Land Disposal Restrictions - Also known as the land ban, these restrictions under RCRA prohibit any land disposal of untreated hazardous wastes, unless a national capacity variance has been granted for a specific waste.

Leachate - Liquid, including any suspended components in the liquid, that has percolated through or drained from hazardous waste.

Listed Waste - Wastes listed as hazardous under 40 CFR Part 261 Subpart D. A waste is listed as a hazardous waste based on the process from which the waste was generated and/or the constituents found in the waste (see also *characteristic waste* and *delisting*).

Manifest - The "cradle-to-grave" paperwork that must accompany a shipment of hazardous waste as it moves from the generator to the transporter and eventually to the TSD facility. The generator originates and signs the manifest (EPA form 8700-22 and, if necessary, EPA form 8700-22a) in accordance with the instructions included in the Appendix to 40 CFR Part 262.

Part A Permit Application of Part A - The first part of the two-part RCRA permit application that TSD facilities must submit to the authorized regulatory agency (EPA or the state).

Part B Permit Application or Part B - The second and more complicated part of the two-part RCRA permit application required for owners/operators of TSD facilities. Applicants must submit a Part B in narrative form to the designated agency and include detailed treatment of a wide range of activities and procedures needed for their facilities to demonstrate proper protection of human health and the environment.

Pollution Prevention - Any source reduction or recycling activity that results in reduction of total volume of hazardous waste, reduction of toxicity of hazardous waste, or both, as long as that reduction is consistent with the goal of minimizing the present and future risks to public health and the environment.

Research, Development and Demonstration (RD&D) Permit - May be issued to a hazardous waste treatment facility that proposes new and innovative or experimental treatment technologies for which there are as yet no permit standards.

Small Quantity Generator - A regulated facility that generates more than 100 kilograms and less than 1000 kilograms of hazardous waste in a calendar month. However, even if a small quantity generator avoids the requirements of full generator status, the facility may still be subject to certain RCRA conditions.

Storage - The holding of hazardous waste for a temporary period, at the end of which the hazardous waste is treated, disposed of, or stored elsewhere. Facilities are required to have a RCRA permit for storage of hazardous waste for more than 90 days; storage for less than 90 days does not require a RCRA permit (this applies to *generators* who store waste).

TSD Facility - A facility that treats, stores, and/or disposes of hazardous wastes.

Toxicity Characteristic Leaching Procedure (TCLP) - The analytical method that is used to determine whether or not a waste is a characteristic hazardous waste based on toxicity. The TCLP is also necessary to comply with provisions of land disposal restrictions as well (see also *toxicity characteristic rule*).

Toxicity Characteristic (TC) Rule - This rule replaces the Extraction Procedure toxicity test (EP TOX) with the TC test to determine whether or not a waste is a characteristic waste based on toxicity. The new TC test requires analysis of 25 organic compounds in addition to the eight metals (including chromium) and six pesticides that were subject to the EP TOX test.

Transporter - A person transporting hazardous waste within the U.S. which requires a manifest. On-site movement of hazardous waste does not apply. Transporters must comply with 40 CFR Part 263.

Treatment - Any method, technique, or process, including neutralization, designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste, or so as to recover energy or material resources from the waste, or so as to render such waste nonhazardous, or less hazardous; safer to transport, store or dispose of; or amenable for recovery, amenable for storage, or reduced in volume.

Treatment Standards - Standards that hazardous wastes must meet prior to land disposal. A treatment standard generally expresses a treatment technology as concentration limits to give generators flexibility in choosing treatment options. Note that concentration limits are based upon the best demonstrated available technology (BDAT) for a particular waste or similar waste.

Waste Analysis Plan (WAP) - A plan that TSD facilities must submit as part of a RCRA Part B permit to provide sufficient confidence that they are properly permitted to handle the wastes they receive. The plan specifies sampling methodologies, analysis parameters and test methods. For a disposal facility, a WAP must also include procedures and analyses used to demonstrate compliance with the land disposal restrictions (see also *land disposal restrictions*).

Waste Minimization - Generators and TSD facilities operating under RCRA permits are required to certify annually that they have waste minimization plans in place and that the plans are being implemented at their facilities (see also *pollution prevention*).

Characteristics of Hazardous Wastes

A solid waste is a hazardous waste if it exhibits any of the following characteristics: ignitability, corrosivity, reactivity or toxicity. The methods for determining whether a waste exhibits any of the above characteristics are described in 40 CFR Parts 261.21-261.24. Specific properties defining characteristic wastes that may be applicable to Na/S battery constituents are described below (See 40 CFR Part 261.2 for a complete list of definitions for characteristic wastes.)

Ignitability. Properties defining ignitability include 1) a substance that is not a liquid and is capable, under standard temperature and pressure, of causing fire through friction, absorption of moisture or spontaneous chemical changes and, when ignited, burns so vigorously and persistently that it creates a hazard; and 2) a substance that is an oxidizer as defined in 49 CFR 173.151 (40 CFR 261.21). A solid waste that exhibits the characteristic of ignitability has the EPA hazardous waste number of D001.

Corrosivity. Properties defining corrosivity include 1) an aqueous waste that has a pH less than or equal to 2 or greater than or equal to 12.5, and 2) a liquid that corrodes steel (SAE 1020) at a rate greater than 6.35 mm per year at a test temperature of 55 degrees centigrade as determined by the test method specified in NACE (National Association of Corrosion Engineers) Standard TM-01-69 (40 CFR 261.22). A solid waste that exhibits the characteristic of corrosivity has the EPA hazardous waste number of D002.

Reactivity. Properties defining reactivity include a substance that 1) reacts violently with water, 2) forms potentially explosive mixtures with water, 3) when mixed with water, it generates toxic gases, vapors or fumes in a quantity sufficient to present a danger to human health or the environment, or 4) It is a cyanide or sulfide bearing waste which, when exposed to pH conditions between 2 and 12.5, can generate toxic gases, vapors or fumes in a quantity sufficient to present a danger to human health or the environment (40 CFR 261.23). A solid waste that exhibits the characteristic of reactivity has the EPA hazardous waste number D003.

Toxicity. A solid waste exhibits the characteristic of toxicity if, using the Toxicity Characteristic Leaching Procedure (TCLP), concentrations in the extract of a representative sample of the waste are above the EPA standards for any of the 25 organic compounds, eight metals or six pesticides for which standards exist. The standard for chromium, which is contained in Na/S batteries, is 5 mg/liter.

RCRA Permitting

RCRA imposes a set of legally enforceable requirements on an owner or operator of a TSD facility - a facility that treats, stores or disposes of solid wastes considered hazardous under RCRA [2]. Obtaining a permit under RCRA gives a TSD owner or operator legal authority, within the limits of the particular permit, to treat, store or dispose of hazardous waste. A permit consists of a two part application (see definitions for Part A and Part B permits).

Table A-1. Selected EPA Technology Codes and Descriptions of Technology-Based Standards

Technology Codes	Description of Technology Based Standard
CHOXD	Chemical or electrolyte oxidation utilizing the following oxidation reagents (or waste reagents) or combinations of reagents: (1) hypochlorite (e.g. bleach); (2) chlorine; (3) chlorine dioxide; (4) ozone or UV (ultraviolet light)assisted ozone; (5) peroxides; (6) persulfates; (7) perchlorates; (8) permanganates; (9) other oxidizing reagents of equivalent efficiency, performed in units operated such that a surrogate compound or indicator parameter has been substantially reduced in concentration in the residuals. Chemical oxidation specifically includes what is commonly referred to as alkaline chlorination.
CHRED	Chemical reduction utilizing the following reducing agents (or waste reagents) or combinations of reagents: (1) sulfur dioxide; (2) sodium potassium, or alkali salts of sulfites, bisulfites, metabisulfites, and polyethylene glycols; (3) sodium hydrosulfide; (4) ferrous salts; and/or (5) other reducing agents of equivalent efficiency, performed in units operated such that a surrogate compound or indicator parameter has been substantially reduced in concentration in the residuals. Chemical reduction is commonly used for the reduction of hexavalent chromium to the trivalent state.
INCIN	Incineration in units operated in accordance with the technical operating requirements of 40 CFR Part 264, subpart O and 40 CFR Part 265, subpart O.
STABL	Stabilization with the following reagents (or waste reagents) or combinations of reagents: (1) Portland cement; or (2) lime/pozzolans (e.g. fly ash and cement kiln dust).

Source: *40 CFR Part 268*

Table A-2. Suggested EPA Technologies For Treating Wastes That May Be Produced from Na/S Batteries

Waste Code/Subcategory	Technology Codes
D002 - Other corrosives based on CFR 261.22(a)(2)	CHOXD
D003 - Reactive sulfides based on CFR 261.23(a)(5)	CHOXD CHRED INCIN
D003 - Other reactives based on CFR 261.23(a)(1)	INCIN CHOXD CHRED

Codes and descriptions for suggested EPA treatment methodologies are given in Table A-2. Use of these treatment technologies is not mandatory as it does not preclude direct reuse, recovery, and/or the use of other pretreatment technologies as long as deactivation is achieved.

Source: *40 CFR Part 268*