

Title of Invention: Discharging Batteries With Ash

Technical Field

The present disclosure refers to a method of discharging batteries, in particular discharging batteries with ash, ash suspension or ash leachate. The present disclosure also refers to a method of reducing at least one ion in ash by contacting the ash, ash suspension or ash leachate with a battery.

Background Art

The current urban lifestyle advocates the increasing usage of mobile electronic devices like laptops and phones, and the latest gadgets like drones and personal mobility devices (PMDs) such as e-scooters or e-bikes. Rechargeable batteries are recommended for these high drain devices, in particular, lithium ion batteries (LIBs) are especially preferred, offering higher energy, power densities, longer lifespan and low self-discharge rates. LIBs are also forecasted to play a greater role in electric vehicles (EVs) due to the urgent need to replace petroleum vehicles with cleaner alternatives with reduced carbon footprints. It is estimated that the number of EVs has grown 10 times in the period between 2013 and 2018, or around 5 million EVs globally in 2018, and is slated to increase further with more countries switching to EVs in the near future.

However, with the increased demand for LIB applications, there is an increased need for proper disposal of LIBs. LIBs should ideally be segregated and recycled as lithium is flammable and poses improper disposal would pose a danger to the public. Additionally, scarce resources which go into producing LIBs would be lost without proper disposal, i.e. segregation and/or recycling.

One method to recover precious metals from LIBs is pyrometallurgy. Pyrometallurgy has typically been used to extract metals either as pure or intermediate compounds using high temperature from ores in mining industry. When used in the recycling of LIBs, this method separates the metals through reduction while burning away the organic components. While LIBs do not have to be discharged beforehand when recycled, pyrometallurgy typically involves high energy consumption products significant pollution to the environment. Additionally, Li cannot be recovered under pyrometallurgy.

Hydrometallurgy, which extracts metal through leaching, has been proposed as an alternative to pyrometallurgy. Recycling of LIBs using hydrometallurgy typically involves shredding as a pre-treatment step and such an action will often result in short-circuiting when the cathode and anode materials come into contact. Hence, the LIBs must be discharged to remove the residual electrical energy in the LIBs prior to hydrometallurgy recycling.

Immersing spent LIBs in NaCl solution is widely adopted as a method to discharge LIBs before shredding. This is despite the very little research done on the correlation between the discharge rate and the type of

salt solutions, or the effect of concentration. Hence, there is scant research on possible methods for discharging batteries.

On the other hand, the world presently has a problem with the increasing amount of waste generated. For example, in Singapore, 4.64 million tonnes of waste were generated in 2000 and this increased to 7.70 million tonnes in 2018, of which 0.534 million tonnes of ash was produced from the incineration of municipal solid waste (MSW). Such ash, also known as fly ash, or incineration fly ash (IFA), typically needs to be landfilled. However, IFA typically contains high heavy metal and chloride content and is classified as hazardous according to EU Council Directive 91/689/EEC. Hence, disposal of IFA in landfills also creates other issues, such as chloride and heavy metal leaching into both surface and ground water. Several methods have been proposed to remove said chlorides and heavy metals from IFA prior to disposal but to little effect.

Instead, as IFA comprises mineral content having Ca- and Si-bearing phases, it has found some traction as recycled and reused material in construction materials production, in particular in cement production. However, its high Cl content (>20% wt.) could result in concrete corrosion and heavy metal leaching. The chloride content requirement for ordinary construction material is low, for example, less than 0.02% in Portland cement. Hence, proper utilization of IFA in cement product is hindered by the sheer amount of treatment needed to make it useable.

Thus, there is a need to find new methods of discharging batteries or new methods of treating ash, that overcome or ameliorate the problems.

Summary

In an aspect of the present disclosure, there is provided a method of discharging a battery comprising contacting the battery with ash, ash suspension, or ash leachate, wherein the ash, ash suspension, or ash leachate comprises at least one ion selected from the group consisting of chloride, sulphate, sulphide, hydroxide, carbonate, and phosphate.

In another aspect of the present disclosure, there is provided a method of reducing at least one ion content in ash comprising contacting a battery with ash, ash suspension or ash leachate, wherein the ion is selected from the group consisting of chloride, sulphate, sulphide, hydroxide, carbonate, and phosphate.

Before dismantling or shredding to recover cathode material, batteries, for example, lithium-ion batteries (LIBs), need to be discharged sufficiently to prevent short-circuiting. The present disclosure has surprisingly found that ash, or suspensions and leachates thereof, may be used to discharge batteries in a pre-treatment step. Concurrently, the present disclosure has also surprisingly found that ash may be treated to remove ions and/or reduce ion content simply by contacting ash, or suspensions and leachates thereof, with a battery. The present disclosure thus provides for a method which discharges batteries and concurrently treats ash at the same time, in a novel waste-treat-waste concept.

Conventionally, NaCl solutions have been used to discharge batteries. The present disclosure has surprisingly found that not only does ash contain ions (e.g., chlorides) and could thus replace NaCl as a discharging medium, but ash, or suspensions and leachates thereof, can also discharge batteries at a significantly faster rate as compared to conventional NaCl solution.

The present disclosure has also found that ash has a high conductivity due to the soluble salts present, which advantageously improves its battery discharging potential. The present disclosure has also found that ash suspensions, or ash leachates prepared therefrom, are advantageously able to discharge batteries in different water:ash ratios (L/S ratios, or LS ratios). In an example, the present disclosure has found that a 3.4 V Lithium Nickel Cobalt Aluminum Oxide (NCA) battery could be discharged in at most 3 hours, a far more practical time duration as compared to conventional methods. This indicates that the presently disclosed method is advantageously faster as compared to conventional methods (i.e. NaCl salt solutions).

Concurrently, the present disclosure has surprisingly found that ash may be treated by electrolysis. The present disclosure has also unexpectedly found that ash may be treated simply by contacting ash, or suspensions and leachates thereof, with a battery. The presently disclosed method may also advantageously reduce metal content, on top of other ion content like chloride, during the discharging process. Hence the presently disclosed method also advantageously treats ash in the process by removing metal ions and/or other ions like chloride. The present disclosure has also advantageously found that the ash, ash suspension or leachate may be re-used in the method to discharge additional batteries, reducing the ion content and treating the ash further.

The present disclosure has also surprisingly found that separating the batteries from the residue in the ash, ash suspension or leachate advantageously increases the discharge rate. Further the present disclosure has also surprisingly found that contacting the battery with only the ash leachate further increases the discharge rate.

The present disclosure thus discloses a method that advantageously uses a waste (ash) to treat a second waste (spent batteries), while being treated itself in the process. Hence, the present disclosure, advantageously treats two waste products in a single method, reducing the economies of scale of recycling, and waste treatment. The spent and sufficiently discharged batteries may be further dismantled to recover the active cathode material, while the ash, having its metal ion and/or other ion content (like chloride, etc.) may advantageously be made use of in other applications, for example, in cement production.

In a further aspect of the present disclosure, there is provided a system for discharging a battery and/or reducing ion content in ash, comprising:

- a reactor chamber;
- a perforated battery container disposed within the reactor chamber, wherein the perforated battery container is configured to contain a battery;
- a motor connected to the perforated battery container, wherein the motor is configured to move the perforated battery container;

an ash inlet connected to the reactor chamber, wherein the ash inlet is configured to feed ash into the reactor chamber; and

a water inlet connected to the reactor chamber, wherein the water inlet is configured to feed water into the reactor chamber.

Definitions

Unless otherwise defined herein, scientific and technical terms used in this application shall have the meanings that are commonly understood by those of ordinary skill in the art. Generally, nomenclature used in connection with, and techniques of, chemistry described herein, are those well-known and commonly used in the art.

Unless the context requires otherwise or specifically stated to the contrary, integers, steps, or elements of the invention recited herein as singular integers, steps or elements clearly encompass both singular and plural forms of the recited integers, steps or elements.

As used herein, ash refers to the residue obtained from combustion and/or incineration processes, typically residue obtained from incineration of garbage, waste, industrial waste, residential waste, commercial waste, or residue obtained from firing of coal, oil, gas, wood or other fuels in a typical power plant, and etc. Ash also covers all sorts of residue obtained from the combustion and/or incineration process, for example, residue remaining after the incineration and/or combustion, residue that is found with and may be filtered from the exhaust product, or residue that is found with and may be obtained by treating exhaust product chemically.

As used herein, leachate refers to a solution obtained from filtering a first mixture of slightly soluble solid and water, in particular ash and water in this application. It is understood that each component in ash may either be soluble, partially soluble, slightly soluble, or insoluble in water. Hence, the leachate obtained may contain a mixture of the soluble, partially soluble or slightly soluble components of ash.

As used herein, flue gas refers to a gas obtained from combustion and/or incineration processes. Flue gas may contain the reaction products from the combustion and/or incineration processes, combustion and/or incineration air, or residual substances such as particular matter, or oxides of nitrogen, sulfur or carbon.

The word “substantially” does not exclude “completely” e.g. a composition which is “substantially free” from Y may be completely free from Y. Where necessary, the word “substantially” may be omitted from the definition of the invention.

As used herein in the specification and in the claims, the phrase "at least," in reference to a list of one or more elements, should be understood to mean at least one element selected from any one or more of the elements in the list of elements, but not necessarily including at least one of each and every element specifically listed within the list of elements and not excluding any combinations of elements

in the list of elements. This definition also allows that elements may optionally be present other than the elements specifically identified within the list of elements to which the phrase "at least one" refers, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, "at least one of A and B" (or, equivalently, "at least one of A or B," or, equivalently "at least one of A and/or B") can refer, in one embodiment, to at least one, optionally including more than one, A, with no B present (and optionally including elements other than B); in another embodiment, to at least one, optionally including more than one, B, with no A present (and optionally including elements other than A); in yet another embodiment, to at least one, optionally including more than one, A, and at least one, optionally including more than one, B (and optionally including other elements); etc.

Unless specified otherwise, the terms "comprising" and "comprise", and grammatical variants thereof, are intended to represent "open" or "inclusive" language such that they include recited elements but also permit inclusion of additional, unrecited elements.

As used herein, the term "about", in the context of concentrations of components of the formulations, typically means $\pm 5\%$ of the stated value, more typically $\pm 4\%$ of the stated value, more typically $\pm 3\%$ of the stated value, more typically, $\pm 2\%$ of the stated value, even more typically $\pm 1\%$ of the stated value, and even more typically $\pm 0.5\%$ of the stated value.

Throughout this disclosure, certain embodiments may be disclosed in a range format. It should be understood that the description in range format is merely for convenience and brevity and should not be construed as an inflexible limitation on the scope of the disclosed ranges. Accordingly, the description of a range should be considered to have specifically disclosed all the possible sub-ranges as well as individual numerical values within that range. For example, description of a range such as from 1 to 6 should be considered to have specifically disclosed sub-ranges such as from 1 to 3, from 1 to 4, from 1 to 5, from 2 to 4, from 2 to 6, from 3 to 6 etc., as well as individual numbers within that range, for example, 1, 2, 3, 4, 5, and 6. This applies regardless of the breadth of the range.

Certain embodiments may also be described broadly and generically herein. Each of the narrower species and subgeneric groupings falling within the generic disclosure also form part of the disclosure. This includes the generic description of the embodiments with a proviso or negative limitation removing any subject matter from the genus, regardless of whether or not the excised material is specifically recited herein.

Brief Description of Drawings

The accompanying drawings illustrate disclosed embodiments and serve to explain the principles of the disclosed embodiments. It is to be understood, however, that the drawings are designed for purposes of illustration only, and not as a definition of the limits of the invention.

Key

RP refers to an ash product obtained from reacting flue gas with powdered lime.

ESP refers to ash obtained from an electrostatic precipitator.

LS ratio, or L/S ratio, refers to water:ash ratio, or Liquid/Solid ratio.

Fig. 1

Fig. 1 is a Scanning Electron Microscopy with Energy Dispersive X-Ray Analysis (SEM-EDX) image of the elements detected on the cathode material in a Lithium Nickel Cobalt Aluminum Oxide (NCA) battery.

Fig. 2a

Fig. 2a is an X-Ray Diffraction (XRD) spectrum of a cathode in an NCA battery.

Fig. 2b

Fig. 2b is an XRD spectrum of an anode in an NCA battery.

Fig. 3

Fig 3 is an image showing a representative setup for discharging a battery with ash.

Fig. 4a

Fig. 4a is a graph showing select elements remaining in the solid residue of RP after discharging at an L/S ratio of 5.

Fig. 4b

Fig. 4b is a graph showing select metals remaining in the solid residue of RP after discharging at an L/S ratio of 5.

Fig. 4c

Fig. 4c is a graph showing select elements remaining in the solid residue of ESP after discharging at an L/S ratio of 5.

Fig. 4d

Fig. 4d is a graph showing select metals remaining in the solid residue of ESP after discharging at an L/S ratio of 5.

Fig. 5a

Fig. 5a is a graph showing the chloride concentration present in the RP leachate after discharging the battery to below 1.0 V, with durations shown in Fig. 8a, at various L/S ratios compared to a control.

Fig. 5b

Fig. 5b is a graph showing the chloride concentration present in the ESP leachate after discharging the battery to below 1.0 V, with durations shown in Fig. 8b, at various L/S ratios compared to a control.

Fig. 6

Fig. 6 is a graph showing the change in pH and conductivity of the ESP leachate at an L/S ratio of 1 plotted against the number of batteries discharged.

Fig. 7a

Fig. 7a is a series of images showing a reaction mixture (i) before and (ii) after discharging a battery with an ash leachate, with inset showing a representative setup for the same.

Fig. 7b

Fig. 7b is a graph showing the discharging rate of a battery in RP ash leachate.

Fig. 8a

Fig. 8a is a graph showing the discharge rate of an NCA battery in an RP ash suspension at various L/S ratios.

Fig. 8b

Fig. 8b is a graph showing the discharge rate of an NCA battery in an ESP ash suspension at various L/S ratios.

Fig. 9

Fig. 9 is a graph showing the conductivity of each ash suspension at various L/S ratios prior to discharge.

Fig. 10

Fig. 10 is a series of images showing the degree of battery corrosion after discharging in the presence of (i) RP and (ii) ESP for various durations.

Fig. 11a

Fig. 11a is an SEM-EDX image of select elements detected on the cathode material of a battery after discharging in an RP ash mixture of L/S ratio 5 for 4 hours.

Fig. 11b

Fig. 11b is an SEM-EDX image of select elements detected on the cathode material of a battery after discharging in an ESP ash mixture of L/S ratio 5 for 6 hours.

Fig. 12a

Fig. 12a shows representative setups for separating a battery from the ash residue during discharging, whereby (i) is separated by a mesh, while (ii) is separated by a mesh sieve cup.

Fig. 12b

Fig. 12b is a series of images showing the reaction setup (i) before and (ii) after discharging.

Fig. 13

Fig. 13 is a cross section image of a representative rotating reactor for discharging batteries using an ash mixture.

Fig. 14

Fig. 14 is a series of images of the rotating cage (1308) in Fig. 13, with (i) showing a top-down view (ii) showing a bottom up view, and (iii) showing the same cage loaded with batteries.

Detailed Disclosure of Drawings

Referring to Fig. 3, an inverted plastic weighing dish (0310), punched with holes, is placed on top of a stir bar (0311) in a beaker (0312). A battery (0313) is then placed on top of the inverted plastic weighing dish (0310), to allow the stir bar (0311) to stir fly ash (not shown) smoothly at the bottom of the beaker (0312) without the stir bar (0311) hitting the battery (0313). 300 ml of distilled water (DI water) (0314) is then added to ensure that the battery (0313) was completely immersed. IFA (ESP or RP) (not shown) is then added to the beaker (0312) and the mixture allowed to stir for a specified duration, following which the battery (0313) is taken out.

Referring to Fig 12a, a stir bar (1212) is first placed in a beaker (1204), following which an ash and water mixture (ash suspension) (1210) is added to the beaker. A mesh (1214) is placed in the beaker (1204), following which a layer of ash leachate (1206) is formed in (i). Alternatively, a mesh sieve cup (1208) is placed in the beaker (1204), following which a layer of ash leachate (1206) is formed in (ii). A battery (1202) is then placed in ash leachate (1206) in either (i) or (ii), to allow the discharge process to proceed.

Referring to Fig. 13, a rotating reactor is provided for discharging batteries. Batteries may be placed in a rotating cage (1308) which is coupled to a rotor (1302) that rotates that cage to stir and homogenise the mixture in the reactor. Fly ash (IFA) may be loaded into the reactor via IFA inlet (1306), while water may be fed into the reactor via water inlet (1310). Sieve (1318) present at the bottom of the reactor may be present to separate the residue, which exits at residue outlet (1316), from the filtrate outlet (1314). The filtrate (1314) may be recirculated through a circulation pump (1312) to be combined with the water feed (1310) and re-enter the reactor. Effervescence resulting from the reaction may exit the reactor via gas valve (1304).

Detailed Disclosure of Embodiments

The present disclosure provides for a method of discharging a battery comprising contacting the battery with ash, ash suspension, or ash leachate, wherein the ash, ash suspension, or ash leachate comprises at least one ion selected from the group consisting of chloride, sulphate, sulphide, hydroxide, carbonate, and phosphate.

The present disclosure also provides for a method of reducing at least one ion content in ash comprising contacting a battery with ash, ash suspension or ash leachate, wherein the ion is selected from the group consisting of chloride, sulphate, sulphide, hydroxide, carbonate, and phosphate.

The present disclosure also provides for a process for discharging lithium-ion batteries comprising:
mixing ash with water to form an ash suspension;

immersing one or more lithium ion batteries (LIBs) in the ash suspension;
 agitating the ash suspension such that the ash is distributed throughout the water; and
 discharging voltage present in the LIB.

The present disclosure further provides for a process for discharging lithium-ion batteries comprising
 mixing ash with water to form an ash suspension;
 agitating the ash suspension such that the ash is distributed throughout the water;
 filtering the ash suspension to obtain an ash leachate;
 immersing one or more lithium ion batteries (LIBs) in the ash leachate; and
 discharging voltage present in the LIB.

Before dismantling or shredding to recover cathode material, batteries, for example, lithium-ion batteries (LIBs), need to be discharged sufficiently to prevent short-circuiting. The present disclosure has surprisingly found that ash, or suspensions and leachates thereof, may be used to discharge batteries in a pre-treatment step. Concurrently, the present disclosure has also surprisingly found that ash may be treated to remove ions and/or reduce ion content simply by contacting ash, or suspensions and leachates thereof, with a battery. The present disclosure thus provides for a method which discharges batteries and concurrently treats ash at the same time, in a novel waste-treat-waste concept.

Conventionally, NaCl solutions have been used to discharge batteries. The present disclosure has surprisingly found that ash contains ions (e.g., chlorides) and could thus replace NaCl as a discharging medium, but further found that ash, or suspensions and leachates thereof, can discharge batteries at a significantly faster rate as compared to conventional NaCl solution.

Concurrently, the present disclosure has surprisingly found that ash may be treated by electrolysis. The present disclosure has also unexpectedly found that ash may be treated simply by contacting ash, or suspensions and leachates thereof, with a battery.

The presently disclosed method also advantageously reduces metal content, on top of other content like chloride, during the discharging process. Hence the presently disclosed method also advantageously treats ash in the process by reducing metal and/or other content, e.g., chloride content.

In some embodiments, the presently disclosed method further comprises reducing metal content in ash.

In some embodiments, the metal may be selected from the group consisting of Li, Na, Mg, Al, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Rb, Sr, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Cs, Ba, La, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, Tl, Pb, Bi, or combinations and mixtures thereof. In some preferred embodiments, the metal may be selected from the group consisting of aluminum, potassium, iron, copper, zinc, calcium, magnesium, cadmium and lead.

In some embodiments, the metal content may be reduced by a range of at least about 0.5%, at least about 1%, at least about 2%, at least about 3%, at least about 5%, at least about 7%, at least about 10%, at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%; or from about 0.5% to about 60%, from about 0.5% to about 50%, from about 0.5% to about 40%, from about 0.5% to

about 30%, from about 0.5% to about 20%, from about 0.5% to about 10%, from about 0.5% to about 7%, from about 0.5% to about 5%, from about 0.5% to about 3%, from about 0.5% to about 2%, from about 0.5% to about 1%, from about 1% to about 60%, from about 1% to about 50%, from about 1% to about 40%, from about 1% to about 30%, from about 1% to about 20%, from about 1% to about 10%, from about 1% to about 7%, from about 1% to about 5%, from about 1% to about 3%, from about 1% to about 2%, from about 2% to about 60%, from about 2% to about 50%, from about 2% to about 40%, from about 2% to about 30%, from about 2% to about 20%, from about 2% to about 10%, from about 2% to about 7%, from about 2% to about 5%, from about 2% to about 3%, from about 3% to about 60%, from about 3% to about 50%, from about 3% to about 40%, from about 3% to about 30%, from about 3% to about 20%, from about 3% to about 10%, from about 3% to about 7%, from about 3% to about 5%, from about 5% to about 60%, from about 5% to about 50%, from about 5% to about 40%, from about 5% to about 30%, from about 5% to about 20%, from about 5% to about 10%, from about 5% to about 7%, from about 7% to about 60%, from about 7% to about 50%, from about 7% to about 40%, from about 7% to about 30%, from about 7% to about 20%, from about 7% to about 10%, from about 10% to about 60%, from about 10% to about 50%, from about 10% to about 40%, from about 10% to about 30%, from about 10% to about 20%, from about 20% to about 60%, from about 20% to about 50%, from about 20% to about 40%, from about 20% to about 30%, from about 30% to about 60%, from about 30% to about 50%, from about 30% to about 40%, from about 40% to about 60%, from about 40% to about 50%, from about 50% to about 60%; or at most about 0.5%, at most about 1%, at most about 2%, at most about 3%, at most about 5%, at most about 7%, at most about 10%, at most about 20%, at most about 30%, at most about 40%, at most about 50%, at most about 60%; or about 0.5%, about 1%, about 2%, about 3%, about 5%, about 7%, about 10%, about 20%, about 30%, about 40%, about 50%, about 60%, or any ranges or values therebetween.

In some embodiments, the ash, ash suspension or ash leachate may comprise chloride, sulphate, sulphide, hydroxide, carbonate, and/or phosphate ions, in a range of at least about 1500 ppm, at least about 3000 ppm, at least about 5000 ppm, at least about 10000 ppm, at least about 15000 ppm, at least about 17000 ppm, at least about 20000 ppm, at least about 24829 ppm, at least about 30000 ppm, at least about 36195 ppm, at least about 40000 ppm, at least about 50000 ppm, at least about 70000 ppm, at least about 100000 ppm, at least about 120000 ppm, at least about 150000 ppm; or from about 1500 ppm to about 150000 ppm, from about 1500 ppm to about 120000 ppm, from about 1500 ppm to about 100000 ppm, from about 1500 ppm to about 70000 ppm, from about 1500 ppm to about 50000 ppm, from about 1500 ppm to about 40000 ppm, from about 1500 ppm to about 36195 ppm, from about 1500 ppm to about 30000 ppm, from about 1500 ppm to about 24829 ppm, from about 1500 ppm to about 20000 ppm, from about 1500 ppm to about 17000 ppm, from about 1500 ppm to about 15000 ppm, from about 1500 ppm to about 10000 ppm, from about 1500 ppm to about 5000 ppm, from about 1500 ppm to about 3000 ppm, from about 3000 ppm to about 150000 ppm, from about 3000 ppm to about 120000 ppm, from about 3000 ppm to about 100000 ppm, from about 3000 ppm to about 70000 ppm, from about 3000 ppm to about 50000 ppm, from about 3000 ppm to about 40000 ppm, from about 3000 ppm to about 36195 ppm, from about 3000 ppm to about 30000 ppm, from about 3000 ppm to about 24829 ppm, from about 3000 ppm to about 20000 ppm, from about 3000 ppm to about 17000 ppm, from about 3000 ppm to about 15000 ppm, from about 3000 ppm to about 10000 ppm, from about 3000 ppm to about 5000 ppm, from about 5000 ppm to about 150000 ppm, from about 5000 ppm to about 120000 ppm, from about 5000 ppm to about 100000 ppm, from about 5000 ppm to about 70000 ppm, from about 5000 ppm to about 50000 ppm, from about 5000 ppm to about 40000 ppm, from about 5000 ppm to about 36195 ppm, from about 5000 ppm to about 30000 ppm, from about

5000 ppm to about 24829 ppm, from about 5000 ppm to about 20000 ppm, from about 5000 ppm to about 17000 ppm, from about 5000 ppm to about 15000 ppm, from about 5000 ppm to about 10000 ppm, from about 10000 ppm to about 150000 ppm, from about 10000 ppm to about 120000 ppm, from about 10000 ppm to about 100000 ppm, from about 10000 ppm to about 70000 ppm, from about 10000 ppm to about 50000 ppm, from about 10000 ppm to about 40000 ppm, from about 10000 ppm to about 36195 ppm, from about 10000 ppm to about 30000 ppm, from about 10000 ppm to about 24829 ppm, from about 10000 ppm to about 20000 ppm, from about 10000 ppm to about 17000 ppm, from about 10000 ppm to about 15000 ppm, from about 15000 ppm to about 150000 ppm, from about 15000 ppm to about 120000 ppm, from about 15000 ppm to about 100000 ppm, from about 15000 ppm to about 70000 ppm, from about 15000 ppm to about 50000 ppm, from about 15000 ppm to about 40000 ppm, from about 15000 ppm to about 36195 ppm, from about 15000 ppm to about 30000 ppm, from about 15000 ppm to about 24829 ppm, from about 15000 ppm to about 20000 ppm, from about 15000 ppm to about 17000 ppm, from about 17000 ppm to about 150000 ppm, from about 17000 ppm to about 120000 ppm, from about 17000 ppm to about 100000 ppm, from about 17000 ppm to about 70000 ppm, from about 17000 ppm to about 50000 ppm, from about 17000 ppm to about 40000 ppm, from about 17000 ppm to about 36195 ppm, from about 17000 ppm to about 30000 ppm, from about 17000 ppm to about 24829 ppm, from about 17000 ppm to about 20000 ppm, from about 20000 ppm to about 150000 ppm, from about 20000 ppm to about 120000 ppm, from about 20000 ppm to about 100000 ppm, from about 20000 ppm to about 70000 ppm, from about 20000 ppm to about 50000 ppm, from about 20000 ppm to about 40000 ppm, from about 20000 ppm to about 36195 ppm, from about 20000 ppm to about 30000 ppm, from about 20000 ppm to about 24829 ppm, from about 24829 ppm to about 150000 ppm, from about 24829 ppm to about 120000 ppm, from about 24829 ppm to about 100000 ppm, from about 24829 ppm to about 70000 ppm, from about 24829 ppm to about 50000 ppm, from about 24829 ppm to about 40000 ppm, from about 24829 ppm to about 36195 ppm, from about 24829 ppm to about 30000 ppm, from about 30000 ppm to about 150000 ppm, from about 30000 ppm to about 120000 ppm, from about 30000 ppm to about 100000 ppm, from about 30000 ppm to about 70000 ppm, from about 30000 ppm to about 50000 ppm, from about 30000 ppm to about 40000 ppm, from about 30000 ppm to about 36195 ppm, from about 36195 ppm to about 150000 ppm, from about 36195 ppm to about 120000 ppm, from about 36195 ppm to about 100000 ppm, from about 36195 ppm to about 70000 ppm, from about 36195 ppm to about 50000 ppm, from about 36195 ppm to about 40000 ppm, from about 40000 ppm to about 150000 ppm, from about 40000 ppm to about 120000 ppm, from about 40000 ppm to about 100000 ppm, from about 40000 ppm to about 70000 ppm, from about 40000 ppm to about 50000 ppm, from about 50000 ppm to about 150000 ppm, from about 50000 ppm to about 120000 ppm, from about 50000 ppm to about 100000 ppm, from about 50000 ppm to about 70000 ppm, from about 70000 ppm to about 150000 ppm, from about 70000 ppm to about 120000 ppm, from about 70000 ppm to about 100000 ppm, from about 100000 ppm to about 150000 ppm, from about 100000 ppm to about 120000 ppm, from about 120000 ppm to about 150000 ppm; or at most about 1500 ppm, at most about 3000 ppm, at most about 5000 ppm, at most about 10000 ppm, at most about 15000 ppm, at most about 17000 ppm, at most about 20000 ppm, at most about 24829 ppm, at most about 30000 ppm, at most about 36195 ppm, at most about 40000 ppm, at most about 50000 ppm, at most about 70000 ppm, at most about 100000 ppm, at most about 120000 ppm, at most about 150000 ppm; or about 1500 ppm, about 3000 ppm, about 5000 ppm, about 10000 ppm, about 15000 ppm, about 17000 ppm, about 20000 ppm, about 24829 ppm, about 30000 ppm, about 36195 ppm, about 40000 ppm, about 50000 ppm, about 70000 ppm, about 100000 ppm, about 120000 ppm, about 150000 ppm, or any ranges or values therebetween. In some preferred embodiments, the ash, ash suspension or ash leachate comprises at least

about 10000 ppm chloride, sulphate, sulphide, hydroxide, carbonate, and/or phosphate ions. In some other preferred embodiments, the ash, ash suspension or ash leachate comprises at least about 50000 ppm chloride, sulphate, sulphide, hydroxide, carbonate, and/or phosphate ions. In some further preferred embodiments, the ash, ash suspension or ash leachate comprises from about 20000 ppm to about 100000 ppm chloride, sulphate, sulphide, hydroxide, carbonate, and/or phosphate ions.

In some embodiments, the ash, ash suspension or ash leachate may comprise chloride ions in a range of at least about 10000 ppm, at least about 20000 ppm, at least about 25000 ppm, at least about 50000 ppm, at least about 95000 ppm, at least about 100000 ppm, at least about 200000 ppm, at least about 250000 ppm, at least about 300000 ppm, at least about 400000 ppm, at least about 450000 ppm, at least about 500000 ppm; or from about 10000 ppm to about 500000 ppm, from about 10000 ppm to about 450000 ppm, from about 10000 ppm to about 400000 ppm, from about 10000 ppm to about 300000 ppm, from about 10000 ppm to about 250000 ppm, from about 10000 ppm to about 200000 ppm, from about 10000 ppm to about 100000 ppm, from about 10000 ppm to about 95000 ppm, from about 10000 ppm to about 50000 ppm, from about 10000 ppm to about 25000 ppm, from about 10000 ppm to about 20000 ppm, from about 20000 ppm to about 500000 ppm, from about 20000 ppm to about 450000 ppm, from about 20000 ppm to about 400000 ppm, from about 20000 ppm to about 300000 ppm, from about 20000 ppm to about 250000 ppm, from about 20000 ppm to about 200000 ppm, from about 20000 ppm to about 100000 ppm, from about 20000 ppm to about 95000 ppm, from about 20000 ppm to about 50000 ppm, from about 20000 ppm to about 25000 ppm, from about 25000 ppm to about 500000 ppm, from about 25000 ppm to about 450000 ppm, from about 25000 ppm to about 400000 ppm, from about 25000 ppm to about 300000 ppm, from about 25000 ppm to about 250000 ppm, from about 25000 ppm to about 200000 ppm, from about 25000 ppm to about 100000 ppm, from about 25000 ppm to about 95000 ppm, from about 25000 ppm to about 50000 ppm, from about 50000 ppm to about 500000 ppm, from about 50000 ppm to about 450000 ppm, from about 50000 ppm to about 400000 ppm, from about 50000 ppm to about 300000 ppm, from about 50000 ppm to about 250000 ppm, from about 50000 ppm to about 200000 ppm, from about 50000 ppm to about 100000 ppm, from about 50000 ppm to about 95000 ppm, from about 95000 ppm to about 500000 ppm, from about 95000 ppm to about 450000 ppm, from about 95000 ppm to about 400000 ppm, from about 95000 ppm to about 300000 ppm, from about 95000 ppm to about 250000 ppm, from about 95000 ppm to about 200000 ppm, from about 95000 ppm to about 100000 ppm, from about 100000 ppm to about 500000 ppm, from about 100000 ppm to about 450000 ppm, from about 100000 ppm to about 400000 ppm, from about 100000 ppm to about 300000 ppm, from about 100000 ppm to about 250000 ppm, from about 100000 ppm to about 200000 ppm, from about 200000 ppm to about 500000 ppm, from about 200000 ppm to about 450000 ppm, from about 200000 ppm to about 400000 ppm, from about 200000 ppm to about 300000 ppm, from about 200000 ppm to about 250000 ppm, from about 250000 ppm to about 500000 ppm, from about 250000 ppm to about 450000 ppm, from about 250000 ppm to about 400000 ppm, from about 250000 ppm to about 300000 ppm, from about 300000 ppm to about 500000 ppm, from about 300000 ppm to about 450000 ppm, from about 300000 ppm to about 400000 ppm, from about 400000 ppm to about 500000 ppm, from about 400000 ppm to about 450000 ppm, from about 450000 ppm to about 500000 ppm; or at most about 10000 ppm, at most about 20000 ppm, at most about 25000 ppm, at most about 50000 ppm, at most about 95000 ppm, at most about 100000 ppm, at most about 200000 ppm, at most about 250000 ppm, at most about 300000 ppm, at most about 400000 ppm, at most about 450000 ppm, at most about 500000 ppm; or about 10000 ppm, about 20000 ppm, about 25000 ppm, about 50000 ppm, about 95000 ppm, about 100000 ppm, about 200000 ppm, about 250000 ppm, about

300000 ppm, about 400000 ppm, about 450000 ppm, about 500000 ppm, or any ranges or values therebetween.

In some embodiments, the ash, ash suspension or ash leachate may comprise phosphate ions in a range of at least about 1000 ppm, at least about 1500 ppm, at least about 2000 ppm, at least about 2500 ppm, at least about 3000 ppm, at least about 4000 ppm, at least about 5000 ppm, at least about 6000 ppm, at least about 8000 ppm; or from about 1000 ppm to about 8000 ppm, from about 1000 ppm to about 6000 ppm, from about 1000 ppm to about 5000 ppm, from about 1000 ppm to about 4000 ppm, from about 1000 ppm to about 3000 ppm, from about 1000 ppm to about 2500 ppm, from about 1000 ppm to about 2000 ppm, from about 1000 ppm to about 1500 ppm, from about 1500 ppm to about 8000 ppm, from about 1500 ppm to about 6000 ppm, from about 1500 ppm to about 5000 ppm, from about 1500 ppm to about 4000 ppm, from about 1500 ppm to about 3000 ppm, from about 1500 ppm to about 2500 ppm, from about 1500 ppm to about 2000 ppm, from about 2000 ppm to about 8000 ppm, from about 2000 ppm to about 6000 ppm, from about 2000 ppm to about 5000 ppm, from about 2000 ppm to about 4000 ppm, from about 2000 ppm to about 3000 ppm, from about 2000 ppm to about 2500 ppm, from about 2500 ppm to about 8000 ppm, from about 2500 ppm to about 6000 ppm, from about 2500 ppm to about 5000 ppm, from about 2500 ppm to about 4000 ppm, from about 2500 ppm to about 3000 ppm, from about 3000 ppm to about 8000 ppm, from about 3000 ppm to about 6000 ppm, from about 3000 ppm to about 5000 ppm, from about 3000 ppm to about 4000 ppm, from about 4000 ppm to about 8000 ppm, from about 4000 ppm to about 6000 ppm, from about 4000 ppm to about 5000 ppm, from about 5000 ppm to about 8000 ppm, from about 5000 ppm to about 6000 ppm, from about 6000 ppm to about 8000 ppm; or at most about 1000 ppm, at most about 1500 ppm, at most about 2000 ppm, at most about 2500 ppm, at most about 3000 ppm, at most about 4000 ppm, at most about 5000 ppm, at most about 6000 ppm, at most about 8000 ppm; or about 1000 ppm, about 1500 ppm, about 2000 ppm, about 2500 ppm, about 3000 ppm, about 4000 ppm, about 5000 ppm, about 6000 ppm, about 8000 ppm, or any ranges or values therebetween.

In some embodiments, the ash, ash suspension or ash leachate may comprise sulphate ions, sulphide ions, and/or elemental sulfur in a range of at least about 25000 ppm, at least about 45000 ppm, at least about 50000 ppm, at least about 95000 ppm, at least about 100000 ppm, at least about 140000 ppm, at least about 150000 ppm; or from about 25000 ppm to about 150000 ppm, from about 25000 ppm to about 140000 ppm, from about 25000 ppm to about 100000 ppm, from about 25000 ppm to about 95000 ppm, from about 25000 ppm to about 50000 ppm, from about 25000 ppm to about 45000 ppm, from about 45000 ppm to about 150000 ppm, from about 45000 ppm to about 140000 ppm, from about 45000 ppm to about 100000 ppm, from about 45000 ppm to about 95000 ppm, from about 45000 ppm to about 50000 ppm, from about 50000 ppm to about 150000 ppm, from about 50000 ppm to about 140000 ppm, from about 50000 ppm to about 100000 ppm, from about 50000 ppm to about 95000 ppm, from about 95000 ppm to about 150000 ppm, from about 95000 ppm to about 140000 ppm, from about 95000 ppm to about 100000 ppm, from about 100000 ppm to about 150000 ppm, from about 100000 ppm to about 140000 ppm, from about 140000 ppm to about 150000 ppm; or at most about 25000 ppm, at most about 45000 ppm, at most about 50000 ppm, at most about 95000 ppm, at most about 100000 ppm, at most about 140000 ppm, at most about 150000 ppm; or about 25000 ppm, about 45000 ppm, about 50000 ppm, about 95000 ppm, about 100000 ppm, about 140000 ppm, about 150000 ppm, or any ranges or values therebetween.

In some embodiments, the presently disclosed method comprises reducing chloride content in ash. In some embodiments the chloride content is reduced by a range of at least about 1%, at least about 2%, at least about 3%, at least about 5%, at least about 7%, at least about 10%, at least about 20%, at least about 30%, at least about 40%; or from about 1% to about 40%, from about 1% to about 30%, from about 1% to about 20%, from about 1% to about 10%, from about 1% to about 7%, from about 1% to about 5%, from about 1% to about 3%, from about 1% to about 2%, from about 2% to about 40%, from about 2% to about 30%, from about 2% to about 20%, from about 2% to about 10%, from about 2% to about 7%, from about 2% to about 5%, from about 2% to about 3%, from about 3% to about 40%, from about 3% to about 30%, from about 3% to about 20%, from about 3% to about 10%, from about 3% to about 7%, from about 3% to about 5%, from about 5% to about 40%, from about 5% to about 30%, from about 5% to about 20%, from about 5% to about 10%, from about 5% to about 7%, from about 7% to about 40%, from about 7% to about 30%, from about 7% to about 20%, from about 7% to about 10%, from about 10% to about 40%, from about 10% to about 30%, from about 10% to about 20%, from about 20% to about 40%, from about 20% to about 30%, from about 30% to about 40%; or at most about 1%, at most about 2%, at most about 3%, at most about 5%, at most about 7%, at most about 10%, at most about 20%, at most about 30%, at most about 40%; or about 1%, about 2%, about 3%, about 5%, about 7%, about 10%, about 20%, about 30%, about 40%, or any ranges or values therebetween.

In some embodiments, the pH of the ash, ash leachate, or ash suspension may be reduced after the discharge. In some embodiments, reducing the ion content of the ash mixture, suspension or leachate also reduces its pH. This advantageously treats the ash so that it can be safely buried in landfills. Further, treating the ash to reduce its pH also makes it compatible for use in other applications, for example in cement production.

In some embodiments, the pH of the ash suspension, mixture or leachate prior to discharge may be in a range of at least about 10.5, at least about 10.6, at least about 11, at least about 11.14, at least about 11.20, at least about 11.27, at least about 11.4, at least about 11.5, at least about 11.7, at least about 11.98, at least about 12; or from about 10.5 to about 12, from about 10.5 to about 11.98, from about 10.5 to about 11.7, from about 10.5 to about 11.5, from about 10.5 to about 11.4, from about 10.5 to about 11.27, from about 10.5 to about 11.20, from about 10.5 to about 11.14, from about 10.5 to about 11, from about 10.5 to about 10.6, from about 10.6 to about 12, from about 10.6 to about 11.98, from about 10.6 to about 11.7, from about 10.6 to about 11.5, from about 10.6 to about 11.4, from about 10.6 to about 11.27, from about 10.6 to about 11.20, from about 10.6 to about 11.14, from about 10.6 to about 11, from about 11 to about 12, from about 11 to about 11.98, from about 11 to about 11.7, from about 11 to about 11.5, from about 11 to about 11.4, from about 11 to about 11.27, from about 11 to about 11.20, from about 11 to about 11.14, from about 11.14 to about 12, from about 11.14 to about 11.98, from about 11.14 to about 11.7, from about 11.14 to about 11.5, from about 11.14 to about 11.4, from about 11.14 to about 11.27, from about 11.14 to about 11.20, from about 11.20 to about 12, from about 11.20 to about 11.98, from about 11.20 to about 11.7, from about 11.20 to about 11.5, from about 11.20 to about 11.4, from about 11.20 to about 11.27, from about 11.27 to about 12, from about 11.27 to about 11.98, from about 11.27 to about 11.7, from about 11.27 to about 11.5, from about 11.27 to about 11.4, from about 11.4 to about 12, from about 11.4 to about 11.98, from about 11.4 to about 11.7, from about 11.4 to about 11.5, from about 11.5 to about 12, from about 11.5 to about 11.98, from about 11.5 to about 11.7, from about 11.7 to about 12, from about 11.7 to about 11.98, from about 11.98 to about 12; or at most about 10.5, at most about 10.6,

at most about 11, at most about 11.14, at most about 11.20, at most about 11.27, at most about 11.4, at most about 11.5, at most about 11.7, at most about 11.98, at most about 12; or about 10.5, about 10.6, about 11, about 11.14, about 11.20, about 11.27, about 11.4, about 11.5, about 11.7, about 11.98, about 12, or any ranges or values therebetween.

In some further embodiments, the pH of the ash, ash leachate, or ash suspension may be reduced to a range of at least about 5, at least about 5.5, at least about 6, at least about 6.02, at least about 6.2, at least about 6.4, at least about 6.5, at least about 6.6, at least about 6.8, at least about 7, at least about 7.2, at least about 7.5, at least about 8, at least about 8.5, at least about 9, at least about 9.5, at least about 10, at least about 10.5, at least about 11; or from about 5 to about 11, from about 5 to about 10.5, from about 5 to about 10, from about 5 to about 9.5, from about 5 to about 9, from about 5 to about 8.5, from about 5 to about 8, from about 5 to about 7.5, from about 5 to about 7.2, from about 5 to about 7, from about 5 to about 6.8, from about 5 to about 6.6, from about 5 to about 6.5, from about 5 to about 6.4, from about 5 to about 6.2, from about 5 to about 6.02, from about 5 to about 6, from about 5 to about 5.5, from about 5.5 to about 11, from about 5.5 to about 10.5, from about 5.5 to about 10, from about 5.5 to about 9.5, from about 5.5 to about 9, from about 5.5 to about 8.5, from about 5.5 to about 8, from about 5.5 to about 7.5, from about 5.5 to about 7.2, from about 5.5 to about 7, from about 5.5 to about 6.8, from about 5.5 to about 6.6, from about 5.5 to about 6.5, from about 5.5 to about 6.4, from about 5.5 to about 6.2, from about 5.5 to about 6.02, from about 5.5 to about 6, from about 6 to about 11, from about 6 to about 10.5, from about 6 to about 10, from about 6 to about 9.5, from about 6 to about 9, from about 6 to about 8.5, from about 6 to about 8, from about 6 to about 7.5, from about 6 to about 7.2, from about 6 to about 7, from about 6 to about 6.8, from about 6 to about 6.6, from about 6 to about 6.5, from about 6 to about 6.4, from about 6 to about 6.2, from about 6 to about 6.02, from about 6.02 to about 11, from about 6.02 to about 10.5, from about 6.02 to about 10, from about 6.02 to about 9.5, from about 6.02 to about 9, from about 6.02 to about 8.5, from about 6.02 to about 8, from about 6.02 to about 7.5, from about 6.02 to about 7.2, from about 6.02 to about 7, from about 6.02 to about 6.8, from about 6.02 to about 6.6, from about 6.02 to about 6.5, from about 6.02 to about 6.4, from about 6.02 to about 6.2, from about 6.2 to about 11, from about 6.2 to about 10.5, from about 6.2 to about 10, from about 6.2 to about 9.5, from about 6.2 to about 9, from about 6.2 to about 8.5, from about 6.2 to about 8, from about 6.2 to about 7.5, from about 6.2 to about 7.2, from about 6.2 to about 7, from about 6.2 to about 6.8, from about 6.2 to about 6.6, from about 6.2 to about 6.5, from about 6.2 to about 6.4, from about 6.4 to about 11, from about 6.4 to about 10.5, from about 6.4 to about 10, from about 6.4 to about 9.5, from about 6.4 to about 9, from about 6.4 to about 8.5, from about 6.4 to about 8, from about 6.4 to about 7.5, from about 6.4 to about 7.2, from about 6.4 to about 7, from about 6.4 to about 6.8, from about 6.4 to about 6.6, from about 6.4 to about 6.5, from about 6.5 to about 11, from about 6.5 to about 10.5, from about 6.5 to about 10, from about 6.5 to about 9.5, from about 6.5 to about 9, from about 6.5 to about 8.5, from about 6.5 to about 8, from about 6.5 to about 7.5, from about 6.5 to about 7.2, from about 6.5 to about 7, from about 6.5 to about 6.8, from about 6.5 to about 6.6, from about 6.6 to about 11, from about 6.6 to about 10.5, from about 6.6 to about 10, from about 6.6 to about 9.5, from about 6.6 to about 9, from about 6.6 to about 8.5, from about 6.6 to about 8, from about 6.6 to about 7.5, from about 6.6 to about 7.2, from about 6.6 to about 7, from about 6.6 to about 6.8, from about 6.8 to about 11, from about 6.8 to about 10.5, from about 6.8 to about 10, from about 6.8 to about 9.5, from about 6.8 to about 9, from about 6.8 to about 8.5, from about 6.8 to about 8, from about 6.8 to about 7.5, from about 6.8 to about 7.2, from about 6.8 to about 7, from about 7 to about 11, from about 7 to about 10.5, from about 7 to about 10, from

about 7 to about 9.5, from about 7 to about 9, from about 7 to about 8.5, from about 7 to about 8, from about 7 to about 7.5, from about 7 to about 7.2, from about 7.2 to about 11, from about 7.2 to about 10.5, from about 7.2 to about 10, from about 7.2 to about 9.5, from about 7.2 to about 9, from about 7.2 to about 8.5, from about 7.2 to about 8, from about 7.2 to about 7.5, from about 7.5 to about 11, from about 7.5 to about 10.5, from about 7.5 to about 10, from about 7.5 to about 9.5, from about 7.5 to about 9, from about 7.5 to about 8.5, from about 7.5 to about 8, from about 8 to about 11, from about 8 to about 10.5, from about 8 to about 10, from about 8 to about 9.5, from about 8 to about 9, from about 8 to about 8.5, from about 8.5 to about 11, from about 8.5 to about 10.5, from about 8.5 to about 10, from about 8.5 to about 9.5, from about 8.5 to about 9, from about 9 to about 11, from about 9 to about 10.5, from about 9 to about 10, from about 9 to about 9.5, from about 9.5 to about 11, from about 9.5 to about 10.5, from about 9.5 to about 10, from about 10 to about 11, from about 10 to about 10.5, from about 10.5 to about 11; or at most about 5, at most about 5.5, at most about 6, at most about 6.02, at most about 6.2, at most about 6.4, at most about 6.5, at most about 6.6, at most about 6.8, at most about 7, at most about 7.2, at most about 7.5, at most about 8, at most about 8.5, at most about 9, at most about 9.5, at most about 10, at most about 10.5, at most about 11; or about 5, about 5.5, about 6, about 6.02, about 6.2, about 6.4, about 6.5, about 6.6, about 6.8, about 7, about 7.2, about 7.5, about 8, about 8.5, about 9, about 9.5, about 10, about 10.5, about 11, or any ranges or values therebetween after the discharge.

The present invention has also found that ash may have a high conductivity due to the soluble salts present, which advantageously improves its battery discharging potential. The present invention has also found that ash suspensions, or ash leachates prepared therefrom, are advantageously able to discharge batteries in different water:ash ratios (L/S **ratios**, or LS ratios).

In some embodiments, the ash suspension comprises ash and water.

In some embodiments, the battery is separated from the ash in the ash suspension. The present disclosure has also surprisingly found that separating the batteries from the residue in the ash, ash suspension or leachate advantageously increases the discharge rate.

Further the inventors have also surprisingly found that contacting the battery with only the ash leachate may further increase the discharge rate. In some embodiments, the presently disclosed method comprises contacting the battery with the ash leachate.

In some embodiments, the ash leachate is obtained by filtering an ash suspension comprising ash and water.

In some embodiments, the ratio of volume of water to mass of ash in the ash suspension is in a range of at least about 1:10, at least about 1:8, at least about 1:5, at least about 1:4, at least about 1:2, at least about 1:1, at least about 2:1, at least about 3:1, at least about 4:1, at least about 5:1, at least about 7:1, at least about 8:1, at least about 9:1, at least about 10:1; or from about 1:10 to about 10:1, from about 1:10 to about 9:1, from about 1:10 to about 8:1, from about 1:10 to about 7:1, from about 1:10 to about 5:1, from about 1:10 to about 4:1, from about 1:10 to about 3:1, from about 1:10 to about 2:1, from about 1:10 to about 1:1, from about 1:10 to about 1:2, from about 1:10 to about 1:4, from about 1:10 to about 1:5, from about 1:10 to about 1:8, from about 1:8 to about 10:1, from about 1:8 to about 9:1, from about 1:8 to about 8:1, from about 1:8 to about 7:1, from about 1:8 to about 5:1, from about 1:8 to about 4:1, from about 1:8 to

about 3:1, from about 1:8 to about 2:1, from about 1:8 to about 1:1, from about 1:8 to about 1:2, from about 1:8 to about 1:4, from about 1:8 to about 1:5, from about 1:5 to about 10:1, from about 1:5 to about 9:1, from about 1:5 to about 8:1, from about 1:5 to about 7:1, from about 1:5 to about 5:1, from about 1:5 to about 4:1, from about 1:5 to about 3:1, from about 1:5 to about 2:1, from about 1:5 to about 1:1, from about 1:5 to about 1:2, from about 1:5 to about 1:4, from about 1:4 to about 10:1, from about 1:4 to about 9:1, from about 1:4 to about 8:1, from about 1:4 to about 7:1, from about 1:4 to about 5:1, from about 1:4 to about 4:1, from about 1:4 to about 3:1, from about 1:4 to about 2:1, from about 1:4 to about 1:1, from about 1:4 to about 1:2, from about 1:2 to about 10:1, from about 1:2 to about 9:1, from about 1:2 to about 8:1, from about 1:2 to about 7:1, from about 1:2 to about 5:1, from about 1:2 to about 4:1, from about 1:2 to about 3:1, from about 1:2 to about 2:1, from about 1:2 to about 1:1, from about 1:1 to about 10:1, from about 1:1 to about 9:1, from about 1:1 to about 8:1, from about 1:1 to about 7:1, from about 1:1 to about 5:1, from about 1:1 to about 4:1, from about 1:1 to about 3:1, from about 1:1 to about 2:1, from about 2:1 to about 10:1, from about 2:1 to about 9:1, from about 2:1 to about 8:1, from about 2:1 to about 7:1, from about 2:1 to about 5:1, from about 2:1 to about 4:1, from about 2:1 to about 3:1, from about 3:1 to about 10:1, from about 3:1 to about 9:1, from about 3:1 to about 8:1, from about 3:1 to about 7:1, from about 3:1 to about 5:1, from about 3:1 to about 4:1, from about 4:1 to about 10:1, from about 4:1 to about 9:1, from about 4:1 to about 8:1, from about 4:1 to about 7:1, from about 4:1 to about 5:1, from about 5:1 to about 10:1, from about 5:1 to about 9:1, from about 5:1 to about 8:1, from about 5:1 to about 7:1, from about 7:1 to about 10:1, from about 7:1 to about 9:1, from about 7:1 to about 8:1, from about 8:1 to about 10:1, from about 8:1 to about 9:1, from about 9:1 to about 10:1; or at most about 1:10, at most about 1:8, at most about 1:5, at most about 1:4, at most about 1:2, at most about 1:1, at most about 2:1, at most about 3:1, at most about 4:1, at most about 5:1, at most about 7:1, at most about 8:1, at most about 9:1, at most about 10:1; or about 1:10, about 1:8, about 1:5, about 1:4, about 1:2, about 1:1, about 2:1, about 3:1, about 4:1, about 5:1, about 7:1, about 8:1, about 9:1, about 10:1, or any ranges or values therebetween. In some preferred embodiments, the ratio of volume of water to mass of ash in the ash suspension is about 1:1 to 10:1.

In some embodiments, the ash is moist ash, i.e. water and ash in a ratio of at least about 1:50, at least about 1:75, at least about 1:100; or from about 1:50 to about 1:100, from about 1:50 to about 1:75, from about 1:75 to about 1:100; or at most about 1:50, at most about 1:75, at most about 1:100; or about 1:50, about 1:75, about 1:100, or any ranges or values therebetween. In a preferred embodiment, the ash is moist ash in a water:ash ratio of about 1:100.

In some embodiments, 1 kg of ash may be capable of discharging a total battery capacity, in a range of at least about 5 Ah, at least about 7 Ah, at least about 10 Ah, at least about 12 Ah, at least about 15 Ah, at least about 17 Ah, at least about 20 Ah, at least about 21 Ah, at least about 24 Ah; or from about 5 Ah to about 24 Ah, from about 5 Ah to about 21 Ah, from about 5 Ah to about 20 Ah, from about 5 Ah to about 17 Ah, from about 5 Ah to about 15 Ah, from about 5 Ah to about 12 Ah, from about 5 Ah to about 10 Ah, from about 5 Ah to about 7 Ah, from about 7 Ah to about 24 Ah, from about 7 Ah to about 21 Ah, from about 7 Ah to about 20 Ah, from about 7 Ah to about 17 Ah, from about 7 Ah to about 15 Ah, from about 7 Ah to about 12 Ah, from about 7 Ah to about 10 Ah, from about 10 Ah to about 24 Ah, from about 10 Ah to about 21 Ah, from about 10 Ah to about 20 Ah, from about 10 Ah to about 17 Ah, from about 10 Ah to about 15 Ah, from about 10 Ah to about 12 Ah, from about 12 Ah to about 24 Ah, from about 12 Ah to about 21 Ah, from about 12 Ah to about 20 Ah, from about 12 Ah to about 17 Ah, from about 12 Ah to about 15 Ah, from about 15 Ah to about 24 Ah, from about 15 Ah to about 21 Ah, from about 15

Ah to about 20 Ah, from about 15 Ah to about 17 Ah, from about 17 Ah to about 24 Ah, from about 17 Ah to about 21 Ah, from about 17 Ah to about 20 Ah, from about 20 Ah to about 24 Ah, from about 20 Ah to about 21 Ah, from about 21 Ah to about 24 Ah; or at most about 5 Ah, at most about 7 Ah, at most about 10 Ah, at most about 12 Ah, at most about 15 Ah, at most about 17 Ah, at most about 20 Ah, at most about 21 Ah, at most about 24 Ah; or about 5 Ah, about 7 Ah, about 10 Ah, about 12 Ah, about 15 Ah, about 17 Ah, about 20 Ah, about 21 Ah, about 24 Ah, or any ranges or values therebetween. In some embodiments, 1 kg of ash is capable of discharging up to about 21 Ah in total battery capacity. In some preferred embodiments, 1 kg of ash is capable of discharging from about 7 Ah to about 15 Ah in total battery capacity.

In some preferred embodiments, the battery may be discharged from its nominal voltage, in at a range of at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, at least about 90%, at least about 95%, at least about 99%; or from about 20% to about 99%, from about 20% to about 95%, from about 20% to about 90%, from about 20% to about 80%, from about 20% to about 70%, from about 20% to about 60%, from about 20% to about 50%, from about 20% to about 40%, from about 20% to about 30%, from about 30% to about 99%, from about 30% to about 95%, from about 30% to about 90%, from about 30% to about 80%, from about 30% to about 70%, from about 30% to about 60%, from about 30% to about 50%, from about 30% to about 40%, from about 40% to about 99%, from about 40% to about 95%, from about 40% to about 90%, from about 40% to about 80%, from about 40% to about 70%, from about 40% to about 60%, from about 40% to about 50%, from about 50% to about 99%, from about 50% to about 95%, from about 50% to about 90%, from about 50% to about 80%, from about 50% to about 70%, from about 50% to about 60%, from about 60% to about 99%, from about 60% to about 95%, from about 60% to about 90%, from about 60% to about 80%, from about 60% to about 70%, from about 70% to about 99%, from about 70% to about 95%, from about 70% to about 90%, from about 70% to about 80%, from about 80% to about 99%, from about 80% to about 95%, from about 80% to about 90%, from about 90% to about 99%, from about 90% to about 95%, from about 95% to about 99%; or at most about 20%, at most about 30%, at most about 40%, at most about 50%, at most about 60%, at most about 70%, at most about 80%, at most about 90%, at most about 95%, at most about 99%; or about 20%, about 30%, about 40%, about 50%, about 60%, about 70%, about 80%, about 90%, about 95%, about 99%, or any ranges or values therebetween. In some preferred embodiments, the battery is discharged by at least about 50% from its nominal voltage. In some further preferred embodiments, the battery is discharged by at least about 80% from its nominal voltage.

In some embodiments, the battery may be discharged to a range of at least about 0.1 V, at least about 0.2 V, at least about 0.3 V, at least about 0.4 V, at least about 0.5 V, at least about 0.6 V, at least about 0.8 V, at least about 0.9 V, at least about 1 V, at least about 1.1 V, at least about 1.2 V, at least about 1.4 V, at least about 1.6 V, at least about 1.8 V, at least about 2 V; or from about 0.1 V to about 2 V, from about 0.1 V to about 1.8 V, from about 0.1 V to about 1.6 V, from about 0.1 V to about 1.4 V, from about 0.1 V to about 1.2 V, from about 0.1 V to about 1.1 V, from about 0.1 V to about 1 V, from about 0.1 V to about 0.9 V, from about 0.1 V to about 0.8 V, from about 0.1 V to about 0.6 V, from about 0.1 V to about 0.5 V, from about 0.1 V to about 0.4 V, from about 0.1 V to about 0.3 V, from about 0.1 V to about 0.2 V, from about 0.2 V to about 2 V, from about 0.2 V to about 1.8 V, from about 0.2 V to about 1.6 V, from about 0.2 V to about 1.4 V, from about 0.2 V to about 1.2 V, from about 0.2 V to about 1.1 V, from about 0.2 V to about 1 V, from about 0.2 V to about 0.9 V, from about 0.2 V to about 0.8 V, from about 0.2 V to about 0.6 V, from about 0.2 V to about 0.5 V, from about 0.2 V to about 0.4 V, from about 0.2 V to about 0.3 V, from about 0.2 V to about 0.2 V.

0.6 V, from about 0.2 V to about 0.5 V, from about 0.2 V to about 0.4 V, from about 0.2 V to about 0.3 V, from about 0.3 V to about 2 V, from about 0.3 V to about 1.8 V, from about 0.3 V to about 1.6 V, from about 0.3 V to about 1.4 V, from about 0.3 V to about 1.2 V, from about 0.3 V to about 1.1 V, from about 0.3 V to about 1 V, from about 0.3 V to about 0.9 V, from about 0.3 V to about 0.8 V, from about 0.3 V to about 0.6 V, from about 0.3 V to about 0.5 V, from about 0.3 V to about 0.4 V, from about 0.4 V to about 2 V, from about 0.4 V to about 1.8 V, from about 0.4 V to about 1.6 V, from about 0.4 V to about 1.4 V, from about 0.4 V to about 1.2 V, from about 0.4 V to about 1.1 V, from about 0.4 V to about 1 V, from about 0.4 V to about 0.9 V, from about 0.4 V to about 0.8 V, from about 0.4 V to about 0.6 V, from about 0.4 V to about 0.5 V, from about 0.5 V to about 2 V, from about 0.5 V to about 1.8 V, from about 0.5 V to about 1.6 V, from about 0.5 V to about 1.4 V, from about 0.5 V to about 1.2 V, from about 0.5 V to about 1.1 V, from about 0.5 V to about 1 V, from about 0.5 V to about 0.9 V, from about 0.5 V to about 0.8 V, from about 0.5 V to about 0.6 V, from about 0.6 V to about 2 V, from about 0.6 V to about 1.8 V, from about 0.6 V to about 1.6 V, from about 0.6 V to about 1.4 V, from about 0.6 V to about 1.2 V, from about 0.6 V to about 1.1 V, from about 0.6 V to about 1 V, from about 0.6 V to about 0.9 V, from about 0.6 V to about 0.8 V, from about 0.8 V to about 2 V, from about 0.8 V to about 1.8 V, from about 0.8 V to about 1.6 V, from about 0.8 V to about 1.4 V, from about 0.8 V to about 1.2 V, from about 0.8 V to about 1.1 V, from about 0.8 V to about 1 V, from about 0.8 V to about 0.9 V, from about 0.9 V to about 2 V, from about 0.9 V to about 1.8 V, from about 0.9 V to about 1.6 V, from about 0.9 V to about 1.4 V, from about 0.9 V to about 1.2 V, from about 0.9 V to about 1.1 V, from about 0.9 V to about 1 V, from about 1 V to about 2 V, from about 1 V to about 1.8 V, from about 1 V to about 1.6 V, from about 1 V to about 1.4 V, from about 1 V to about 1.2 V, from about 1 V to about 1.1 V, from about 1.1 V to about 2 V, from about 1.1 V to about 1.8 V, from about 1.1 V to about 1.6 V, from about 1.1 V to about 1.4 V, from about 1.1 V to about 1.2 V, from about 1.2 V to about 2 V, from about 1.2 V to about 1.8 V, from about 1.2 V to about 1.6 V, from about 1.2 V to about 1.4 V, from about 1.4 V to about 2 V, from about 1.4 V to about 1.8 V, from about 1.4 V to about 1.6 V, from about 1.6 V to about 2 V, from about 1.6 V to about 1.8 V, from about 1.8 V to about 2 V; or at most about 0.1 V, at most about 0.2 V, at most about 0.3 V, at most about 0.4 V, at most about 0.5 V, at most about 0.6 V, at most about 0.8 V, at most about 0.9 V, at most about 1 V, at most about 1.1 V, at most about 1.2 V, at most about 1.4 V, at most about 1.6 V, at most about 1.8 V, at most about 2 V; or about 0.1 V, about 0.2 V, about 0.3 V, about 0.4 V, about 0.5 V, about 0.6 V, about 0.8 V, about 0.9 V, about 1 V, about 1.1 V, about 1.2 V, about 1.4 V, about 1.6 V, about 1.8 V, about 2 V, or any ranges or values therebetween. In some preferred embodiments, the battery is discharged to below about 1 V.

In some embodiments, the battery may be discharged to a range of at least about 0.1%, at least about 0.2%, at least about 0.5%, at least about 1%, at least about 2%, at least about 5%, at least about 10%, at least about 20%; or from about 0.1% to about 20%, from about 0.1% to about 10%, from about 0.1% to about 5%, from about 0.1% to about 2%, from about 0.1% to about 1%, from about 0.1% to about 0.5%, from about 0.1% to about 0.2%, from about 0.2% to about 20%, from about 0.2% to about 10%, from about 0.2% to about 5%, from about 0.2% to about 2%, from about 0.2% to about 1%, from about 0.2% to about 0.5%, from about 0.5% to about 20%, from about 0.5% to about 10%, from about 0.5% to about 5%, from about 0.5% to about 2%, from about 0.5% to about 1%, from about 1% to about 20%, from about 1% to about 10%, from about 1% to about 5%, from about 1% to about 2%, from about 2% to about 20%, from about 2% to about 10%, from about 2% to about 5%, from about 5% to about 20%, from about 5% to about 10%, from about 10% to about 20%; or at most about 0.1%, at most about 0.2%, at most about 0.5%, at

most about 1%, at most about 2%, at most about 5%, at most about 10%, at most about 20%; or about 0.1%, about 0.2%, about 0.5%, about 1%, about 2%, about 5%, about 10%, about 20%, or any ranges or values therebetween, of its full battery capacity. In some preferred embodiments, the battery is discharged to less than about 0.2% energy of full battery capacity.

In some embodiments, the battery comprises a lithium ion battery, a sodium ion battery, a zinc ion battery, an aluminum ion battery, or combinations and mixtures thereof. The aforementioned batteries may also be generally referred to as rechargeable batteries.

In some embodiments, the lithium ion battery comprises a Lithium Nickel Cobalt Aluminum Oxide battery (e.g. $\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$), a Lithium Cobalt Oxide battery (e.g. LiCoO_2), a Lithium Nickel Oxide battery (e.g. LiNiO_2), a Lithium Manganese Oxide battery (e.g. LiMn_2O_4), a Lithium Iron Phosphate battery (e.g. LiFePO_4), a Lithium Nickel Manganese Cobalt Oxide battery (e.g. $\text{LiNi}_{0.33}\text{Mn}_{0.3}\text{Co}_{0.3}\text{O}_2$), a Lithium Titanate battery (e.g. $\text{Li}_4\text{Ti}_5\text{O}_{12}$), or combinations and/or mixtures thereof.

In some embodiments, the sodium ion battery comprises $\text{Na}_{2/3}\text{Fe}_{1/3}\text{Mn}_{2/3}\text{O}_2$, $\text{Na}_{2/3}\text{Fe}_{1/2}\text{Mn}_{1/2}\text{O}_2$, $\text{Na}_{2/3}\text{Fe}_{0.47}\text{Mn}_{0.53}\text{Al}_{0.03}\text{O}_2$, $\text{Na}_{2/3}\text{Fe}_{2/5}\text{Mn}_{3/5}\text{O}_2$, $\text{Na}_{2/3}\text{Fe}_{0.198}\text{Mn}_{0.702}\text{Ti}_{0.1}\text{O}_2$, $\text{Na}_{2/3}\text{Mg}_{0.28}\text{Mn}_{0.72}\text{O}_2$, $\text{Na}_{0.7}\text{Zn}_{0.15}\text{Mn}_{0.72}\text{O}_2$, $\text{Na}_{2/3}\text{Ni}_{1/3}\text{Mn}_{2/3}\text{O}_2$, $\text{Na}_{2/3}\text{Ni}_{2/9}\text{Mg}_{1/9}\text{Mn}_{2/3}\text{O}_2$, $\text{Na}_{0.8}\text{Li}_{0.12}\text{Ni}_{0.22}\text{Mn}_{0.66}\text{O}_2$, $\text{NaNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$, $\text{Na}_{2/3}\text{Fe}_{1/2}\text{Co}_{1/2}\text{O}_2$, a sodium manganese oxide battery, a sodium iron phosphate battery, a sodium titanium phosphate battery, a sodium vanadium phosphate battery, or combinations and/or mixtures thereof.

In some embodiments, the aluminum ion battery comprises an Al-Graphite battery, an Al- FeCl_3 battery, an Al- Mn_2O_4 battery, an Al- V_2O_5 battery, an Al- Mo_6S_8 battery, an Al-NiS battery, or combinations and/or mixtures thereof.

In some embodiments, the zinc ion battery comprises a Zn- MnO_2 (manganese oxide) battery, a Zn-vanadium based battery (e.g., $\text{Ca}_{0.25}\text{V}_2\text{O}_5 \cdot x\text{H}_2\text{O}$, $\text{Zn}_{0.25}\text{V}_2\text{O}_5 \cdot n\text{H}_2\text{O}$, $\text{Ba}_{1.2}\text{V}_6\text{O}_{16} \cdot 3\text{H}_2\text{O}$ and $\text{Na}_2\text{V}_6\text{O}_{16} \cdot 3\text{H}_2\text{O}$), a Zn- MoS_2 battery, a Zn- VSe_2 battery, or combinations and/or mixtures thereof.

In some embodiments, the battery comprises a Lithium Nickel Cobalt Aluminum Oxide battery (e.g. $\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$), a Lithium Cobalt Oxide battery (e.g. LiCoO_2), a Lithium Nickel Oxide battery (e.g. LiNiO_2), a Lithium Manganese Oxide battery (e.g. LiMn_2O_4), a Lithium Iron Phosphate battery (e.g. LiFePO_4), a Lithium Nickel Manganese Cobalt Oxide battery (e.g. $\text{LiNi}_{0.33}\text{Mn}_{0.3}\text{Co}_{0.3}\text{O}_2$), a Lithium Titanate battery (e.g. $\text{Li}_4\text{Ti}_5\text{O}_{12}$), a sodium ion battery, a zinc ion battery, a rechargeable battery or combinations and mixtures thereof.

In some embodiments, the battery has a cylindrical (e.g. 26650, 18650, 14500, 16340), prismatic, or laminated form factor.

In some embodiments, the presently disclosed method may discharge a battery sequentially, consecutively, simultaneously, or combinations thereof.

The present invention has also advantageously found that the ash, ash suspension or leachate may be re-used in the method to discharge additional batteries, reducing the ion content and treating the ash further. This also advantageously treats the ash further, reducing both its ion content, pH, and other characteristics, making it more suitable for other applications, or so that it may be more safely buried in landfills.

In some embodiments, the presently disclosed method may discharge a battery consecutively, i.e. using the ash to discharge a first battery, then using the same ash recovered to discharge a second battery and/or subsequent batteries. In some embodiments, the ash may be used to discharge batteries for more than one time, in a range of about 1, 2, 3, 4, 5, 7, 10 times, or any ranges or values therebetween.

In some embodiments, the presently disclosed method may discharge more than one battery simultaneously, i.e. using the ash to discharge more than one batteries at the same time in one run. In some embodiments, the ash may be used to discharge about 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 15, 20 batteries, or any ranges or values therebetween, at the same time.

In some embodiments, the presently disclosed method may be performed for a range of at least about 0.25 hours, at least about 0.5 hours, at least about 0.75 hours, at least about 1 hour, at least about 2 hours, at least about 3 hours, at least about 4 hours, at least about 5 hours, at least about 6 hours, at least about 7 hours, at least about 8 hours, at least about 9 hours, at least about 10 hours, at least about 12 hours, at least about 14 hours; or from about 0.25 hours to about 14 hours, from about 0.25 hours to about 12 hours, from about 0.25 hours to about 10 hours, from about 0.25 hours to about 9 hours, from about 0.25 hours to about 8 hours, from about 0.25 hours to about 7 hours, from about 0.25 hours to about 6 hours, from about 0.25 hours to about 5 hours, from about 0.25 hours to about 4 hours, from about 0.25 hours to about 3 hours, from about 0.25 hours to about 2 hours, from about 0.25 hours to about 1 hour, from about 0.25 hours to about 0.75 hours, from about 0.25 hours to about 0.5 hours, from about 0.5 hours to about 14 hours, from about 0.5 hours to about 12 hours, from about 0.5 hours to about 10 hours, from about 0.5 hours to about 9 hours, from about 0.5 hours to about 8 hours, from about 0.5 hours to about 7 hours, from about 0.5 hours to about 6 hours, from about 0.5 hours to about 5 hours, from about 0.5 hours to about 4 hours, from about 0.5 hours to about 3 hours, from about 0.5 hours to about 2 hours, from about 0.5 hours to about 1 hour, from about 0.5 hours to about 0.75 hours, from about 0.75 hours to about 14 hours, from about 0.75 hours to about 12 hours, from about 0.75 hours to about 10 hours, from about 0.75 hours to about 9 hours, from about 0.75 hours to about 8 hours, from about 0.75 hours to about 7 hours, from about 0.75 hours to about 6 hours, from about 0.75 hours to about 5 hours, from about 0.75 hours to about 4 hours, from about 0.75 hours to about 3 hours, from about 0.75 hours to about 2 hours, from about 0.75 hours to about 1 hour, from about 1 hour to about 14 hours, from about 1 hour to about 12 hours, from about 1 hour to about 10 hours, from about 1 hour to about 9 hours, from about 1 hour to about 8 hours, from about 1 hour to about 7 hours, from about 1 hour to about 6 hours, from about 1 hour to about 5 hours, from about 1 hour to about 4 hours, from about 1 hour to about 3 hours, from about 1 hour to about 2 hours, from about 2 hours to about 14 hours, from about 2 hours to about 12 hours, from about 2 hours to about 10 hours, from about 2 hours to about 9 hours, from about 2 hours to about 8 hours, from about 2 hours to about 7 hours, from about 2 hours to about 6 hours, from about 2 hours to about 5 hours, from about 2 hours to about 4 hours, from about 2 hours to about 3 hours, from about 3 hours to about 14 hours, from about 3 hours to about 12 hours, from about 3 hours to about 10 hours, from about 3 hours to about 9 hours, from about 3 hours to

about 8 hours, from about 3 hours to about 7 hours, from about 3 hours to about 6 hours, from about 3 hours to about 5 hours, from about 3 hours to about 4 hours, from about 4 hours to about 14 hours, from about 4 hours to about 12 hours, from about 4 hours to about 10 hours, from about 4 hours to about 9 hours, from about 4 hours to about 8 hours, from about 4 hours to about 7 hours, from about 4 hours to about 6 hours, from about 4 hours to about 5 hours, from about 5 hours to about 14 hours, from about 5 hours to about 12 hours, from about 5 hours to about 10 hours, from about 5 hours to about 9 hours, from about 5 hours to about 8 hours, from about 5 hours to about 7 hours, from about 5 hours to about 6 hours, from about 6 hours to about 14 hours, from about 6 hours to about 12 hours, from about 6 hours to about 10 hours, from about 6 hours to about 9 hours, from about 6 hours to about 8 hours, from about 6 hours to about 7 hours, from about 7 hours to about 14 hours, from about 7 hours to about 12 hours, from about 7 hours to about 10 hours, from about 7 hours to about 9 hours, from about 7 hours to about 8 hours, from about 8 hours to about 14 hours, from about 8 hours to about 12 hours, from about 8 hours to about 10 hours, from about 8 hours to about 9 hours, from about 9 hours to about 14 hours, from about 9 hours to about 12 hours, from about 9 hours to about 10 hours, from about 10 hours to about 14 hours, from about 10 hours to about 12 hours, from about 12 hours to about 14 hours; or at most about 0.25 hours, at most about 0.5 hours, at most about 0.75 hours, at most about 1 hour, at most about 2 hours, at most about 3 hours, at most about 4 hours, at most about 5 hours, at most about 6 hours, at most about 7 hours, at most about 8 hours, at most about 9 hours, at most about 10 hours, at most about 12 hours, at most about 14 hours; or about 0.25 hours, about 0.5 hours, about 0.75 hours, about 1 hour, about 2 hours, about 3 hours, about 4 hours, about 5 hours, about 6 hours, about 7 hours, about 8 hours, about 9 hours, about 10 hours, about 12 hours, about 14 hours, or any ranges or values therebetween.

In some embodiments, the presently disclosed method may be performed for at least about, about, or at most about 30 days.

The present invention has found that the high conductivity of the ash mixture is responsible for its unparalleled discharging effectiveness. The conductivity of the ash mixture, suspension or leachate, may come from the high concentration of various ions, for example metals, heavy metals, ions, anion, chlorides, and etc. In some embodiments, the conductivity of the ash suspension, mixture or leachate may be in a range of at least about 43 mS/cm, at least about 48 mS/cm, at least about 50 mS/cm, at least about 52 mS/cm, at least about 57.2 mS/cm, at least about 60 mS/cm, at least about 61 mS/cm, at least about 64.5 mS/cm, at least about 65 mS/cm, at least about 69 mS/cm, at least about 70 mS/cm, at least about 80 mS/cm, at least about 82 mS/cm, at least about 85 mS/cm, at least about 91 mS/cm, at least about 100 mS/cm, at least about 116 mS/cm, at least about 120 mS/cm, at least about 147.6 mS/cm, at least about 154.7 mS/cm, at least about 160 mS/cm; or from about 43 mS/cm to about 160 mS/cm, from about 43 mS/cm to about 154.7 mS/cm, from about 43 mS/cm to about 147.6 mS/cm, from about 43 mS/cm to about 120 mS/cm, from about 43 mS/cm to about 116 mS/cm, from about 43 mS/cm to about 100 mS/cm, from about 43 mS/cm to about 91 mS/cm, from about 43 mS/cm to about 85 mS/cm, from about 43 mS/cm to about 82 mS/cm, from about 43 mS/cm to about 80 mS/cm, from about 43 mS/cm to about 70 mS/cm, from about 43 mS/cm to about 69 mS/cm, from about 43 mS/cm to about 65 mS/cm, from about 43 mS/cm to about 64.5 mS/cm, from about 43 mS/cm to about 61 mS/cm, from about 43 mS/cm to about 60 mS/cm, from about 43 mS/cm to about 57.2 mS/cm, from about 43 mS/cm to about 52 mS/cm, from about 43 mS/cm to about 50 mS/cm, from about 43 mS/cm to about 48 mS/cm, from about 48 mS/cm to about 160 mS/cm, from about 48 mS/cm to about 154.7 mS/cm, from about 48 mS/cm to about 147.6 mS/cm, from

[illegible]

to about 80 mS/cm, from about 64.5 mS/cm to about 70 mS/cm, from about 64.5 mS/cm to about 69 mS/cm, from about 64.5 mS/cm to about 65 mS/cm, from about 65 mS/cm to about 160 mS/cm, from about 65 mS/cm to about 154.7 mS/cm, from about 65 mS/cm to about 147.6 mS/cm, from about 65 mS/cm to about 120 mS/cm, from about 65 mS/cm to about 116 mS/cm, from about 65 mS/cm to about 100 mS/cm, from about 65 mS/cm to about 91 mS/cm, from about 65 mS/cm to about 85 mS/cm, from about 65 mS/cm to about 82 mS/cm, from about 65 mS/cm to about 80 mS/cm, from about 65 mS/cm to about 70 mS/cm, from about 65 mS/cm to about 69 mS/cm, from about 69 mS/cm to about 160 mS/cm, from about 69 mS/cm to about 154.7 mS/cm, from about 69 mS/cm to about 147.6 mS/cm, from about 69 mS/cm to about 120 mS/cm, from about 69 mS/cm to about 116 mS/cm, from about 69 mS/cm to about 100 mS/cm, from about 69 mS/cm to about 91 mS/cm, from about 69 mS/cm to about 85 mS/cm, from about 69 mS/cm to about 82 mS/cm, from about 69 mS/cm to about 80 mS/cm, from about 69 mS/cm to about 70 mS/cm, from about 70 mS/cm to about 160 mS/cm, from about 70 mS/cm to about 154.7 mS/cm, from about 70 mS/cm to about 147.6 mS/cm, from about 70 mS/cm to about 120 mS/cm, from about 70 mS/cm to about 116 mS/cm, from about 70 mS/cm to about 100 mS/cm, from about 70 mS/cm to about 91 mS/cm, from about 70 mS/cm to about 85 mS/cm, from about 70 mS/cm to about 82 mS/cm, from about 70 mS/cm to about 80 mS/cm, from about 80 mS/cm to about 160 mS/cm, from about 80 mS/cm to about 154.7 mS/cm, from about 80 mS/cm to about 147.6 mS/cm, from about 80 mS/cm to about 120 mS/cm, from about 80 mS/cm to about 116 mS/cm, from about 80 mS/cm to about 100 mS/cm, from about 80 mS/cm to about 91 mS/cm, from about 80 mS/cm to about 85 mS/cm, from about 80 mS/cm to about 82 mS/cm, from about 82 mS/cm to about 160 mS/cm, from about 82 mS/cm to about 154.7 mS/cm, from about 82 mS/cm to about 147.6 mS/cm, from about 82 mS/cm to about 120 mS/cm, from about 82 mS/cm to about 116 mS/cm, from about 82 mS/cm to about 100 mS/cm, from about 82 mS/cm to about 91 mS/cm, from about 82 mS/cm to about 85 mS/cm, from about 85 mS/cm to about 160 mS/cm, from about 85 mS/cm to about 154.7 mS/cm, from about 85 mS/cm to about 147.6 mS/cm, from about 85 mS/cm to about 120 mS/cm, from about 85 mS/cm to about 116 mS/cm, from about 85 mS/cm to about 100 mS/cm, from about 85 mS/cm to about 91 mS/cm, from about 91 mS/cm to about 160 mS/cm, from about 91 mS/cm to about 154.7 mS/cm, from about 91 mS/cm to about 147.6 mS/cm, from about 91 mS/cm to about 120 mS/cm, from about 91 mS/cm to about 116 mS/cm, from about 91 mS/cm to about 100 mS/cm, from about 100 mS/cm to about 160 mS/cm, from about 100 mS/cm to about 154.7 mS/cm, from about 100 mS/cm to about 147.6 mS/cm, from about 100 mS/cm to about 120 mS/cm, from about 100 mS/cm to about 116 mS/cm, from about 116 mS/cm to about 160 mS/cm, from about 116 mS/cm to about 154.7 mS/cm, from about 116 mS/cm to about 147.6 mS/cm, from about 116 mS/cm to about 120 mS/cm, from about 120 mS/cm to about 160 mS/cm, from about 120 mS/cm to about 154.7 mS/cm, from about 120 mS/cm to about 147.6 mS/cm, from about 147.6 mS/cm to about 160 mS/cm, from about 147.6 mS/cm to about 154.7 mS/cm, from about 154.7 mS/cm to about 160 mS/cm; or at most about 43 mS/cm, at most about 48 mS/cm, at most about 50 mS/cm, at most about 52 mS/cm, at most about 57.2 mS/cm, at most about 60 mS/cm, at most about 61 mS/cm, at most about 64.5 mS/cm, at most about 65 mS/cm, at most about 69 mS/cm, at most about 70 mS/cm, at most about 80 mS/cm, at most about 82 mS/cm, at most about 85 mS/cm, at most about 91 mS/cm, at most about 100 mS/cm, at most about 116 mS/cm, at most about 120 mS/cm, at most about 147.6 mS/cm, at most about 154.7 mS/cm, at most about 160 mS/cm; or about 43 mS/cm, about 48 mS/cm, about 50 mS/cm, about 52 mS/cm, about 57.2 mS/cm, about 60 mS/cm, about 61 mS/cm, about 64.5 mS/cm, about 65 mS/cm, about 69 mS/cm, about 70 mS/cm, about 80 mS/cm, about 82 mS/cm, about 85 mS/cm, about 91 mS/cm, about 100 mS/cm, about 116 mS/cm, about 120 mS/cm, about 147.6 mS/cm, about 154.7 mS/cm, about 160 mS/cm, or any ranges or values therebetween.

The present invention thus discloses a method that advantageously uses a waste (ash) to treat a second waste (spent batteries), while being treated itself in the process. Hence, the present invention, advantageously treats two waste products in a single method, reducing the economies of scale of recycling, and waste treatment. The spent and sufficiently discharged batteries may be further dismantled to recover the active cathode material, while the ash, having its metal ion and/or other ion content (like chloride, etc.) may advantageously be made use of in other applications, for example, in cement production.

The present disclosure also provides for a system for discharging a battery and/or reducing ion content in ash, comprising:

- a reactor chamber;
- a perforated battery container disposed within the reactor chamber, wherein the perforated battery container is configured to contain a battery;
- a motor connected to the perforated battery container, wherein the motor is configured to move the perforated battery container;
- an ash inlet connected to the reactor chamber, wherein the ash inlet is configured to feed ash into the reactor chamber; and
- a water inlet connected to the reactor chamber, wherein the water inlet is configured to feed water into the reactor chamber.

The reactor chamber may be capable of holding multiple batteries and/or battery packs. In a typical discharging process, the batteries would first be placed in the reactor chamber, following which IFA and water may be introduced into the reactor chamber via an IFA inlet and a water inlet/feed respectively.

In some embodiments, the system may comprise one inlet configured to introduce an ash/water mixture into the perforated battery container. In further embodiments, the ash and water may first be introduced into a holding container and optionally mixed. The ash and water mixture may then be drawn from the holding container into the reactor chamber.

In some other embodiments, the system may comprise separate inlets configured to introduce ash and water into the reactor chamber.

The reactor chamber may further comprise a battery container for containing the batteries. The battery container may be perforated. In other embodiments, the battery container may be permeable to either the solution in the ash/water mixture, or may be permeable to the ash/water mixture itself. In some embodiments, the perforated battery container may comprise one or more dividers configured to divide the perforated battery container into a plurality of sectors, and wherein each of the plurality of sectors is configured to contain a set of batteries. Containing the batteries for discharging in separate sectors advantageously prevents contact between each battery and/or battery pack and thus improves safety design.

To agitate the mixture of IFA and water in the reactor chamber, an agitation mechanism may be present. Current agitation methods presently used in industrial processes would be well-known to the skilled person. In some embodiments, the agitation mechanism may be a motor connected to a propeller within the reactor

chamber. In other embodiments, the agitation mechanism comprises a motor coupled to the perforated battery container. In some embodiments, the motor may be configured to rotate the perforated battery container within the reactor chamber.

The process may produce some effervescence due to redox reactions happening at the battery terminals. Hence, a gas outlet may be present to vent off such gases produced. In some embodiments, the presently disclosed system may further comprise a valve connected to the reactor chamber, wherein the valve is configured to exhaust air from the reactor chamber.

The inventors have found that segregating the batteries from the solids in the ash/water suspension may be advantageous to increasing the discharge rate, and subsequently reduce the ion content further. Hence, the system may comprise a means to separate the ash in the ash/water suspension from the battery. In some embodiments, this means may be performed by the perforated battery container, i.e. the perforated battery container may be only permeable to water, and not ash, in the ash/water suspension. In some other embodiments, the means to separate the ash from the battery may comprise a sieve or mesh.

In a typical discharging process, the reactor chamber may further comprise an outlet for removing ash and/or water. In some embodiments, an outlet may be present for removing both ash and/water.

The system may comprise a means for sieving the ash out from the water at the outlet. In some embodiments, the sieving to filter the ash may happen after the ash/water mixture exits the reactor chamber. In some embodiments, the sieving to filter the ash may happen inside the chamber. In further embodiments, a sieve may be present in the reactor chamber to sieve ash out from water before the water exits the reactor chamber. In some further embodiments, the system may comprise an outlet for collecting the ash sieved from the water leaving the reactor chamber. In some embodiments, the presently disclosed system may further comprise a fluid outlet and a sieve, wherein the sieve is disposed adjacent to the fluid outlet and configured to collect ash from water exiting the reactor chamber via the fluid outlet.

In some embodiments, the water at the fluid outlet may be further re-introduced into the reactor chamber. In some embodiments, a pump means may be present to re-circulate and re-introduce the water from the fluid outlet into the reactor chamber. The water from the fluid outlet may be directly re-introduced into the reactor chamber. In other embodiments, the water from the fluid outlet may be first mixed with new ash prior to being re-introduced into the reactor chamber.

In some embodiments, the water at the fluid outlet may be used to clean the ash residue present on the batteries. In some other embodiments, the water at the fluid outlet may re-introduced into the reactor chamber, to clean the ash residue present on the batteries after the discharging process is complete.

In some other embodiments, the presently disclosed method may discharge a battery in a flow reactor setup, or in a batch reactor setup. Modification of the system disclosed in the present invention to either a batch or flow process would be obvious to the skilled person.

In some embodiments, the battery may be placed in a flow reactor that recirculates fresh ash mixtures, suspensions or leachates thereof, to contact the battery, thus discharging it.

In a batch reactor, the battery may be placed in a batch reactor that agitates the same ash mixture, suspension or leachate thereof, until the discharging is complete, following which a new battery may be placed, and the ash mixture, suspension or leachate thereof, may optionally be replaced.

Statements of Invention

1. A method of discharging a battery comprising contacting the battery with ash, ash suspension, or ash leachate, wherein the ash, ash suspension, or ash leachate comprises at least one ion selected from the group consisting of chloride, sulphate, sulphide, hydroxide, carbonate, and phosphate.
2. A method of reducing at least one ion content in ash comprising contacting a battery with ash, ash suspension or ash leachate, wherein the ion is selected from the group consisting of chloride, sulphate, sulphide, hydroxide, carbonate, and phosphate.
3. The method of statement 2, comprising reducing chloride content in ash.
4. The method of statement 2 or statement 3, wherein the method further comprises reducing metal content in ash.
5. The method of statement 4, wherein the metal is selected from the group consisting of aluminum, potassium, iron, copper, zinc, calcium, magnesium, cadmium and lead.
6. The method of any one of statements 1 to 5, wherein the ash, ash suspension or ash leachate comprises at least about 10000 ppm chloride, sulphate, sulphide, hydroxide, carbonate, and/or phosphate ions.
7. The method of statement 1 or statement 6, wherein the pH of the ash, ash leachate, or ash suspension is reduced after the discharge.
8. The method of any one of statements 1 to 7, comprising contacting the battery with ash leachate.
9. The method of statement 8, wherein the ash leachate is obtained by filtering an ash suspension.
10. The method of any one of statements 1 to 7 and 9, wherein the ash suspension comprises ash and water.
11. The method of any one of statements 1 to 7 and 9-10, wherein the ratio of volume of water to mass of ash in the ash suspension is about 1:1 to 10:1.
12. The method of any one of statements 1 to 7 and 9-11, wherein the battery is separated from the ash in the ash suspension.

13. The method of any one of statements 1 and 6 to 12, wherein 1 kg of ash is capable of discharging up to about 21 Ah in total battery capacity.
14. The method of any one of statements 1 and 6 to 13, wherein the battery is discharged by at least about 80% from its initial voltage.
15. The method of any one of statements 1 and 6 to 14, wherein the battery is discharged to below about 1 V.
16. The method of any one of statements 1 to 15, wherein the battery is selected from the group consisting of a Lithium Nickel Cobalt Aluminum Oxide battery (e.g. $\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$), a Lithium Cobalt Oxide battery (e.g. LiCoO_2), a Lithium Nickel Oxide battery (e.g. LiNiO_2), a Lithium Manganese Oxide battery (e.g. LiMn_2O_4), a Lithium Iron Phosphate battery (e.g. LiFePO_4), a Lithium Nickel Manganese Cobalt Oxide battery (e.g. $\text{LiNi}_{0.33}\text{Mn}_{0.3}\text{Co}_{0.3}\text{O}_2$), a Lithium Titanate battery (e.g. $\text{Li}_4\text{Ti}_5\text{O}_{12}$), a sodium ion battery, a sodium manganese oxide battery, a sodium iron phosphate battery, a sodium titanium phosphate battery, a sodium vanadium phosphate battery, a zinc ion battery, an aluminum ion battery, a rechargeable battery or combinations and mixtures thereof.
17. A system for discharging a battery and/or reducing ion content in ash, comprising:
 - a reactor chamber;
 - a perforated battery container disposed within the reactor chamber, wherein the perforated battery container is configured to contain a battery;
 - a motor connected to the perforated battery container, wherein the motor is configured to move the perforated battery container;
 - an ash inlet connected to the reactor chamber, wherein the ash inlet is configured to feed ash into the reactor chamber; and
 - a water inlet connected to the reactor chamber, wherein the water inlet is configured to feed water into the reactor chamber.
18. The system of statement 17, wherein the perforated battery container comprises one or more dividers configured to divide the perforated battery container into a plurality of sectors, and wherein each of the plurality of sectors is configured to contain a set of batteries.
19. The system of statement 17 or 18, wherein the motor is configured to rotate the perforated battery container within the reactor chamber.
20. The system of any one of statements 17 to 19, further comprising a valve connected to the reactor chamber, wherein the valve is configured to exhaust air from the reactor chamber.
21. The system of any one of statements 17 to 20, further comprising a fluid outlet and a sieve, wherein the sieve is disposed adjacent to the fluid outlet and configured to collect ash from water exiting the reactor chamber via the fluid outlet.

Examples

Non-limiting examples of the invention and comparative examples will be further described in greater detail by reference to specific examples, which should not be construed as in any way limiting the scope of the invention.

Material and Methods

Incineration fly ash (IFA) from burning a general solid waste mixture was collected. In particular, two types of IFA were collected:

- (1) from an electrostatic precipitator (IFA denoted as ESP); and
- (2) after reacting flue gas with powdered lime (IFA denoted as RP).

Spent 18650 LIBs were collected within the Nanyang Technological University (NTU) campus. The collected LIBs were then sorted and evaluated based on the type of LIBs.

Example 1: Incineration Fly Ash

The compositions of the two IFA (ESP and RP) were evaluated using X-ray fluorescence (XRF, Olympus Vanta C series) and X-ray Diffraction (XRD, Powder Shimadzu LabX RD-6000). The powder XRD setting used was Cu K α radiation ($\lambda = 1.5406 \text{ \AA}$) in continuous scan mode with a step size of 0.02° at $0.4^\circ/\text{min}$.

Table 1 below shows the concentration of certain elements, ions and metals in ash used in this invention.

Table 1: Representative composition of elements, ions and metals in ash used in the present invention

Non-Metals	RP (ppm)	ESP (ppm)
Cl	250,000-400,000	25,000-95,000
P	1,500-3,000	2,500-5,000
S	45,000-100,000	95,000-140,000
Metals		
K	7,000-12,000	55,000-70,000
Fe	900-3,500	40,000-75,000
Cu	400-700	3,500-5,000
Zn	2,000-7,000	11,000-50,000
Pb	900-2,500	4,000-8,000

Example 2: Batteries

NCA ($\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$) batteries with graphite anodes were chosen as they were collected as a pack used for drones and hence, identical in terms of composition. A battery tester was used to discharge some of the LIBs to 0 V before they were manually opened in the dry room. The batteries used in the study had initial voltages in the range of $3.4 \pm 0.1 \text{ V}$.

The cathode and anode materials were analysed using X-ray diffraction (XRD, Thin film Shimadzu LabX RD-6000) and Scanning Electron Microscopy Energy-dispersive X-ray Analyzer (SEM-EDX, JOEL JSM-7600F). The XRD thin film setting used was Cu K α radiation ($\lambda = 1.5406 \text{ \AA}$) in continuous scan mode with a step size of 0.02° at $1^\circ/\text{min}$. The EDS spectrum of the cathode may be found in Fig. 1 while the XRD spectra of the cathode (a) and anode (b) material may be found in Figs. 2a and 2b respectively.

Example 3: Discharging Batteries

A representative experiment is shown in Fig. 3.

Briefly, an inverted plastic weighing dish (0310), punched with holes, was placed on top of a stir bar (0311) in a beaker (0312). A battery (0313) was then placed on top of the inverted plastic weighing dish (0310), the arrangement was to allow the stir bar (0311) to stir fly ash (not shown) smoothly at the bottom of the beaker (0312) without the stir bar (0311) hitting the battery (0313). 300 ml of DI water (0314) was then added to ensure that each battery (0313) was completely immersed. IFA (ESP or RP) (not shown) was then added to the beaker (0312) and the mixture allowed to stir for a specified duration, following which the battery (0313) was taken out.

While the fly ash was not fully soluble in the water, it was not removed during the experiment and instead left to stir to observe its effects. It was postulated that as the soluble chloride ions were removed from the fly ash as chlorine gas during discharging, more chloride ions would be dissolved from the insoluble fly ash to replace the liberated chlorine.

A handheld multimeter (Amprobe AM-510) was used to measure the voltage of the battery before, during, and after the specified period of discharge. Each battery was taken out at 1 to 2 hour intervals to measure its residual voltage. The conductivity and pH of the solution in the beaker at that same interval were then measured using Mettler Toledo Seven2Go and SevenCompact, respectively.

Batteries that were discharged to less than 1 V, equivalent to less than 0.2% energy of its full battery capacity, were manually opened in a dry room and the cathode material was evaluated using SEM-EDX.

Water/IFA Ratio (Liquid/Solid, or LS Ratio, or L/S Ratio)

The conductivities of the fly ashes were determined at different L/S ratios. It was found that at an L/S ratio of 5 (i.e., LS5), the conductivity of the leachate obtained from the fly ashes was sufficient to discharge the NCA batteries at a reasonable rate (i.e. within 8 hrs). Smaller L/S ratios, 1:1 L/S (i.e., LS1) and 3:1 L/S (LS3), were then used to investigate the effect of IFA.

Table 2: Mixtures of RP/ESP with DI water

ESP	L/S Ratios	RP	L/S Ratios
LS1-ESP	300 ml/300 g ESP	LS1-RP	300 ml/300 g RP
LS3-ESP	300 ml/100 g ESP	LS3-RP	300 ml/100 g RP

LS5-ESP	300 ml/60 g ESP	LS5-RP	300 ml/60 g RP
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In the following Examples, the ESP/RP was added to the beaker according to the values in Table 2 to make up the IFA/water mixture. Each experiment was performed in triplicate.

Example 3a: Ash control mixtures

A control experiment was also used for comparison, whereby the IFA (RP or ESP) was mixed with DI water, and the mixture stirred, but no battery was added to the mixture. Values for the control experiments are labelled in Table 3 as follows:

Table 3: Control Mixtures of RP/ESP with DI water

ESP	L/S Ratios	RP	L/S Ratios
LS1-ESP-control	300 ml/300 g ESP	LS1-RP-control	300 ml/300 g RP
LS3-ESP-control	300 ml/100 g ESP	LS3-RP-control	300 ml/100 g RP
LS5-ESP-control	300 ml/60 g ESP	LS5-RP-control	300 ml/60 g RP

Example 4: Electrochemical Changes to IFA During Discharging

The high conductivity of the IFA leachates was hypothesised to be due to the soluble salts found in the IFA, such as chlorides, sulphates, hydroxides, carbonates, etc, in particular due to soluble chlorides that are present in IFA in very high concentrations. The high chloride concentration is likely to aid in electrochemically discharging the batteries according to the following half-cell reaction [1]:



It was observed that electrochemical reactions due to the discharging of batteries changed the composition of the IFA in the water/IFA mixture. Effervescence was further observed at both the cathode and anode regions during the discharging process.

The chloride concentration in the leachate and residue after discharging was compared to the leachate and residue in the control (i.e. leaching without discharge for the same duration of time).

To analyse the elemental composition of the mixture (filtrate and residue) at each time interval, a sample of the mixture was taken out and filtered through a 0.45 µm membrane under vacuum with a vacuum pump to provide a filtrate and a residue.

The filtrate was analysed for its dissolved salts by Ion-Chromatography system (IC, Dionex IC-1000) and Inductively Coupled Plasma-Optical emission spectrometer (ICP-OES, PerkinElmer® Optima™ 8300). The residue was collected and dried at 60°C, following which its mineralogical changes was evaluated by XRD and XRF.

Elemental Composition of Residue

Figs. 4a-4d and Table 6 show concentrations of select elements remaining in the solid IFA residue after discharging at an L/S ratio of 5. Elements P, S and Cl were measured using ion-exchange chromatography, while the metal elements (K, Fe, Cu, Zn, Pb) were measured using Inductively Coupled Plasma (ICP) analysis.

For the anions, it observed that the chloride concentration in the residue was reduced upon mixing the IFA with water. This is likely due to the dissolution of soluble chlorides into the suspension. It was further observed that the chloride concentration fluctuated as the discharging progressed and did not follow a common trend. This may imply that the electrochemical reaction did not solely involve chlorides, but other anions as well, e.g. phosphates and sulphides (Figs. 4a and 4c).

For the cations, the iron concentration was observed to gradually increase as the batteries were discharged with LS5-RP (see Figs. 4b and 4d and Table 6). This could be due to the battery's steel casing dissolving and/or corroding when in contact with the water/IFA mixture, after which the released iron ions further precipitated onto the IFA residue.

Table 4. Chloride-soluble content of raw IFA (Example 1), control residue and sample residue after a single discharge (%)

	Raw IFA*	Control IFA	Discharge IFA
RP	86 ± 5 %	16.65 %	14.46 %
ESP	16 ± 1 %	2.25%	2.19%

* Average numbers were calculated from 4 different untreated RP and ESP samples

Table 5: Ca-based chloride content in raw ash (Example 1), and ash before and after discharging as analysed by Rietveld method (%)

RP	
Raw RP	75.59 ± 3.13 %
LS5-RP-4	9.5 %
LS5-RP-control	16.4 %

Table 4 shows the chloride-soluble content in IFA before dissolution, and before and after discharge. From Table 4, the chloride-soluble content in IFA decreased significantly for both discharge and control samples. However, for Ca-based chlorides, which was only found in RP, the chloride reduction in LS5-RP-4 was more significant as compared to LS5-RP-control, as shown in Table 5. While this may imply that the discharging process aided in the reduction in the amount of soluble chlorides, combining with the result from XRF, it is more likely that Ca-based chlorides may have been transformed into a different mineral, possibly Friedel's salt or a Ca/Al-based chloride oxide (Ca₆Al₇ClO₁₆).

While Friedel's salt is known to affect cement performance, IFA obtained after discharging may still be used in cement, or in other applications which would not be affected by the insolubility of the Friedel's salt.

It was further observed that the concentration of the heavy metals (Cu and Pb) appeared to decrease over time when the batteries were discharged with ESP.

Table 6: Changes in element/ion/metal concentrations in ash residue during discharging (Figs. 4a-4d)

Ash	Duration (hour)	Element/Ion	concentration (ppm)	Metal	concentration (ppm)
RP	Control	P	1461	K	3250
		S	114458	Fe	3640
		Cl	107367	Cu	847
				Zn	10685
				Pb	1837
	2	P	1367	K	4966
		S	108265	Fe	15145
		Cl	121987	Cu	1065
				Zn	12847
				Pb	4033
	3	P	1448	K	4278
		S	103951	Fe	9825
		Cl	104253	Cu	754
				Zn	10496
				Pb	2520
	4	P	1236s	K	4086
		S	108593	Fe	12366
		Cl	111931	Cu	927
				Zn	11626
				Pb	2935
ESP	Control	P	4759	K	18121
		S	159289	Fe	57686
		Cl	17623	Cu	5279
				Zn	53579
				Pb	10056
	2	P	4494	K	20408
		S	147328	Fe	54391
		Cl	21806	Cu	4643
				Zn	50940
				Pb	9480
	4	P	4081	K	20468
		S	140510	Fe	62865
		Cl	18636	Cu	4945
				Zn	49110
				Pb	9643

	6	P	4138	K	19498
		S	151335	Fe	72375
		Cl	17305	Cu	4995
				Zn	48163
				Pb	9341
	7	P	4096	K	19774
		S	145360	Fe	57209
		Cl	19039	Cu	3849
				Zn	37811
				Pb	6926

Hence, from the above it can be shown that the chloride content in ash can be significantly reduced using the discharging process of the present invention, while discharging batteries at the same time.

Elemental Composition of Leachate

The soluble chloride content (measured by Ion-Exchange Chromatography) in the RP and ESP leachates before and after discharging are shown in Figs. 5a and 5b, and further summarized in Table 7.

Table 7: Chloride concentration in leachate after discharging (Figs. 5a and 5b)

LS ratio	Chloride Concentration (mg/L)			
	RP	Control	ESP	Control
1	-	-	83473	75228
3	90497	85304	27200	25405
5	52787	52817	13891	16293

As shown in Figs. 5a, 5b and Table 7, after the same duration, the chloride concentration in the control leachate was instead lower than that of the leachates after discharge, suggesting that the chloride concentration in the leachate was not reduced but instead increased after the discharging. However, it is also possible that the chlorides removed from the leachate (as chlorine gas) were simply replaced by more chloride dissolving from the residue.

From the above, while the chloride content in the ash leachate did not change significantly after discharging (as compared to the control), the chloride content in the residue reduced significantly upon discharging as compared to the raw ash in Example 1. Hence, it can be shown that the method of the invention can discharge batteries using either ESP or RP while reducing chloride content in the process.

Example 5: Discharge Rate

Figs. 8a-8b and Table 8 show the discharge rate of the batteries subjected to the method described in Example 3.

Table 8: Battery Voltages (V) plotted against discharge duration (Figs. 8a and 8b)

Duration (hours)	RP		Duration (hours)	ESP		
	LS3	LS5		LS1	LS3	LS5
0	3.43	3.43	0	3.43	3.43	3.43
2	2.45	2.71	2	2.62	3.22	3.22
3	1.17	2.23	3	0.67	2.60	2.76
4	0.37	0.50	4		1.60	2.57
			5		1.18	1.87
			6		1.09	1.46
			7			0.53

The longest discharge observed was 7 hours (for the LS5-ESP suspension), which performed better than the 25 hours discharge observed in literature.

The discharge using LS1-RP surprisingly took more than 8 hrs and hence, was excluded from Fig. 8a and further investigation. The unexpected longer discharge rate for LS1-RP could be due to the increased viscosity of the solution. Without sufficient solution, the ions could not move through the solution efficiently during discharging, thus resulting in a slower discharging rate.

Otherwise, generally, it was observed that RP leachates (LS3-RP and LS5-RP) were able to discharge the batteries faster as compared to ESP leachates at the same L/S ratios. This may be due to the difference in the conductivities of the leachates, as shown in Fig. 9. From Fig. 9 and Table 9, it was observed that the conductivities of the RP leachates prior to discharge were about twice that of the ESP leachates at the same L/S ratios.

Table 9: Conductivity of ash leachates against LS ratio (Fig. 9)

LS ratio	Conductivity (mS/cm)	
	RP	ESP
LS1	-	85.2
LS3	116.1	57.2
LS5	91.2	48.0

Example 6: Corrosion

Due to the high salt content and alkaline nature of the IFA leachate, the cathode side of the batteries showed signs of corrosion only after 2 hours of discharge (Fig. 10). As the IFA was in direct contact with the batteries, some IFA was observed to contaminate the cathode and along the side of the batteries, the same IFA could not be removed with simple wiping.

Leachate contamination is a concern since the corrosion of the cathode gasket could possibly expose the inner cell to infiltration of the leachate. Cross contamination between the cathode material in the discharged batteries and the leachate were studied and further discussed below.

Contamination between the cathode material in the battery and IFA

The batteries, after being discharged sufficiently using the method described in Example 3, were examined for contaminants using SEM-EDX. The SEM images are shown in Fig. 1 (reference battery) and Figs. 11a-11b (for batteries discharged with RP and ESP respectively). The compositions are further shown in Table 10.

Table 10: Elemental composition (weight %) of cathode material before and after discharging

Elements (wt%)	Cathode material in reference battery (wt%)	Cathode material in battery after discharge with LS5-RP-4 (wt%)	Cathode material in battery after discharge with LS5-ESP-6
Ni	35.92	34.13	34.52
Co	6.3	6.36	6.60
Al	0.91	1.04	1.14
O	30.42	29.33	24.47
F	7.99	8.72	8.17
P	-	0.43	0.46

It should be noted that P was not observed in the cathode material of a reference battery that was discharged using a battery tester (Fig. 1). F observed in the cathode material might be due to the PVDF binder.

As seen from Figs. 11a-11b and Table 10, aside from Ni, Co, Al and O originating from the active cathode material, there were also trace amounts of P and F detected on the cathode foil surface which could be attributed to LiPF_6 salt from the battery electrolyte. This could be explained by LiPF_6 deposition of the battery electrolyte onto the cathode surface during the IFA leachate discharging process or the contribution from the infiltration of the leachate. On the other hand, corrosion of the gasket could also cause the leaching of cathode material to the external leachate.

Despite the visible corrosion, there is no evidence suggesting dissolution of battery materials into the ash suspension.

While the IFA residue present on the discharged batteries might contaminate the downstream recovery process as suggested above, this issue could be easily avoided by segregating the IFA from the batteries during the discharging process with a membrane allowing only the leachate to flow through.

Example 7: Multiple discharge

To show that the ash may be reused after one cycle of discharge, the method in Example 3 was repeated for 4 batteries, i.e. the ash mixture after sufficiently discharging a first battery was subsequently used in a second process to discharge a second battery and so on. Each of the four batteries were discharged sufficiently prior to the subsequent discharging run, i.e., the first battery was discharged after about 3 hours, a second battery was then placed into the ash mixture and so on. Discharging of a fifth battery was attempted but failed as it took more than 1 day and hence, was not recorded above.

Using the leachate with the highest conductivity, i.e. that of L/S ratio of 1, it was found that 300 g of ESP ash was able to discharge 4 NCA batteries with initial voltages ranging from 3.4 V to 3.8 V. The conductivity of the leachate was initially around 82 mS/cm and eventually reached around 43 mS/cm after discharging 4 NCA batteries, after which the discharging time for one battery took almost a day and hence, the experiment was stopped. Table 11 summarises the composition of ESP evaluated after multiple discharges. As can be seen from the comparison with the control leachate, after multiple discharges, the reduction in the Cl content in ESP ash is more significant, showing that discharging using ESP ash has the potential to reduce Cl content while allowing the spent LIBs to be safely discharged.

Table 11. Comparison of composition of ESP based on leachate and ash of different conditions.

	LS1-ESP-Control	LS1-ESP-Multiple
Cl content in leachate (mg/L)	66,491	42,640
Al content in leachate (mg/L)	1.22	7.00
Using XRF (in ppm)		
Cl	36,195	24,829
S	108,984	95,777
P	3,365	3,220
K	49,369	31,767
Fe	40,015	51,120
Cu	2,926	2,627
Zn	30,613	27,332
Pb	5,890	5,174

Example 8: Segregating batteries from IFA

To improve discharge efficiency, IFA was segregated from the batteries during the discharge process as described in Example 3, but using a modified setup as shown in Fig. 12a. In particular, a sieve (mesh layer of up to 800 microns, or a mesh sieve of up to 100 microns) was used to separate the battery from the residue in the mixture, while maximizing the mixing flow rate of ash inside the beaker. The discharge duration for the first 5 batteries took no longer than 3 hours. For the last 2, it took overnight. After that, the experiment was stopped since the discharge took more than a day.

After discharging, a dark grey slurry was found on the top of both the sieve and the batteries as shown in Fig. 12b. It proved the hypothesis about the formation of other minerals which was mentioned previously. The change in pH and conductivity of the leachate to the number of batteries during multiple-discharge process were illustrated in Fig. 6. The pH of the leachate fluctuated after discharging while the variation of conductivity was more significant. By using the new setup, up to 7 batteries could be discharged consecutively, compared with 3 batteries with the same amount of ash without segregation. Hence, it can be shown that segregating the IFA from the batteries improves the discharging process significantly.

Example 9: Discharging batteries using IFA leachate

To further prevent the contamination from fly ash residue to batteries as well as the contamination of discharge by-products to fly ash, batteries were discharged using only fly ash leachate. In particular, the experiment was performed as mentioned in Example 3, except that 20 ml of RP ash leachate (obtained from filtering an RP ash suspension) was used instead.

The experiment process is illustrated by Fig. 7a after discharging for 30 mins. The RP ash leachate was obtained from filtering an RP ash suspension of LS ratio 3. As shown in Fig. 7a, gas and solid residue were observed as the discharging progressed.

As shown in Fig. 7b and Table 12, the batteries were discharged sufficiently within 1-2 hours, as compared to 4-6 hours observed in the previous Examples. Formation of solid and gaseous by-products were also observed around the positive/negative terminals of the batteries (Fig. 7a), likely due to electrochemical reactions arising from the discharging process as similarly observed in the previous Examples.

Table 12: Change in battery voltage (V) over time when discharged with ash leachate only (Fig. 7b)

Duration (hours)	Voltage (V)	
	Run 1	Run 2
0	3.767	3.771
0.25	3.695	3.67
0.5	3.654	3.634
0.75	3.605	3.602
1	2.986	0.635
2	0.86	-

From Table 13, it was observed that the pH of the fly ash leachate was reduced from about 11 to about 6 after the discharging was complete, indicating a reduction of ions to by-products due to the electrochemical reactions. This is further evidenced by the change in color and appearance of the leachate as the discharging progressed. The results suggests that the presently disclosed process for discharging batteries could also treat and reduce the toxicity of IFA leachate efficiently.

Table 13. Conductivity and pH of RP leachate before and after discharging

	Conductivity (mS/cm)	pH
Before	154.7	11.52
After	147.6	6.04

In view of the above, it is shown that segregation of battery and fly ash during the discharge process not only improves the discharging rate of the batteries, but also aids in separating the discharging by-products from the fly ash residue, as well as further reducing and removing ions from the leachate.

Example 10: Discharge batteries by moist fly ash

From results in the earlier Examples, it was postulated that the batteries could be discharged at very low L/S ratios. Hence, moist fly ash (L/S ratios) were tested to see if they could effectively discharge batteries.

Briefly, fly ash was first wet with water, following which a battery was buried and covered by the moist fly ash. The battery was left buried in the moist fly ash for a few weeks, after which it was taken out and its voltage tested as per the preceding Examples.

From the study, it was observed that batteries could be simply discharged by burying in moist fly ash for few weeks. In particular, after 30 days, the voltage of the batteries dropped from 3.7 V to under 0.6 V. The results show that moist fly ash may also be used to discharge and/or store spent batteries. In the event of electrolyte leaking, the moist fly ash could still effectively absorb the electrolyte while continuing to discharge the batteries, preventing fire incidents.

Example 11: Industrial scale of process

In the laboratory, the discharging experiments were executed in 500 mL or 1000 mL beakers which only allowed for a maximum capacity of 4 batteries per batch run. Hence, the batteries needed to be manually separated from the packs before they could be discharged.

To scale up the process from the laboratory-level to a semi-industrial level, several essential design requirements need to be considered.

(1) To maximize the discharging efficiency for all batteries, the process needs to be capable of homogeneously agitating or stirring the IFA suspension.

(2) The machine should be able to accommodate multiple battery packs. However, as a safety precaution, the packs should not be stacked or be in contact with other battery packs.

(3) To avoid the contamination of batteries with fly ash, segregation between the fly ash and the batteries is required.

A rotating reactor for discharging batteries is thus proposed, as shown in Fig. 13. The reactor would include 2 main parts:

- (1) a reactor chamber, and
- (2) a rotating cage for containing batteries.

The rotating cage may be divided into different sectors to prevent contact between the battery packs during discharging (Fig. 14). IFA would be fed into the reactor chamber, followed by water. The L/S (v/w) ratio may be controlled this step. During discharging, the rotating cage would rotate producing a centrifugal force, thus facilitating the mixing of the IFA and water. It is estimated that a 10 L-reactor may accommodate up to 50 batteries per batch. During discharging, the gas formed may be exhausted by a gas valve at the top of the reactor. After the discharging process is finished, the fly ash may be collected by a sieve, while the leachate may be reused for cleaning batteries, which may also be performed in the same reactor after the IFA has been removed. The cleaning process is primarily to remove the residue along the side and/or on top of the batteries.

Industrial Applicability

The present invention relates to a method of discharging batteries, in particular discharging batteries with ash. The method of the present invention advantageously utilise a waste (fly ash) to discharge batteries, another waste to produce both treated fly ash and discharged batteries. The discharged batteries may be further dismantled to recover the precious cathode material, while the treated fly ash, being lower in various heavy metal and ion content, may be further utilised in other applications, like cement production. By using a waste to treat a second waste to produce 2 treated products, the present invention advantageously results in cheaper economies of scale and lower costs.

It will be apparent that various other modifications and adaptations of the invention will be apparent to the person skilled in the art after reading the foregoing disclosure without departing from the spirit and scope of the invention and it is intended that all such modifications and adaptations come within the scope of the appended claims.

CLAIMS

1. A method of discharging a battery comprising contacting the battery with ash, ash suspension, or ash leachate, wherein the ash, ash suspension, or ash leachate comprises at least one ion selected from the group consisting of chloride, sulphate, sulphide, hydroxide, carbonate, and phosphate.
2. A method of reducing at least one ion content in ash comprising contacting a battery with ash, ash suspension or ash leachate, wherein the ion is selected from the group consisting of chloride, sulphate, sulphide, hydroxide, carbonate, and phosphate.
3. The method of claim 2, comprising reducing chloride content in ash.
4. The method of claim 2 or claim 3, wherein the method further comprises reducing metal content in ash.
5. The method of claim 4, wherein the metal is selected from the group consisting of aluminum, potassium, iron, copper, zinc, calcium, magnesium, cadmium and lead.
6. The method of any one of claims 1 to 5, wherein the ash, ash suspension or ash leachate comprises at least about 10000 ppm chloride, sulphate, sulphide, hydroxide, carbonate, and/or phosphate ions.
7. The method of claim 1 or claim 6, wherein the pH of the ash, ash leachate, or ash suspension is reduced after the discharge.
8. The method of any one of claims 1 to 7, comprising contacting the battery with ash leachate.
9. The method of claim 8, wherein the ash leachate is obtained by filtering an ash suspension.
10. The method of any one of claims 1 to 7 and 9, wherein the ash suspension comprises ash and water.
11. The method of any one of claims 1 to 7 and 9-10, wherein the ratio of volume of water to mass of ash in the ash suspension is about 1:1 to 10:1.
12. The method of any one of claims 1 to 7 and 9-11, wherein the battery is separated from the ash in the ash suspension.
13. The method of any one of claims 1 and 6 to 12, wherein 1 kg of ash is capable of discharging up to about 21 Ah in total battery capacity.
14. The method of any one of claims 1 and 6 to 13, wherein the battery is discharged by at least about 80% from its initial voltage.

15. The method of any one of claims 1 and 6 to 14, wherein the battery is discharged to below about 1 V.
16. The method of any one of claims 1 to 15, wherein the battery is selected from the group consisting of a Lithium Nickel Cobalt Aluminum Oxide battery (e.g. $\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$), a Lithium Cobalt Oxide battery (e.g. LiCoO_2), a Lithium Nickel Oxide battery (e.g. LiNiO_2), a Lithium Manganese Oxide battery (e.g. LiMn_2O_4), a Lithium Iron Phosphate battery (e.g. LiFePO_4), a Lithium Nickel Manganese Cobalt Oxide battery (e.g. $\text{LiNi}_{0.33}\text{Mn}_{0.3}\text{Co}_{0.3}\text{O}_2$), a Lithium Titanate battery (e.g. $\text{Li}_4\text{Ti}_5\text{O}_{12}$), a sodium ion battery, a sodium manganese oxide battery, a sodium iron phosphate battery, a sodium titanium phosphate battery, a sodium vanadium phosphate battery, a zinc ion battery, an aluminum ion battery, a rechargeable battery or combinations and mixtures thereof.
17. A system for discharging a battery and/or reducing ion content in ash, comprising:
 - a reactor chamber;
 - a perforated battery container disposed within the reactor chamber, wherein the perforated battery container is configured to contain a battery;
 - a motor connected to the perforated battery container, wherein the motor is configured to move the perforated battery container;
 - an ash inlet connected to the reactor chamber, wherein the ash inlet is configured to feed ash into the reactor chamber; and
 - a water inlet connected to the reactor chamber, wherein the water inlet is configured to feed water into the reactor chamber.
18. The system of claim 17, wherein the perforated battery container comprises one or more dividers configured to divide the perforated battery container into a plurality of sectors, and wherein each of the plurality of sectors is configured to contain a set of batteries.
19. The system of claim 17 or 18, wherein the motor is configured to rotate the perforated battery container within the reactor chamber.
20. The system of any one of claims 17 to 19, further comprising a valve connected to the reactor chamber, wherein the valve is configured to exhaust air from the reactor chamber.
21. The system of any one of claims 17 to 20, further comprising a fluid outlet and a sieve, wherein the sieve is disposed adjacent to the fluid outlet and configured to collect ash from water exiting the reactor chamber via the fluid outlet.