CLAIMS

1. A method of operating an osmotic battery, comprising:

providing a source of a dilute salt solution;

separating the dilute salt solution to form a concentrated solution and a substantially dilute working solution;

storing the concentrated solution in fluid isolation from the substantially dilute working solution; and

maintaining a concentration gradient between the concentrated solution and the substantially dilute working solution to store energy as a chemical energy potential difference between the concentrated solution and the substantially dilute working solution.

2. The method of claim 1, wherein separating the dilute salt solution comprises introducing the dilute salt solution to a distillation column.

3. The method of claim 1, further comprising converting the chemical energy potential difference to electrical power.

4. The method of claim 3, wherein the chemical energy potential difference is converted to electrical power in response to detecting a power demand.

5. The method of claim 3, wherein converting the chemical energy potential difference to electrical power is performed using a pressure retarded osmosis process.

6. The method of claim 4, wherein the pressure retarded osmosis process comprises pressurizing at least a portion of the concentrated solution.

7. The method of claim 6, wherein the pressure retarded osmosis process further comprises increasing a volume of at least a portion of the pressurized concentrated solution to form a pressurized solution expanded in volume.

8. The method of claim 7, wherein increasing the volume comprises introducing at least a portion of the dilute working solution to the pressurized concentrated solution.

9. The method of claim 8, wherein increasing the volume comprises promoting water flux using a semi-permeable membrane.

10. The method of claim 7, wherein the pressure retarded osmosis process further comprises decreasing the pressure of the pressurized solution to generate electrical power and to produce the dilute salt solution.

11. The method of claim 10, wherein decreasing the pressure comprises flowing the pressurized solution through a turbine.

12. The method of claim 10, further comprising introducing the dilute salt solution to a separation unit.

13. The method of claim 12, wherein the separation unit is selected from the group consisting of a distillation column, a pervaporation unit, a reverse osmosis membrane separation unit, a nanofiltration membrane separation unit and an electrodialysis device.

14. The method of claim 12, further comprising powering the separation unit with electricity.

15. The method of claim 12, further comprising powering the separation unit with heat generated by an upstream unit operation.

16. The method of claim 15, wherein the separation unit is powered with heat generated by combustion of a fuel source.

17. The method of claim 15, further comprising powering the separation unit with heat produced as a byproduct of a renewable energy source.

18. The method of claim 12, further comprising providing water generated by the separation unit to a point of use.

19. The method of claim 10, further comprising delivering the electrical power to a point of use.

20. The method of claim 1, wherein the concentrated solution comprises a thermolytic salt.

21. The method of claim 20, wherein the concentrated solution comprises an ammonia-carbon dioxide solution.

10

22. The method of claim 1, wherein the concentrated solution comprises ammonia and carbon dioxide in a molar ratio of greater than 1 to 1.

23. The method of claim 4, wherein converting the chemical energy potential difference to electrical power is performed using an electrochemical process.

24. The method of claim 10, further comprising transferring at least a portion of the pressure from the pressurized solution to a turbine fluid stream distinct from the concentrated solution and the substantially dilute working solution, and depressurizing the pressurized turbine fluid stream
20 in a turbine.

25. An osmotic energy system, comprising:

a pressure retarded osmosis unit comprising a semipermeable membrane;

a potential energy storage unit comprising a source of a concentrated solution fluidly connected to a first inlet of the pressure retarded osmosis unit and a source of a dilute working solution fluidly connected to a second inlet of the pressure retarded osmosis unit;

a turbine fluidly connected downstream of the pressure retarded osmosis membrane unit; and

an electrical generator connected to the turbine unit.

30

26. The system of claim 25, further comprising a distillation column fluidly connected downstream of the turbine.

27. The system of claim 26, wherein the distillation column is fluidly connected to the concentrated solution source and the dilute working solution source.

28. The system of claim 27, further comprising a renewable energy source thermally connected to the distillation column.

29. The system of claim 27, further comprising a source of industrial waste heat thermally connected to the distillation column.

30. The system of claim 27, further comprising a source of electricity connected to the distillation column.

31. The system of claim 25, further comprising a pervaporation unit, a secondary membrane separation unit, or an electrodialysis device fluidly connected downstream of the turbine.

32. The system of claim 26, further comprising an industrial, irrigation or potable water point of use fluidly connected to an outlet of the distillation column.

33. The system of claim 25, further comprising a grid energy distribution system electrically connected downstream of the turbine.

34. The system of claim 33, further comprising a base load electricity generation plant connected to the grid energy distribution system.

35. The system of claim 34, further comprising a controller configured to detect an energy demand from the grid energy distribution system.

36. The system of claim 25, further comprising a reverse osmosis or nanofiltration unit fluidly connected downstream of the turbine.

37. The system of claim 25, wherein the concentrated solution comprises a thermolytic salt.

38. A method of operating an osmotic battery, comprising:

providing a source of a dilute salt solution;

using electrical energy to separate the dilute salt solution to form a concentrated solution and a substantially dilute working solution;

storing the concentrated solution and the substantially dilute working solution;

maintaining a concentration gradient between the concentrated solution and the substantially dilute working solution to harness potential energy; and

introducing the concentrated solution and the substantially dilute working solution to process which generates electricity from the potential energy in response to a power demand.

39. The method of claim 38, wherein the step of using electrical energy to separate the dilute salt solution comprises introducing the dilute salt solution to a nanofiltration, reverse osmosis or electrodeionization (EDI) process.

40. The method of claim 38, wherein the process which generates electricity from the potential energy comprises a pressure retarded osmosis process.

41. The method of claim 38, wherein the process which generates electricity from the potential energy comprises a reverse electrodialysis (RED) process.

42. A method of operating an osmotic battery, comprising:

introducing a dilute salt solution to a thermal separation process to form a concentrated solution and a substantially dilute working solution;

storing the concentrated solution and the substantially dilute working solution;

maintaining a concentration gradient between the concentrated solution and the substantially dilute working solution to harness potential energy; and

introducing the concentrated solution and the substantially dilute working solution to a pressure retarded osmosis process to generate electricity from the potential energy in response to a power demand.

43. The method of claim 42, wherein the thermal separation process comprises a distillation process.

44. An osmotic energy system, comprising:

a grid energy delivery system;

an electrochemical generator electrically coupled to the grid energy delivery system; and

a potential energy storage unit comprising a source of a concentrated solution fluidly connected to a first inlet of the electrochemical generator and a source of a dilute working solution fluidly connected to a second inlet of the electrochemical generator.

45. The system of claim 44, wherein the electrochemical generator comprises a reverse electrodialysis (RED) unit.

CLAIMS

1. A method of operating an electrochemical generator, comprising the steps of:

providing a separation unit configured for separating a dilute salt solution using at least one of electrical energy or thermal energy;

providing a membrane module in fluid communication with the separation unit;

introducing the dilute salt solution to the separation unit;

introducing at least one of electrical energy or thermal energy to the separation unit to separate the dilute salt solution into a dilute working fluid and a concentrated draw solution;

directing the dilute working fluid to a first storage tank;

directing the concentrated draw solution to a second storage tank;

maintaining the first and second storage tanks in fluidic isolation;

providing means for interconnecting the membrane module and the first and second storage tanks, wherein the means for interconnecting comprises a controller and a valve;

in response to a power demand signal, interconnecting the first and second storage tanks with the membrane module, pressurizing a first side of the membrane module, wherein the first side of the membrane module receives the concentrated draw solution from the second storage tank, and fluxing at least a portion of the dilute working fluid across the membrane to produce a pressurized dilute draw solution;

directing the pressurized dilute draw solution to a pressure exchanger;

pressurizing a separate working fluid with the pressure exchanger; and

directing the pressurized separate working fluid to a turbine to generate electrical power.

2. The method of claim 1 further comprising the step of providing an electrical generator coupled to the turbine for generating electricity.

3. The method of claim 2 further comprising the step of providing a grid energy distribution system coupled to the electrical generator for delivering the electricity to an electrical grid.

4. The method of claim 1, wherein the controller controls the system to maintain a salinity

difference between the substantially dilute working fluid in the first storage tank and the concentrated draw solution in the second storage tank.

5. The method of claim 1, wherein the separation unit comprises at least one of a distillation column, a pervaporation unit, a membrane separation unit, a reverse osmosis system, a nanofiltration unit, an electrodialysis unit, an ion exchange unit, a capacitive deionization unit, or an electrodeionization unit.

6. The method of claim 1, wherein the membrane module provides at least a portion of the source of dilute salt solution to the separation unit.

7. The method of claim 1, wherein the pressure exchanger is in fluid communication with the separation unit for providing at least a portion of the source of dilute salt solution to the separation unit.

8. The method of claim 1, wherein the dilute draw solution comprises ammonia and carbon dioxide in a ratio of at least 1:1.

9. A method of operating an electrochemical generator, comprising the steps of:

providing a separation unit configured for separating a dilute salt solution using at least one of electrical energy or thermal energy;

providing a membrane module in fluid communication with the separation unit;

introducing the dilute salt solution to the separation unit;

introducing at least one of electrical energy or thermal energy to the separation unit to separate the dilute salt solution into a dilute working fluid and a concentrated draw solution;

directing the dilute working fluid to a first storage tank;

directing the concentrated draw solution to a second storage tank;

maintaining the first and second storage tanks in fluidic isolation;

periodically directing at least a portion of the dilute working fluid to a secondary separation unit to maintain a low concentration of solutes therein;

providing means for interconnecting the membrane module and the first and second storage tanks, wherein the means for interconnecting comprise a controller and a valve; and

in response to a power demand signal:

interconnecting the first and second storage tanks with the membrane module pressurizing a first side of the membrane module, wherein the first side of the membrane module receives the concentrated draw solution from the second storage tank; and

fluxing at least a portion of the dilute working fluid across the membrane to produce a pressurized dilute draw solution.

10. The method of claim 9, wherein the secondary separation unit comprises at least one of a distillation column, an ion exchange system, or a reverse osmosis membrane system.

11. The method of claim 9 further comprising the steps of:

coupling the separation unit to an unreliable power source; and

directing a portion of power from the unreliable power source to the separation unit to provide the at least one of electrical energy or thermal energy to the separation unit.

12. The method of claim 11 further comprising the step of directing a second portion of power from the unreliable power source to a grid energy distribution system.

13. The method of claim 11, wherein the unreliable power source is selected from the group consisting of solar, thermal, photovoltaic, wind, hydro, biomass, and tidal.