Claims

1. A non-flammable sodium-ion battery comprising:

a cathode for a sodium-ion battery;

an anode for a sodium-ion battery;

a separator; and

an electrolyte comprising a salt and a glyme solvent, wherein:

the glyme solvent is selected from one or more of the group consisting of tetraglyme and analogues thereof

where the analogue of tetraglyme is selected from the compounds where one or both of the $–CH_3$ end members in a tetraglyme molecule are modified to either $–C_2H_5$ or to $–CH_2CH_2Cl$;

the anode is selected from the group consisting of TiO_2, $Na_2Ti_3O_7 \leftrightharpoons Na_{3-x}Ti_3O_7$ pathway, $Na_2Ti_6O_{13}$, graphite, hard carbon, and sodium metal;

the cathode does not include α-$NaMnO_2$;

the salt comprises $NaBF_4$;

the battery has an average voltage of from 1.5 V to 6.0 V; and

a coulombic efficiency after 5 charge/discharge cycles of at least 95%, wherein the charge/discharge cycles are conducted at a charge rate of C/5 and a discharge rate of C/5.

2. The battery according to Claim 1, wherein the average voltage is from 1.75 to 5.5 V.

3. The battery according to Claim 1, wherein the battery has a cycle life of from 50 charge/discharge cycles to 50,000 charge/discharge cycles.

4. The battery according to Claim 1, wherein the battery has a coulombic efficiency after 5 charge/discharge cycles of at least 97%.

5. The battery according to Claim 1, wherein the $NaBF_4$ is provided at a concentration of from greater than 0 to less than or equal to 2.5 M in the glyme solvent.

6. The battery according to Claim 1, wherein the glyme solvent further comprises one or more solvents selected from the group consisting of a cyclic carbonate, a linear carbonate, a cyclic ester, a linear ester, a cyclic or linear ether other than a glyme, a nitrile, dioxolane or a derivative thereof, ethylene sulfide, sulfolane, and sultone or a derivative thereof.

7. The battery according to Claim 6, wherein the glyme solvent further comprises one or more of the group selected from propylene carbonate, ethylene carbonate, diethyl carbonate, dimethyl carbonate, ethyl methyl carbonate, tetrahydrofuran, sulfolane, and acetonitrile.

8. The battery according to Claim 1, wherein the salt further comprises one or more salts selected from the group consisting of NaCN, $NaClO_4$, $NaAsF_6$, $NaPF_6$, $NaPF_{6-x}(C_nF_{2n+1})_x$ ($1<x<6$, $n=1$ or 2), NaSCN, NaBr, NaI, Na_2SO_4, $Na_2B_{10}Cl_{10}$, NaCl, NaF, $NaPF_4$, NaOCN, $Na(CF_3SO_3)$, $NaN(CF_3SO_2)_2$, $NaN(FSO_2)$, $NaN(C_2F_5SO_2)_2$, $NaN(CF_3SO_2)(C_4F_9SO_2)$, $NaC(CF_3SO_2)_3$, $NaC(C_2F_5SO_2)_3$, $(CH_3)_4NBF_4$, $(CH_3)_4NBr$, $(C_2H_5)_4NClO_4$, $(C_2H_5)_4NI$, $(C_3H_7)_4NBr$, $(n\text{-}C_4H_9)_4NClO_4$, $(n\text{-}C_4H_9)_4NI$, $(C_2H_5)_4N$-maleate, $(C_2H_5)_4N$-benzoate, $(C_2H_5)_4N$-phtalate, sodium stearyl sulfonate, sodium octyl sulfonate, and sodium dodecylbenzene sulfonate.

9. The battery according to Claim 8, wherein each of the one or more salts of Claim 10, when present, are provided in a concentration of greater than 0 to less than 2.5 M.

10. The battery according to Claim 1, wherein the cathode comprises an active material selected from one or more of the group consisting of $Na_a[Cu_bFe_cMn_dNi_eTi_fM_g]O_2$ (where: $0 \le a \le 1$; $0 \le b \le 0.3$; $0 \le c \le 0.5$; $0 \le d \le 0.6$; $0 \le e \le 0.3$; $0 \le f \le 0.2$; and $0 \le g \le 0.4$, and M is selected from one or more of the group consisting of Mo, Zn, Mg, Cr, Co, Zr, Al, Ca, K, Sr, Li, H, Sn, Te, Sb, Nb, Sc, Rb, Cs, and Na), M-$Na_2Fe_2(CN)_6.2H_2O$; R-$Na_2Fe_2(CN)_6$, NVP, and $Na_4Mn_3(PO_4)_2(P_2O_7)$.

11. The battery according to Claim 1, wherein the cathode and anode comprise active material pairs selected from the group consisting of: M-$Na_2Fe_2(CN)_6.2H_2O$// TiO_2, R-$Na_2Fe_2(CN)_6$//TiO_2, NVP//TiO_2, $Na_a[Cu_bFe_cMn_dNi_eTi_fM_g]O_2$ // graphite, $Na_a[Cu_bFe_cMn_dNi_eTi_fM_g]O_2$ // $Na_2Ti_6O_{13}$, $Na_a[Cu_bFe_cMn_dNi_eTi_fM_g]O_2$ // TiO_2, $Na_4Mn_3(PO_4)_2(P_2O_7)$//TiO_2, $Na_a[Cu_bFe_cMn_dNi_eTi_fM_g]O_2$ // $Na_2Ti_3O_7 \leftrightharpoons Na_{3-x}Ti_3O_7$ pathway, $Na_a[Cu_bFe_cMn_dNi_eTi_fM_g]O_2$ // hard carbon, $Na_a[Cu_bFe_cMn_dNi_eTi_fM_g]O_2$ // sodium metal, M-$Na_2Fe_2(CN)_6.2H_2O$// $Na_2Ti_3O_7 \leftrightharpoons Na_{3-x}Ti_3O_7$ pathway; M-$Na_2Fe_2(CN)_6.2H_2O$// $Na_2Ti_6O_{13}$; M-$Na_2Fe_2(CN)_6.2H_2O$// graphite; M-$Na_2Fe_2(CN)_6.2H_2O$//hard carbon; M-$Na_2Fe_2(CN)_6.2H_2O$//sodium metal; R-$Na_2Fe_2(CN)_6$//$Na_2Ti_3O_7 \leftrightharpoons Na_{3-x}Ti_3O_7$ pathway; R-$Na_2Fe_2(CN)_6$//$Na_2Ti_6O_{13}$; R-$Na_2Fe_2(CN)_6$//graphite; R-$Na_2Fe_2(CN)_6$//hard carbon; R-$Na_2Fe_2(CN)_6$//sodium metal; NVP// $Na_2Ti_3O_7 \leftrightharpoons Na_{3-x}Ti_3O_7$ pathway; NVP//$Na_2Ti_6O_{13}$; NVP//graphite; NVP//hard carbon; NVP//sodium metal; $Na_4Mn_3(PO_4)_2(P_2O_7)$ // $Na_2Ti_3O_7 \leftrightharpoons Na_{3-x}Ti_3O_7$ pathway; $Na_4Mn_3(PO_4)_2(P_2O_7)$ // $Na_2Ti_6O_{13}$; $Na_4Mn_3(PO_4)_2(P_2O_7)$//graphite; $Na_4Mn_3(PO_4)_2(P_2O_7)$//hard carbon; and $Na_4Mn_3(PO_4)_2(P_2O_7)$//sodium metal, where: $0 < a \le 1$;

$0 \leq b \leq 0.3$; $0 \leq c \leq 0.5$; $0 \leq d \leq 0.6$; $0 \leq e \leq 0.3$; $0 \leq f \leq 0.2$; and $0 \leq g \leq 0.4$, and M is selected from one or more of the group consisting of Mo, Zn, Mg, Cr, Co, Zr, Al, Ca, K, Sr, Li, H, Sn, Te, Sb, Nb, Sc, Rb, Cs, and Na.

12. The battery according to according to Claim 11, wherein the cathode and anode are selected from the group consisting of: M-$Na_2Fe_2(CN)_6.2H_2O$// $Na_2Ti_3O_7$ ⇋ $Na_{3-x}Ti_3O_7$ pathway; M-$Na_2Fe_2(CN)_6.2H_2O$// $Na_2Ti_6O_{13}$; M-$Na_2Fe_2(CN)_6.2H_2O$// graphite; M-$Na_2Fe_2(CN)_6.2H_2O$//hard carbon; M-$Na_2Fe_2(CN)_6.2H_2O$//sodium metal; R-$Na_2Fe_2(CN)_6$//$Na_2Ti_3O_7$ ⇋ $Na_{3-x}Ti_3O_7$ pathway; R-$Na_2Fe_2(CN)_6$//$Na_2Ti_6O_{13}$; R-$Na_2Fe_2(CN)_6$//graphite; R-$Na_2Fe_2(CN)_6$//hard carbon; R-$Na_2Fe_2(CN)_6$//sodium metal; NVP// $Na_2Ti_3O_7$ ⇋ $Na_{3-x}Ti_3O_7$ pathway; NVP//$Na_2Ti_6O_{13}$; NVP//graphite; NVP//hard carbon; NVP//sodium metal; $Na_4Mn_3(PO_4)_2(P_2O_7)$ // $Na_2Ti_3O_7$ ⇋ $Na_{3-x}Ti_3O_7$ pathway; $Na_4Mn_3(PO_4)_2(P_2O_7)$ // $Na_2Ti_6O_{13}$; $Na_4Mn_3(PO_4)_2(P_2O_7)$//graphite; $Na_4Mn_3(PO_4)_2(P_2O_7)$//hard carbon; and $Na_4Mn_3(PO_4)_2(P_2O_7)$//sodium metal.

13. The battery according to according to Claim 11, wherein the cathode and anode are selected from the group consisting of: M-$Na_2Fe_2(CN)_6.2H_2O$// graphite, M-$Na_2Fe_2(CN)_6.2H_2O$// $Na_2Ti_6O_{13}$, R-$Na_2Fe_2(CN)_6$//graphite, R-$Na_2Fe_2(CN)_6$//$Na_2Ti_6O_{13}$, NVP//graphite, NVP//$Na_2Ti_6O_{13}$, M-$Na_2Fe_2(CN)_6.2H_2O$// TiO_2, R-$Na_2Fe_2(CN)_6$//TiO_2, NVP//TiO_2, $Na_a[Cu_bFe_cMn_dNi_eTi_fM_g]O_2$ // graphite, $Na_a[Cu_bFe_cMn_dNi_eTi_fM_g]O_2$ // $Na_2Ti_6O_{13}$, and $Na_a[Cu_bFe_cMn_dNi_eTi_fM_g]O_2$ // TiO_2.

14. The battery according to according to Claim 13, wherein the cathode and anode are selected from the group consisting of: M-$Na_2Fe_2(CN)_6.2H_2O$// graphite, M-$Na_2Fe_2(CN)_6.2H_2O$// $Na_2Ti_6O_{13}$, R-$Na_2Fe_2(CN)_6$//graphite, R-$Na_2Fe_2(CN)_6$//$Na_2Ti_6O_{13}$, NVP//graphite, and NVP//$Na_2Ti_6O_{13}$.

15. The battery according to according to Claim 11, wherein the cathode and anode are selected from the group consisting of: M-$Na_2Fe_2(CN)_6.2H_2O$//$Na_2Ti_3O_7$ ⇋ $Na_{3-x}Ti_3O_7$ pathway, M-$Na_2Fe_2(CN)_6.2H_2O$//hard carbon, M-$Na_2Fe_2(CN)_6.2H_2O$//sodium metal, R-$Na_2Fe_2(CN)_6$//$Na_2Ti_3O_7$⇋ $Na_{3-x}Ti_3O_7$ pathway, R-$Na_2Fe_2(CN)_6$//hard carbon, R-$Na_2Fe_2(CN)_6$//sodium metal, NVP// $Na_2Ti_3O_7$ ⇋ $Na_{3-x}Ti_3O_7$ pathway, NVP//hard carbon, NVP//sodium metal, $Na_4Mn_3(PO_4)_2(P_2O_7)$//$Na_2Ti_3O_7$ ⇋ $Na_{3-x}Ti_3O_7$ pathway, $Na_4Mn_3(PO_4)_2(P_2O_7)$ // $Na_2Ti_6O_{13}$ $Na_4Mn_3(PO_4)_2(P_2O_7)$ // graphite, $Na_4Mn_3(PO_4)_2(P_2O_7)$ // hard carbon, $Na_4Mn_3(PO_4)_2(P_2O_7)$//sodium metal, $Na_4Mn_3(PO_4)_2(P_2O_7)$//TiO_2,

$Na_a[Cu_bFe_cMn_dNi_eTi_fM_g]O_2$ // $Na_2Ti_3O_7 \leftrightharpoons Na_{3-x}Ti_3O_7$ pathway, $Na_a[Cu_bFe_cMn_dNi_eTi_fM_g]O_2$ // hard carbon, and $Na_a[Cu_bFe_cMn_dNi_eTi_fM_g]O_2$ // sodium metal.

16. The battery according to according to Claim 15, wherein the cathode and anode are selected from the group consisting of: M-$Na_2Fe_2(CN)_6.2H_2O$//$Na_2Ti_3O_7 \leftrightharpoons Na_{3-x}Ti_3O_7$ pathway, M-$Na_2Fe_2(CN)_6.2H_2O$//hard carbon, M-$Na_2Fe_2(CN)_6.2H_2O$//sodium metal, R-$Na_2Fe_2(CN)_6$//$Na_2Ti_3O_7 \leftrightharpoons Na_{3-x}Ti_3O_7$ pathway, R-$Na_2Fe_2(CN)_6$//hard carbon, R-$Na_2Fe_2(CN)_6$//sodium metal, NVP// $Na_2Ti_3O_7 \leftrightharpoons Na_{3-x}Ti_3O_7$ pathway, NVP//hard carbon, NVP//sodium metal, $Na_4Mn_3(PO_4)_2(P_2O_7)$//$Na_2Ti_3O_7 \leftrightharpoons Na_{3-x}Ti_3O_7$ pathway, $Na_4Mn_3(PO_4)_2(P_2O_7)$ // $Na_2Ti_6O_{13}$ $Na_4Mn_3(PO_4)_2(P_2O_7)$ // graphite, $Na_4Mn_3(PO_4)_2(P_2O_7)$ // hard carbon, and $Na_4Mn_3(PO_4)_2(P_2O_7)$//sodium metal.

17. The battery according to Claim 1, wherein the electrolyte further comprises an additive selected from one or more of the group consisting of fluoroethylene carbonate (FEC), vinylene carbonate (VC), vinyl ethylene carbonate (VEC), and adiponitrile.

18. The battery according to Claim 1, wherein the anode is selected from the group consisting of TiO_2, $Na_2Ti_3O_7 \leftrightharpoons Na_{3-x}Ti_3O_7$ pathway, $Na_2Ti_6O_{13}$, graphite, hard carbon, and a metal consisting essentially of sodium.

19. The battery according to Claim 1, wherein the anode is selected from the group consisting of TiO_2, $Na_2Ti_3O_7 \leftrightharpoons Na_{3-x}Ti_3O_7$ pathway, $Na_2Ti_6O_{13}$, graphite, hard carbon, and a metal consisting of sodium.