CLAIMS

1. An anion exchange membrane, comprising:

a porous support membrane, wherein the porous support membrane is in the form of a non-woven fabric or mesh, veil, knit fabric, woven fabric or mesh, open-cell structure, fibril and node structure, or open-cell foam; and

a silica-based ceramic that coats at least a portion of the porous support membrane, wherein the silica-based ceramic comprises quaternary ammonium groups covalently bound to the silica-based ceramic, and wherein the silica-based ceramic has an average pore diameter of less than or equal to 10 nm.

2. An anion exchange membrane, comprising:

a porous support membrane, wherein the porous support membrane is in the form of a non-woven fabric or mesh, veil, knit fabric, woven fabric or mesh, open-cell structure, fibril and node structure, or open-cell foam; and

a silica-based ceramic that forms a coating on and/or within the porous support membrane, wherein the silica-based ceramic comprises quaternary ammonium groups covalently bound to the silica-based ceramic, and wherein the anion exchange membrane has a chloride ion conductivity of greater than or equal to 0.00001 S/cm.

~~3. An anion exchange membrane, comprising:~~

~~a silica-based ceramic, wherein the anion exchange membrane has a water uptake of greater than or equal to 10 wt% and a linear expansion of less than or equal to 10%.~~

~~4. An anion exchange membrane, comprising:~~

~~a porous support membrane; and~~

~~a silica-based ceramic that coats at least a portion of the porous support membrane, wherein the silica-based ceramic comprises quaternary ammonium groups covalently bound to the silica-based ceramic, and wherein greater than or equal to 50% of the pore volume of the porous support membrane is filled by the silica-based ceramic.~~

3~~5~~. An anion exchange membrane, comprising:

a porous support membrane wherein the porous support membrane is in the form of a non-woven fabric or mesh, veil, knit fabric, woven fabric or mesh, open-cell structure, fibril and node structure, or open-cell foam; and

a silica-based ceramic that forms a coating on and/or within the porous support membrane, wherein the silica-based ceramic comprises quaternary ammonium groups covalently bound to the silica-based ceramic, and wherein the anion exchange membrane has an anion exchange capacity of greater than or equal to 0.01 meq/g.

~~6. An anion exchange membrane, comprising:~~

~~a porous support membrane; and~~

~~a silica-based ceramic that coats at least a portion of the porous support membrane, wherein the silica-based ceramic comprises quaternary ammonium groups covalently bound to the silica-based ceramic, and wherein the quaternary ammonium groups are present in the anion exchange membrane in an amount of greater than or equal to 0.01 mmol per gram of the anion exchange membrane.~~

~~7. An anion exchange material, comprising:~~

~~a silica-based ceramic that comprises quaternary ammonium groups covalently bound to the silica-based ceramic, wherein the silica-based ceramic comprises Si in an amount greater than or equal to 6 wt% of the silica-based ceramic,~~

~~wherein the anion exchange material has an anion exchange capacity of greater than or equal to 0.01 meq/g, and~~

~~wherein the silica-based ceramic has an average pore diameter of less than 10 nm.~~

~~8. An anion exchange membrane, comprising:~~

~~a silica-based ceramic comprising Si in an amount greater than or equal to 6 wt% of the silica-based ceramic, wherein the anion exchange membrane has an anion exchange capacity of greater than or equal to 0.01 meq/g.~~

~~9. An anion exchange membrane, comprising:~~

~~a silica-based ceramic, wherein the anion exchange membrane has an anion exchange capacity of greater than or equal to 0.01 meq/g and a linear expansion of less than or equal to 10%.~~

~~10. An anion exchange membrane, comprising:~~

~~a silica-based ceramic comprising Si in an amount greater than or equal to 6 wt% of the silica-based ceramic, wherein the anion exchange membrane has an anion permselectivity of greater than or equal to 65%.~~

~~11. An anion exchange membrane, comprising:~~

~~a silica-based ceramic comprising Si in an amount greater than or equal to 6 wt% of the silica-based ceramic, wherein the anion exchange membrane has a chloride ion conductivity of greater than or equal to 0.00001 S/cm.~~

~~12. An anion exchange membrane, comprising:~~

~~a silica-based ceramic, wherein the anion exchange membrane has a chloride ion conductivity of greater than or equal to 0.00001 S/cm and a linear expansion of less than or equal to 10%.~~

~~13. An anion exchange membrane, comprising:~~

~~a silica-based ceramic comprising Si in an amount greater than or equal to 6 wt% of the silica-based ceramic, wherein the anion exchange membrane has an osmotic water permeance of less than or equal to 100 mL/(hr·bar·m^2).~~

~~14. An anion exchange membrane, comprising:~~

~~a silica-based ceramic comprising Si in an amount greater than or equal to 6 wt% of the silica-based ceramic, the silica-based ceramic comprising pores, wherein an average diameter of the pores of the silica-based ceramic is larger when the anion exchange membrane is in a hydrated state than when the anion exchange membrane is in a dry state by a factor of greater than or equal to 1.1.~~

15. An anion exchange membrane, comprising:

a silica-based ceramic comprising Si in an amount greater than or equal to 6 wt% of the silica-based ceramic, the silica-based ceramic comprising pores, wherein:

when the anion exchange membrane is in a dry state, the pores of the silica-based ceramic fit a model of small angle scattering spectra with intensity (I) as a function of a scattering vector, q, as follows:

$$I(q) = \frac{1}{a+c_1q^2+c_2q^4} + bck,$$

wherein a, c_1, and c_2 are adjustable parameters and bck is background scattering; and

when the anion exchange membrane is in a hydrated state the pores of the silica-based ceramic fit a core-shell model of small angle scattering spectra with intensity (I) as a function of a scattering vector, q, as follows:

$$I(q) = P(q)S(q) + bck,$$

$$S(q) = 1 + \frac{D_f\Gamma(D_f-1)}{[1+1/q\xi)^2]^{(D_f-1)/2}} \frac{sin[(D_f-1)tan^{-1}(q\xi)]}{(qR_\theta)^{D_f}},$$

$$P(q) = \frac{scale}{V_s}\left[3V_e(\rho_e-\rho_s)\frac{[sin(qr_e)-qr_e cos(qr_e)]}{(qr_e)^3} + 3V_s(\rho_s-\rho_{block})\frac{[sin(qr_s)-qr\,cos(qr_s)]}{(qr_s)^3}\right]^2 + bck,$$

wherein R_θ is a radius of the building blocks (pores), $\rho_{solvent}$ is a scattering length density of the silica based ceramic, D_f is a fractal dimension, ξ is a correlation length, Γ is the standard mathematical gamma function, *scale* is a volume fraction of building blocks of the measured silica-based ceramic, V_e is a volume of the core, V_s is a volume of the shell, ρ_e is a scattering length density of the core, ρ_s is a scattering length density of the shell, ρ_{block} is a scattering length density of the pores, r_e is a radius of the core, r_s is a radius of the shell, and bck is background scattering.

16. The anion exchange membrane or anion exchange material of any one of the preceding claims, further comprising a porous support membrane coated by the silica-based ceramic

~~17. The anion exchange membrane or anion exchange material of any one of the preceding claims, wherein the silica-based ceramic comprises quaternary ammonium groups covalently bound to the silica-based ceramic.~~

~~18. The anion exchange membrane or anion exchange material of any one of the preceding claims, wherein the silica-based ceramic has an average pore diameter of less than or equal to 10 nm.~~

~~19. The anion exchange membrane or anion exchange material of any one of the preceding claims, wherein the quaternary ammonium groups are directly adjacent to a surface of the porous support membrane.~~

~~4~~20. The anion exchange membrane ~~or anion exchange material of any one of the preceding claims~~of any one of claims 1-3, wherein the quaternary ammonium groups are present in the anion exchange membrane ~~or anion exchange material~~ in an amount of greater than or equal to 0.01 mmol per gram of the anion exchange membrane ~~or anion exchange material~~.

5. The anion exchange membrane of any one of claims 1-4, wherein the silica-based ceramic comprises Si in an amount greater than or equal to 6 wt% of the silica-based ceramic.

6. The anion exchange membrane of any one of claims 1-5, wherein the anion exchange membrane has a linear expansion of less than or equal to 5%.

7. The anion exchange membrane of any one of claims 1-6, wherein the anion exchange membrane has an anion permselectivity of greater than or equal to 65%.

8. The anion exchange membrane of any one of claims 1-7, wherein an average diameter of the pores of the silica-based ceramic is larger when the anion exchange membrane is in a hydrated state than when the anion exchange membrane is in a dry state by a factor of greater than or equal to 1.1.

9. The anion exchange membrane of claim 8, wherein the silica-based ceramic comprises pores, and wherein an average diameter of the pores of the silica-based ceramic is larger when the anion exchange membrane is in a hydrated state than when the anion exchange membrane is in a dry state by a factor of less than or equal to 5.

10. The anion exchange membrane of any one of claims 1-9, wherein:

when the anion exchange membrane is in a dry state, the pores of the silica-based ceramic fit a model of small angle scattering spectra with intensity (I) as a function of a scattering vector, q, as follows:

$$I(q) = \frac{1}{a+c_1q^2+c_2q^4} + bck,$$

wherein a, c_1, and c_2 are adjustable parameters and bck is background scattering; and

when the anion exchange membrane is in a hydrated state the pores of the silica-based ceramic fit a core-shell model of small angle scattering spectra with intensity (I) as a function of a scattering vector, q, as follows:

$$I(q) = P(q)S(q) + bck,$$

$$S(q) = 1 + \frac{D_f\Gamma(D_f-1)}{[1+1/q\xi)^2]^{(D_f-1)/2}} \frac{sin[(D_f-1)tan^{-1}(q\xi)]}{(qR_0)^{D_f}},$$

$$P(q) = \frac{scale}{V_s}\left[3V_c(\rho_c-\rho_s)\frac{[sin(qr_c)-qr_c\,cos(qr_c)]}{(qr_c)^3} + 3V_s(\rho_s-\rho_{block})\frac{[sin(qr_s)-qr\,cos(qr_s)]}{(qr_s)^3}\right]^2 + bck,$$

wherein R_o is a radius of the building blocks (pores), $\rho_{solvent}$ is a scattering length density of the silica-based ceramic, D_f is a fractal dimension, ξ is a correlation length, Γ is the standard mathematical gamma function, *scale* is a volume fraction of building blocks of the measured silica-based ceramic, V_c is a volume of the core, V_s is a volume of the shell, ρ_c is a scattering length density of the core, ρ_s is a scattering length density of the shell, ρ_{block} is a scattering length

density of the pores, r_c is a radius of the core, r_s is a radius of the shell, and *bck* is background scattering.

11. The anion exchange membrane of any one of claims 1-10, wherein the silica-based ceramic is derived from the co-condensation of a silicon-containing precursor comprising an ammonium group or a moiety comprising a leaving group.

12. The anion exchange membrane of any one of claims 1-11, wherein the silica-based ceramic has a silicon to nitrogen molar ratio of greater than or equal to 1:1.

13. The anion exchange membrane of any one of claims 1-12, wherein the silica-based ceramic has a silicon to nitrogen molar ratio of less than or equal to 120:1.

14. The anion exchange membrane of any one of claims 1-13, wherein the porous support membrane is in the form of a non-woven fabric or mesh.

15. The anion exchange membrane of any one of claims 1-14, wherein the porous support membrane comprises a polymeric material comprising polypropylene, polyethylene, polyvinyl chloride, polystyrene, polyamide, polyimide, polyacetonitrile, polyvinylacetate, polyethylene glycol, poly ether ether ketone, polysulfone, polyacrylamide, polydimethylsiloxane, polyvinylidene fluoride, polyacrylic acid, polyvinyl alcohol, polyphenylene sulfide, polytetrafluoroethylene, cellulose, microfibrillated cellulose, nanofibrillated cellulose, or combinations or derivatives thereof.

16. The anion exchange membrane of any one of claims 1-15, wherein greater than or equal to 50% of the pore volume of the porous support membrane is filled by the silica-based ceramic.

17. The anion exchange membrane of any one of claims 1-16, wherein the porous support membrane has a mechanical burst pressure of greater than or equal to 2.0 pounds per square inch (PSI).

18. The anion exchange membrane of any one of claims 1-17, wherein the porous support membrane comprises an outer surface, and wherein the anion exchange membrane comprises a layer comprising the silica-based ceramic that forms a coating on at least a portion of the outer surface of the porous support membrane.

19. The anion exchange membrane of any one of claims 1-18, wherein the weight ratio of the silica-based ceramic to the porous support membrane in the anion exchange membrane is greater than or equal to 1:10.

20. The anion exchange membrane of any one of claims 1-19, wherein the porous support membrane has a volumetric porosity of greater than or equal to 10% and less than or equal to 99%.