Claims

1. A hydrogen purifier comprising a hydrogen-separation membrane module, the membrane module comprising:

at least one membrane cell, comprising:

(i) a hydrogen-selective membrane defining a permeate face and an opposed mixed gas face;

(ii) a fluid-permeable support structure that physically contacts and supports at least a central region of the permeate face;

(iii) a permeate-side frame member interposed between the hydrogen-selective membrane and the fluid-permeable support structure such that the permeate-side frame member physically contacts a peripheral region of the permeate face and a peripheral region of the fluid-permeable support structure;

(iv) a mixed gas-side frame member that physically contacts a peripheral region of the mixed gas face of the hydrogen-selective membrane;

wherein at least one of the permeate-side frame member and the mixed gas-side frame member is a graphite frame member; and

wherein the graphite frame member comprises a granular particulate having a non-graphite composition, wherein the granular particulate consists of granular particles having a maximum dimension that is at most 400 micrometers and at least 0.01 micrometers.

2. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the graphite frame member comprises at least 99 weight percent (wt%) carbon.

3. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the mixed gas-side frame member is the graphite frame member.

4. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the permeate-side frame member is the graphite frame member.

5. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the mixed gas-side frame member and the permeate-side frame member are graphite frame members.

6. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the graphite frame member comprises at least 99.8 wt% carbon and at most 99.999 wt% carbon.

7. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the graphite frame member is a flexible graphite frame member.

8. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the graphite frame member comprises at least 0.001 wt% granular particulate, and wherein the graphite frame member comprises at most 1 wt% granular particulate~~, at most 0.9 wt% granular particulate, at most 0.8 wt% granular particulate, at most 0.7 wt% granular particulate, at most 0.6 wt% granular particulate, at most 0.5 wt% granular particulate, at most 0.4 wt% granular particulate, at most 0.3 wt% granular particulate, at most 0.2 wt% granular particulate, at most 0.1 wt% granular particulate, or at most 0.01 wt% granular particulate~~.

9. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the granular particulate comprises one or more of ash, MgO, Al_2O_3, SiO_2, CaO, and Fe_2O_3.

10. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein each of the mixed gas-side frame member, the permeate-side frame member, and the graphite frame member comprise sulfur, wherein the graphite frame member comprises at least 1 ppm sulfur, and wherein the graphite frame member comprises ~~at least one of~~ at most 450 ppm sulfur~~, at most 400 ppm sulfur, at most 350 ppm sulfur, at most 300 ppm sulfur, at most 250 ppm sulfur, at most 200 ppm sulfur, at most 100 ppm sulfur, at most 50 ppm sulfur, and at most 20 ppm sulfur~~.

11. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the permeate-side frame member, the mixed gas-side frame member, and the graphite frame member comprise a halide, wherein the graphite frame member comprises at least 0.2 ppm halide, and wherein the graphite frame member comprises ~~at least one of~~ at most 100 ppm halide~~, at most 80 ppm halide, at most 60 ppm halide, at most 40 ppm halide, at most 20 ppm halide, at most 10 ppm halide, and at most 1 ppm halide~~.

12. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the graphite frame member comprises a membrane-contacting face that physically contacts and supports the peripheral region of the mixed gas face of the hydrogen-selective membrane or the permeate gas face of the hydrogen-selective membrane, wherein the membrane-contacting face of the graphite frame member comprises a surface roughness resulting from the granular particulate having a maximum amplitude (R_p) of at least 0.01 micrometers and at most 400 micrometers~~, at most 300 micrometers, at most 200 micrometers, at most 150 micrometers, at most 100 micrometers, at most 50 micrometers, at most 25 micrometers, at most 10~~

~~micrometers, at most 5 micrometers, at most 1 micrometer, at most 0.5 micrometers, or at most 0.2 micrometers~~.

13. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the hydrogen-selective membrane has a membrane thickness, and wherein the membrane thickness is at least one of at most 25 microns~~, at most 20 microns, at most 15 microns, at most 10 microns, at most 5 microns,~~ and at least 1 micron~~, at least 2 microns, at least 4 microns, at least 6 microns, at least 8 microns, at least 10 microns, and at least 12 microns~~.

14. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the graphite frame member has a density of at least one of:

(i) at least 0.7 grams per cubic centimeter (g/cc)~~, at least 0.8 g/cc, at least 0.9 g/cc, at least 1 g/cc, at least 1.1 g/cc, at least 1.2 g/cc, at least 1.3 g/cc, at least 1.4 g/cc, and at least 1.5 g/cc~~; and

(ii) at most 1.8 g/cc~~, at most 1.7 g/cc, at most 1.6 g/cc, at most 1.5 g/cc, at most 1.4 g/cc, at most 1.3 g/cc, at most 1.2 g/cc, at most 1.1 g/cc, and at most 1 g/cc~~.

15. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the permeate-side frame member supports the peripheral region of the permeate face of the hydrogen-selective membrane, and further wherein the mixed gas-side frame member forms a fluid seal with the peripheral region of the mixed gas face of the hydrogen-selective membrane.

16. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the at least one membrane cell includes a pair of hydrogen-selective membranes, wherein the hydrogen-selective membrane is a first hydrogen-selective membrane of the pair of hydrogen-selective membranes, in which the permeate face is a first permeate face and the mixed gas face is a first mixed gas face, the mixed gas-side frame member is a first mixed gas-side frame member, and the permeate-side frame member is a first permeate-side frame member, wherein the at least one membrane cell further includes:

(i) a second hydrogen-selective membrane of the pair of hydrogen-selective membranes, wherein the second hydrogen-selective membrane defines a second permeate face and an opposed second mixed gas face, wherein the fluid-permeable support structure is positioned between the first hydrogen-selective membrane and the second hydrogen-selective membrane such that the fluid-permeable support structure physically contacts at least the central region of the first permeate face and at least the central region of the second permeate face and also such that the central region of the first permeate face is spaced-apart from the central region of the second permeate face;

(ii) a second permeate-side frame member interposed between the second hydrogen-selective membrane and the fluid-permeable support structure such that the second permeate-side frame member physically contacts a peripheral region of the second permeate face and the peripheral region of the fluid-permeable support structure;

(iii) a second mixed gas-side frame member that physically contacts a peripheral region of the second mixed gas face; and

wherein at least one of the second permeate-side frame member and the second mixed gas-side frame member is the graphite frame member.

17. The ~~membrane module of claim~~hydrogen purifier of claim 16, wherein the second permeate-side frame member supports the peripheral region of the second permeate face and the peripheral region of the fluid-permeable support structure, and further wherein the second mixed gas-side frame member forms a fluid seal with the peripheral region of the second mixed gas face.

18. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the membrane module comprises a plurality of membrane cells.

19. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the hydrogen purifier is configured to receive a mixed gas stream that includes hydrogen gas and one or more other gasses and to separate the mixed gas stream into a purified hydrogen stream and a byproduct stream, wherein the hydrogen-selective membrane separates the hydrogen-separation membrane module into a mixed gas region and a permeate region, wherein the membrane module is configured to receive the mixed gas stream in the mixed gas region, and wherein the hydrogen-selective membrane is configured to permit the hydrogen gas contained within the mixed gas stream to diffuse through the hydrogen-selective membrane to the permeate region to separate the mixed gas stream into the purified hydrogen stream and the byproduct stream, and wherein the purified hydrogen stream is the portion of the mixed gas stream that diffuses through the hydrogen-selective membrane.

20. A fuel processor, comprising:

a hydrogen-producing region configured to receive a feed stream and to produce the mixed gas stream from the feed stream; and

the hydrogen purifier of claim 19, wherein the membrane module is configured to receive the mixed gas stream and to separate the mixed gas steam into the purified hydrogen stream and the byproduct stream.

21. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the granular particulate comprises a hardness greater than the hardness of a remainder of the graphite frame member.

22. The ~~membrane module of claim~~hydrogen purifier of claim 1, wherein the granular particulate of the graphite frame member is fine granular particulate, wherein the fine granular particulate produces reduced surface roughness in the graphite frame member relative to a coarse granular particulate.