**Extended Data Table 1**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Membranes** | **Fuel cell** | **Temperature** | **Peak power density [W cm–2]** | **Pt loading [mg cm–2]** | **Fuel** | **Conductivity [S cm–1]** | **Ref** |
| Plasma-coated BPSH membrane | LT-PEMFC | 80-120 | 0.45 (120℃) | 1.0 | H2/air | 0.51  (80℃ RH 100%) | 2 |
| PBI/H3PO4 | HT-PEMFC | 140-180 | 0.60 (180℃) | 0.5 | H2/air | 0.083 (150℃) | 30 |
| TiO2 composite PBI/H3PO4 | HT-PEMFC | 125-175 | 1 (175℃) | 1 | H2/O2 | 0.075 (175℃) | 15 |
| TiSO4 composite PBI/ H3PO4 | HT-PEMFC | 150 | 0.60 (150℃) | 1 | H2/O2 | 0.048 (150℃) | 31 |
| SiO2 nanoparticles composite PBI/H3PO4 | HT-PEMFC | 160 | 0.5 (160℃) | 1.2 | H2/O2 | 0.02 (160℃) | 14 |
| Cross-linked PBI/ H3PO4 | HT-PEMFC | 160 | 0.53 (160℃) | 0.6 | H2/O2 | 0.253 (200℃) | 32 |
| PWA meso- silica composite PBI/ H3PO4 | HT-PEMFC | 200 | 0.38(200℃) | 1.7 | H2/air | 0.023 (200℃) | 16 |
| QAPOH/ H3PO4 | HT-PEMFC | 120-240 | 1.74 (240℃) | 1.1 | H2/O2 | 0.023 (220℃) | 18 |
| SnP2O7–Nafion composite membrane | IT-PEMFC | 200-240 | 0.87 (240℃) | 1.2 | H2/O2 | 0.102 (290℃) | 17 |
| Ce0.9Gd0.1P2O7 composite PBI/ H3PO4 | IT-PEMFC | 160-250 | 0.31 (160℃) | 1 | H2/air | 0.182 (180℃) | 33 |
| CeP2O7 electrolyte membranes | IT-FC(SCFC) | 150-250 | 0.025 (200℃) | 1.2mm | H2/O2 | 0.018 (200℃) | 34 |
| Molten CsH5(PO4)2 electrolyte composite/ PBI | IT-FC(MCFC) | 150-250 | 0.12 (200℃) | 0.5 | H2/O2 | 0.064 (250℃) | 35 |
| CsH2PO4-ZrO2 composite electrolytes | IT-FC | 250-275 | 0.040 (275℃) | 0.7 | H2/air | 0.02 (250℃) | 36 |
| In3+-Doped SnP2O7 electrolyte membranes | IT-FC(SCFC) | 250 | 0.265 (250℃) | 0.6 | H2/O2 | 0.195 (250℃) | 37 |
| Thin CsH2PO4 electrolyte membranes | IT-FC(SCFC) | 240 | 0.415 (240℃) | 0.77 | H2/O2 | 0.01 (230℃) | 38 |
|  | PCFC | ≥350 (350-600) | 0.10 (350℃) |  | H2/air |  | 39 |
| Ceria-based solid electrolyte | SOFC | >800(400-800) | 0.10 (350℃) |  | H2/air |  | 40 |
| SAN-CeHP-PBI/ H3PO4 | This work | 150-250 | 2.4 (250℃) | 1.5 | H2/O2 | 0.257 (280℃) |  |
| SAN-CeHP-PBI/ H3PO4 | This work | 150-250 | 1.8 (250℃) | 1.5 | H2/air | 0.257 (280℃) |  |

**Extended Data Table 2**

|  |  |  |  |
| --- | --- | --- | --- |
| **Symbol** | **PA-doped SAN-CeHP-PBI** | **De-doped SAN-CeHP -PBI** | **Assignment** |
| + | 728 | - | C–H out-of-plane ring deformation |
|  | - | 905 | Stretching mode of PO4 (ν1) |
| ↑ | 911 | - | Free phosphoric acid |
| **O** | 964 | 964 | Ring breathing vibration of benzene ring |
|  | 1144, 1120 | 1144 | C-C skeletal stretching |
|  | - | 1218 | Amide (N-H) |
| α | 1281,1327 | 1281,1331 | C–H in-plane bending vibrations |
| β | 1390,1420,1454 | 1395,1443,1474 | C=C/C=N benzimidazole ring stretching vibrations  (or C-H in plane vibrations) |
| γ | 1544,1560,1615 | 1535,1562,1612,1632 | C=C/C=N benzimidazole ring stretching vibrations |

**Extended Data Table 3**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Name of H2 carrier** | **Abbreviation** | **T (DoDH 95%) [°C]** | **T (DoDH 99%) [°C]** | **T (DoDH) Range [°C]** | | **Heat of Reaction**  **[kJ /mol\_H2]** | **Reaction stoichiometry** |
| Ammonia | NH3 | 250\* | 350\* | 400 [1][2] | 550 [1][2] | 30.60\* | 2NH3 → 3H2 + N2 |
| Methane | CH4 | 800\* | 1050\* | 800 (1 bar) [3] | 900 (1bar) [3] | 68.60\* | CH4 + H2O → CO + 3H2 |
| 800 (5~20bar) [3] | 1000 (5~20bar) [3] |
| 2-propanol | C3H8O | 400\* | 440\* | 400 [4][5] | 500 [4][5] | 70.80\* | CH3CH(OH)CH3 + 2H2O  → 6H2 + 3CO |
| 380\* | 600\* | 33.50\* | CH3CH(OH)CH3 + 5H2O  → 9H2 + 3CO2 |
| Formic acid | HCOOH | X | X | 25 [6][7] | 90 [6][7] | 14.60\* | HCOOH → H2 +CO2 |
| Formate (Na) | Na+ HCOO- | X | X | 30 [8] | 80 [8] | 20.50 | NaHCOO + H2O  → NaHCO3 + H2 |
| Methylcyclohexane | MCH | 300\* | 320\* | 280 [9] | 350 [9] | 68.30\* | C7H14 → C7H8 + 3H2 |
| Dibenzyltoluene | DBT | 270 | 280 | 250 [10] | 310 [10] | 65.40 | C18H36 → C18H18 + 9H2 |
| N-ethylcarbazole | NEC | 174 | 180 | 120 [11] | 200 [11] | 8.40 | C14H25N → C14H13N + 6H2 |
| Dimethyl Ether | DME | 170\* | 270\* | 350 [12] | 450 [12] | 20.5\* | CH3OCH3 + 3H2O → 2CO2 + 6H2 |
| Methanol | MeOH | 60\* | 150\* | 230 [13] | 300 [13] | 16.5\* | CH3OH + H2O → CO2 + 3H2 |

\* calculated using Peng-Robinson equation of state in Aspen plus v 11.

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