



**Supplementary Figure 1.** Actual testing setup to measure the bending behavior of SPEES/PVDF/SGO/Pt based IPMC actuator.



**Supplementary Figure 2.** Load characterization of (a) SPEES/PVDF/Pt and (b) SPEES/PVDF/SGO/Pt based IPMC membrane actuators.

**Supplementary Table 1.** The IEC and proton conductivity of the SPEES, SPEES/PVDF/Pt and SPEES/PVDF/SGO/Pt based Composite membranes.

S.No.	Sample	IEC (meq/g)	Degree of Sulfonation (%)	WH (%) At R.T
1	SPEES	2.80±0.007	126±0.28	-
2	SPEES/PVDF/Pt	1.50±0.007	68±0.28	86± 0.63 (24 h)
3	SPEES/PVDF/SGO/Pt	1.95±0.007	88±0.28	78±0.64 (24 h)

**Supplementary Table 2.** Deflection data of SPEES/PVDF/Pt IPMC membrane at different applied voltages.

Deflection (mm)	Voltage (V)										
	0 V	0.5V	1.0V	1.5V	2.0V	2.5V	3.0V	3.5V	4.0V	4.5V	
d1	0.593	0.794	3.605	5.159	4.132	5.377	6.385	6.729	12.294	10.328	12.293
d2	0.395	0.512	2.829	2.382	4.376	3.607	6.057	8.106	11.483	10.584	11.967
d3	0.014	0.163	2.502	2.219	6.857	4.902	5.847	8.070	11.032	10.865	11.929
d4	0.198	0.742	1.921	4.007	7.561	5.570	7.779	8.873	9.852	10.849	12.427
d5	0.752	0.682	3.096	3.789	4.650	5.970	7.364	9.562	8.513	11.531	12.579
d6	0.535	0.494	0.861	5.089	7.201	4.295	5.100	10.852	11.207	10.361	12.101
d7	0.164	0.752	3.143	5.137	5.873	5.894	5.282	7.552	11.268	10.567	12.314
d8	0.483	0.567	4.398	4.063	6.008	5.436	7.214	7.071	10.651	10.223	11.884
d9	0.091	0.508	2.855	2.637	7.118	3.919	6.949	10.227	8.351	10.192	12.132
d10	0.419	0.434	2.033	2.437	7.098	4.451	5.489	9.159	8.821	10.605	11.623
										Mean	12.1253
										Standard Deviation	0.286

**Supplementary Table 3.** Deflection data of SPEES/PVDF/Pt IPMC membrane at different applied voltages.

Deflection (mm)	Voltage (V)										
	0 V	0.5V	1.0V	1.5V	2.0V	2.5V	3.0V	3.5V	4.0V	4.5V	
d1	0.760	0.342	3.975	3.745	5.154	6.641	5.467	8.083	10.765	10.213	12.208
d2	0.268	0.309	4.571	4.729	3.483	6.125	7.094	10.431	12.731	10.586	12.041
d3	0.215	0.143	3.909	2.331	6.397	4.128	4.817	7.587	12.272	10.815	11.916
d4	0.246	0.781	2.433	3.972	5.388	3.921	5.889	10.367	12.295	10.874	12.501
d5	0.261	0.659	2.190	4.149	5.232	3.923	8.193	9.0161	11.774	11.552	12.536
d6	0.426	0.691	1.336	5.553	4.433	4.973	6.439	6.920	11.440	10.264	12.091
d7	0.222	0.117	3.165	5.981	3.872	6.553	8.523	7.942	11.808	10.668	12.309
d8	0.712	0.324	1.438	3.318	6.966	6.920	5.378	9.032	11.486	10.347	11.873
d9	0.522	0.694	1.376	3.303	6.936	4.299	6.633	7.824	11.175	10.260	12.032
d10	0.611	0.812	3.798	2.212	5.771	7.112	4.867	7.022	8.867	10.643	11.655
										Mean	12.131
										Standard deviation	0.268

**Supplementary Table 4.** Deflection data of SPEES/PVDF/SGO/Pt IPMC membrane at different applied voltages.

Deflection (mm)	Voltage (V)										
	0 V	0.5V	1.0V	1.5V	2.0V	2.5V	3.0V	3.5V	4.0V	4.5V	
d1	0.303	0.717	3.361	6.290	4.259	9.062	10.415	13.418	13.601	14.130	14.953
d2	0.741	0.421	4.007	4.454	3.999	7.591	10.381	12.438	13.197	13.260	14.819
d3	0.303	0.500	2.618	3.374	6.435	7.653	9.832	12.282	13.082	14.508	15.303
d4	0.468	0.928	2.539	5.394	4.108	5.748	10.234	11.843	15.705	14.618	15.057
d5	0.116	0.950	1.705	4.975	4.262	8.977	9.383	13.045	13.085	14.886	15.125
d6	0.287	0.353	1.199	4.800	6.297	8.832	13.141	11.326	14.199	14.948	14.999
d7	0.121	0.425	1.975	5.012	7.522	6.286	12.347	10.560	15.296	14.636	14.850
d8	0.571	0.741	2.086	2.529	5.492	7.726	12.477	13.508	15.852	15.230	15.515
d9	0.657	0.518	3.547	4.661	6.446	6.219	9.262	13.518	14.348	15.089	15.201
d10	0.264	0.871	4.776	3.876	3.922	7.313	12.230	13.597	14.274	15.082	15.278
										Mean	15.110
										Standard deviation	0.218

**Supplementary Table 5.** Deflection data of SPEES/PVDF/SGO/Pt IPMC membrane at different applied voltages.

Deflection (mm)	Voltage (V)										
	0 V	0.5V	1.0V	1.5V	2.0V	2.5V	3.0V	3.5V	4.0V	4.5V	5.0V
d1	0.066	0.888	2.760	5.250	6.309	6.449	11.647	13.301	13.253	14.041	14.999
d2	0.614	0.679	4.979	4.734	7.627	8.335	11.649	13.878	14.623	13.205	14.898
d3	0.757	0.205	4.723	4.064	4.533	8.065	10.006	10.936	12.761	14.553	15.376
d4	0.051	0.466	3.535	4.736	7.326	8.405	10.287	11.536	13.123	14.546	15.066
d5	0.719	0.639	5.195	4.934	5.001	5.739	12.021	10.400	13.170	14.906	15.136
d6	0.013	0.132	4.200	4.159	7.184	9.209	11.330	12.380	11.749	14.986	15.000
d7	0.523	0.281	2.161	4.231	5.738	9.529	12.221	11.081	14.162	14.55	14.813
d8	0.600	0.872	3.478	4.459	5.071	8.717	9.656	14.022	16.064	15.295	15.478
d9	0.409	0.919	1.887	3.969	4.480	5.072	9.316	11.201	14.842	15.014	15.169
d10	0.678	0.871	2.094	2.333	3.808	6.629	11.854	10.878	12.110	15.041	15.289
Mean											15.122
Standard Deviation											0.210

**Supplementary Table 6.** Experimental force data of SPEES/PVDF/Pt IPMC membrane at different voltages.

Force (mN)	Voltage (V)									
	0 V	1V	1.5V	2.0V	2.5V	3.0V	3.5V	4.0V	4.5V	5V
F1	0	0.011	0.050	0.148	2.059	3.336	3.924	4.215	4.237	4.430
F2	0	0.008	0.024	0.886	1.866	3.139	3.847	4.041	4.136	4.334
F3	0	0.006	0.049	0.444	1.914	2.796	3.137	3.823	3.847	4.072
F4	0	0.014	0.023	0.575	1.653	3.177	3.833	3.931	3.941	3.989
F5	0	0.014	0.031	0.119	1.824	3.764	4.728	5.021	5.097	5.145
F6	0	0.013	0.023	0.416	1.535	3.551	4.591	4.620	4.728	4.822
F7	0	0.012	0.044	0.231	1.650	2.963	3.216	3.514	3.548	3.751
F8	0	0.012	0.031	0.630	1.532	3.783	4.630	4.822	4.854	4.904
F9	0	0.013	0.0333	0.338	1.653	3.208	3.727	3.992	4.088	4.195
F10	0	0.012	0.0303	0.229	1.428	3.388	4.139	4.532	4.627	4.646
Operating voltage										5 V
Mean										4.429 mN
Standard deviation										0.445 mN
Repeatability										90.50%

**Supplementary Table 7.** Experimental force data of SPEES/PVDF/SGO/Pt IPMC membrane at different voltages.

Force (mN)	Voltage (V)									5V
	0 V	1V	1.5V	2.0V	2.5V	3.0V	3.5V	4.0V	4.5V	
F1	0	0.005	0.035	0.231	1.603	3.551	4.433	5.434	5.924	5.97
F2	0	0.010	0.041	0.188	1.609	2.963	4.377	5.312	5.900	5.901
F3	0	0.008	0.031	0.178	1.426	3.188	4.146	5.199	5.866	5.989
F4	0	0.012	0.046	0.226	1.318	2.411	4.558	5.129	5.744	5.883
F5	0	0.013	0.082	0.150	1.101	2.306	3.976	5.404	5.777	5.901
F6	0	0.007	0.033	0.210	1.209	3.386	4.558	5.139	5.511	5.608
F7	0	0.012	0.045	0.153	1.101	3.453	4.234	5.063	5.610	5.836
F8	0	0.013	0.045	0.183	1.011	3.150	4.116	4.920	5.514	5.901
F9	0	0.016	0.035	0.136	1.218	3.412	4.166	4.839	5.423	5.651
F10	0	0.011	0.012	0.182	1.066	3.382	4.084	4.933	5.323	5.689
									Operating voltage	5 V
									Mean	5.834 mN
									Standard deviation	0.135 mN
									Repeatability	94.60%