SUPPLEMENTARY MATERIALS

Table S1 Experimental data in the processes of kiln, NH_3, urea, MeOH

Kiln

Composition	Vol%
CO_2	18.9
N_2	60.6
H_2O	12.8
O_2	7.7

Ammonia synthesis reaction

Pressure (atm)	Mole fraction of ammonia
11.90476	0.517301
29.10053	0.632353
50.26455	0.759516
100.5291	0.810554
201.0582	0.878893
400.7937	0.911765
1001.323	0.964533

Urea synthesis reaction

Ratio of NH_3/CO_2	Mole fraction of urea
1.942141	0.639897
2.517574	0.688657
2.990019	0.720177
3.498908	0.770122
4.004426	0.79986
4.542522	0.824844
5.509972	0.8231
7.551729	0.86003
9.525555	0.889826
11.49789	0.910707
19.54686	0.950847

Methanol synthesis reaction

10 bar		30 bar		60 bar	
Temperature (℃)	CO_2 Conversion	Temperature (℃)	CO_2 Conversion	Temperature (℃)	CO_2 Conversion
100.6378	0.398769	99.36224	0.738949	101.2755	0.923694
149.7449	0.227071	149.7449	0.439681	149.7449	0.738801
200.7653	0.16827	200.7653	0.298769	200.1276	0.460061
250.5102	0.16959	248.5969	0.248775	249.2347	0.327952
300.2551	0.216365	300.2551	0.23836	350.6378	0.311526

350	0.274871	349.3622	0.299799	300.8929	0.288211
399.7449	0.35537	399.7449	0.3671	399.7449	0.397892
450.1276	0.428536	449.4898	0.450532	450.1276	0.481322
499.8724	0.511968	499.8724	0.517833	499.8724	0.519299
550.2551	0.548477	550.2551	0.549943	550.2551	0.548477
599.3622	0.571793	599.3622	0.579125	599.3622	0.580591

Table S2 Mathematical models of PEM water electrolysis

Voltage	$\mathrm{V(T,p)} = \mathrm{e_{rev}(T,p)} - \mathrm{e_{rev}(T,p)}e^{\frac{-5I}{0.02}} + IR_{\mathrm{i}}(T,p)$
Current	$I(T,p) = 0 \quad \mathrm{V} \leqq \mathrm{e_{rev}(T,p)}$ $I(T,p) = \frac{1}{R_{\mathrm{i}}(T,p)}(V - \mathrm{e_{rev}(T,p)}) \quad \mathrm{V} \geqq \mathrm{e_{rev}(T,p)}$
Initial resistance of PEM system	$R_{\mathrm{i}}(T,p) = R_{\mathrm{i0}} + kln\left(\frac{p}{p_0}\right) + dR_t(T - T_0)$
Reverse voltage	$e_{rev}(\mathrm{T,p}) = e_{rev,0} + \frac{R(273+T)}{2F}\ln(\frac{p}{p_0})$
The ideal voltage	$V_{\mathrm{i}} = \frac{\Delta G}{2F}$
Gibbs free energy change of H_2	$\Delta G = 285.84 - 163.2(273 + T)$
Hydrogen production rate	$v_H = \frac{60000 v_m I}{2F}$
Molar volume rate (Ideal Gas)	$v_m = \frac{R(273+T)}{p}$
Input power	$\mathrm{P} = I^2 R_{\mathrm{i}} + Ie_{rev} = R_{\mathrm{i}}(\frac{2Fv_H}{60000v_m})^2 + (\frac{2Fv_H}{60000v_m})\,e_{rev}$

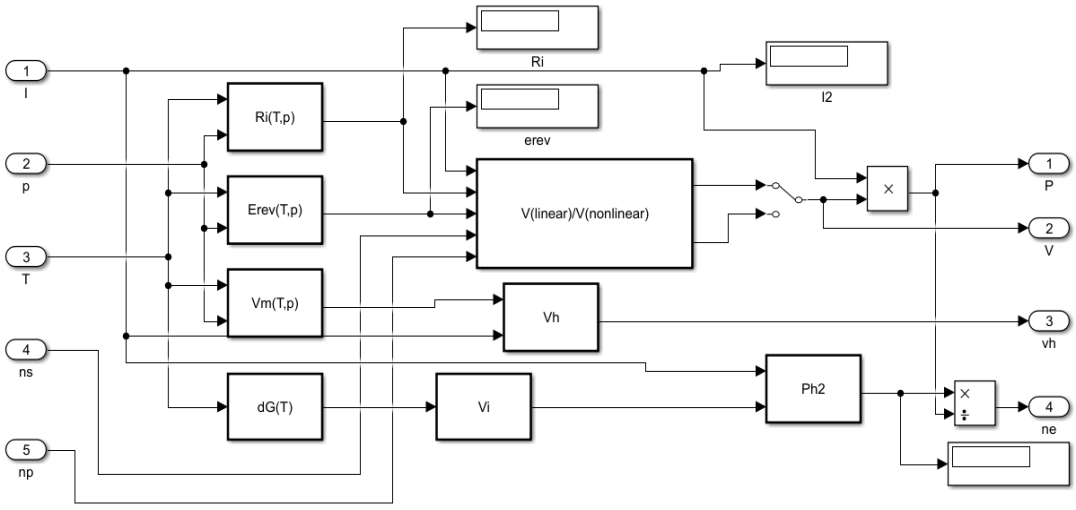

Figure S1 Flowchart of PEM water electrolysis with Simulink™