

Scenario-Based Techno-economic Analysis of Steam Methane Reforming Process for Hydrogen Production

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Supplementary Materials

A. Process flow diagram

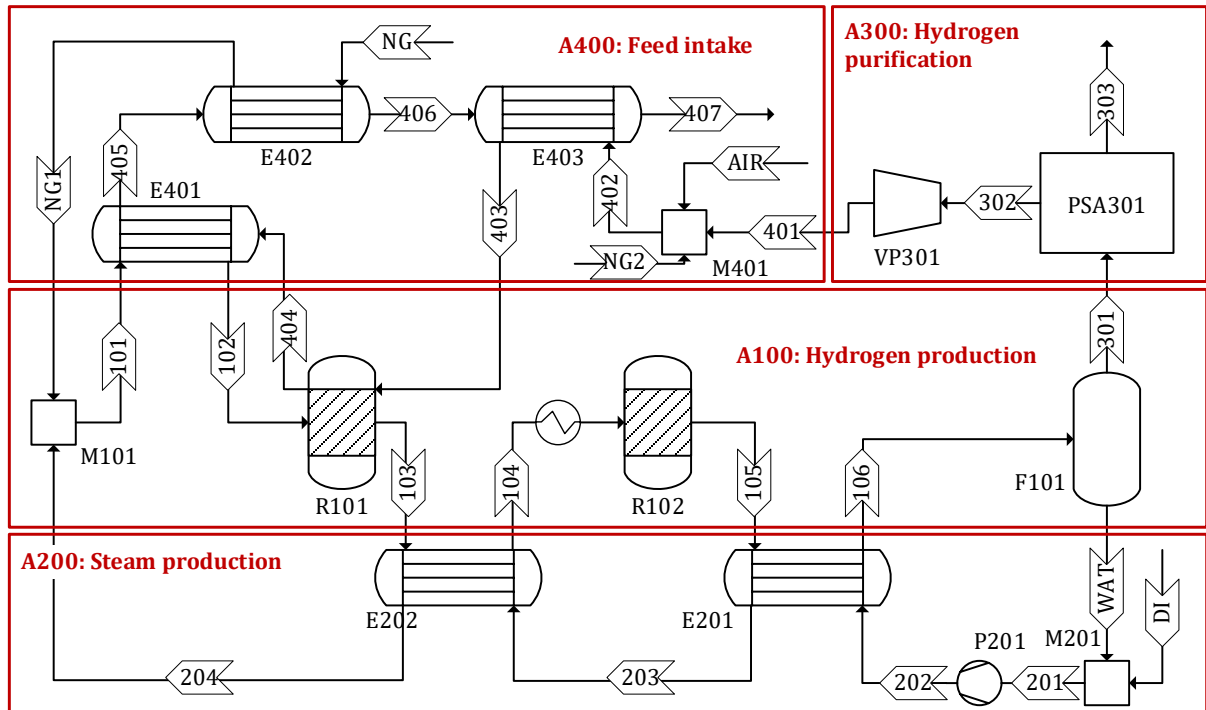


Figure S1. Process flow diagram of steam methane reforming process in scenario 2.

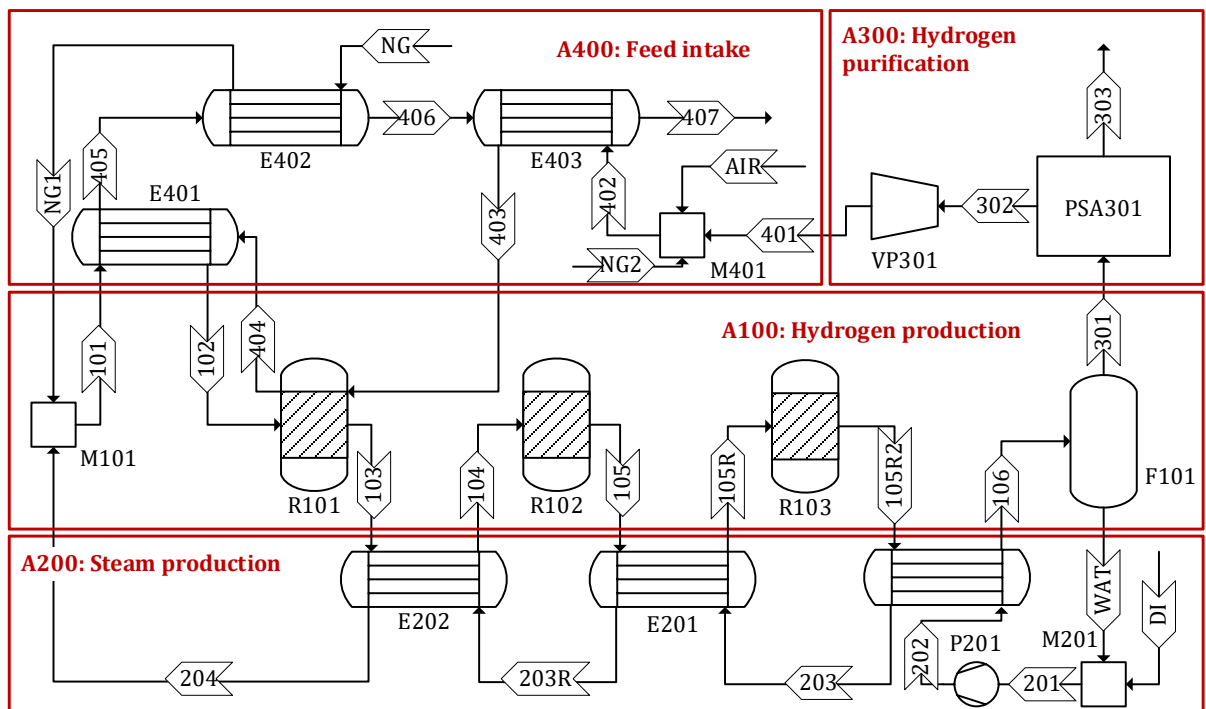


Figure S2. Process flow diagram of steam methane reforming process in scenario 3.

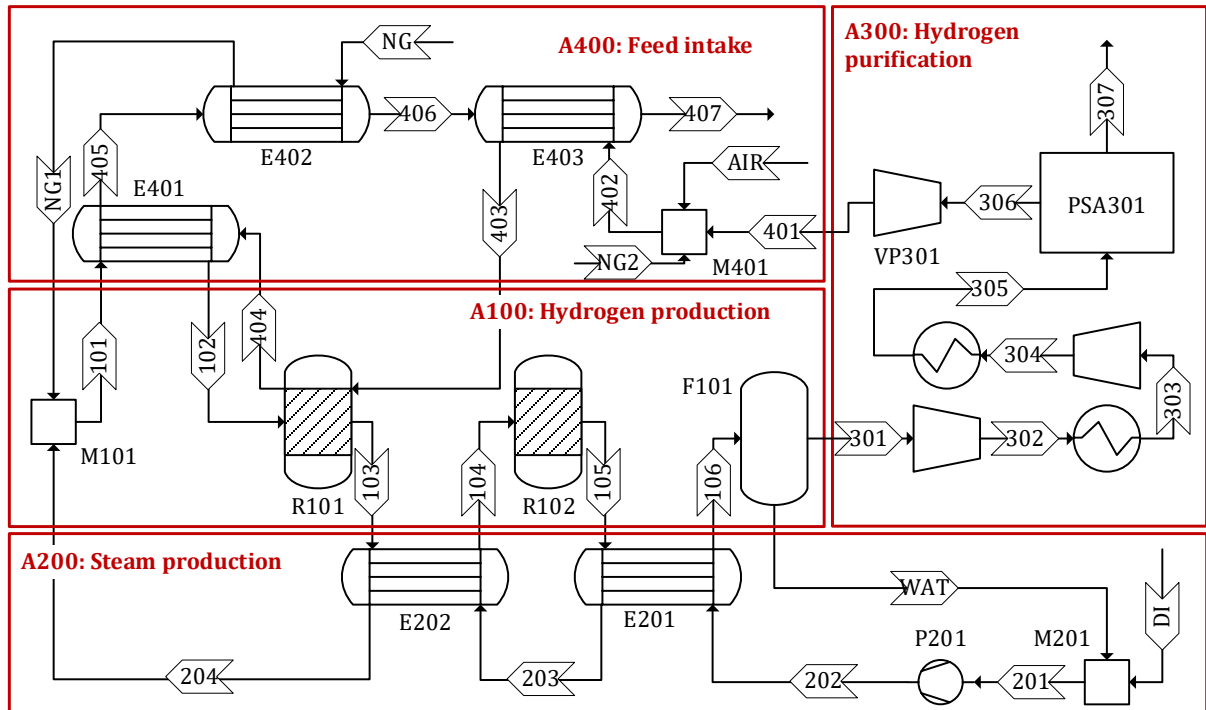


Figure S3. Process flow diagram of steam methane reforming process in scenario 4.

B. Stream information

Table S1. Process stream information for scenario 1.

Stream number	101	102	103	104	105	106	201	202	203	204	301	302	303
Temperature (°C)	216	800	800	385	450	118	32	32	170	216	40	40	40
Pressure (bar)	8	8	8	8	8	8	1	8	8	8	8	0.2	8
Vapor fraction	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.29	1.00	1.00	1.00	1.00
Mass flow (kg/h)	286	286	286	286	286	286	221	221	221	221	185	164	21
Mole flow (kmol/h)	16	16	24	24	24	24	12	12	12	12	18	8	10
Volume flow (m ³ /h)	81	182	264	162	178	95	0	0	16	60	59	1,001	34
Enthalpy flow (MJ/h)	-3,155	-2,728	-1,949	-2,293	-2,293	-2,557	-3,491	-3,491	-3,227	-2,883	-1,260	-1,264	5
Composition													
Mass fraction H ₂ O	0.769	0.769	0.450	0.450	0.363	0.363	0.997	0.997	0.997	0.997	0.017	0.019	0.000
Mass fraction CH ₄	0.228	0.228	0.023	0.023	0.023	0.023	0.000	0.000	0.000	0.000	0.035	0.040	0.000
Mass fraction CO	0.000	0.000	0.221	0.221	0.085	0.085	0.000	0.000	0.000	0.000	0.132	0.149	0.000
Mass fraction CO ₂	0.002	0.002	0.218	0.218	0.432	0.432	0.003	0.003	0.003	0.003	0.665	0.749	0.000
Mass fraction H ₂	0.000	0.000	0.087	0.087	0.097	0.097	0.000	0.000	0.000	0.000	0.150	0.042	1.000
Mass fraction O ₂	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mass fraction N ₂	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stream number	401	402	403	404	405	406	407	AIR	DI	NG	NG1	WAT	
Temperature (°C)	50	33	142	1,727	900	396	355	25	25	25	216	40	
Pressure (bar)	1	1	1	1	1	1	1	1	1	8	8	8	
Vapor fraction	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	0.00	
Mass flow (kg/h)	164	654	654	654	654	654	654	490	119	65	65	101	
Mole flow (kmol/h)	8	25	25	23	23	23	23	17	7	4	4	6	
Volume flow (m ³ /h)	206	629	852	3,749	2,199	1,254	1,178	421	0	12	21	0	
Enthalpy flow (MJ/h)	-1,261	-1,261	-1,179	-1,179	-1,958	-2,385	-2,417	0	-1,895	-304	-272	-1,596	
Composition													
Mass fraction H ₂ O	0.019	0.005	0.005	0.122	0.122	0.122	0.122	0.000	1.000	0.000	0.000	0.993	
Mass fraction CH ₄	0.040	0.010	0.010	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000	
Mass fraction CO	0.149	0.037	0.037	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	
Mass fraction CO ₂	0.749	0.188	0.188	0.272	0.272	0.272	0.272	0.000	0.000	0.000	0.000	0.006	
Mass fraction H ₂	0.042	0.011	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Mass fraction O ₂	0.000	0.175	0.175	0.030	0.030	0.030	0.030	0.233	0.000	0.000	0.000	0.000	
Mass fraction N ₂	0.000	0.575	0.575	0.575	0.575	0.575	0.575	0.767	0.000	0.000	0.000	0.000	

Table S2. Process stream information for scenario 2.

Stream number	101	102	103	104	105	106	201	202	203	204	301	302	303
Temperature (°C)	216	800	800	184	250	114	31	31	146	216	40	40	40
Pressure (bar)	8	8	8	8	8	8	1	8	8	8	8	0.2	8
Vapor fraction	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00
Mass flow (kg/h)	271	271	271	271	271	271	209	209	209	209	188	167	21
Mole flow (kmol/h)	15	15	22	22	22	22	12	12	12	12	18	7	10
Volume flow (m ³ /h)	77	172	250	106	122	89	0	0	0	57	58	973	34
Enthalpy flow (MJ/h)	-2,991	-2,587	-1,848	-2,323	-2,354	-2,456	-3,311	-3,310	-3,209	-2,734	-1,399	-1,402	5
Composition													
Mass fraction H ₂ O	0.769	0.769	0.450	0.450	0.315	0.315	0.997	0.997	0.997	0.997	0.017	0.019	0.000
Mass fraction CH ₄	0.228	0.228	0.023	0.023	0.023	0.023	0.000	0.000	0.000	0.000	0.033	0.037	0.000
Mass fraction CO	0.000	0.000	0.221	0.221	0.011	0.011	0.000	0.000	0.000	0.000	0.016	0.018	0.000
Mass fraction CO ₂	0.002	0.002	0.218	0.218	0.548	0.548	0.003	0.003	0.003	0.003	0.786	0.884	0.000
Mass fraction H ₂	0.000	0.000	0.087	0.087	0.102	0.102	0.000	0.000	0.000	0.000	0.148	0.042	1.000
Mass fraction O ₂	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mass fraction N ₂	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stream number	401	402	403	404	405	406	407	AIR	DI	NG	NG1	NG2	WAT
Temperature (°C)	50	33	183	1,673	900	431	394	25	25	25	216	25	40
Pressure (bar)	1	1	1	1	1	1	1	1	1	8	8	1	8
Vapor fraction	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00
Mass flow (kg/h)	167	660	660	660	660	660	660	489	126	62	62	3	83
Mole flow (kmol/h)	7	25	25	23	23	23	23	17	7	4	4	0	5
Volume flow (m ³ /h)	201	627	935	3,700	2,231	1,340	1,269	420	0	12	20	5	0
Enthalpy flow (MJ/h)	-1,400	-1,416	-1,300	-1,300	-2,039	-2,444	-2,474	0	-2,004	-288	-258	-16	-1,307
Composition													
Mass fraction H ₂ O	0.019	0.005	0.005	0.131	0.131	0.131	0.131	0.000	1.000	0.000	0.000	0.000	0.992
Mass fraction CH ₄	0.037	0.014	0.014	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	1.000	0.000
Mass fraction CO	0.018	0.005	0.005	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Mass fraction CO ₂	0.884	0.224	0.224	0.270	0.270	0.270	0.270	0.000	0.000	0.000	0.000	0.000	0.008
Mass fraction H ₂	0.042	0.011	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mass fraction O ₂	0.000	0.173	0.173	0.029	0.029	0.029	0.029	0.233	0.000	0.000	0.000	0.000	0.000
Mass fraction N ₂	0.000	0.569	0.569	0.569	0.569	0.569	0.569	0.767	0.000	0.000	0.000	0.000	0.000

Table S3. Process stream information for scenario 3.

Stream number	101	102	103	104	105	105R	105R2	106	201	202	203	203R	204	301	302
Temperature (°C)	290	800	800	385	450	212	250	114	31	31	146	170	290	40	40
Pressure (bar)	8	8	8	8	8	8	8	8	1	8	8	8	8	8	0.2
Vapor fraction	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.37	1.00	1.00	1.00
Mass flow (kg/h)	271	271	271	271	271	271	271	271	209	209	209	209	209	188	167
Mole flow (kmol/h)	15	15	22	22	22	22	22	22	12	12	12	12	12	18	7
Volume flow (m ³ /h)	89	172	250	153	169	113	122	89	0	0	0	19	66	58	973
Enthalpy flow (MJ/h)	-2,946	-2,587	-1,848	-2,174	-2,174	-2,354	-2,354	-2,456	-3,311	-3,310	-3,209	-3,028	-2,702	-1,399	-1,402
Composition															
Mass fraction H ₂ O	0.769	0.769	0.450	0.450	0.363	0.363	0.315	0.315	0.997	0.997	0.997	0.997	0.997	0.017	0.019
Mass fraction CH ₄	0.228	0.228	0.023	0.023	0.023	0.023	0.023	0.023	0.000	0.000	0.000	0.000	0.000	0.033	0.037
Mass fraction CO	0.000	0.000	0.221	0.221	0.085	0.085	0.011	0.011	0.000	0.000	0.000	0.000	0.000	0.016	0.018
Mass fraction CO ₂	0.002	0.002	0.218	0.218	0.432	0.432	0.548	0.548	0.003	0.003	0.003	0.003	0.003	0.786	0.884
Mass fraction H ₂	0.000	0.000	0.087	0.087	0.097	0.097	0.102	0.102	0.000	0.000	0.000	0.000	0.000	0.148	0.042
Mass fraction O ₂	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mass fraction N ₂	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stream number	303	401	402	403	404	405	406	407	AIR	DI	NG	NG1	NG2	WAT	
Temperature (°C)	40	50	49	212	1,689	900	477	422	25	25	25	216	25	40	
Pressure (bar)	8	1	1	1	1	1	1	1	1	1	8	8	1	8	
Vapor fraction	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00	
Mass flow (kg/h)	21	167	170	645	645	645	645	645	475	126	62	62	3	83	
Mole flow (kmol/h)	10	7	8	24	22	22	22	22	16	7	4	4	0	5	
Volume flow (m ³ /h)	34	201	205	972	3,645	2,179	1,393	1,291	408	0	12	20	4	0	
Enthalpy flow (MJ/h)	5	-1,400	-1,412	-1,278	-1,278	-2,017	-2,376	-2,420	0	-2,004	-288	-258	-12	-1,307	
Composition															
Mass fraction H ₂ O	0.000	0.019	0.018	0.005	0.132	0.132	0.132	0.132	0.000	1.000	0.000	0.000	0.000	0.992	
Mass fraction CH ₄	0.000	0.037	0.052	0.014	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	1.000	0.000	
Mass fraction CO	0.000	0.018	0.018	0.005	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	
Mass fraction CO ₂	0.000	0.884	0.871	0.229	0.273	0.273	0.273	0.273	0.000	0.000	0.000	0.000	0.000	0.008	
Mass fraction H ₂	1.000	0.042	0.041	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Mass fraction O ₂	0.000	0.000	0.000	0.172	0.029	0.029	0.029	0.029	0.233	0.000	0.000	0.000	0.000	0.000	
Mass fraction N ₂	0.000	0.000	0.000	0.565	0.565	0.565	0.565	0.565	0.767	0.000	0.000	0.000	0.000	0.000	

Table S4. Process stream information for scenario 4.

Stream number	101	102	103	104	105	106	201	202	203	204	301	302	303	304	305
Temperature (°C)	322	800	800	379	450	61	29	29	100	322	40	40	65	65	40
Pressure (bar)	1	1	1	1	1	1	1	1	1	1	1	0.2	3	8	8
Vapor fraction	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.49	1.00	1.00	1.00	1.00	0.93	0.93
Mass flow (kg/h)	260	260	260	260	260	260	200	200	200	200	200	167	200	200	200
Mole flow (kmol/h)	15	15	22	22	22	22	11	11	11	11	19	7	19	19	19
Volume flow (m ³ /h)	732	1,323	1,983	1,204	1,336	617	0	0	168	549	492	973	188	57	57
Enthalpy flow (MJ/h)	-2,803	-2,480	-1,689	-2,008	-2,008	-2,290	-3,176	-3,176	-2,894	-2,575	-1,503	-1,402	-1,488	-1,557	-1,557
Composition															
Mass fraction H ₂ O	0.771	0.771	0.425	0.425	0.328	0.328	1.000	1.000	1.000	1.000	0.127	0.019	0.127	0.127	0.127
Mass fraction CH ₄	0.229	0.229	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.001	0.037	0.001	0.001	0.001
Mass fraction CO	0.000	0.000	0.259	0.259	0.109	0.109	0.000	0.000	0.000	0.000	0.142	0.018	0.142	0.142	0.142
Mass fraction CO ₂	0.000	0.000	0.220	0.220	0.455	0.455	0.000	0.000	0.000	0.000	0.592	0.884	0.592	0.592	0.592
Mass fraction H ₂	0.000	0.000	0.096	0.096	0.107	0.107	0.000	0.000	0.000	0.000	0.139	0.042	0.139	0.139	0.139
Mass fraction O ₂	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mass fraction N ₂	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stream number	306	307	401	402	403	404	405	406	407	AIR	DI	NG	NG1	NG2	WAT
Temperature (°C)	40	0	50	49	239	1,727	900	528	469	25	25	25	216	25	40
Pressure (bar)	8	1	1	1	1	1	1	1	1	1	1	8	8	1	1
Vapor fraction	1.00	1.00	0.95	0.96	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00
Mass flow (kg/h)	21	21	179	184	645	645	645	645	645	462	140	59	62	4	60
Mole flow (kmol/h)	10	10	9	9	25	23	23	23	23	16	8	4	4	0	3
Volume flow (m ³ /h)	34	232	219	226	1,057	3,762	2,207	1,507	1,397	397	0	11	20	7	0
Enthalpy flow (MJ/h)	5	-7	-1,521	-1,542	-1,367	-1,367	-2,157	-2,480	-2,529	0	-2,229	-277	-258	-21	-947
Composition															
Mass fraction H ₂ O	0.000	0.000	0.142	0.139	0.039	0.151	0.151	0.151	0.151	0.000	1.000	0.000	0.000	0.000	0.999
Mass fraction CH ₄	0.000	0.000	0.001	0.025	0.007	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	1.000	0.000
Mass fraction CO	0.000	0.000	0.158	0.154	0.044	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Mass fraction CO ₂	0.000	0.000	0.661	0.644	0.183	0.270	0.270	0.270	0.270	0.000	0.000	0.000	0.000	0.000	0.001
Mass fraction H ₂	1.000	1.000	0.039	0.038	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mass fraction O ₂	0.000	0.000	0.000	0.000	0.167	0.029	0.029	0.029	0.029	0.233	0.000	0.000	0.000	0.000	0.000
Mass fraction N ₂	0.000	0.000	0.000	0.000	0.549	0.549	0.549	0.549	0.549	0.767	0.000	0.000	0.000	0.000	0.000

C. Equipment costs

Table S5. Equipment cost in scenario 1.

Area	Equipment ID	Equipment cost (\$)	Installed cost (\$)
Hydrogen production	R101	108,280	184,076
	R102	68,880	117,096
	F101	3,358	6,716
Steam production	P201	6,041	13,894
	E201	2,622	5,768
	E202	1,793	3,945
Hydrogen purification	PSA301+VP301	54,077	102,747
Feed intake	E402	4,198	9,236
	E403	449	988
	E404	965	2,124

Table S6. Equipment cost in scenario 2.

Area	Equipment ID	Equipment cost (\$)	Installed cost (\$)
Hydrogen production	R101	104,302	177,313
	R102	82,554	140,341
	E103	1,224	2,692
	F101	3,235	6,470
Steam production	P201	5,785	13,306
	E201	2,006	4,413
	E202	3,460	7,612
Hydrogen purification	PSA301+VP301	54,754	104,032
Feed intake	E402	3,767	8,287
	E403	391	860
	E404	1,225	2,695

Table S7. Equipment cost in scenario 3.

Area	Equipment ID	Equipment cost (\$)	Installed cost (\$)
Hydrogen production	R101	104,302	177,314
	R102	66,350	112,796
	R103	57,058	96,998
	F101	3,235	6,470
Steam production	P201	5,785	13,306
	E201	2,006	4,413
	E202	1,824	4,014
	E203	2,164	4,760
Hydrogen purification	PSA301+VP301	54,754	104,032
Feed intake	E402	3,664	8,061
	E403	517	1,137
	E404	1,369	3,011

Table S8. Equipment cost in scenario 4.

Area	Equipment ID	Equipment cost (\$)	Installed cost (\$)
Hydrogen production	R101	101,300	172,209
	R102	65,505	111,359
	F101	3,140	6,281
Steam production	E201	3,192	7,022
	E202	1,699	3,737
Hydrogen purification	PSA301+VP301	57,028	108,352
	CP301	64,863	90,808
	CP302	68,829	96,360
Feed intake	E402	3,277	7,209
	E403	511	1,125
	E404	1,588	3,493

D. Discounted cash flow

Table S9. Discounted cash flow for scenario 1.

[illegible]

[illegible]

[illegible]

Table S11. Discounted cash flow for scenario 3.

[illegible]

[illegible]

Table S12. Discounted cash flow for scenario 4.

[illegible]

[illegible]

[illegible]

[illegible]

Table S14. Discounted cash flow for scenario 6.

[illegible]

[illegible]