

Fuel Production from CO₂ Using Solar-Thermal Energy: System Level Analysis

Jiyong Kim, Terry A. Johnson, James E. Miller, Ellen B. Stechel, Christos T. Maravelias

Supplementary Information

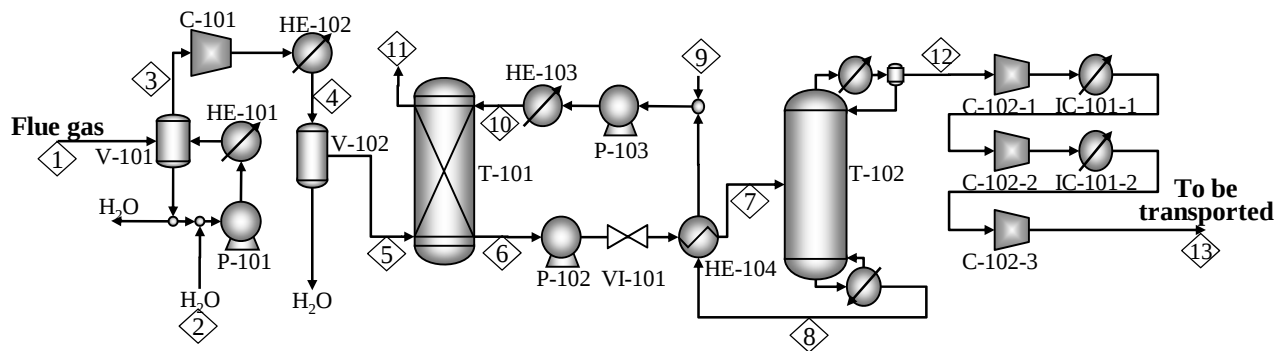


Fig S1. Aspen flowsheet model of CO₂ capture from flue gas.

Table S1. Major stream information of CO₂ capture from flue gas (corresponds to Fig. S1)

Stream No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Total flow (kmol/hr)	3,490	3,442	3,164	3,164	3,049	12,619	12,619	12,206	143	12,349	2,779	412	398
Temperature (C)	57	25	42	40	38	38	78	121	25	42	52	40	40
Pressure (kPa)	101	101	86	136	121	120	201	200	136	121	120	200	15,000
Mole flow (kmol/hr)													
O ₂	84	0	84	84	84	0	0	0	0	0	84	0	0
N ₂	2,352	0	2,352	2,352	2,352	0	0	0	0	0	2,352	0	0
CO ₂	468	0	468	468	468	735	735	338	0	338	71	397	397
H ₂ O	586	3,442	260	260	145	10,537	10,537	10,522	142	10,664	271	15	1
MEA	0	0	0	0	0	1,347	1,347	1,347	1	1,348	1	0	0

Table S2. Capital and operating costs of CO₂ capture from flue gas

Amount of CO ₂ captured = 140 Billion g/yr		
Total project investment (TPI)	USD	% of total
Direct cost	7,622,700	88%
Indirect cost	1,082,423	12%
Total	8,705,123	100%
Annual cost	USD/yr	USD/kg
Annualized TPI	773,254	0.0055
Operating cost	4,774,657	0.0341
Electricity	1,521,989	0.0109
Low P steam	2,737,764	0.0196
Cooling water	474,838	0.0034
Others	40,066	0.0003
Total cost	5,547,911	-
CO₂ capture cost (USD/kg)	-	0.0396

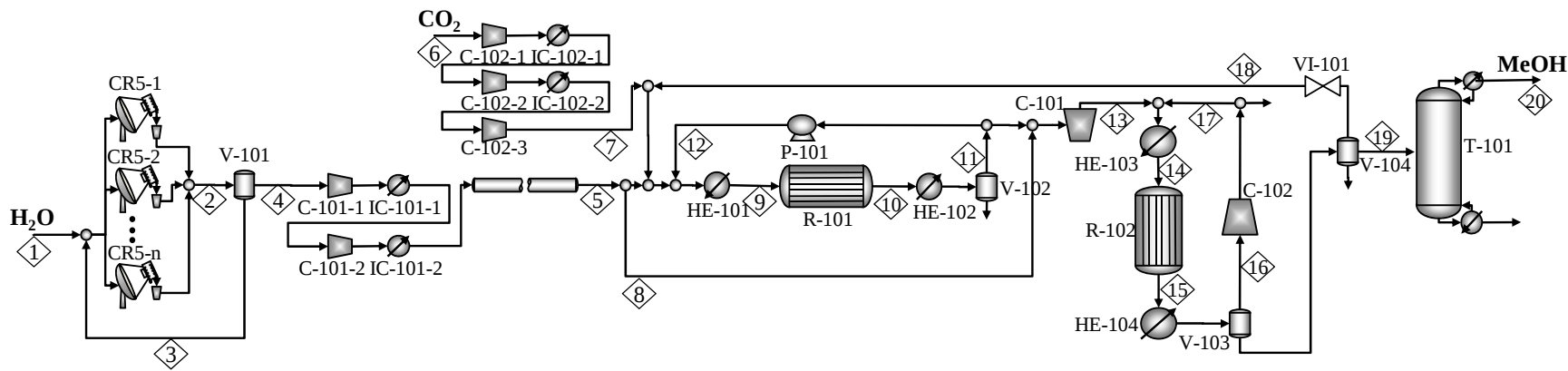


Fig S2 Aspen flowsheet model of the H₂O pathway to MeOH production.

Table S3. Major stream information of the H₂O pathway to MeOH production (corresponds to Fig. S2)

Stream No.	1	2	3	4	5	6	7	8	9	10
Total flow (kmol/hr)	1,119	4,462	3,358	1,104	1,104	430	430	430	8,063	8,055
Temperature (C)	26	40	441	26	211	26	26	211	321	301
Pressure (kPa)	261	20	261	261	1,000	999	999	1,000	1,666	1,465
Mole flow (kmol/hr)										
CO ₂	0	0	0	0	0	430	430	0	1,898	1,748
H ₂	0	1,105	15	1,090	1,090	0	0	54	5,362	5,205
CO	0	0	0	0	0	0	0	0	754	899
H ₂ O	1,119	3,357	3,343	14	14	0	0	0	26	175
CH ₃ OH	0	0	0	0	0	0	0	0	22	26

Stream No.	11	12	13	14	15	16	17	18	19	20
Total flow (kmol/hr)	7,901	4,730	4,740	10,861	10,196	9,558	7,646	1,854	560	323
Temperature (C)	36	54	123	123	207	277	42	29	17	34
Pressure (kPa)	1,438	1,700	4,700	4,700	4,666	4,473	4,700	1,700	300	100
Mole Flow (kmol/hr)										
CO ₂	1,746	1,045	699	2,432	2,230	2,167	1,734	420	18	2
H ₂	5,203	3,122	2,136	7,104	6,236	6,210	4,968	1,205	1	0
CO	898	539	359	1,247	1,117	1,109	887	215	0	0
H ₂ O	36	21	14	23	226	11	9	2	215	1
CH ₃ OH	17	10	7	55	388	60	48	12	326	320

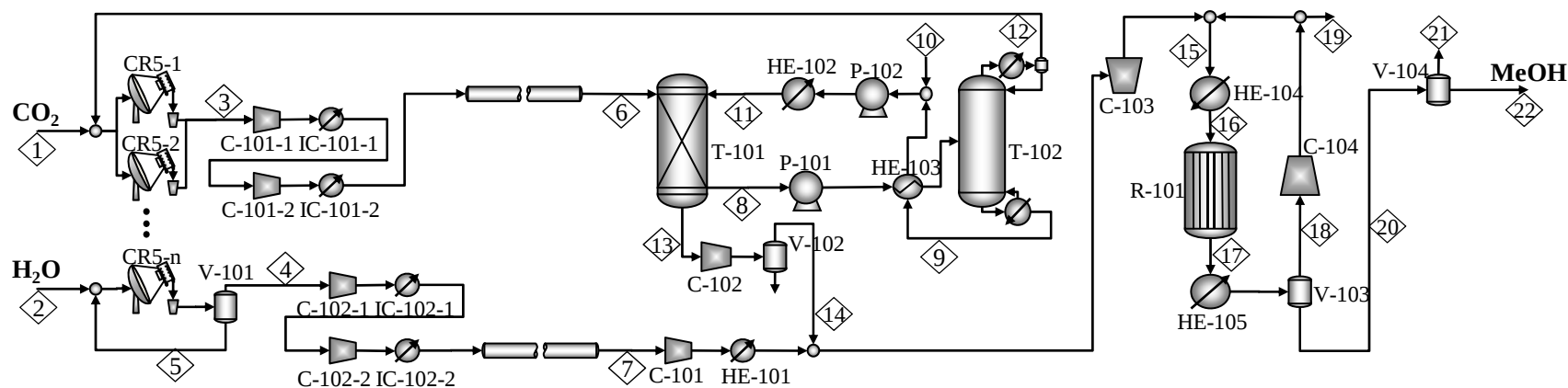


Fig S3 Aspen flowsheet model of the mixed pathway to MeOH production.

Table S4. Major stream information of the mixed pathway to MeOH production (corresponds to Fig. S3)

Stream No.	1	2	3	4	5	6	7	8	9	10	11
Total flow (kmol/hr)	397	724	1,500	725	2,172	1,500	725	23,491	22,359	55	22,413
Temperature (C)	35	26	727	40	40	89	161	41	130	25	42
Pressure (kPa)	20	261	20	20	20	253	999	253	285	101	254
Mole flow (kmol/hr)											
CO ₂	397	0	1,125	0	0	1,125	0	1,869	767	0	767
H ₂	0	0	0	724	0	0	724	0	0	0	0
CO	0	0	375	0	0	375	0	0	0	0	0
H ₂ O	0	724	0	1	2,172	0	1	18,656	18,626	55	18,680
MEA	0	0	0	0	0	0	0	2,966	2,966	0	2,967
CH ₃ OH	0	0	0	0	0	0	0	0	0	0	0

Stream No.	12	13	14	15	16	17	18	19	20	21	22
Total flow (kmol/hr)	11,324	422	398	1,563	1,563	838	441	1	397	35	361
Temperature (C)	40	58	129	209	213	200	35	35	35	11	11
Pressure (kPa)	285	253	4,803	4,740	4,726	4,725	4,705	4,705	4,705	65	65
Mole flow (kmol/hr)											
CO ₂	1,102	23	22	68	68	70	46	0	24	22	2
H ₂	0	0	0	890	890	167	167	0	0	0	0
CO	0	375	374	600	600	236	226	0	10	10	0
H ₂ O	30	25	1	2	2	0	0	1	0	0	0
MEA	0	0	0	0	0	0	0	0	0	0	0
CH ₃ OH	0	0	0	2	2	365	2	0	363	3	359

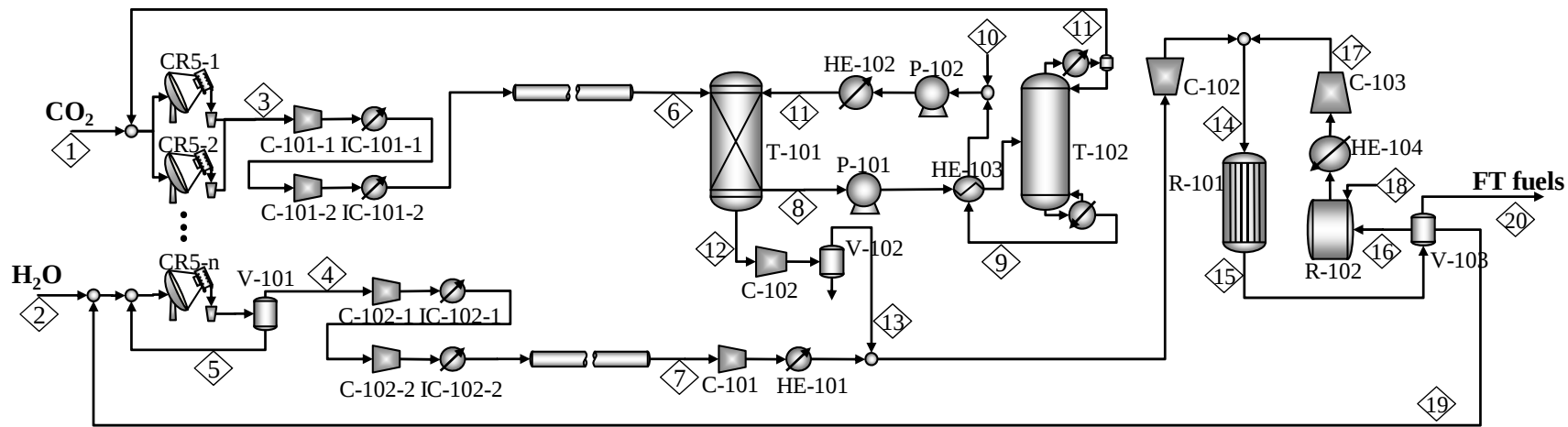


Fig S4 Aspen flowsheet model of the mixed pathway to FT fuel production.

Table S5. Major stream information of the mixed pathway to FT fuel production (corresponds to Fig. S4)

Stream No.	1	2	3	4	5	6	7	8	9	10
Total flow (kmol/hr)	352	395	1,453	728	2,180	1,453	728	22,755	21,664	50
Temperature (C)	26	26	122	41	41	89	163	42	131	26
Pressure (kPa)	20	20	19	20	20	259	999	253	285	101
Mole flow (kmol/hr)										
CO ₂	352	0	1,090	0	0	1,090	0	1,813	751	0
H ₂	0	0	0	727	0	0	727	0	0	0
CO	0	0	363	0	0	363	0	0	0	0
H ₂ O	0	395	0	1	2,180	0	1	18,069	18,040	50
MEA	0	0	0	0	0	0	0	2,873	2,873	0
CH ₃ OH	0	0	0	0	0	0	0	0	0	0
CH ₄	0	0	0	0	0	0	0	0	0	0
LIGHTS	0	0	0	0	0	0	0	0	0	0
GAS	0	0	0	0	0	0	0	0	0	0
DIESEL	0	0	0	0	0	0	0	0	0	0
WAX	0	0	0	0	0	0	0	0	0	0

Stream No.	11	12	13	14	15	16	17	18	19	20
Total Flow kmol/hr	1,091	412	391	1,541	535	89	1,060	250	367	75
Temperature C	41	56	129	210	223	41	317	501	41	41
Pressure kPa	285	253	4,803	3,800	3,710	3,710	3,800	3,500	3,710	3,710
Mole Flow kmol/hr										
CO ₂	1,062	28	27	92	65	47	65	0	0	18
H ₂	0	0	0	426	0	0	426	0	0	0
CO	0	363	363	653	21	20	200	0	0	1
H ₂ O	29	21	1	153	367	0	152	250	367	0
MEA	0	0	0	0	0	0	0	0	0	0
CH ₃ OH	0	0	0	0	0	0	0	0	0	0
CH ₄	0	0	0	217	7	6	217	0	0	1
LIGHTS	0	0	0	0	40	15	0	0	0	25
GAS	0	0	0	0	24	0	0	0	0	24
DIESEL	0	0	0	0	10	0	0	0	0	10
WAX	0	0	0	0	1	0	0	0	0	1

Table S6. Results of economic evaluations of four alternative pathways using S2P process

	CO ₂ pathway	H ₂ O pathway	Mixed pathway	Mixed FT pathway
Capital cost (\$)				
Direct cost				
Dish/CR5 system	517,960,922	525,039,686	532,326,686	531,412,630
Separation system	7,257,900	-	5,964,836	5,811,341
WGS system	7,288,100	-	-	-
RWGS system	-	3,060,592	-	-
MS system	2,204,400	2,726,428	4,325,100	-
FT system	-	-	-	4,102,300
Indirect cost	80,201,100	79,719,915	76,330,000	76,110,000
Total project investment	614,512,422	610,546,621	618,946,622	617,436,271
Operating cost (\$/y)				
Variable cost	204,672,218	101,091,419	67,758,761	66,032,734
Electricity	55,767,474	49,038,480	25,894,998	25,201,206
Heat	133,487,110	36,455,253	29,054,732	30,016,422
Cooling water	3,098,090	3,306,726	1,766,797	1,026,024
Raw materials cost	12,319,544	12,290,960	11,042,235	9,789,083
Fixed costs	2,814,549	2,808,843	2,848,749	2,846,790
Operating labor cost	832,000	830,000	842,000	841,000
Maintenance cost	575,000	574,200	578,200	578,100
Operating charges	124,800	124,800	124,800	124,200
Plant overhead	562,800	562,500	563,800	563,600
G&A cost	719,949	717,343	739,949	739,890
Total operating cost	207,486,767	103,900,262	70,607,510	68,879,524
ROI (\$/y)	54,585,561	54,242,172	54,979,440	54,845,279
Capital depreciation (\$/y)	20,483,747	20,354,887	20,631,554	20,581,209
Income tax (\$/y)	18,362,515	18,246,999	18,495,015	18,449,883.95
Revenue (\$/y)	280,434,844	176,389,434	144,081,966	142,174,687
Minimum selling price (\$/GGE)	11.77	8.73	6.73	7.01

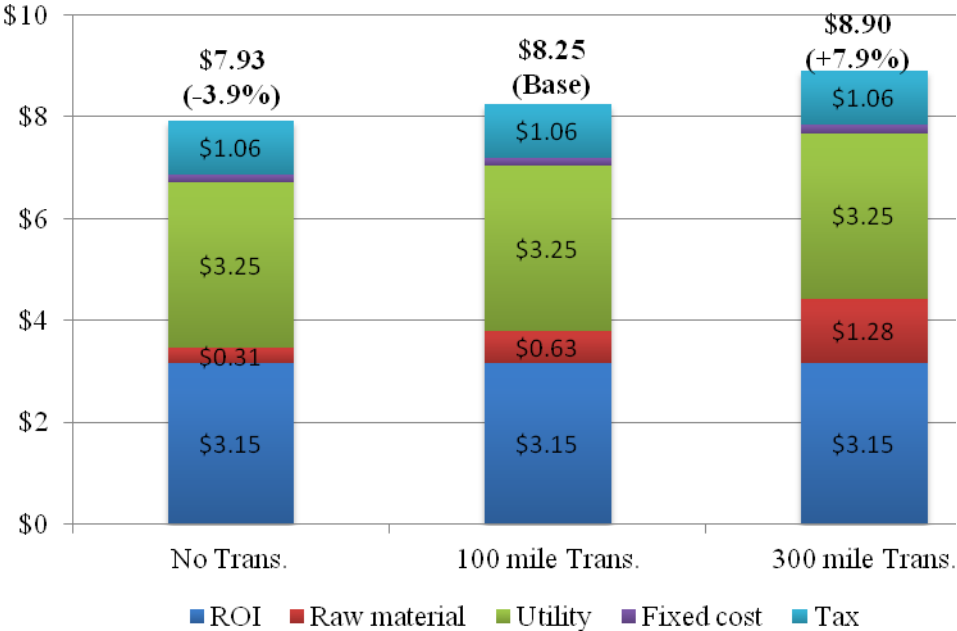


Fig. S5 Effect of CO₂ transport distance on the MSP of mixed pathway to MeOH production.