

Supplementary Information

Assessment of location and energy utility options for the implementation of pyrolytic biocrude production

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1. Greenhouse gas (GHG) contributions

Table SI-1: GHG contributions for *fast pyrolysis (FP), standalone (SA)* biorefinery cases

Case → Unit →	FP-1 g CO ₂ e/MJ	FP-2 g CO ₂ e/MJ	FP-3 g CO ₂ e/MJ	FP-4 g CO ₂ e/MJ
Feedstock	18.79	18.79	18.79	18.79
Feedstock to colocation	-	-	-	-
Natural gas	-	-	-	-
Catalysts & chemicals	0.09	0.09	0.09	0.09
Bio-oil transport	1.28	1.28	1.28	1.28
Hydrogen purchase	-	-	-	-
Electricity purchase	2.24	5.87	5.59	5.60
Others	0.11	0.11	0.11	0.11
Electricity export	-	-	-	-
Hydrogen export	-	-	-	-
Fuel gas export	-	-	(5.09)	-
Steam export	-	(6.36)	(0.58)	-
Chemical coproducts	-	-	-	-
Total	22.52	19.78	20.20	25.88

Table SI-2: GHG contributions for *fast pyrolysis (FP), collocated (CL)* biorefinery cases

Case → Unit →	FP-1 g CO ₂ e/MJ	FP-2 g CO ₂ e/MJ	FP-3 g CO ₂ e/MJ	FP-4 g CO ₂ e/MJ
Feedstock	18.79	18.79	18.79	18.79
Feedstock to colocation	1.91	1.91	1.91	1.91
Natural gas	-	-	-	-
Catalysts & chemicals	0.09	0.09	0.09	0.09
Bio-oil transport	-	-	-	-
Hydrogen purchase	-	-	-	-
Electricity purchase	2.24	5.87	5.59	5.60
Others	0.11	0.11	0.11	0.11
Electricity export	-	-	-	-
Hydrogen export	-	-	-	-
Fuel gas export	-	-	(5.09)	-
Steam export	-	(6.36)	(0.58)	-
Chemical coproducts	-	-	-	-
Total	23.15	20.42	20.83	26.51

Table SI-3: GHG contributions for *catalytic fast pyrolysis (CFP), standalone (SA) biorefinery cases*

Case → Unit →	CFP-1 g CO ₂ e/MJ	CFP-2 g CO ₂ e/MJ	CFP-3 g CO ₂ e/MJ	CFP-4 g CO ₂ e/MJ	CFP-5 g CO ₂ e/MJ	CFP-6 g CO ₂ e/MJ	CFP-7 g CO ₂ e/MJ
Feedstock	35.58	35.58	35.58	35.58	35.58	35.58	35.58
Feedstock to colocation	-	-	-	-	-	-	-
Natural gas	-	-	-	-	-	-	-
Catalysts & chemicals	1.24	1.24	1.24	1.24	1.24	1.24	1.24
Bio-oil transport	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Hydrogen purchase	-	-	-	26.07	26.07	26.07	26.07
Electricity purchase	-	-	23.64	-	20.66	17.35	17.49
Others	0.20	0.24	0.22	0.22	0.22	0.22	0.22
Electricity export	(12.60)	-	-	(24.55)	-	-	-
Hydrogen export	-	(24.13)	(33.23)	-	-	-	-
Fuel gas export	-	-	-	-	-	(68.00)	-
Steam export	-	-	(32.67)	-	(75.95)	(10.34)	-
Chemical coproducts	(7.53)	(7.53)	(7.53)	(7.53)	(7.53)	(7.53)	(7.53)
Total	17.66	6.18	(11.97)	31.80	1.06	(4.64)	73.85

Table SI-4: GHG contributions for *catalytic fast pyrolysis (CFP), collocated (CL) biorefinery cases*

Case → Unit →	CFP-1 g CO ₂ e/MJ	CFP-2 g CO ₂ e/MJ	CFP-3 g CO ₂ e/MJ	CFP-4 g CO ₂ e/MJ	CFP-5 g CO ₂ e/MJ	CFP-6 g CO ₂ e/MJ	CFP-7 g CO ₂ e/MJ
Feedstock	35.58	35.58	35.58	35.58	35.58	35.58	35.58
Feedstock to colocation	3.61	3.61	3.61	3.61	3.61	3.61	3.61
Natural gas	-	-	-	-	-	-	-
Catalysts & chemicals	1.24	1.24	1.24	1.24	1.24	1.24	1.24
Bio-oil transport	-	-	-	-	-	-	-
Hydrogen purchase	-	-	-	26.07	26.07	26.07	26.07
Electricity purchase	-	-	23.64	-	20.66	17.35	17.49
Others	0.20	0.24	0.22	0.22	0.22	0.22	0.22
Electricity export	(12.60)	-	-	(24.55)	-	-	-
Hydrogen export	-	(24.13)	(33.23)	-	-	-	-
Fuel gas export	-	-	-	-	-	(68.00)	-
Steam export	-	-	(32.67)	-	(75.95)	(10.34)	-
Chemical coproducts	(7.53)	(7.53)	(7.53)	(7.53)	(7.53)	(7.53)	(7.53)
Total	20.49	9.01	(9.14)	34.63	3.89	(1.81)	76.68

2. Minimum selling price (MSP) breakdown and Total Capital Investment (TCI)

Table SI-5: MSP breakdown (cents/GGE) and TCI for FP, standalone (SA), 2000 tonnes/day cases

Case →	FP-1	FP-2	FP-3	FP-4
Capital & other charges	69.28	66.36	64.02	64.12
Feedstock	69.51	69.51	69.51	69.51
Natural gas	-	-	-	-
Bio-oil transport	30.10	30.10	30.10	30.10
Hydrogen purchase	-	-	-	-
Electricity purchase	4.11	10.75	10.25	10.26
Other variable operating costs	2.93	2.93	2.93	2.93
Fixed operating costs	28.00	27.21	26.57	26.60
Electricity export	-	-	-	-
Hydrogen export	-	-	-	-
Fuel gas export	-	-	(1.90)	-
Steam export	-	(2.84)	(0.26)	-
Chemical coproducts	-	-	-	-
MSP (cents/GGE)	203.93	204.01	201.22	203.52
Capital & other charges	69.28	66.36	64.02	64.12
Total variable operating costs	106.65	113.29	112.79	112.80
Fixed operating costs	28.00	27.21	26.57	26.60
Total coproduct credit	-	(2.84)	(2.15)	-
MSP (cents/GGE)	203.93	204.01	201.22	203.52
TCI (million \$)	417	399	384	385

Table SI-6: MSP breakdown (cents/GGE) and TCI for FP, colocated (CL), 2000 tonnes/day cases

Case →	FP-1	FP-2	FP-3	FP-4
Capital & other charges	69.42	66.50	64.16	64.26
Feedstock	110.02	110.02	110.02	110.02
Natural gas	-	-	-	-
Bio-oil transport	-	-	-	-
Hydrogen purchase	-	-	-	-
Electricity purchase	4.11	10.75	10.25	10.26
Other variable operating costs	2.93	2.93	2.93	2.93
Fixed operating costs	28.00	27.21	26.57	26.60
Electricity export	-	-	-	-
Hydrogen export	-	-	-	-
Fuel gas export	-	-	(1.90)	-
Steam export	-	(2.84)	(0.26)	-
Chemical coproducts	-	-	-	-
MSP (cents/GGE)	214.48	214.56	211.78	214.07
Capital & other charges	69.42	66.50	64.16	64.26
Total variable operating costs	117.06	123.70	123.20	123.21
Fixed operating costs	28.00	27.21	26.57	26.60
Total coproduct credit	-	(2.84)	(2.15)	-
MSP (cents/GGE)	214.48	214.56	211.78	214.07
TCI (million \$)	417	399	384	385

Table SI-7: MSP breakdown (cents/GGE) and TCI for FP, colocated (CL), 5000 tonnes/day cases

Case →	FP-1	FP-2	FP-3	FP-4
Capital & other charges	63.73	61.34	59.68	59.77
Feedstock	110.02	110.02	110.02	110.02
Natural gas	-	-	-	-
Bio-oil transport	-	-	-	-
Hydrogen purchase	-	-	-	-
Electricity purchase	4.11	10.75	10.25	10.26
Other variable operating costs	2.85	2.85	2.86	2.86
Fixed operating costs	20.85	20.20	19.75	19.77
Electricity export	-	-	-	-
Hydrogen export	-	-	-	-
Fuel gas export	-	-	(1.90)	-
Steam export	-	(2.84)	(0.26)	-
Chemical coproducts	-	-	-	-
MSP (cents/GGE)	201.56	202.32	200.39	202.68
Capital & other charges	63.73	61.34	59.68	59.77
Total variable operating costs	116.98	123.62	123.12	123.13
Fixed operating costs	20.85	20.20	19.75	19.77
Total coproduct credit	-	(2.84)	(2.15)	-
MSP (cents/GGE)	201.56	202.32	200.39	202.68
TCI (million \$)	957	920	895	896

Table SI-8: MSP breakdown (cents/GGE) and TCI for FP, colocated (CL), 10000 tonnes/day cases

Case →	FP-1	FP-2	FP-3	FP-4
Capital & other charges	61.84	59.75	58.46	58.56
Feedstock	110.02	110.02	110.02	110.02
Natural gas	-	-	-	-
Bio-oil transport	-	-	-	-
Hydrogen purchase	-	-	-	-
Electricity purchase	4.11	10.75	10.25	10.26
Other variable operating costs	2.81	2.81	2.81	2.81
Fixed operating costs	18.47	17.90	17.55	17.58
Electricity export	-	-	-	-
Hydrogen export	-	-	-	-
Fuel gas export	-	-	(1.90)	-
Steam export	-	(2.84)	(0.26)	-
Chemical coproducts	-	-	-	-
MSP (cents/GGE)	197.24	198.39	196.93	199.22
Capital & other charges	61.84	59.75	58.46	58.56
Total variable operating costs	116.93	123.57	123.07	123.09
Fixed operating costs	18.47	17.90	17.55	17.58
Total coproduct credit	-	(2.84)	(2.15)	-
MSP (cents/GGE)	197.24	198.39	196.93	199.22
TCI (million \$)	1,858	1,794	1,755	1,758

Table SI-9: MSP breakdown (cents/GGE) and TCI for CFP, standalone (SA), 2000 tonnes/day cases

Case →	CFP-1	CFP-2	CFP-3	CFP-4	CFP-5	CFP-6	CFP-7
Capital & other charges	193.41	196.27	184.23	180.69	155.64	140.95	142.72
Feedstock	131.59	131.59	131.59	131.59	131.59	131.59	131.59
Natural gas	-	-	-	-	-	-	-
Bio-oil transport	18.42	18.42	18.42	18.42	18.42	18.42	18.42
Hydrogen purchase	-	-	-	45.04	45.04	45.04	45.04
Electricity purchase	-	-	37.77	-	33.00	27.72	27.95
Other variable operating costs	8.25	8.55	8.60	8.05	8.05	8.10	8.10
Fixed operating costs	66.68	67.39	64.08	63.10	56.27	52.25	52.73
Electricity export	(20.13)	-	-	(39.23)	-	-	-
Hydrogen export	-	(38.53)	(53.06)	-	-	-	-
Fuel gas export	-	-	-	-	-	(30.92)	-
Steam export	-	-	(12.74)	-	(29.60)	(4.03)	-
Chemical coproducts	(58.15)	(58.15)	(58.15)	(58.15)	(58.15)	(58.15)	(58.15)
MSP (cents/GGE)	340.07	325.55	320.75	349.52	360.26	330.98	368.42
Capital & other charges	193.41	196.27	184.23	180.69	155.64	140.95	142.72
Total variable operating costs	158.27	158.57	196.39	203.11	236.11	230.88	231.11
Fixed operating costs	66.68	67.39	64.08	63.10	56.27	52.25	52.73
Total coproduct credit	(78.29)	(96.68)	(123.95)	(97.38)	(87.75)	(93.10)	(58.15)
MSP (cents/GGE)	340.07	325.55	320.75	349.52	360.26	330.98	368.42
TCI (million \$)	578	587	547	536	455	408	413

Table SI-10: MSP breakdown (cents/GGE) and TCI for **CFP, colocated (CL), 2000 tonnes/day** cases

Case →	CFP-1	CFP-2	CFP-3	CFP-4	CFP-5	CFP-6	CFP-7
Capital & other charges	194.21	197.07	185.02	181.49	156.43	141.74	143.52
Feedstock	208.29	208.29	208.29	208.29	208.29	208.29	208.29
Natural gas	-	-	-	-	-	-	-
Bio-oil transport	-	-	-	-	-	-	-
Hydrogen purchase	-	-	-	45.04	45.04	45.04	45.04
Electricity purchase	-	-	37.77	-	33.00	27.72	27.95
Other variable operating costs	8.25	8.55	8.60	8.05	8.05	8.10	8.10
Fixed operating costs	66.68	67.39	64.08	63.10	56.27	52.25	52.73
Electricity export	(20.13)	-	-	(39.23)	-	-	-
Hydrogen export	-	(38.53)	(53.06)	-	-	-	-
Fuel gas export	-	-	-	-	-	(30.92)	-
Steam export	-	-	(12.74)	-	(29.60)	(4.03)	-
Chemical coproducts	(58.15)	(58.15)	(58.15)	(58.15)	(58.15)	(58.15)	(58.15)
MSP (cents/GGE)	399.15	384.62	379.82	408.60	419.34	390.05	427.49
Capital & other charges	194.21	197.07	185.02	181.49	156.43	141.74	143.52
Total variable operating costs	216.54	216.84	254.67	261.39	294.39	289.16	289.39
Fixed operating costs	66.68	67.39	64.08	63.10	56.27	52.25	52.73
Total coproduct credit	(78.29)	(96.68)	(123.95)	(97.38)	(87.75)	(93.10)	(58.15)
MSP (cents/GGE)	399.15	384.62	379.82	408.60	419.34	390.05	427.49
TCI (million \$)	578	587	547	536	455	408	413

Table SI-11: MSP breakdown (cents/GGE) and TCI for **CFP, colocated (CL), 5000 tonnes/day** cases

Case →	CFP-1	CFP-2	CFP-3	CFP-4	CFP-5	CFP-6	CFP-7
Capital & other charges	159.04	160.54	150.25	150.57	129.45	118.86	120.63
Feedstock	208.29	208.29	208.29	208.29	208.29	208.29	208.29
Natural gas	-	-	-	-	-	-	-
Bio-oil transport	-	-	-	-	-	-	-
Hydrogen purchase	-	-	-	45.04	45.04	45.04	45.04
Electricity purchase	-	-	37.77	-	33.00	27.72	27.95
Other variable operating costs	8.10	8.40	8.46	7.90	7.90	7.95	7.95
Fixed operating costs	46.43	46.76	43.92	44.02	38.27	35.37	35.85
Electricity export	(20.13)	-	-	(39.23)	-	-	-
Hydrogen export	-	(38.53)	(53.06)	-	-	-	-
Fuel gas export	-	-	-	-	-	(30.92)	-
Steam export	-	-	(12.74)	-	(29.60)	(4.03)	-
Chemical coproducts	(58.15)	(58.15)	(58.15)	(58.15)	(58.15)	(58.15)	(58.15)
MSP (cents/GGE)	343.58	327.31	324.75	358.46	374.20	350.13	387.57
Capital & other charges	159.04	160.54	150.25	150.57	129.45	118.86	120.63
Total variable operating costs	216.39	216.70	254.52	261.24	294.24	289.01	289.24
Fixed operating costs	46.43	46.76	43.92	44.02	38.27	35.37	35.85
Total coproduct credit	(78.29)	(96.68)	(123.95)	(97.38)	(87.75)	(93.10)	(58.15)
MSP (cents/GGE)	343.58	327.31	324.75	358.46	374.20	350.13	387.57
TCI (million \$)	1,163	1,172	1,088	1,091	921	835	850

Table SI-12: MSP breakdown (cents/GGE) and TCI for CFP, collocated (CL), 10000 tonnes/day cases

Case →	CFP-1	CFP-2	CFP-3	CFP-4	CFP-5	CFP-6	CFP-7
Capital & other charges	138.47	139.19	129.97	132.39	113.59	105.32	107.09
Feedstock	208.29	208.29	208.29	208.29	208.29	208.29	208.29
Natural gas	-	-	-	-	-	-	-
Bio-oil transport	-	-	-	-	-	-	-
Hydrogen purchase	-	-	-	45.04	45.04	45.04	45.04
Electricity purchase	-	-	37.77	-	33.00	27.72	27.95
Other variable operating costs	8.01	8.31	8.37	7.81	7.81	7.87	7.87
Fixed operating costs	37.24	37.36	34.81	35.50	30.38	28.11	28.59
Electricity export	(20.13)	-	-	(39.23)	-	-	-
Hydrogen export	-	(38.53)	(53.06)	-	-	-	-
Fuel gas export	-	-	-	-	-	(30.92)	-
Steam export	-	-	(12.74)	-	(29.60)	(4.03)	-
Chemical coproducts	(58.15)	(58.15)	(58.15)	(58.15)	(58.15)	(58.15)	(58.15)
MSP (cents/GGE)	313.73	296.47	295.26	331.65	350.36	329.24	366.68
Capital & other charges	138.47	139.19	129.97	132.39	113.59	105.32	107.09
Total variable operating costs	216.30	216.61	254.43	261.15	294.15	288.92	289.15
Fixed operating costs	37.24	37.36	34.81	35.50	30.38	28.11	28.59
Total coproduct credit	(78.29)	(96.68)	(123.95)	(97.38)	(87.75)	(93.10)	(58.15)
MSP (cents/GGE)	313.73	296.47	295.26	331.65	350.36	329.24	366.68
TCI (million \$)	1,992	1,999	1,848	1,889	1,586	1,452	1,481

3. Capital cost worksheets

Please see Table 1 in the main article for applicable operations in each of the cases presented below.

Table SI-13: Capital cost breakdown and factored estimates for the FP-1 case

FP-1 (2,000 tons/day): Total Capital Investment in 2020\$			
Process Area	Description	Purchased Equip Cost	Installed Cost
A100	Feed Handling & Drying	\$186,275	\$367,136
A200	Fast Pyrolysis & Vapor Upgrading	\$59,764,778	\$166,802,101
A300	Pyrolysis Vapor Quench	\$7,007,364	\$12,531,297
A500	Hydrogen Plant & Fuel Combustion	\$1,597,198	\$4,204,013
A600	Steam System and Power Generation	\$9,696,324	\$18,519,094
A700	Cooling Water and Other Utilities	\$4,541,020	\$8,956,127
A800	Water Management	\$1,023,528	\$2,269,792
Subtotal		\$83,816,487	\$213,649,560
Warehouse	4.0% of ISBL		\$7,188,021
Site Development	10.0% of ISBL		\$17,970,053
Additional Piping	4.5% of ISBL		\$8,086,524
Total Direct Costs (TDC)			\$246,894,159
Prorateable Expenses	10.0% of TDC		\$24,689,416
Field Expenses	10.0% of TDC		\$24,689,416
Home Office & Construction Fee	20.0% of TDC		\$49,378,832
Project Contingency	10.0% of TDC		\$24,689,416
Other Costs (Start-Up, Permits, etc.)	10.0% of TDC		\$24,689,416
Total Indirect Costs			\$148,136,496
Fixed Capital Investment (FCI)			\$395,030,655
Land			\$1,848,000
Working Capital	5.0% of FCI		\$19,751,533
Total Capital Investment (TCI)			\$416,630,187

Table SI-14: Capital cost breakdown and factored estimates for the FP-2 case

FP-2 (2,000 tons/day): Total Capital Investment in 2020\$			
Process Area	Description	Purchased Equip Cost	Installed Cost
A100	Feed Handling & Drying	\$186,275	\$367,136
A200	Fast Pyrolysis & Vapor Upgrading	\$59,751,635	\$166,767,465
A300	Pyrolysis Vapor Quench	\$7,038,718	\$12,632,862
A500	Hydrogen Plant & Fuel Combustion	\$1,588,508	\$4,181,112
A600	Steam System and Power Generation	\$3,315,895	\$7,843,297
A700	Cooling Water and Other Utilities	\$4,541,190	\$8,956,518
A800	Water Management	\$1,023,563	\$2,269,854
Subtotal		\$77,445,783	\$203,018,245
	Warehouse	4.0% of ISBL	\$7,190,699
	Site Development	10.0% of ISBL	\$17,976,746
	Additional Piping	4.5% of ISBL	\$8,089,536
Total Direct Costs (TDC)			\$236,275,226
	Prorateable Expenses	10.0% of TDC	\$23,627,523
	Field Expenses	10.0% of TDC	\$23,627,523
	Home Office & Construction Fee	20.0% of TDC	\$47,255,045
	Project Contingency	10.0% of TDC	\$23,627,523
	Other Costs (Start-Up, Permits, etc.)	10.0% of TDC	\$23,627,523
Total Indirect Costs			\$141,765,135
Fixed Capital Investment (FCI)			\$378,040,361
	Land		\$1,848,000
	Working Capital	5.0% of FCI	\$18,902,018
Total Capital Investment (TCI)			\$398,790,379

Table SI-15: Capital cost breakdown and factored estimates for the **FP-3** case

FP-3 (2,000 tons/day): Total Capital Investment in 2020\$			
Process Area	Description	Purchased Equip Cost	Installed Cost
A100	Feed Handling & Drying	\$158,272	\$312,925
A200	Fast Pyrolysis & Vapor Upgrading	\$60,397,160	\$168,468,659
A300	Pyrolysis Vapor Quench	\$7,020,602	\$12,491,454
A500	Hydrogen Plant & Fuel Combustion	\$64,401	\$164,532
A600	Steam System and Power Generation	\$877,261	\$1,781,105
A700	Cooling Water and Other Utilities	\$4,443,582	\$8,734,732
A800	Water Management	\$1,026,033	\$2,274,289
Subtotal		\$73,987,311	\$194,227,696
Warehouse	4.0% of ISBL		\$7,250,922
Site Development	10.0% of ISBL		\$18,127,304
Additional Piping	4.5% of ISBL		\$8,157,287
Total Direct Costs (TDC)			\$227,763,208
Prorateable Expenses	10.0% of TDC		\$22,776,321
Field Expenses	10.0% of TDC		\$22,776,321
Home Office & Construction Fee	20.0% of TDC		\$45,552,642
Project Contingency	10.0% of TDC		\$22,776,321
Other Costs (Start-Up, Permits, etc.)	10.0% of TDC		\$22,776,321
Total Indirect Costs			\$136,657,925
Fixed Capital Investment (FCI)			\$364,421,134
Land			\$1,848,000
Working Capital	5.0% of FCI		\$18,221,057
Total Capital Investment (TCI)			\$384,490,190

Table SI-16: Capital cost breakdown and factored estimates for the **CFP-1** case

CFP-1 (2,000 tons/day): Total Capital Investment in 2020\$			
Process Area	Description	Purchased Equip Cost	Installed Cost
A100	Feed Handling & Drying	\$260,612	\$511,047
A200	Fast Pyrolysis & Vapor Upgrading	\$47,958,454	\$114,902,427
A300	Pyrolysis Vapor Quench & Liquid Chemicals Recovery	\$36,590,942	\$56,795,122
A500	Hydrogen Plant & Fuel Combustion	\$27,214,895	\$54,995,663
A600	Steam System and Power Generation	\$31,702,404	\$58,807,281
A700	Cooling Water and Other Utilities	\$4,543,450	\$9,130,145
A800	Water Management	\$6,844,561	\$16,088,874
Subtotal		\$155,115,318	\$311,230,559
	Warehouse	4.0% of ISBL	\$6,888,344
	Site Development	10.0% of ISBL	\$17,220,860
	Additional Piping	4.5% of ISBL	\$7,749,387
Total Direct Costs (TDC)			\$343,089,149
	Prorateable Expenses	10.0% of TDC	\$34,308,915
	Field Expenses	10.0% of TDC	\$34,308,915
	Home Office & Construction Fee	20.0% of TDC	\$68,617,830
	Project Contingency	10.0% of TDC	\$34,308,915
	Other Costs (Start-Up, Permits, etc.)	10.0% of TDC	\$34,308,915
Total Indirect Costs			\$205,853,490
Fixed Capital Investment (FCI)			\$548,942,639
	Land		\$1,848,000
	Working Capital	5.0% of FCI	\$27,447,132
Total Capital Investment (TCI)			\$578,237,771

Table SI-17: Capital cost breakdown and factored estimates for the **CFP-2** case

CFP-2 (2,000 tons/day): Total Capital Investment in 2020\$			
Process Area	Description	Purchased Equip Cost	Installed Cost
A100	Feed Handling & Drying	\$230,868	\$453,464
A200	Fast Pyrolysis & Vapor Upgrading	\$48,111,949	\$115,306,943
A300	Pyrolysis Vapor Quench & Liquid Chemicals Recovery	\$36,815,505	\$57,356,867
A500	Hydrogen Plant & Fuel Combustion	\$37,786,074	\$74,171,642
A600	Steam System and Power Generation	\$23,175,805	\$43,078,443
A700	Cooling Water and Other Utilities	\$4,480,129	\$8,987,634
A800	Water Management	\$7,073,319	\$16,683,942
Subtotal		\$157,673,649	\$316,038,935
	Warehouse	4.0% of ISBL	\$6,924,691
	Site Development	10.0% of ISBL	\$17,311,727
	Additional Piping	4.5% of ISBL	\$7,790,277
Total Direct Costs (TDC)			\$348,065,631
	Prorateable Expenses	10.0% of TDC	\$34,806,563
	Field Expenses	10.0% of TDC	\$34,806,563
	Home Office & Construction Fee	20.0% of TDC	\$69,613,126
	Project Contingency	10.0% of TDC	\$34,806,563
	Other Costs (Start-Up, Permits, etc.)	10.0% of TDC	\$34,806,563
Total Indirect Costs			\$208,839,379
Fixed Capital Investment (FCI)			\$556,905,009
	Land		\$1,848,000
	Working Capital	5.0% of FCI	\$27,845,250
Total Capital Investment (TCI)			\$586,598,260

Table SI-18: Capital cost breakdown and factored estimates for the **CFP-3** case

CFP-3 (2,000 tons/day): Total Capital Investment in 2020\$			
Process Area	Description	Purchased Equip Cost	Installed Cost
A100	Feed Handling & Drying	\$224,763	\$441,647
A200	Fast Pyrolysis & Vapor Upgrading	\$48,174,010	\$115,470,495
A300	Pyrolysis Vapor Quench & Liquid Chemicals Recovery	\$36,873,495	\$57,539,753
A500	Hydrogen Plant & Fuel Combustion	\$41,202,152	\$80,318,801
A600	Steam System and Power Generation	\$5,392,527	\$12,984,692
A700	Cooling Water and Other Utilities	\$4,456,303	\$8,933,998
A800	Water Management	\$7,181,738	\$16,963,611
Subtotal		\$143,504,988	\$292,652,997
Warehouse	4.0% of ISBL		\$6,938,076
Site Development	10.0% of ISBL		\$17,345,190
Additional Piping	4.5% of ISBL		\$7,805,335
Total Direct Costs (TDC)			\$324,741,597
Prorateable Expenses	10.0% of TDC		\$32,474,160
Field Expenses	10.0% of TDC		\$32,474,160
Home Office & Construction Fee	20.0% of TDC		\$64,948,319
Project Contingency	10.0% of TDC		\$32,474,160
Other Costs (Start-Up, Permits, etc.)	10.0% of TDC		\$32,474,160
Total Indirect Costs			\$194,844,958
Fixed Capital Investment (FCI)			\$519,586,556
Land			\$1,848,000
Working Capital	5.0% of FCI		\$25,979,328
Total Capital Investment (TCI)			\$547,413,883

Table SI-19: Capital cost breakdown and factored estimates for the **CFP-4** case

CFP-4 (2,000 tons/day): Total Capital Investment in 2020\$			
Process Area	Description	Purchased Equip Cost	Installed Cost
A100	Feed Handling & Drying	\$281,697	\$551,866
A200	Fast Pyrolysis & Vapor Upgrading	\$47,833,537	\$114,573,226
A300	Pyrolysis Vapor Quench & Liquid Chemicals Recovery	\$36,428,959	\$56,368,237
A500	Hydrogen Plant & Fuel Combustion	\$6,292,757	\$16,575,225
A600	Steam System and Power Generation	\$39,294,125	\$72,718,808
A700	Cooling Water and Other Utilities	\$4,612,103	\$9,284,507
A800	Water Management	\$6,847,760	\$16,068,002
Subtotal		\$141,590,939	\$286,139,871
Warehouse	4.0% of ISBL		\$6,859,733
Site Development	10.0% of ISBL		\$17,149,333
Additional Piping	4.5% of ISBL		\$7,717,200
Total Direct Costs (TDC)			\$317,866,137
Prorateable Expenses	10.0% of TDC		\$31,786,614
Field Expenses	10.0% of TDC		\$31,786,614
Home Office & Construction Fee	20.0% of TDC		\$63,573,227
Project Contingency	10.0% of TDC		\$31,786,614
Other Costs (Start-Up, Permits, etc.)	10.0% of TDC		\$31,786,614
Total Indirect Costs			\$190,719,682
Fixed Capital Investment (FCI)			\$508,585,820
Land			\$1,848,000
Working Capital	5.0% of FCI		\$25,429,291
Total Capital Investment (TCI)			\$535,863,111

Table SI-20: Capital cost breakdown and factored estimates for the CFP-5 case

CFP-5 (2,000 tons/day): Total Capital Investment in 2020\$			
Process Area	Description	Purchased Equip Cost	Installed Cost
A100	Feed Handling & Drying	\$281,697	\$551,866
A200	Fast Pyrolysis & Vapor Upgrading	\$47,844,812	\$114,602,939
A300	Pyrolysis Vapor Quench & Liquid Chemicals Recovery	\$36,443,210	\$56,405,795
A500	Hydrogen Plant & Fuel Combustion	\$6,319,030	\$16,644,462
A600	Steam System and Power Generation	\$9,900,822	\$24,473,915
A700	Cooling Water and Other Utilities	\$4,612,325	\$9,285,013
A800	Water Management	\$6,850,161	\$16,074,281
Subtotal		\$112,252,058	\$238,038,270
	Warehouse	4.0% of ISBL	\$6,862,424
	Site Development	10.0% of ISBL	\$17,156,060
	Additional Piping	4.5% of ISBL	\$7,720,227
Total Direct Costs (TDC)			\$269,776,981
	Prorateable Expenses	10.0% of TDC	\$26,977,698
	Field Expenses	10.0% of TDC	\$26,977,698
	Home Office & Construction Fee	20.0% of TDC	\$53,955,396
	Project Contingency	10.0% of TDC	\$26,977,698
	Other Costs (Start-Up, Permits, etc.)	10.0% of TDC	\$26,977,698
Total Indirect Costs			\$161,866,189
Fixed Capital Investment (FCI)			\$431,643,170
	Land		\$1,848,000
	Working Capital	5.0% of FCI	\$21,582,158
Total Capital Investment (TCI)			\$455,073,328

Table SI-21: Capital cost breakdown and factored estimates for the **CFP-6** case

CFP-6 (2,000 tons/day): Total Capital Investment in 2020\$			
Process Area	Description	Purchased Equip Cost	Installed Cost
A100	Feed Handling & Drying	\$185,129	\$364,917
A200	Fast Pyrolysis & Vapor Upgrading	\$48,872,707	\$117,311,818
A300	Pyrolysis Vapor Quench & Liquid Chemicals Recovery	\$37,708,260	\$59,642,644
A500	Hydrogen Plant & Fuel Combustion	\$143,755	\$370,349
A600	Steam System and Power Generation	\$2,644,087	\$6,090,606
A700	Cooling Water and Other Utilities	\$4,177,760	\$8,303,150
A800	Water Management	\$7,052,057	\$16,591,275
Subtotal		\$100,783,755	\$208,674,759
	Warehouse	4.0% of ISBL	\$7,092,775
	Site Development	10.0% of ISBL	\$17,731,938
	Additional Piping	4.5% of ISBL	\$7,979,372
Total Direct Costs (TDC)			\$241,478,845
	Prorateable Expenses	10.0% of TDC	\$24,147,884
	Field Expenses	10.0% of TDC	\$24,147,884
	Home Office & Construction Fee	20.0% of TDC	\$48,295,769
	Project Contingency	10.0% of TDC	\$24,147,884
	Other Costs (Start-Up, Permits, etc.)	10.0% of TDC	\$24,147,884
Total Indirect Costs			\$144,887,307
Fixed Capital Investment (FCI)			\$386,366,152
	Land		\$1,848,000
	Working Capital	5.0% of FCI	\$19,318,308
Total Capital Investment (TCI)			\$407,532,459

4. Unit price assumptions for energy products

Most of our cost assumptions were inherited from our 2020 State of Technology report for CFP (NREL/TP-5100-80291, <https://www.nrel.gov/docs/fy21osti/80291.pdf>). It is however important to note that energy prices have gone through significant swings during the last few years; considering that, we explicitly state unit price assumptions for key energy byproducts that impact our analysis, noting that many of those prices move in tandem based on energy demand-supply situations, including disruptions. The table below will allow the interested reader to use a different set of assumptions and estimate prorated impacts using the breakdowns in the MSP breakdown tables presented in Section 2 above.

Table SI-22: Energy unit cost assumptions

Energy Utility	Unit Price* (2020\$)
Electricity	\$0.059/kWh
Fuel Gas/Natural Gas	\$2.625/million Btu
Steam	\$3/1000 lb
Purchased Hydrogen	\$0.74/lb
Sold Hydrogen	\$0.68/lb

5. Inventory for lifecycle analysis

Table SI-23: Major contributors to lifecycle inventory for 2000 dry metric tonnes/day standalone FP cases. Transportation distances for feedstock and bio-oil become 800 miles and 0 miles respectively in the colocated cases. Minor contributors are not included in this table; order of magnitudes of minor contributors can be found in our previous publication (NREL/TP-5100-80291, <https://www.nrel.gov/docs/fy21osti/80291.pdf>)

Units are in lb/h unless otherwise noted in row caption	FP-1	FP-2	FP-3
Products	lb/h	lb/h	lb/h
Bio-Oil Intermediate	136,511	136,511	136,511
Other Liquid Products			
Total	136,511	136,511	136,511
By-products			
Biogenic fuel gas (million Btu/h , LHV basis)	0	0	88
Exported steam (1321 psi, 1000F)	0	82,717	7,563
Excess electricity, positive is export (kW)	-6,127	-16,037	-15,288
Biorefinery Resource Consumption	lb/h	lb/h	lb/h
Blended woody biomass (wet)	204,131	204,131	204,131
Blended woody biomass (dry)	183,718	183,718	183,718
Biomass wet transportation (0 miles)	204,131	204,131	204,131
Sand makeup	157	157	157
50 wt% Caustic	231	231	231
Net Water Makeup	59,594	59,648	58,556
Bio-Oil Transportation (800 miles)	136,511	136,511	136,511
No. 2 diesel fuel	71	71	71
Waste Streams	lb/h	lb/h	lb/h
Solids purge from fluidized bed reactors	3,751	3,751	3,751
Wastewater	15,014	15,016	15,226
Air Emissions	lb/h	lb/h	lb/h
CO2 (Fossil)	0	0	0
CO2 (Biogenic)	88,929	88,929	53,921
CH4	0	0	0
CO	0	0	0
NO2	5	5	0
SO2	84	84	84
H2O	82,281	82,333	75,333
H2S	0	0	0
Combustor Feed Stream Heating Values	% Carbon Biogenic	% Carbon Biogenic	% Carbon Biogenic
Char Combustor	100.0%	100.0%	100.0%
Reformer Fuel Combustor	100.0%	100.0%	100.0%

Table SI-24: Major contributors to lifecycle inventory for 2000 dry metric tonnes/day standalone CFP cases. Transportation distances for feedstock and bio-oil become 800 miles and 0 miles respectively in the colocated cases. Minor contributors are not included in this table; order of magnitudes of minor contributors can be found in our previous publication (NREL/TP-5100-80291, <https://www.nrel.gov/docs/fy21osti/80291.pdf>)

Units are in lb/h unless otherwise noted in row caption	CFP-1	CFP-2	CFP-3	CFP-4	CFP-5	CFP-6
Products	lb/h	lb/h	lb/h	lb/h	lb/h	lb/h
Bio-Oil Intermediate	44,130	44,130	44,130	44,130	44,130	44,130
Other Liquid Products						
Total	44,130	44,130	44,130	44,130	44,130	44,130
By-products						
Exported hydrogen (pure H2 basis)	3	2,994	4,123	0	0	0
Biogenic fuel gas (million Btu/h, LHV basis)	0	0	0	0	0	623
Exported steam (1321 psi, 1000F)	0	0	224,446	0	521,693	71,014
Excess electricity, positive is export (kW)	18,190	-32	-34,126	35,441	-29,814	-25,043
MEK	926	926	926	926	926	926
Acetone	5,336	5,336	5,336	5,336	5,336	5,336
Biorefinery Resource Consumption	lb/h	lb/h	lb/h	lb/h	lb/h	lb/h
Blended woody biomass (wet)	204,131	204,131	204,131	204,131	204,131	204,131
Blended woody biomass (dry)	183,718	183,718	183,718	183,718	183,718	183,718
Biomass wet transportation (0 miles)	204,131	204,131	204,131	204,131	204,131	204,131
Sand makeup	159	159	159	159	159	159
Fixed-Bed VPU Catalyst (0.5% Pt/TiO2)	14	14	14	14	14	14
50 wt% Caustic	231	231	231	231	231	231
Net Water Makeup	52,226	72,707	80,558	37,551	37,643	31,958
Purchased hydrogen (pure H2 basis)	0	0	0	3,235	3,235	3,235
Bio-Oil Transportation (800 miles)	44,130	44,130	44,130	44,130	44,130	44,130
No. 2 diesel fuel	71	71	71	71	71	71
Waste Streams	lb/h	lb/h	lb/h	lb/h	lb/h	lb/h
Solids purge from fluidized bed reactors	3,742	3,742	3,742	3,742	3,742	3,742
Wastewater	17,215	19,729	20,661	14,450	14,455	15,987
Air Emissions	lb/h	lb/h	lb/h	lb/h	lb/h	lb/h
CO2 (Fossil)	0	0	0	0	0	0
CO2 (Biogenic)	204,023	203,298	203,026	204,808	204,808	67,957
CH4	0	0	0	0	0	0
CO	0	0	0	0	0	0
NO2	18	18	18	18	18	0
SO2	84	84	84	84	84	84
H2O	131,297	119,997	115,892	151,134	151,221	74,529
H2S	0	0	0	0	0	0
Combustor Feed Stream Heating Values	% Carbon Biogenic	% Carbon Biogenic	% Carbon Biogenic	% Carbon Biogenic	% Carbon Biogenic	% Carbon Biogenic
Char Combustor	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Reformer Fuel Combustor	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

6. Assumptions for key emission factors

Key emission factors for feedstock, transportation, and energy byproducts that are the primary subjects of this analysis are shown below. Most of the values were sourced or derived from GREET2020 (2020 version of GREET <https://greet.es.anl.gov/>). The table below will allow the interested reader to use a different set of emission factor assumptions and estimate prorated impacts using the breakdowns in the GHG contribution tables presented in Section 1 above.

Table SI-25: Key emission factors used in the analysis

Contributor/Displacer	GHG Emission Factor Used	Source/Basis
Feedstock (ready for plant)	251 kg CO ₂ e/dry ton	<ul style="list-style-type: none"> •GREET2020 •Blended biomass with 50% clean pine and 50% forest residues.
Transportation (800 miles)	0.011467 kg CO ₂ e/dry lb	<ul style="list-style-type: none"> •GREET2020 •Trip from biomass depot to destination by diesel rail with energy intensity of 272 Btu/ton-mile.
Electricity	0.4490 kg CO ₂ e/kWh	<ul style="list-style-type: none"> •GREET2020 •Average U.S. Mix
Fuel Gas (for combustion)	70.760 kg CO ₂ e/million Btu	<ul style="list-style-type: none"> •GREET2020 •Including emissions for NG production and transmission (11.215 kg CO₂e/million Btu) and NG combustion (59.544 kg CO₂e/million Btu).
Steam	0.0943 kg CO ₂ e/lb	<ul style="list-style-type: none"> •Estimate •150 psi steam produced from NG boiler with an efficiency of 82% and using NG fuel emission factor of 70.76 kg CO₂e/million Btu.
Hydrogen	5.2227 kg CO ₂ e/lb	<ul style="list-style-type: none"> •GREET2020 •Gaseous hydrogen from natural gas