

Sustainability assessment of biojet fuel produced from pyrolysis oil of woody biomass

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Figure S1. Simplified Process flow diagram A100-A400

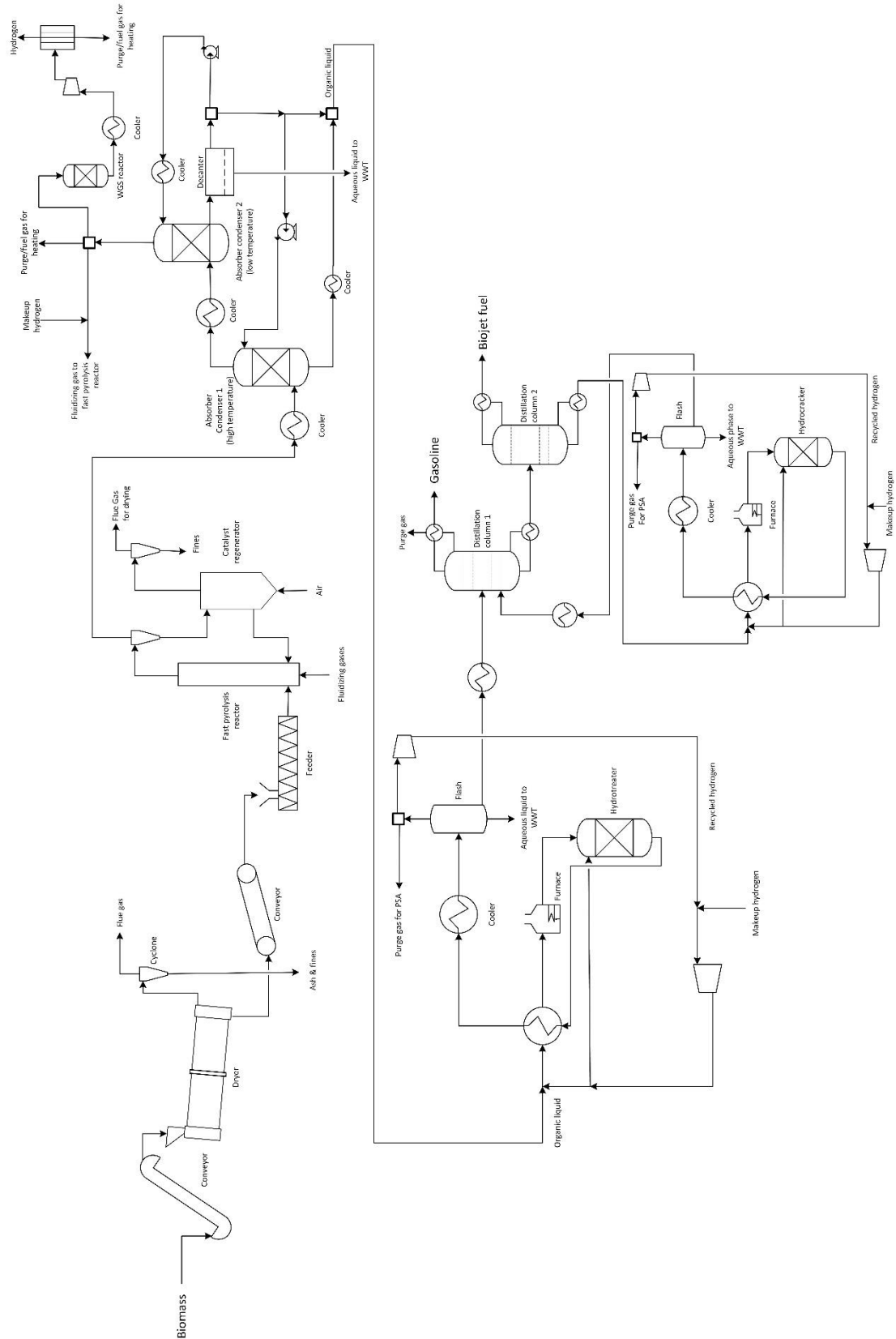


Table S1. Product yield for biojet fuel range compared to renewable diesel

Hydrocarbon formula	Composition (wt%)	
	Renewable diesel (NREL 2015)	Biojet fuel
C10H8	1.97%	2.50%
C10H8O	0.01%	0.00%
C10H12	0.18%	0.22%
C10H18	0.05%	0.05%
C11H10-1	4.15%	5.07%
C11H20-N8	11.67%	14.20%
C12H10	0.48%	0.57%
C14H20-N35	10.85%	10.41%
C14H24-N5	7.17%	4.59%
C14H30-N26	34.28%	41.79%
C15H26-N4	6.88%	6.51%
C15H32-N10	17.63%	14.02%
C16H14-N14	0.91%	0.00%
C16H34	1.01%	0.04%
C18H28-X1	2.22%	0.00%
C21H34	0.55%	0.00%
Total	100.0%	100.0%

Table S2. Summary of equipment cost for main process area

Equipment	Scaling exponential (n)	Purchased equipment cost (2021)	Installation factor (f)	Installed cost (2021)
A100: Feed Handling and drying				
Blower	0.78	\$ 219,299.96	1.94	\$ 425,441.93
Dryer	0.8	\$ 139,371.69	2.00	\$ 278,743.38
Total A100		\$ 358,671.66	1.96	\$ 704,185.31
A200: Fast pyrolysis and vapor upgrading				
Fluidizing gas compressor	0.9	\$ 4,654,405.46	1.60	\$ 7,447,048.73
Combustor air compressor	0.78	\$ 8,813,915.98	1.60	\$ 14,102,265.56
Fluidized bed reactor	0.5	\$ 10,471,399.40	4.01	\$ 41,990,311.58
Char combustor	0.5	\$ 8,765,574.90	3.97	\$ 34,799,332.37
Catalyst cooler	0.8	\$ 5,045,241.31	3.00	\$ 15,135,723.94
Catalyst stripper	0.3	\$ 2,051,176.40	3.00	\$ 6,153,529.19
Heat exchanger network		\$ 3,517,160.33	2.64	\$ 9,285,303.26
Total A200		\$ 43,318,873.77	2.98	\$ 128,913,514.63
A300: Pyrolysis Vapor Quench and Product Recovery				
Heavy fraction condenser absorber	0.6	\$ 1,477,707.88	1.40	\$ 2,068,791.03
Light fraction condenser absorber	0.6	\$ 1,527,989.00	1.33	\$ 2,032,225.37
Vapor heat exchanger	0.6	\$ 933,125.53	1.32	\$ 1,231,725.70
Feed cooler	0.7	\$ 244,700.45	2.03	\$ 496,741.92
Feed exchanger	0.7	\$ 1,038,052.91	1.52	\$ 1,577,840.42
Liquid feed chiller	0.7	\$ 192,252.10	2.33	\$ 447,947.39
Heavy fraction heat exchanger	0.6	\$ 47,745.95	2.42	\$ 115,545.21
Quench circulation chiller	0.7	\$ 230,030.19	4.63	\$ 1,065,039.78
Bottoms pump	0.8	\$ 15,572.00	4.38	\$ 68,205.36
Circulation filter charge pump	0.8	\$ 75,768.03	4.61	\$ 349,290.60
Aqueous filter charge pump	0.8	\$ 21,328.05	4.20	\$ 89,577.81
Organic product pump	0.8	\$ 18,285.57	4.63	\$ 84,662.17
Quench recycle pump	0.8	\$ 23,202.60	4.88	\$ 113,228.68
Bottoms filter	0.8	\$ 39,049.16	1.84	\$ 71,850.46

Equipment	Scaling exponential (n)	Purchased equipment cost (2021)	Installation factor (f)	Installed cost (2021)
Bottoms decanter	0.7	\$ 444,668.17	1.82	\$ 809,296.07
Quench circulation filter	0.8	\$ 369,978.88	1.71	\$ 632,663.89
Aqueous phase filter	0.8	\$ 75,359.67	1.77	\$ 133,386.61
Organic product surge tank	0.7	\$ 67,453.11	3.24	\$ 218,548.08
Circulation surge tank	0.7	\$ 94,326.76	3.24	\$ 305,618.71
Heat exchanger network condensation and separation		\$ 199,323.82	2.64	\$ 526,214.88
Post-WGS heat exchanger	0.6	\$ 208,360.68	1.71	\$ 356,296.76
Post-WGS Cooler	0.7	\$ 67,330.46	4.05	\$ 272,688.38
PSA compressor	0.9	\$ 4,768,672.13	1.60	\$ 7,629,875.40
PSA compressor	0.6	\$ 1,441,977.16	1.80	\$ 2,595,558.88
Compressor condensate pump	0.8	\$ 14,438.91	4.38	\$ 63,242.41
High-temperature WGS	0.6	\$ 720,704.96	1.42	\$ 1,023,401.04
PSA compressor suction KO	0.7	\$ 67,755.55	2.00	\$ 135,511.10
PSA compressor disch KO	0.7	\$ 79,211.90	2.56	\$ 202,782.47
Compressor condensate tank	0.7	\$ 34,746.76	3.24	\$ 112,579.49
Heat exchanger network hydrogen recycle and WGS		\$ 619,123.90	2.64	\$ 1,634,487.09
Total A300		\$ 15,158,242.22	1.75	\$ 26,464,823.17
A400: Hydroprocessing and product separation				
Feed-effluent exchanger	0.7	\$ 879,813.07	2.23	\$ 1,961,983.15
Feed furnace	0.6	\$ 410,207.13	1.31	\$ 537,371.34
HT product heat exchanger	0.6	\$ 85,989.55	1.93	\$ 165,959.82
HT product cooler	0.7	\$ 128,605.23	3.20	\$ 411,536.73
Quench hydrogen stage 2 cooler	0.7	\$ 40,074.94	7.10	\$ 284,532.05
Quench hydrogen stage 3 cooler	0.7	\$ 40,074.94	7.10	\$ 284,532.05
Hydrogen makeup compressor	0.64	\$ 4,520,407.94	1.60	\$ 7,232,652.70
Hydrogen recycle compressor	0.9	\$ 2,628,660.21	1.60	\$ 4,205,856.34
HT feed pump	0.8	\$ 113,534.97	3.58	\$ 406,455.18
Hydrotreater, 2000 psi	1	\$ 9,689,829.43	1.43	\$ 13,856,456.08
Vapor KO drum	0.7	\$ 66,147.20	3.45	\$ 228,207.84

Equipment	Scaling exponential (n)	Purchased equipment cost (2021)	Installation factor (f)	Installed cost (2021)
HP HT effluent flash: 3 phase	0.7	\$ 1,011,517.93	2.05	\$ 2,073,611.75
LP HT effluent flash: 3 phase	0.7	\$ 52,338.25	4.99	\$ 261,167.87
Heat exchanger network hydrotreating		\$ 301,869.33	2.64	\$ 796,935.03
Gasoline column	0.7	\$ 635,154.43	1.69	\$ 1,073,410.99
Biojet fuel column	0.7	\$ 393,485.31	1.91	\$ 751,556.94
Condenser (Gasoline column)	0.7	\$ 44,587.79	4.58	\$ 204,212.09
Reboiler (Gasoline column)	0.7	\$ 69,737.41	2.83	\$ 197,356.88
Condenser (Biojet fuel column)	0.7	\$ 19,478.59	6.66	\$ 129,727.39
Reboiler (Biojet fuel column)	0.7	\$ 39,134.18	2.83	\$ 110,749.72
Gasoline product cooler	0.7	\$ 27,039.50	4.04	\$ 109,239.59
Biojet fuel product cooler	0.7	\$ 16,224.26	5.63	\$ 91,342.58
Overhead vapor cooler	0.7	\$ 13,789.44	6.30	\$ 86,873.44
Reflux pump (Gasoline column)	0.8	\$ 46,072.10	4.31	\$ 198,570.75
Reflux pump (Biojet fuel pump)	0.8	\$ 10,744.16	3.96	\$ 42,546.89
Overhead accumulator (Gasoline column)	0.7	\$ 179,303.08	4.01	\$ 719,005.33
Overhead accumulator (Biojet fuel column)	0.7	\$ 45,231.69	4.34	\$ 196,305.53
Heat exchanger network hydroprocessing		\$ 636,628.98	2.64	\$ 1,680,700.52
Feed-effluent exchanger	0.7	\$ 202,748.18	3.37	\$ 683,261.37
Feed furnace	0.6	\$ 159,782.68	1.52	\$ 242,869.67
HC product heat exchanger	0.6	\$ 34,817.84	2.05	\$ 71,376.56
HC product cooler	0.7	\$ 38,306.31	3.23	\$ 123,729.38
Quench hydrogen stage 2 cooler	0.7	\$ 13,587.35	7.10	\$ 96,470.16
Quench hydrogen stage 3 cooler	0.7	\$ 13,587.35	7.10	\$ 96,470.16
Hydrogen makeup compressor	0.64	\$ 2,057,225.13	1.60	\$ 3,291,560.20
Hydrogen recycle compressor	0.9	\$ 567,908.98	1.60	\$ 908,654.37
HC feed pump	0.8	\$ 36,791.34	3.58	\$ 131,712.99
Hydrocracker	1	\$ 1,663,296.62	1.97	\$ 3,276,694.33

Equipment	Scaling exponential (n)	Purchased equipment cost (2021)	Installation factor (f)	Installed cost (2021)
Vapor KO drum	0.7	\$ 19,110.65	3.45	\$ 65,931.73
Hp effluent flash: 3 phase	0.7	\$ 166,809.80	2.15	\$ 358,641.06
LP effluent flash	0.7	\$ 11,686.32	8.99	\$ 105,059.98
Heat exchanger network hydrocracking		\$ 112,758.67	2.64	\$ 297,682.88
Total A400		\$ 27,244,098.21	1.76	\$ 48,048,971.45

Table S3. Summary of annual operating cost

Material	Quoted price	Base Year	Cost (MM\$/year)
Feedstock, Catalyst & Chemicals			
Wood chips	\$ 80.00/ton	2011	\$ 52.56
Zeolite catalyst	\$ 9.75/lb	2011	\$ 26.44
Natural gas	\$ 0.12/lb	2011	\$ 0.05
Caustic soda 50%	\$ 0.08/lb	2011	\$ 0.18
Boiler chemical	\$ 75.00/lb	2011	\$ 0.00
Cooling tower chemicals	\$ 33.84/ton cool/year	2011	\$ 0.16
Net water makeup	\$ 0.31/ton	2011	\$ 0.05
Diesel fuel	\$ 0.40/lb	2011	\$ 0.22
Waste Streams			
CFP purge	\$ 0.03/lb	2011	\$ 0.53
Quench filter solids	\$ 0.03/lb	2011	\$ 0.01
WWT cost	\$ 0.003/lb	2011	\$ 0.51
Subtotal			\$ 80.72
Coproduct credits			
Electricity	\$ 0.06/kWh	2011	\$ (2.36)
Subtotal			\$ (2.36)
Total			\$ 78.36

Table S4. Percentages for calculating total capital investment

Cost distribution	Percentages	Cost
Direct cost		
Warehouse	4% of ISBL	\$8,165,259.78
Site Development	9% of ISBL	\$18,371,834.51
Additional piping	5% of ISBL	\$10,206,574.73
Indirect cost		
Portable expenses	10% of TDC	\$24,087,516.36
Field expenses	10% of TDC	\$24,087,516.36
Home office and construction fee	20% of TDC	\$48,175,032.72
Project contingency	10% of TDC	\$24,087,516.36
Other costs (start-up, permits, etc.)	10% of TDC	\$24,087,516.36
Land	6% of IC	\$12,247,889.67
Working capital	20% of ISBL	\$19,270,013.09

Table S5. Jet Fuel price in the market December 16th, 2022 (Source: IATA)¹

Area	Share in world index	\$/L	Vs. 1 year ago
Asia & Oceania	22%	0.88	36.4%
Europe & CIS	28%	0.91	39.4%
Middle East & Africa	7%	0.86	35.6%
North America	39%	0.92	39.2%
Latin & Central America	4%	0.94	40.3%
Jet Fuel Price	100%	0.91	38.4%

Table S6. List of Ecoinvent databases selected for the feedstock assumptions

Feedstock	Inventory	Composition
Pulpwood	Wood chips, dry, measured as dry mass {GLO} wood chips production, pulpwood, at forest APOS, S	45%
Woody residues	Shavings, hardwood, measured as dry mass {RoW} market for shavings, hardwood, measured as dry mass Cut-off, S	32%
Switchgrass	Switchgrass, ground and stored, 2022/ton/RNA	3%
Construction and demolition waste	Wood chips, from post-consumer wood, measured as dry mass {RER} market for wood chips, from post-consumer wood, measured as dry mass APOS, S	20%

Table S7. LCA results in the WTP stage according to CML-IA baseline method

Impact category	Unit	Biojet fuel	Kerosene/Jet A1
Abiotic depletion (fossil fuel)	kJ	-2941.387617	1163.609206
Global warming (GWP100a)	g CO2 eq	4.322208645	9.363303738
Ozone layer depletion (ODP)	g CFC-11 eq	4.12531E-06	6.0876E-08
Human toxicity	g 1,4-DB eq	35.50076402	0.584699533
Photochemical oxidation	g C2H4 eq	-0.590155327	0.006255909
Acidification	g SO2 eq	0.02374189	0.063307762
Eutrophication	g PO4--- eq	0.097128397	0.003364805

References:

- 1 IATA - Fuel Price Monitor, <https://www.iata.org/en/publications/economics/fuel-monitor/>, (accessed 5 March 2023).