Milestone 3 Report: Summary of the Final Process Design

Design/Cost Study and Commercialization Analysis for Synthetic Jet Fuel Production at a Mississippi site from Lignite and Woody Biomass with CO_2 Capture and Storage via EOR

(DOE/NETL DE-FE0023697)

prepared by

Eric D. Larson (project PI)

The Energy Systems Analysis Group

Andlinger Center for Energy & the Environment, Princeton University

with input from

Chris Greig (University of Queensland)

Worley Parsons Engineering

Emerging Fuels Technology

Politecnico di Milano

January 15, 2016

Report Content

As of mid-December 2015, the process design for the "LBJ" project was essentially complete. Minor revisions will be made through about the first quarter of 2016 as additional inputs are received from technology providers, but the final design is not expected to differ in any substantial way from the design shown in this report.*

Slide #3 gives a process overview and feedstock compositions and heating values.

Slide #4 gives the current estimate of overall process performance. The plant produces 1402 barrels per day of liquids, of which 80% is SPK, the primary product. Net electricity output (after supplying on site needs) is 56 MW_e. Some changes in the estimated plant outputs are expected as the process design is "tweaked" in the coming months, but performance is not expected to be substantially different from that shown in slide #5.

The detailed process flows for the plant are represented in three sets of slides:

Slides #5-#8 show the process flow diagram (PFD) and stream tables for the syngas production area, as prepared by Worley Parsons Engineering with inputs from Princeton and others. Slide #9 includes a detailed composition for the gas turbine fuel stream (stream 53 on slide #5). The stream is relatively rich in methane because of operating characteristics of the TRIG gasifier and the generation of some methane during F-T synthesis. As a result, the fuel gas is readily combustible in the Siemens SGT-700 gas turbine that has been selected for the plant. A summary of the power island is shown on slide #5, including gross production of 44 MWe from the gas turbine combined cycle (GTCC) and 37 MWe from a separate heat recovery steam cycle (HRSC) that utilizes waste heat recovery from the process (detailed in slide #12) to provide steam for a steam turbine separate from the GTCC bottoming cycle turbine.

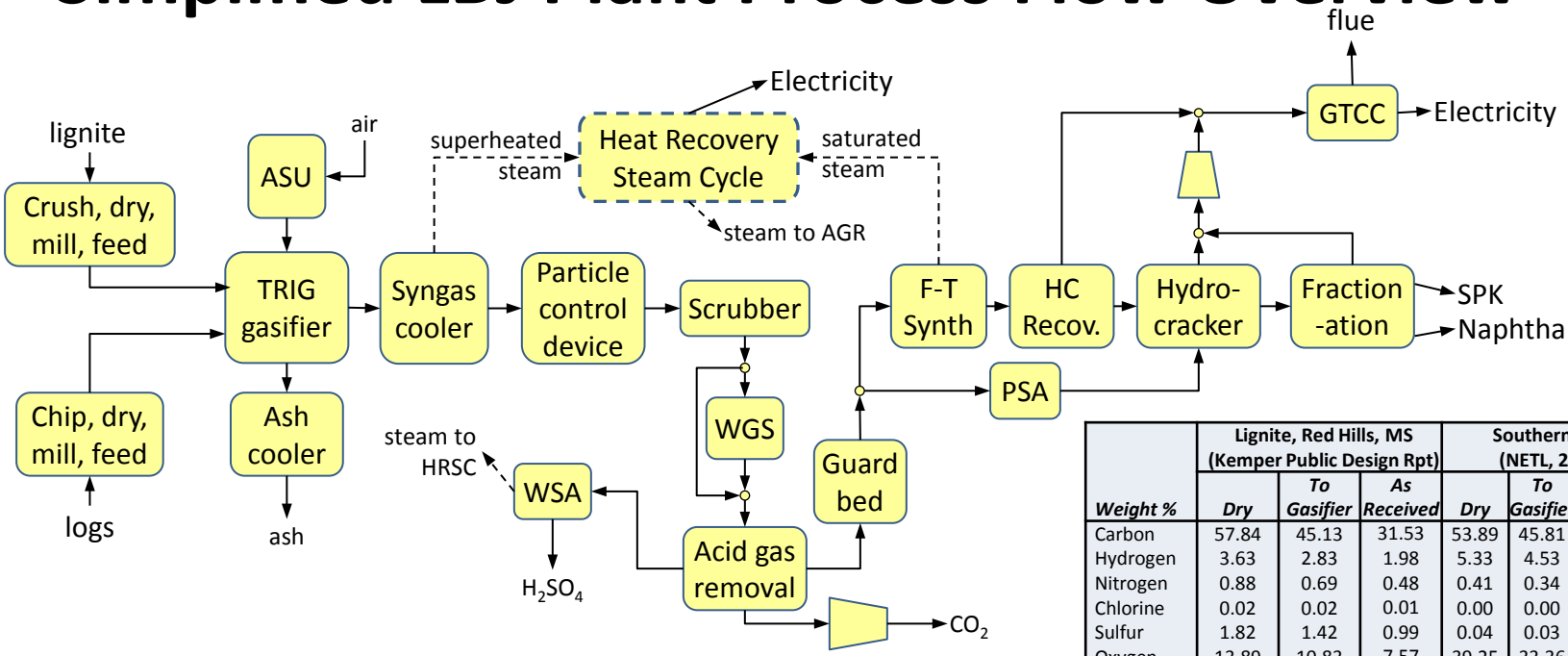
Slides #9 - #11 include a PDF and stream tables for the F-T synthesis and upgrading areas, as prepared by Emerging Fuels Technology, the selected F-T technology provider for the project.

Slide #12 includes a PFD with stream data for the HRSC, as prepared jointly by Princeton and consultants from the Politecnico di Milano.

---

* The process design reported here is a compilation of PFDs from different sources, among which there may be some minor inconsistencies.

Simplified LBJ Plant Process Flow Overview



Weight %	Lignite, Red Hills, MS (Kemper Public Design Rpt) Dry	To Gasifier	As Received	Southern Pine (NETL, 2014) Dry	To Gasifier	As Received
Carbon	57.84	45.13	31.53	53.89	45.81	30.56
Hydrogen	3.63	2.83	1.98	5.33	4.53	3.02
Nitrogen	0.88	0.69	0.48	0.41	0.34	0.23
Chlorine	0.02	0.02	0.01	0.00	0.00	0.00
Sulfur	1.82	1.42	0.99	0.04	0.03	0.02
Oxygen	13.89	10.83	7.57	39.25	33.36	22.25
Ash	21.92	17.10	11.95	1.09	0.93	0.62
Moisture		22.00	45.50		15.00	43.30
HHV, MJ/kg	22.58	17.61	12.30	20.19	17.17	11.45
LHV, MJ/kg	21.79	16.46	10.76	19.03	15.81	9.73

The plant receives lignite and pulpwood-grade logs having ultimate analysis and heating values as shown. The as-received feedstocks are separately subjected to sizing and drying before being fed to a pressurized oxygen-blown TRIG gasifier supplied with 99.5% purity oxygen from a dedicated air separation unit (ASU). The resulting syngas is cooled, filtered, and wet scrubber to prepare it for further gas conditioning. A portion of the syngas is then subjected to a sour water gas shift (WGS) to set the H_2/CO ratio at the Fischer-Tropsch (F-T) synthesis inlet to the desired value. The recombined syngas streams are sent to the acid gas removal (AGR) island, where CO_2, H_2S, and trace impurities are removed using a methanol solvent (Rectisol®). The CO_2 is compressed for delivery by pipeline. The H_2S is converted in a wet sulfuric acid (WSA) plant into saleable acid. A guard bed downstream of the AGR is included to protect the cobalt-based F-T synthesis catalyst from poisoning. F-T synthesis produces a crude liquid product, along with unconverted and other permanent gases that are separated in the hydrocarbon recovery step. The permanent gases are collected for use as fuel in the gas turbine combined cycle (GTCC) power island. The crude F-T liquids are subjected to hydrocracking and fractionation, resulting in the synthetic paraffinic kerosene and naphtha as final products. Hydrogen for the hydrocracker is supplied from a slipstream of post-AGR syngas by separating out H_2 using pressure swing adsorption (PSA). The PSA raffinate and the light ends from the hydrocracking and fractionation (after compressing) are collected and used as additional gas turbine fuel. Electricity produced by the GTCC is supplemented with electricity from a separate heat recovery steam cycle (HRSC) that utilizes process heat primarily from syngas cooling and F-T synthesis. Process heat is also used for feedstock drying and some other needs.

LBJ Plant Performance

(current estimates*)

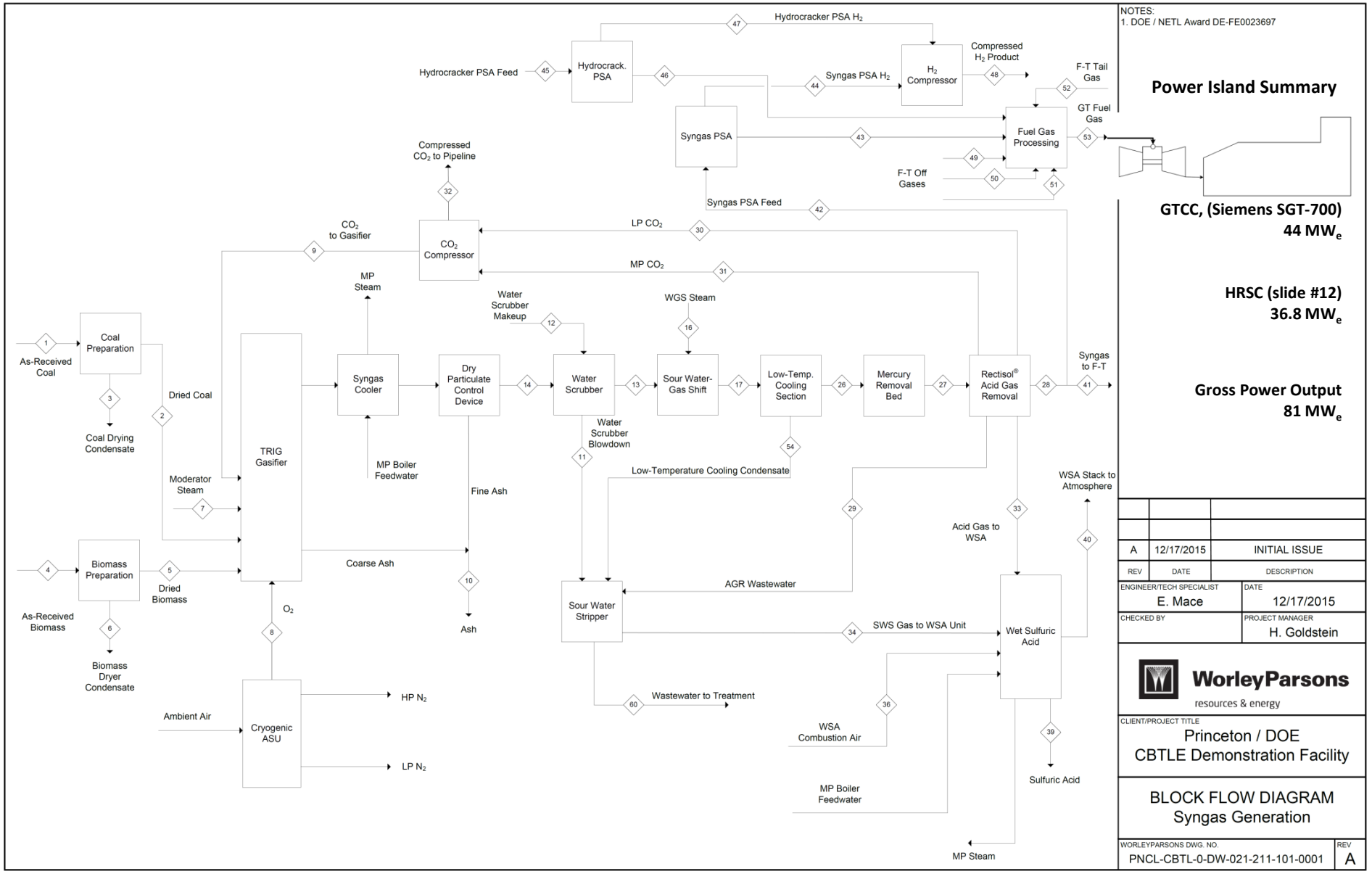
PLANT CARBON BALANCE (tCO_{2eq}/day)	
Lignite input	1,786
Biomass input	620
TOTAL INPUT	2,406
SPK product	415
Naphtha product	90
Captured CO_2	1,309
Vented, GT exhaust	494
Vented, WSA comb.	76
TOTAL OUTPUT	2,384

ON-SITE ELECTRICITY USE (MW_e)	
Air separation unit	11.6
Acid gas removal (incl. refrig.)	7.6
CO_2 compressor	2.8
Other	3.0
TOTAL	25.0

FEEDSTOCK INPUTS		
Total feedstock input	MW, HHV	293
Biomass % of feedstock	% of HHV	25%
Lignite	metric t/d A.R.	1,545
	MW, HHV	220
Biomass	metric t/d A.R.	553
	MW, HHV	73
LIQUID OUTPUTS		
Synthetic Paraffinic Kerosene (SPK)	standard barrels/day	1,125
	lbs/hour	12,304
	BTU/lb, LHV	18,401
	million BTU/hr, LHV	226.4
	MW, LHV	66
Synthetic naphtha	standard barrels/day	277
	lbs/hour	2,710
	BTU/lb, LHV	18,710
	million BTU/hr, LHV	50.7
	MW, LHV	15
Total liquids production	barrels/day (STP)	1,402
	MW, LHV	81
ELECTRICITY		
GTCC gross generation (SGT-700 GT)	MW_e	44
HRSC gross generation	MW_e	37
On-site use, MW_e	MW_e	25
Net electricity production	MW_e	56

* Sources
- Feedstock inputs and CO_2 captured and vented values from WP.
- Liquid flows and carbon values from EFT.
- Electricity: *GT World* for GTCC, Politecnico di Milano for HRSC, Princeton estimates for on-site use.

Syngas Production Process Flow Diagram



WorleyParsons
resources & energy

Princeton Coal and Biomass to Liquids and Energy - Heat and Material Balance Table
Gasifier (See Block Flow Diagram PNCL-CBTL-0-DW-021-211-101-0001)

PNCL-CBTL-0-HT-021-0001 — **Rev A 14-Dec-2015**

STREAM	1	2	3	4	5	6	7	8	9	10	11	12	13
Description	**As-Received Coal**	**Dried Coal**	**Coal Drying Condensate**	**As-Received Biomass**	**Dried Biomass**	**Biomass Drying Condensate**	**Moderator Steam**	**Oxygen**	**CO_2 to Gasifier**	**Ash**	**Water Scrubber Blowdown**	**Water Scrubber Makeup**	**Raw Syngas from Water Scrubber**
Vapors and Liquids													
Mole Flow, lbmole/hr	0	0	2,373	0	0	939	2,434	2,002	489	0	406	755	11,086
Mass Flow, lb/hr	0	0	42,754	0	0	16,916	43,843	64,151	21,457	0	7,327	13,594	250,295
Solids													
Mass Flow, lb/hr													
Coal	141,907	99,153	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	50,809	33,893	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	18,469	0	0	0
Total	141,907	99,153	0	50,809	33,893	0	0	0	0	18,469	0	0	0
All Phases													
Total Mass Flow, lb/hr	141,907	99,153	42,754	50,809	33,893	16,916	43,843	64,151	21,457	18,469	7,327	13,594	250,295
Total Mole Flow, lbmole/hr	N/A	N/A	2,373	N/A	N/A	939	2,434	2,002	489	N/A	406	755	11,086
Temperature, °F	64	241	213	64	241	213	797	60	110	121	375	59	369
Pressure, psia	14.6	14.6	14.3	14.6	14.6	14.3	797.7	750.0	896.5	14.6	630.0	14.6	610.0
Molar Vapor Frac	N/A	N/A	0.00	N/A	N/A	0.00	1.00	1.00	1.00	N/A	0.00	0.00	1.00
Enthalpy, Btu/lb	-3,503	-1,990	-6,719	-4,187	-2,785	-6,719	-5,475	-11	-3,865	-337	-6,495	-6,886	-3,387
Density, lb/ft^3	96.7	96.7	49.9	81.7	81.7	49.9	1.2	4.5	9.6	217.7	54.3	53.3	1.6
Molecular Weight	N/A	N/A	18.0	N/A	N/A	18.0	18.0	32.0	43.9	N/A	18.0	18.0	22.6

Notes

1. Flow rates represent the entire facility.
2. Enthalpies are referenced to the constituent elements in their standard states at 77 °F and 14.696 psia.
3. Coal, biomass and ash densities are calculated on a dry basis.
4. Ash includes unburned carbon.

WorleyParsons
resources & energy

Princeton Coal and Biomass to Liquids and Energy - Heat and Material Balance Table
Sour Shift and Low-Temperature Cooling (See Block Flow Diagram PNCL-CBTL-0-DW-021-211-101-0001)

PNCL-CBTL-0-HT-021-0001 — **Rev A 14-Dec-2015**

STREAM	14	15	16	17	18	19	20	21	22	23	24	25	26
Description	**Sour Shift Bypass**	**Syngas to Sour Shift**	**Sour Shift Steam**	**Cooled Shifted Syngas**	**Low-Temperature Cooler 1 Feed**	**Low-Temperature Cooler 1 Condensate**	**Low-Temperature Cooler 2 Feed**	**Low-Temperature Cooler 2 Condensate**	**Low-Temperature Cooler 3 Feed**	**Low-Temperature Cooler 3 Condensate**	**Low-Temperature Cooler 4 Feed**	**Low-Temperature Cooler 4 Condensate**	**Mercury Removal Bed Feed**
Vapors and Liquids													
Mole Flow, lbmole/hr	5,229	5,857	1,235	7,092	12,322	1,176	11,145	1,478	9,668	332	9,336	490	8,846
Mass Flow, lb/hr	118,064	132,231	22,257	154,488	272,552	21,211	251,341	26,637	224,704	5,983	218,720	8,809	209,911
Solids													
Mass Flow, lb/hr													
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0
All Phases													
Total Mass Flow, lb/hr	118,064	132,231	22,257	154,488	272,552	21,211	251,341	26,637	224,704	5,983	218,720	8,809	209,911
Total Mole Flow, lbmole/hr	5,229	5,857	1,235	7,092	12,322	1,176	11,145	1,478	9,668	332	9,336	490	8,846
Temperature, °F	374	374	797	372	372	332	332	271	271	242	242	100	100
Pressure, psia	610.0	610.0	797.7	584.0	584.0	574.5	574.5	565.0	565.0	555.5	555.5	546.0	546.0
Molar Vapor Frac	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00
Enthalpy, Btu/lb	-3,387	-3,387	-5,475	-3,849	-3,649	-6,565	-3,495	-6,627	-3,259	-6,652	-3,203	-6,693	-3,153
Density, lb/ft^3	1.6	1.6	1.2	1.5	1.5	46.5	1.6	48.3	1.7	49.1	1.8	52.0	2.3
Molecular Weight	22.6	22.6	18.0	21.8	22.1	18.0	22.6	18.0	23.2	18.0	23.4	18.0	23.7

Notes

1. Flow rates represent the entire facility.
2. Enthalpies are referenced to the constituent elements in their standard states at 77 °F and 14.696 psia.
3. Coal, biomass and ash densities are calculated on a dry basis.
4. Ash includes unburned carbon.

WorleyParsons
resources & energy

Princeton Coal and Biomass to Liquids and Energy - Heat and Material Balance Table

AGR, CO_2 Compressor and WSA (See Block Flow Diagram PNCL-CBTL-0-DW-021-211-101-0001)

PNCL-CBTL-0-HT-021-0001 Rev A 14-Dec-2015

STREAM	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Description	Acid Gas Removal Feed	Sweetened Syngas	AGR Wastewater	LP CO_2 to Compressor	MP CO_2 to Compressor	Compressed CO_2 to Pipeline	Acid Gas to WSA Unit	SWS Gas to WSA Unit	Mixed WSA Feed	WSA Combustion Air	Hydrogen Peroxide to SO_2 Scrubber	Acid Diluent Water	Sulfuric Acid to Storage	WSA Stack to Atmosphere
Vapors and Liquids														
Mole Flow, lbmole/hr	8,846	5,392	737	2,669	558	2,737	213	53	266	37,413	0	14	62	845
Mass Flow, lb/hr														
Total	209,911	59,945	13,476	117,411	23,924	119,877	8,450	1,027	9,477	1,078,806	9	261	4,634	25,288
Solids														
Mass Flow, lb/hr														
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0
All Phases														
Total Mass Flow, lb/hr	209,911	59,945	13,476	117,411	23,924	119,877	8,450	1,027	9,477	1,078,806	9	261	4,634	25,288
Total Mole Flow, lbmole/hr	8,846	5,392	737	2,669	558	2,737	213	53	266	37,413	0	14	62	845
Temperature, °F	99	83	100	89	88	110	105	187	120	64	59	59	72	160
Pressure, psia	536.0	500.0	24.9	20.0	50.0	2,215.0	29.0	23.0	23.0	14.6	50.0	14.6	14.9	14.6
Molar Vapor Frac	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	1.00
Enthalpy, Btu/lb	-3,153	-1,521	-6,743	-3,844	-3,809	-3,932	-3,100	-2,970	-3,086	-49	-2,418	-6,886	-3,802	-1,466
Density, lb/ft^3	2.2	0.9	58.8	0.2	0.4	46.9	0.2	0.1	0.1	0.1	89.5	53.3	60.7	0.1
Molecular Weight	23.7	11.1	18.3	44.0	42.9	43.8	39.6	19.5	35.6	28.8	34.0	18.0	74.8	29.9

Notes

1. Flow rates represent the entire facility.
2. Enthalpies are referenced to the constituent elements in their standard states at 77 °F and 14.696 psia.
3. Coal, biomass and ash densities are calculated on a dry basis.
4. Ash includes unburned carbon.

WorleyParsons
resources & energy

Princeton Coal and Biomass to Liquids and Energy - Heat and Material Balance Table

H2 Recovery & Fuel Gas (See Block Flow Diagram PNCL-CBTL-0-DW-021-211-101-0001)

PNCL-CBTL-0-HT-021-0001 Rev A 14-Dec-2015

STREAM	41	42	43	44	45	46	47	48	49	50	51	52	53
Description	Sweetened Syngas to F-T	Syngas PSA Feed	Syngas PSA Offgas	Syngas PSA H_2	Hydrocracker PSA Feed	Hydrocracker PSA Off Gas	Hydrocracker PSA H_2	Compressed H_2 Product	Main Fractionator Off Gas	F-T Middle Distillate Off Gas	F-T Heavy Distllate Off Gas	F-T Tail Gas	GT Fuel Gas
Vapors and Liquids													
Mole Flow, lbmole/hr	5,045	347	175	173	388	99	288	461	37	5	4	733	1,052
Mass Flow, lb/hr	56,085	3,860	3,501	358	1,882	1,300	582	940	1,640	162	111	15,185	21,898
Solids													
Mass Flow, lb/hr													
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0
All Phases													
Total Mass Flow, lb/hr	56,085	3,860	3,501	358	1,882	1,300	582	940	1,640	162	111	15,185	21,898
Total Mole Flow, lbmole/hr	5,045	347	175	173	388	99	288	461	37	5	4	733	1,052
Temperature, °F	83	86	90	110	110	90	110	110	110	90	250	110	237
Pressure, psia	500.0	500.0	34.7	490.0	714.7	34.7	704.7	849.7	24.7	14.7	14.7	341.2	439.7
Molar Vapor Frac	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Enthalpy, Btu/lb	-1,521	-1,521	-1,676	107	-644	-986	110	109	-1,028	-1,595	-2,259	-2,071	-1,805
Density, lb/ft^3	0.9	0.9	0.1	0.2	0.6	0.1	0.2	0.3	0.2	0.1	0.1	1.2	1.2
Molecular Weight	11.1	11.1	20.1	2.1	4.9	13.1	2.0	2.0	44.8	34.7	28.2	20.7	20.8

Notes

1. Flow rates represent the entire facility.
2. Enthalpies are referenced to the constituent elements in their standard states at 77 °F and 14.696 psia.
3. Coal, biomass and ash densities are calculated on a dry basis.
4. Ash includes unburned carbon.

GT Fuel Gas (stream 53) details on next page

WorleyParsons
resources & energy

Princeton Coal and Biomass to Liquids and Energy - Heat and Material Balance Table

Sour Water Stripper (See Block Flow Diagram PNCL-CBTL-0-DW-021-211-101-0001)

PNCL-CBTL-0-HT-021-0001 Rev A 14-Dec-2015

STREAM	54	55	56	57	58	59	60
Description	Low-Temperature Cooling Condensate	Sour Water Drum Off Gas	Sour Water Stripper Feed	NaOH to Sour Water Stripper	Sour Water Stripper Overhead	Sour Water Stripper Bottoms to Cooler	Wastewater to Treatment
Vapors and Liquids							
Mole Flow, lbmole/hr	3,476	10	4,608	5	43	4,571	4,571
Mass Flow, lb/hr	62,641	230	83,214	86	797	82,503	82,503
Solids							
Mass Flow, lb/hr							
Coal	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0
All Phases							
Total Mass Flow, lb/hr	62,641	230	83,214	86	797	82,503	82,503
Total Mole Flow, lbmole/hr	3,476	10	4,608	5	43	4,571	4,571
Temperature, °F	265	220	221	59	178	250	120
Pressure, psia	546.0	27.4	47.4	14.6	23.0	30.0	27.4
Molar Vapor Frac	0.00	1.00	0.00	0.00	1.00	0.00	0.00
Enthalpy, Btu/lb	-6,618	-4,399	-6,633	-6,486	-2,558	-6,636	-6,766
Density, lb/ft^3	48.4	0.1	59.1	76.2	0.1	58.7	61.7
Molecular Weight	18.0	23.0	18.1	18.4	18.7	18.1	18.1

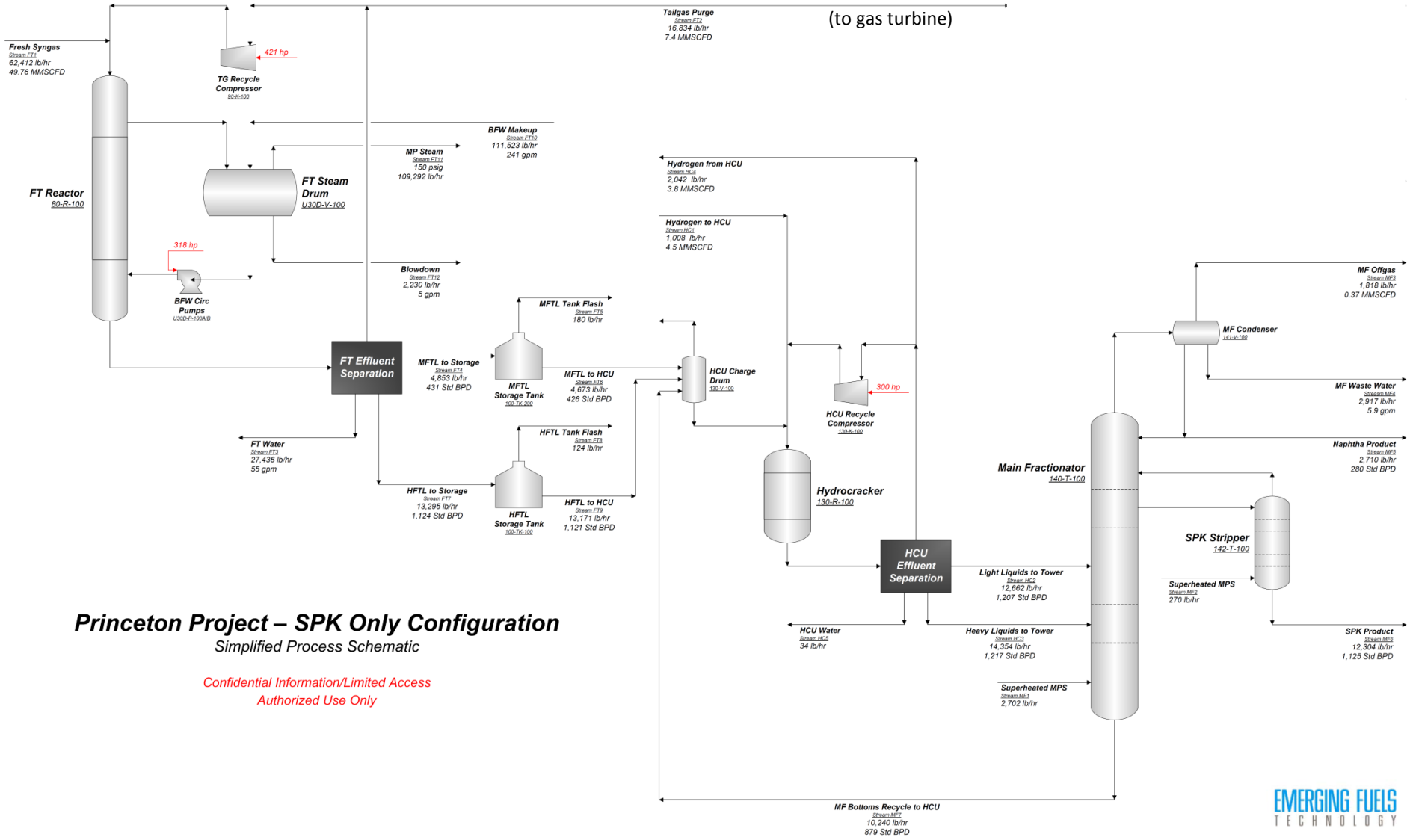
Notes

1. Flow rates represent the entire facility.
2. Enthalpies are referenced to the constituent elements in their standard states at 77 °F and 14.696 psia.
3. Coal, biomass and ash densities are calculated on a dry basis.
4. Ash includes unburned carbon.

GT Fuel Gas (stream 53) details

Mole Flow, lbmole/hr		**Vol %**
Ar	6	0.58
CO	230	21.88
CO_2	70	6.68
H_2	217	20.60
H_2O	7	0.66
N_2	7	0.67
CH_4	429	40.79
C_2H_6	20	1.91
C_3H_8	16	1.53
n-C_4H_{10}	4	0.40
n-C_5H_{12}	4	0.35
n-C_6H_{14}	2	0.23
n-C_7+	2	0.15
C_2=	2	0.21
C_3=	7	0.70
1-C_4=	5	0.44
1-C_5=	1	0.11
1-C_6=	1	0.05
i-C_4H_{10}	10	0.94
i-C_5H_{12}	6	0.59
2-Methylpentane	3	0.30
2-Methylhexane	1	0.11
Ethanol	1	0.05
Total Mole Flow, lbmole/hr	1,052	100.00
Total Mass Flow, lb/hr	21,898	
Temperature, °F	237	
Pressure, psia	439.7	
Density, lb/ft^3	1.2	
Molecular Weight	20.8	

F-T Synthesis and Refining Process Flow Diagram



Princeton Project – SPK Only Configuration

Simplified Process Schematic

Confidential Information/Limited Access
Authorized Use Only

EMERGING FUELS TECHNOLOGY

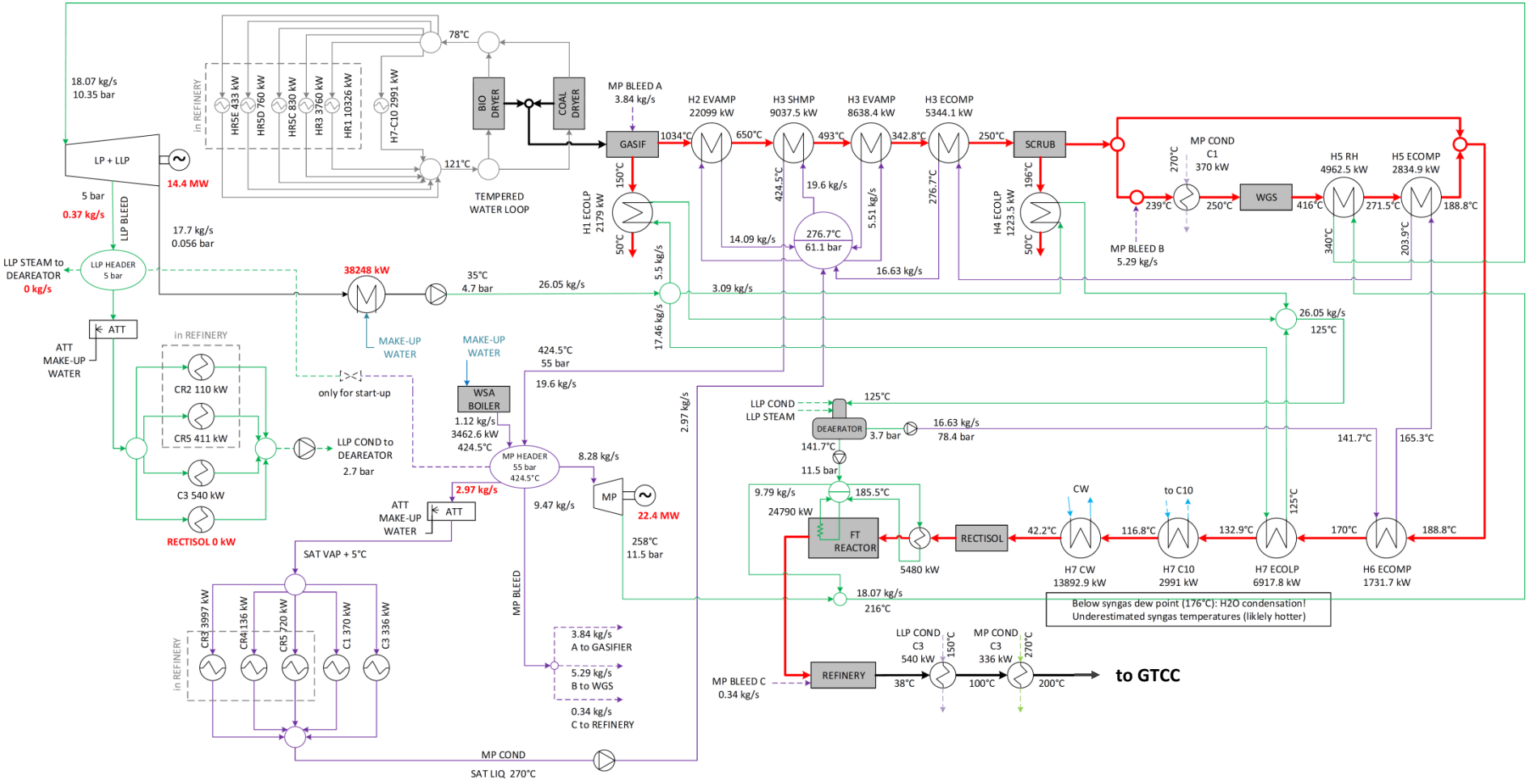
Stream Designation	FT1	FT2	FT3	FT4	FT5	FT6	FT7
Stream Description	Fresh Syngas	Tailgas Purge	FT Water	MFTL to Storage	MFTL Tank Flash	MFTL to HCU	HFTL to Storage
Property [Units]							
Pressure [psig]	375.00	326.50	50.00	150.00	0.00	50.00	150.00
Vapour Fraction	1.00	1.00	0.00	0.04	1.00	0.00	0.05
Temperature [F]	130.00	109.86	110.71	109.52	90.00	250.00	320.98
Volumetric Flow							
-Liquid (Actual GPM)	0.00	0.00	55.22	13.58	0.00	14.51	37.80
-Liquid (std barrels/day)	0.00	0.00	1885.51	456.10	0.00	439.13	1130.81
-Gas (MMSCFD)	49.76	7.38	0.00	0.02	0.05	0.00	0.02
-Gas (ACFM)	1490.46	234.51	0.05	1.08	34.45	0.00	1.77
Molar Flow [lbmole/hr]	5474.11	812.41	1517.79	40.61	5.19	35.42	42.00
Mass Flow [lb/hr]	62411.95	16834.43	27436.33	4852.70	179.85	4672.84	13294.79
-Vapor	62411.95	16834.43	0.93	42.29	179.85	0.00	48.28
-Liquid	0.00	0.00	1.16	4810.41	0.00	4672.84	13246.51
-Aqueous	0.00	0.00	27434.24	0.00	0.00	0.00	0.00
Molecular Weight	11.40	20.72	18.08	119.50	34.68	131.93	316.53
Lower Heating Value [Btu/lb]	10,636	12,695	48	18,181	14,375	18,328	18,168
Heat Flow (LHV Basis) [MMBtu/hr]	663.79	213.71	1.32	88.23	2.59	85.64	241.53

Stream Designation	FT8	FT9	FT10	FT11	FT12	HC1	HC2
Stream Description	HFTL Tank Flash	HFTL to HCU	BFW Makeup	MP Steam	Blowdown	Hydrogen to HCU	Light Liquids to Tower
Property [Units]							
Pressure [psig]	0.00	50.00	155.00	150.00	135.00	835.00	42.00
Vapour Fraction	1.00	0.00	0.00	1.00	0.01	1.00	0.08
Temperature [F]	250.00	250.07	287.07	366.58	358.27	120.00	110.23
Volumetric Flow							
-Liquid (Actual GPM)	0.00	36.01	240.90	0.00	4.97	0.00	36.01
-Liquid (std barrels/day)	0.00	1122.09	7651.68	0.00	151.15	0.00	1206.73
-Gas (MMSCFD)	0.04	0.00	0.00	55.15	0.01	4.55	0.08
-Gas (ACFM)	37.69	0.00	0.00	5028.20	1.38	62.31	16.19
Molar Flow [lbmole/hr]	4.38	37.62	6190.51	6066.70	123.81	500.00	112.36
Mass Flow [lb/hr]	123.48	13171.31	111522.62	109292.17	2230.45	1008.00	12662.15
-Vapor	123.48	0.00	0.00	109292.17	27.38	1008.00	236.81
-Liquid	0.00	13171.31	0.00	0.00	0.00	0.00	12425.34
-Aqueous	0.00	0.00	111522.62	0.00	2203.07	0.00	0.00
Molecular Weight	28.21	350.07	18.02	18.02	18.02	2.02	112.69
Lower Heating Value [Btu/lb]	12,069	18,225	0	0	0	51,489	18,583
Heat Flow (LHV Basis) [MMBtu/hr]	1.49	240.04	0.00	0.00	0.00	51.90	235.30

Stream Designation	HC3	HC4	HC5	MF1	MF2	MF3	MF4
Stream Description	Heavy Liquids to Tower	Hydrogen from HCU	HCU Water	Superheated MPS	Superheated MPS	MF Offgas	MF Waste Water
Property [Units]							
Pressure [psig]	37.00	700.00	50.00	17.00	17.00	10.00	10.00
Vapour Fraction	0.14	1.00	0.00	1.00	1.00	1.00	0.00
Temperature [F]	450.78	109.94	111.82	550.00	550.00	110.00	110.00
Volumetric Flow							
-Liquid (Actual GPM)	44.71	0.00	0.07	0.00	0.00	0.00	5.86
-Liquid (std barrels/day)	1216.81	0.00	2.33	0.00	0.00	0.00	200.12
-Gas (MMSCFD)	0.08	3.83	0.00	1.36	0.14	0.37	0.00
-Gas (ACFM)	27.37	60.79	0.00	849.36	84.94	163.65	0.00
Molar Flow [lbmole/hr]	61.94	420.80	1.89	149.97	15.00	40.58	161.90
Mass Flow [lb/hr]	14354.40	2042.16	34.00	2701.65	270.17	1818.22	2916.68
-Vapor	393.36	2042.16	0.00	2701.65	270.17	1818.22	0.00
-Liquid	13961.03	0.00	0.00	0.00	0.00	0.00	0.00
-Aqueous	0.00	0.00	34.00	0.00	0.00	0.00	2916.68
Molecular Weight	231.74	4.85	18.01	18.02	18.02	44.81	18.02
Lower Heating Value [Btu/lb]	18,342	31,594	0	0	0	18,957	0
Heat Flow (LHV Basis) [MMBtu/hr]	263.29	64.52	0.00	0.00	0.00	34.47	0.00

Stream Designation	MF5	MF6	MF7
Stream Description	Naphtha Product	SPK Product	MF Bottoms Recycle to HCU
Property [Units]			
Pressure [psig]	0.00	0.00	50.00
Vapour Fraction	0.01	0.00	0.00
Temperature [F]	100.00	100.00	250.14
Volumetric Flow			
-Liquid (Actual GPM)	8.29	33.49	28.26
-Liquid (std barrels/day)	276.98	1124.95	878.77
-Gas (MMSCFD)	0.00	0.00	0.00
-Gas (ACFM)	2.91	0.00	0.00
Molar Flow [lbmole/hr]	30.28	73.88	32.63
Mass Flow [lb/hr]	2710.22	12303.52	10239.72
-Vapor	25.70	0.00	0.00
-Liquid	2684.52	12291.50	10239.72
-Aqueous	0.00	12.02	0.00
Molecular Weight	89.52	166.54	313.78
Lower Heating Value [Btu/lb]	18,710	18,401	18,263
Heat Flow (LHV Basis) [MMBtu/hr]	50.71	226.40	187.01

Heat Exchange Network and Heat Recovery Steam Cycle Process Flow Diagram



Heat recovery steam cycle gross output: 36.8 MW_e