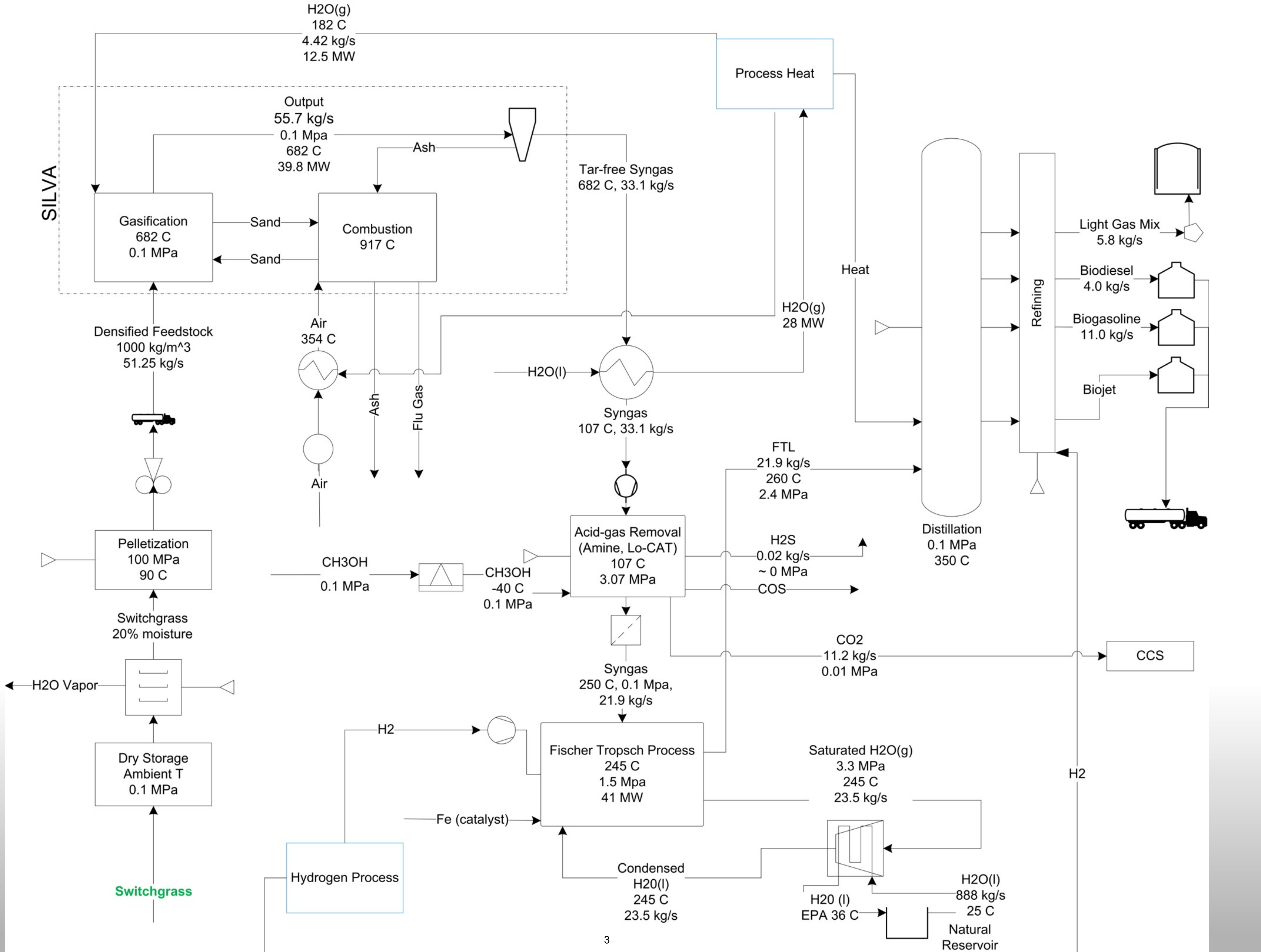
Biofuels Subgroup Progress Report

Alex, Lizzy, Ogie, Matt, and Kathryn
November 14, 2011

Outline

- Overall Design of Biofuels Plant
- Switchgrass
- Gasification & Tar Removal
- Acid Gas Removal
- Fischer-Tropsch Reactor
- Distillation
- Refining
- Final Products and Carbon Sequestration
- Concluding Thoughts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12.5 MW
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39.8 MW
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682 C, 33.1 kg/s
Gasification
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Combustion
917 C
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Light Gas Mix
5.8 kg/s
Biodiesel
4.0 kg/s
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Biojet
Refining
H2O(g)
28 MW
Densified Feedstock
1000 kg/m^3
51.25 kg/s
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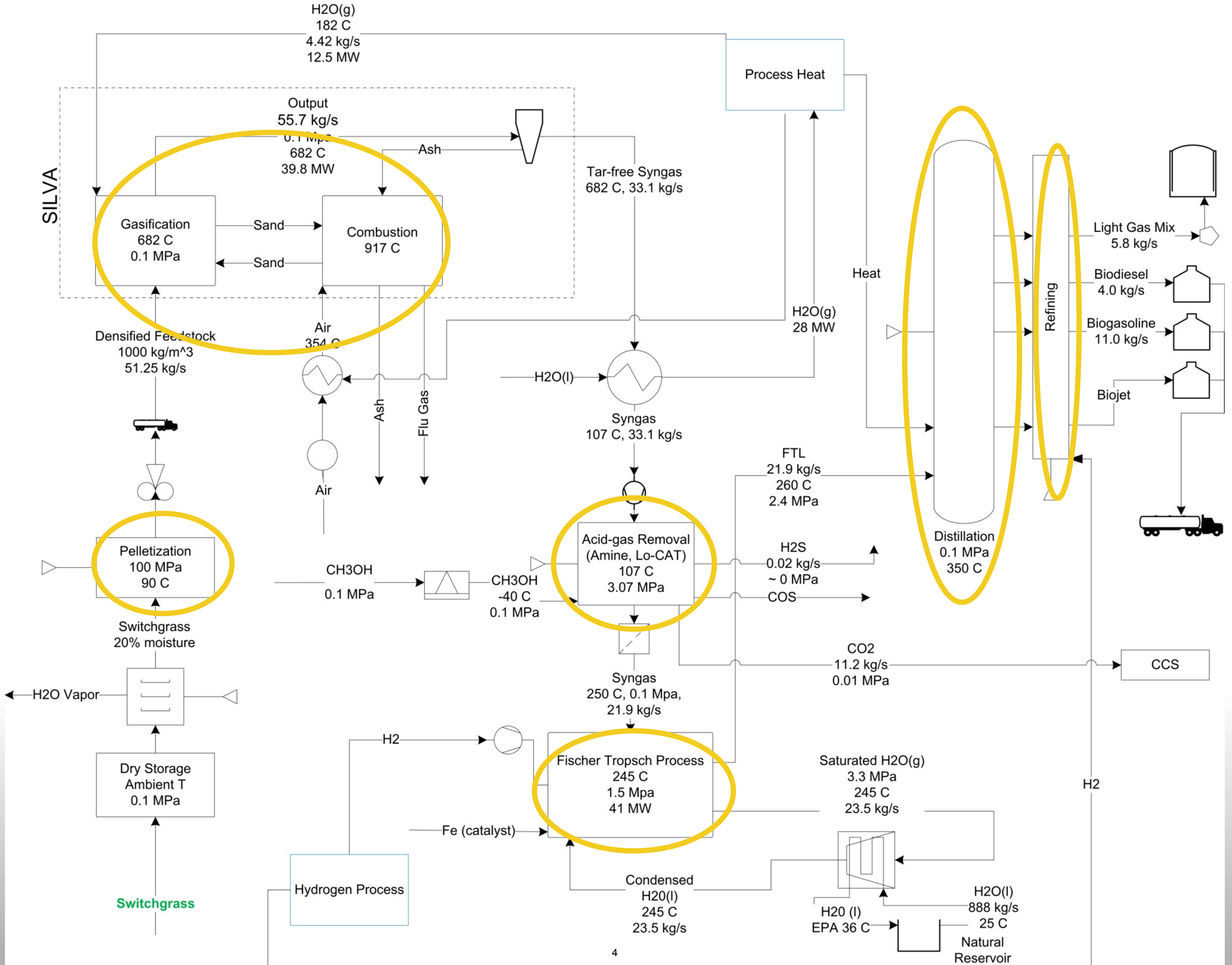
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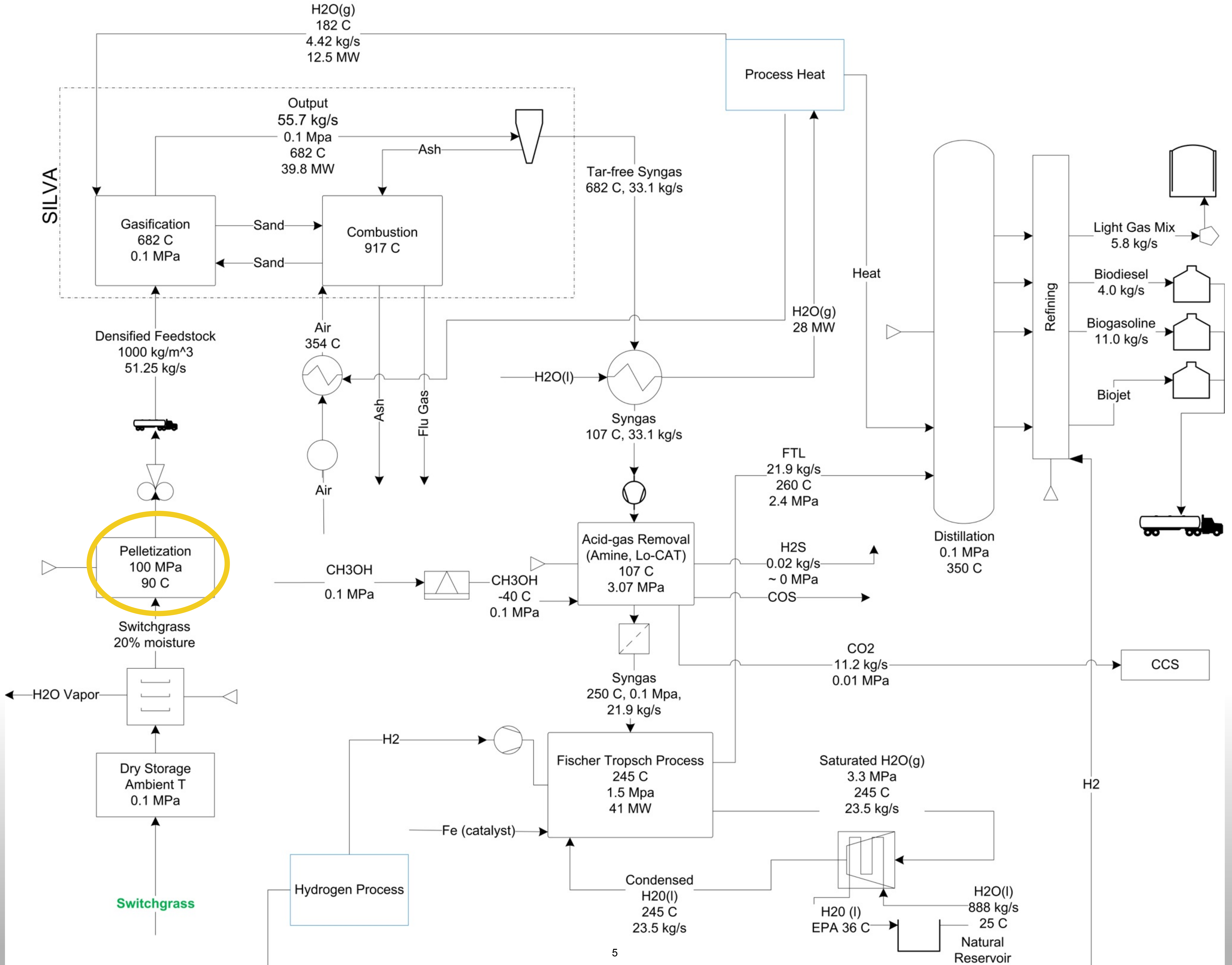
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Switchgrass I

Preparation

- Outsource switchgrass ("SG") production and preparation to local farmers (possibly in Texas or Minnesota)

- Densification

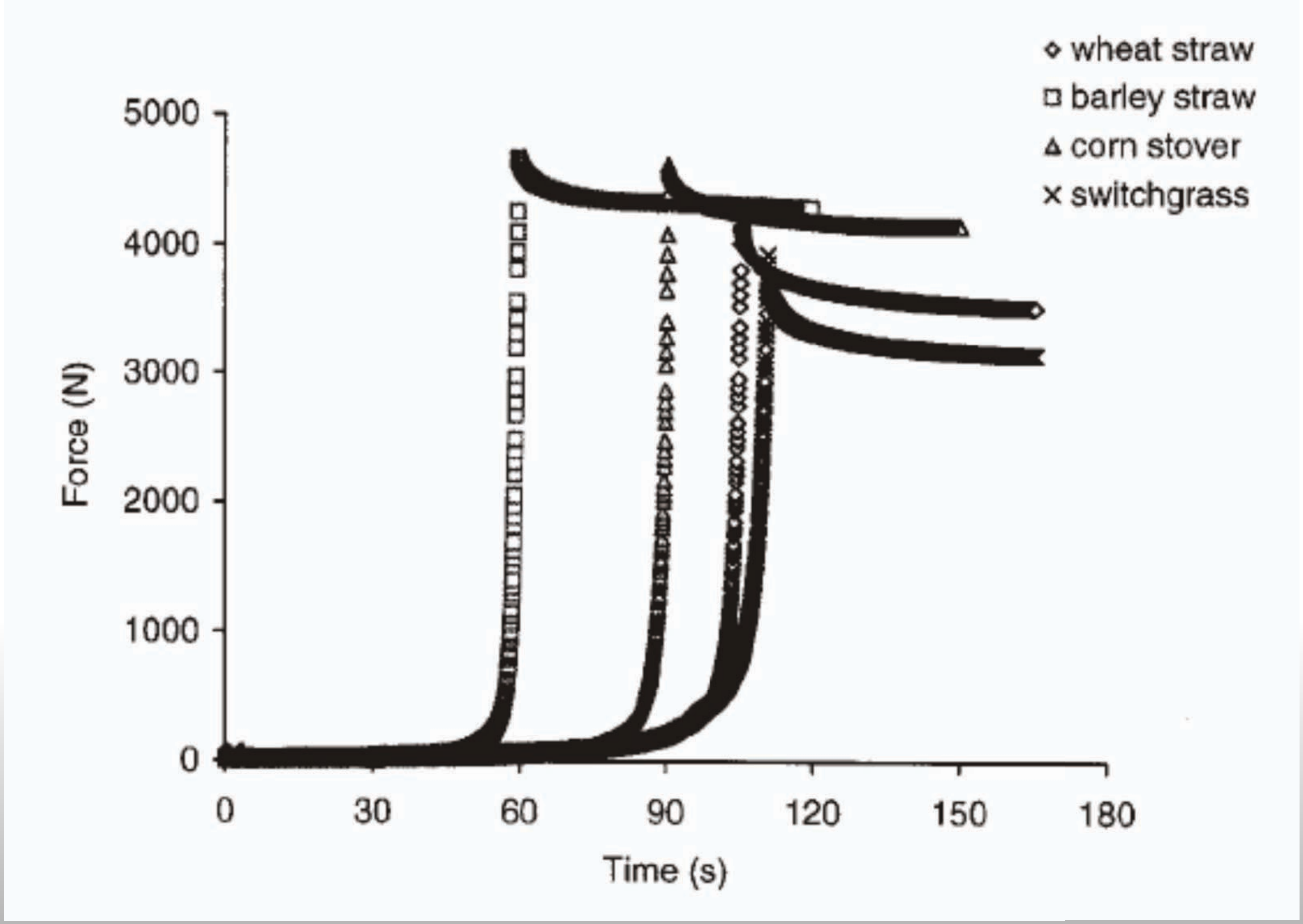
  - SG is originally 100 kg/m^3, 51.77% of which is lignin and cellulose

  - Densify at 137 MPa, 90°C with a screen size of 3.2 mm

  - New density is around 1000 kg/m^3, which is appropriate for injection into SILVA gasification.

Switchgrass II

Densification Graph

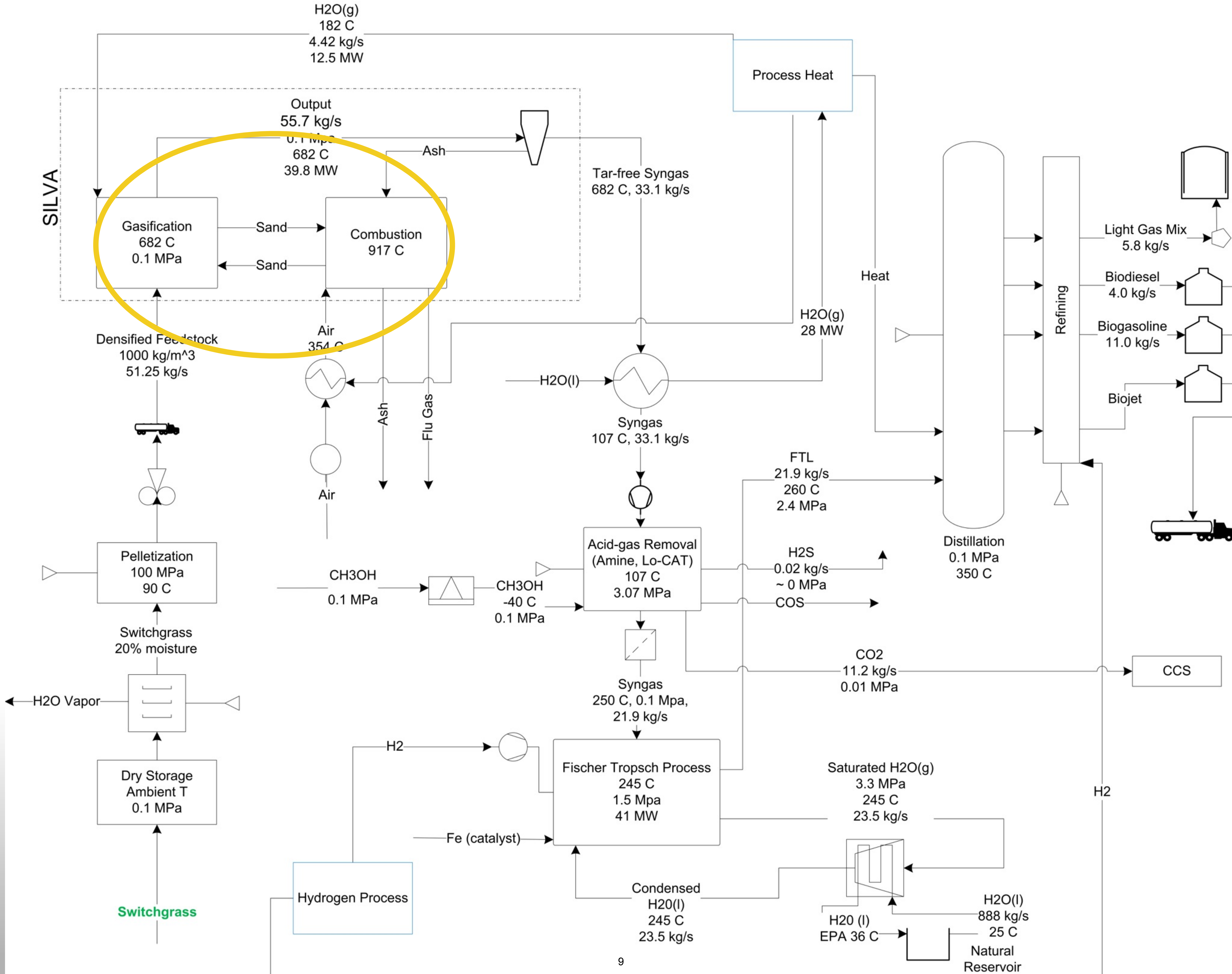


Switchgrass III

Preparation

- Moisture content: 20%
- Field drying
- We will use all components of SG in pellets.
- 3500 tons/day

Courtesy of Oak Ridge National Laboratory.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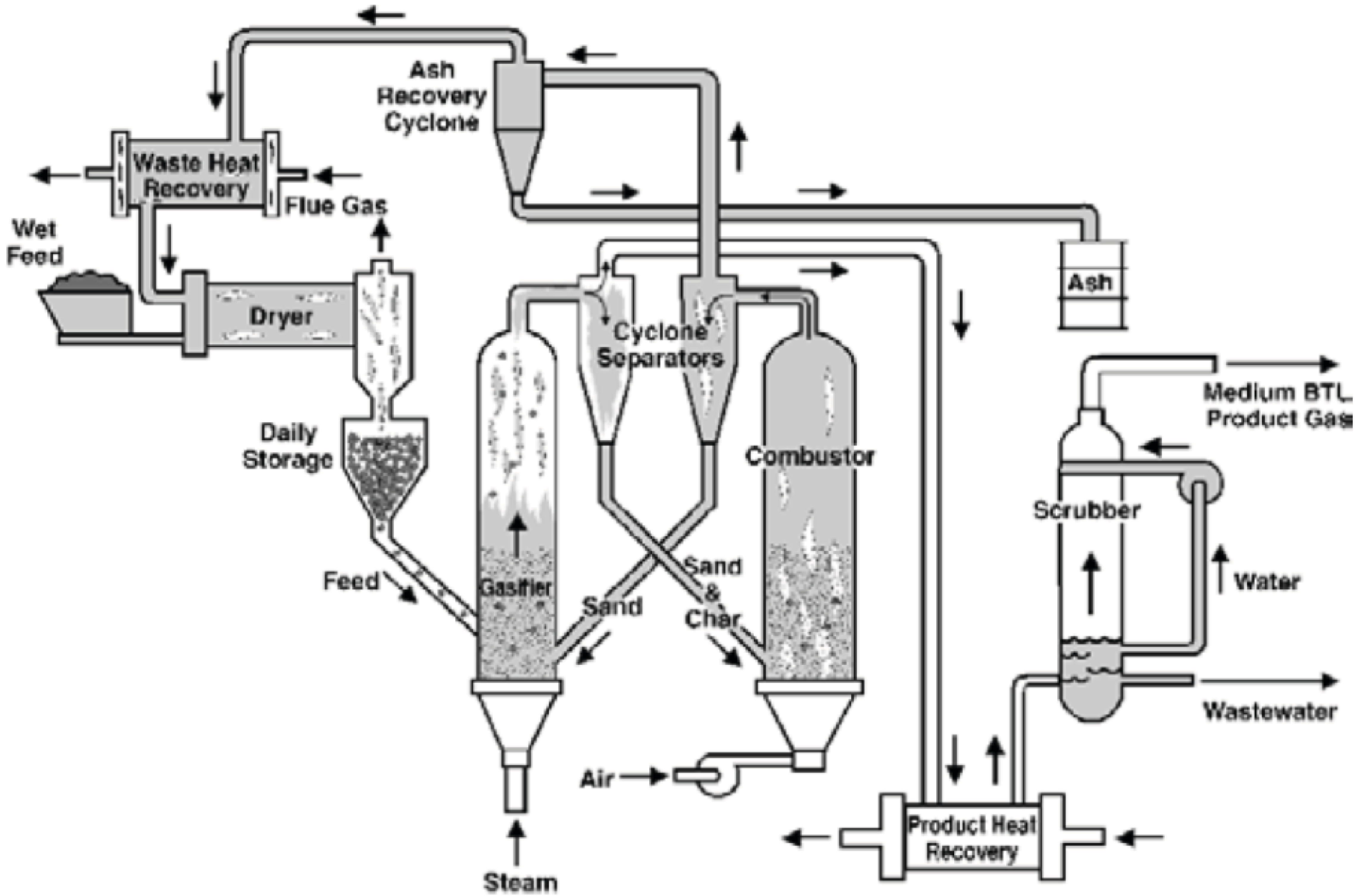
Gasification I

Silvagas Dual Fluidized Bed Cycle



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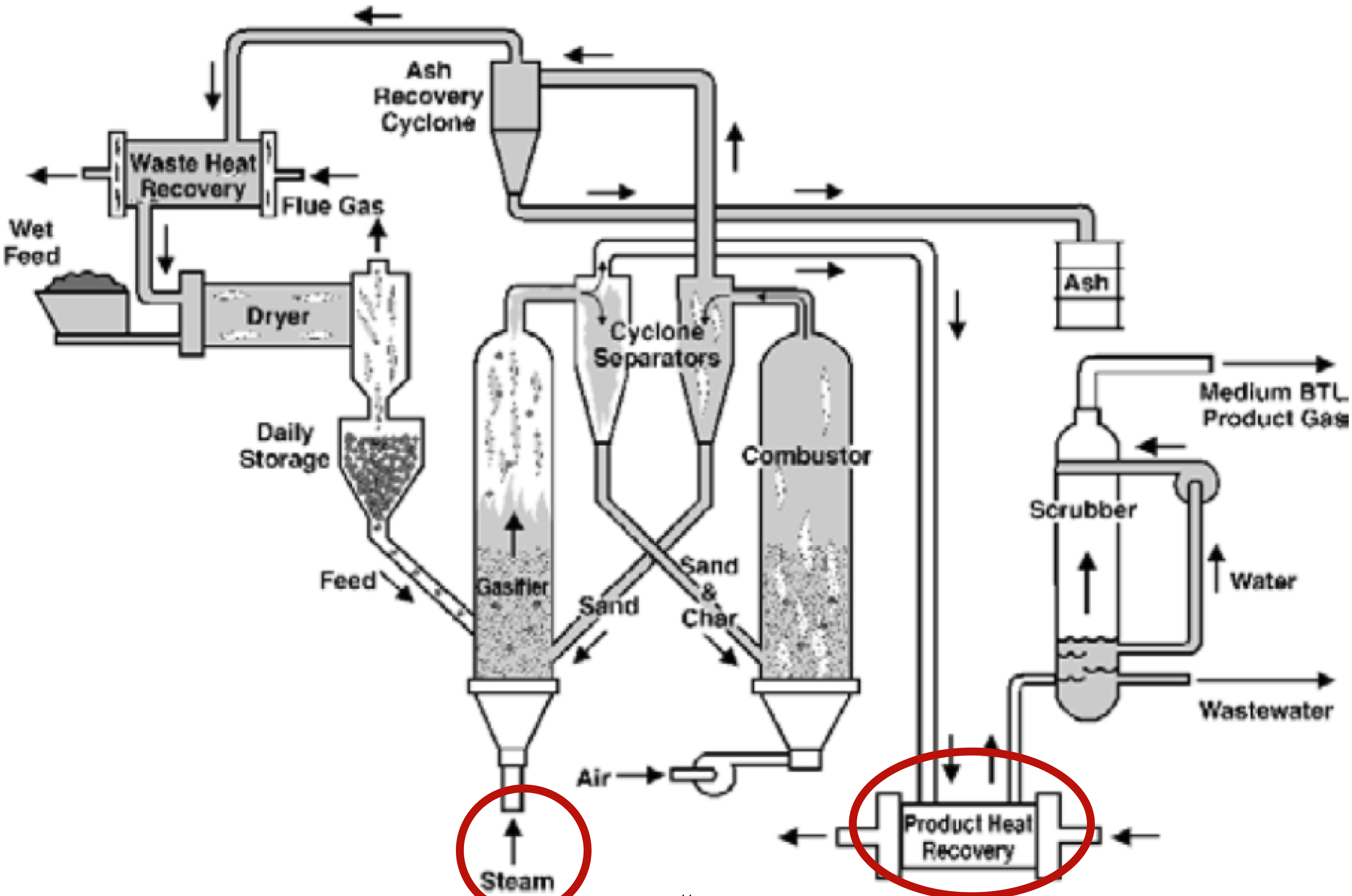

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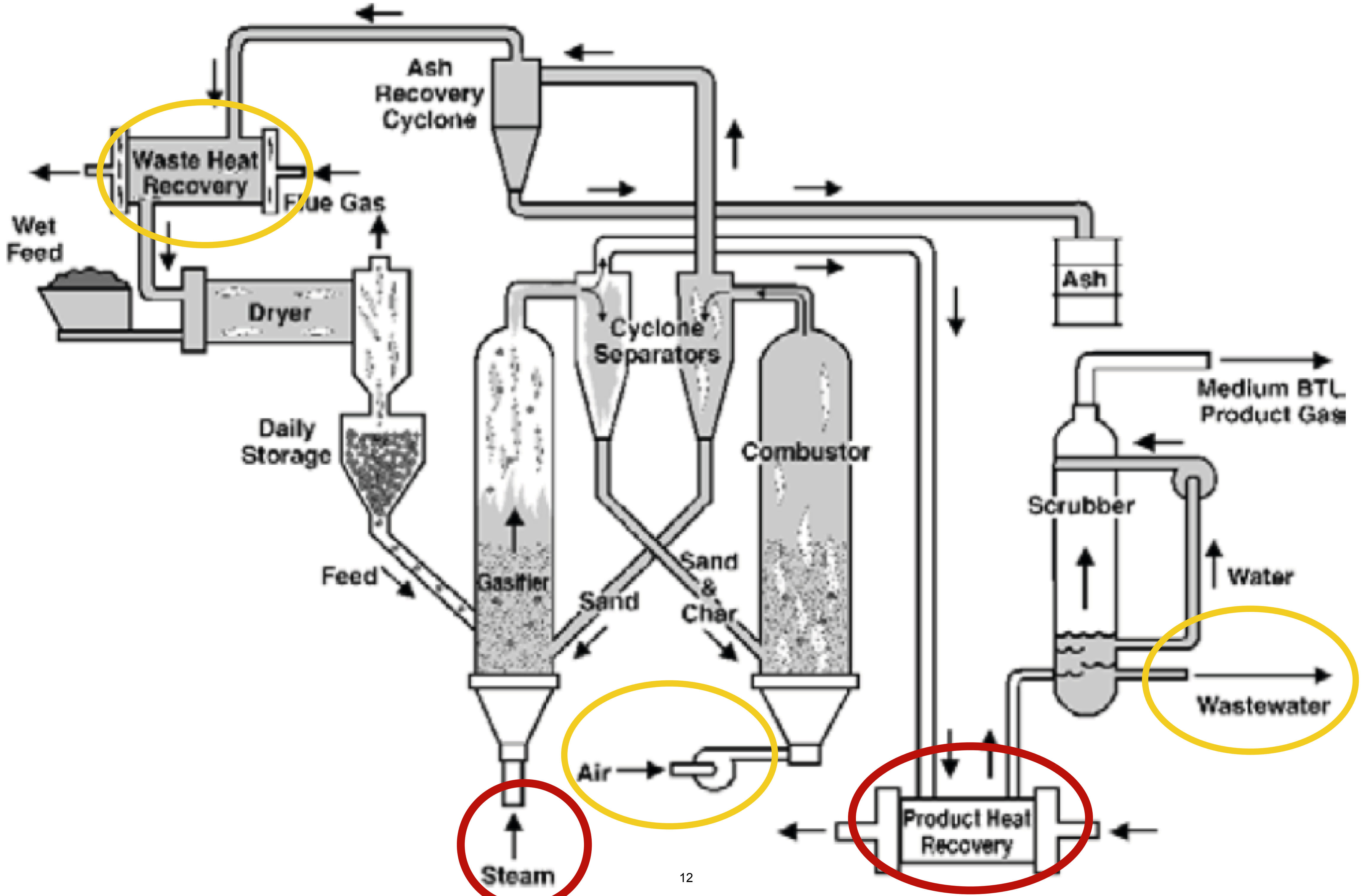
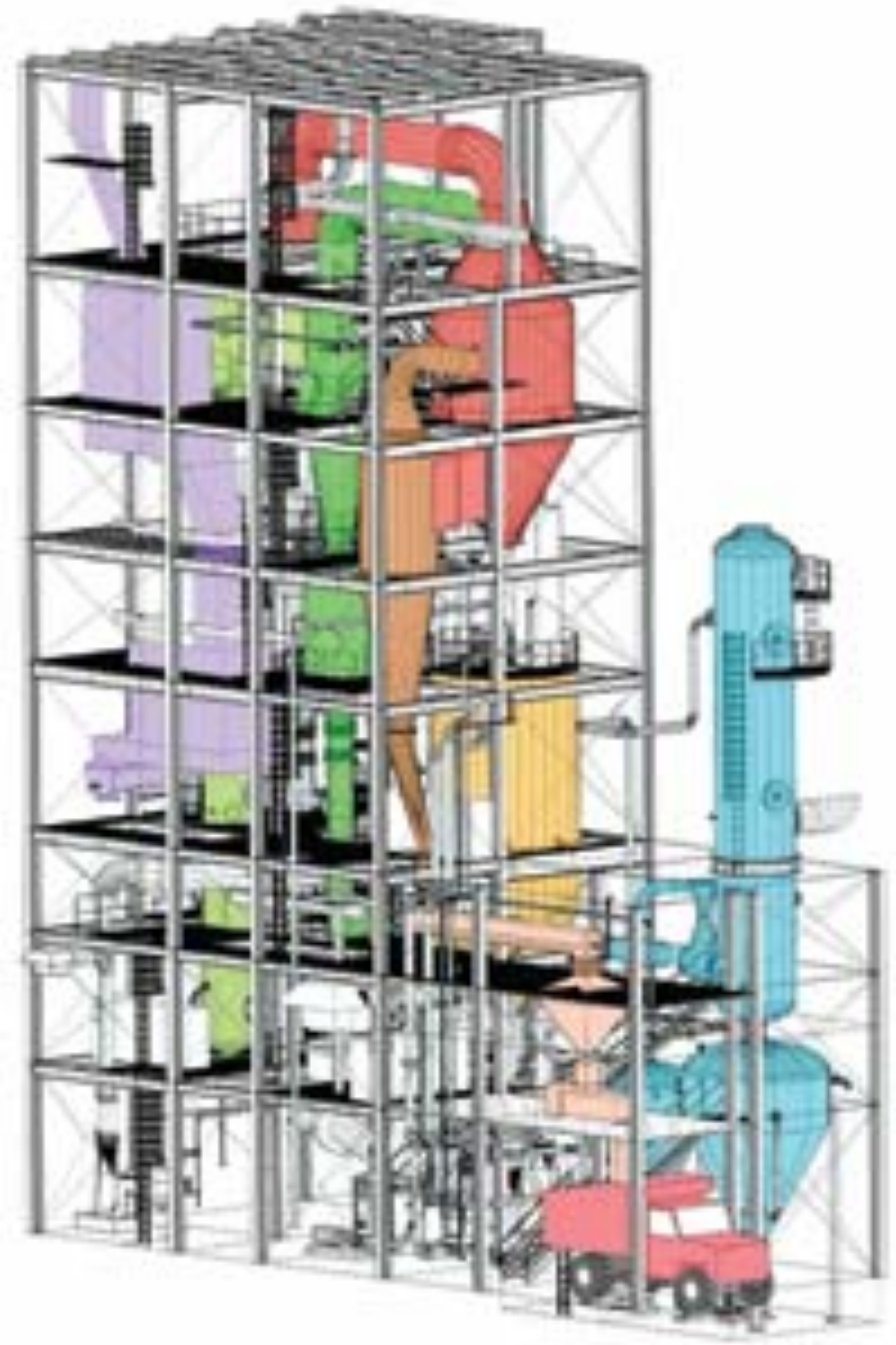


Gasification II

Inputs and Outputs

- Biomass Input: 41 kg/s dry, 20% moisture = 51.25 kg/s total
- Steam Input: 182°C, 4.42 kg/s
- Air Input: 354°C, 4 kg/s
- Total Mass Input: 55.67 kg/s
- Total Syngas Output: 33.2 kg/s, 800°C
- Total Flue Gas Output: 26.47 kg/s



Gasification III

Elemental Mass Balance

Major Element	Input (kmol/s)	Output in Syngas (kmol/s)	Output in Flue Gas (kmol/s)
Total Carbon	1.686	1.231	0.255
Total Hydrogen	4.114	1.442	2.672
Total Oxygen	1.942	1.060	0.882

Estimated flow rates calculated using http://chippewa.gtsav.gatech.edu/outreach/workshop/presentations/gfarris.pdf &Twin-Bed Gasification Concepts for Bio-SNG Production (Paisely)

Gasification IV

Composition of Syngas Output

Compound	% by Volume	Mass Flow (kg/s)
CO	47	18.459
H2	18	0.252
CO2	14.3	8.824
CH4	14.9	3.352
C2H4	4.7	1.849
C2H6	1.1	0.464
Total	**100**	33.200

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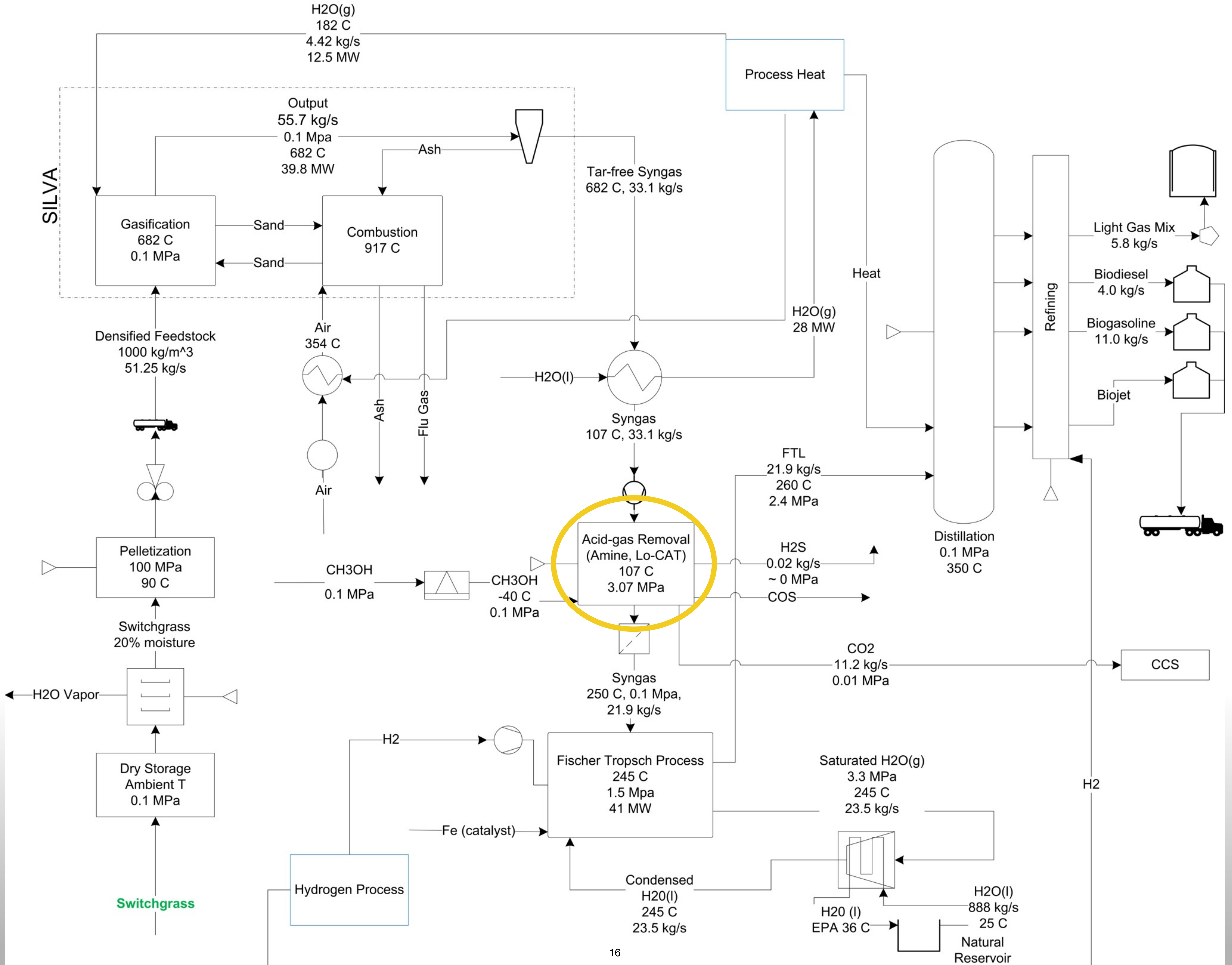

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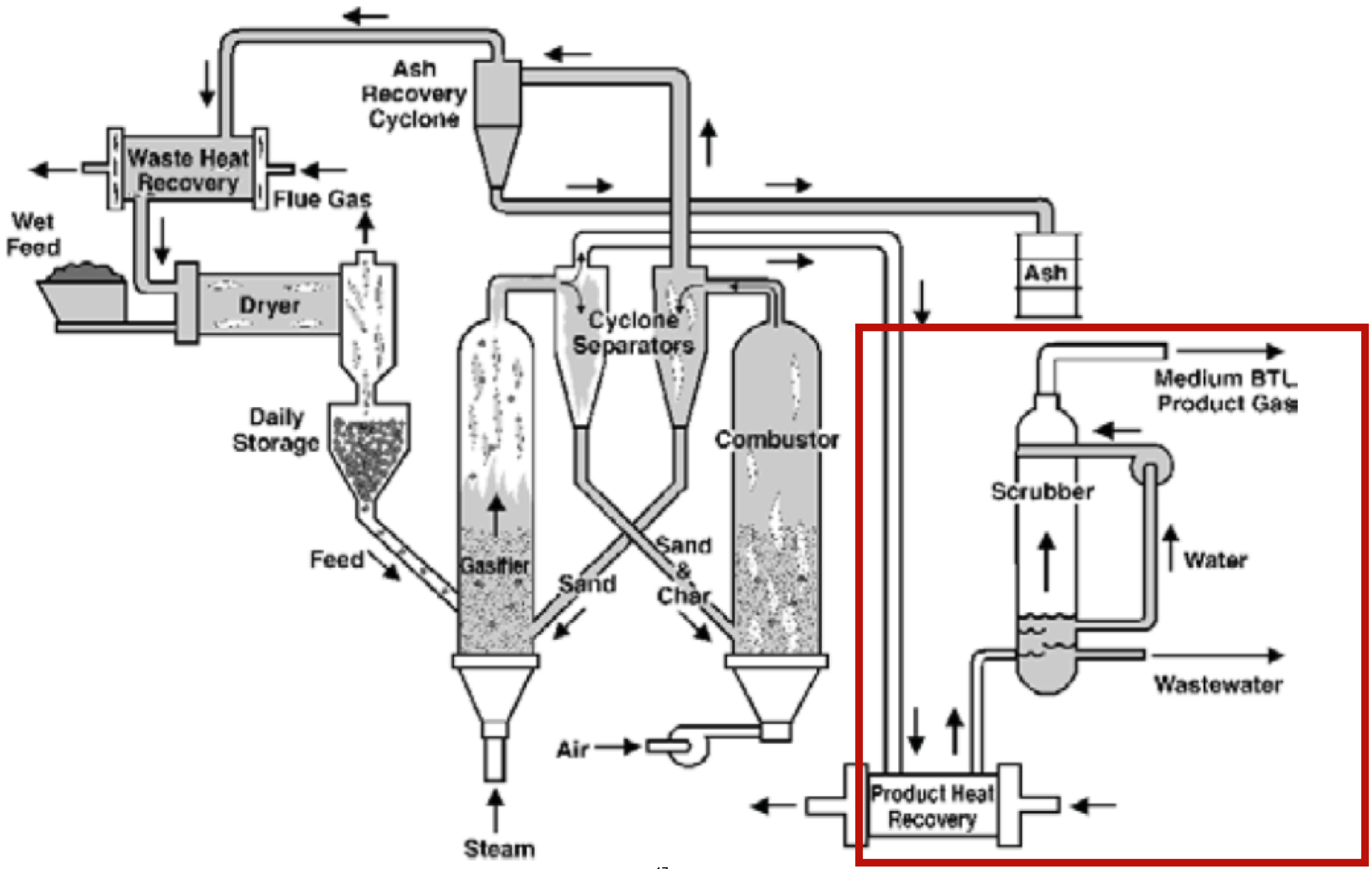
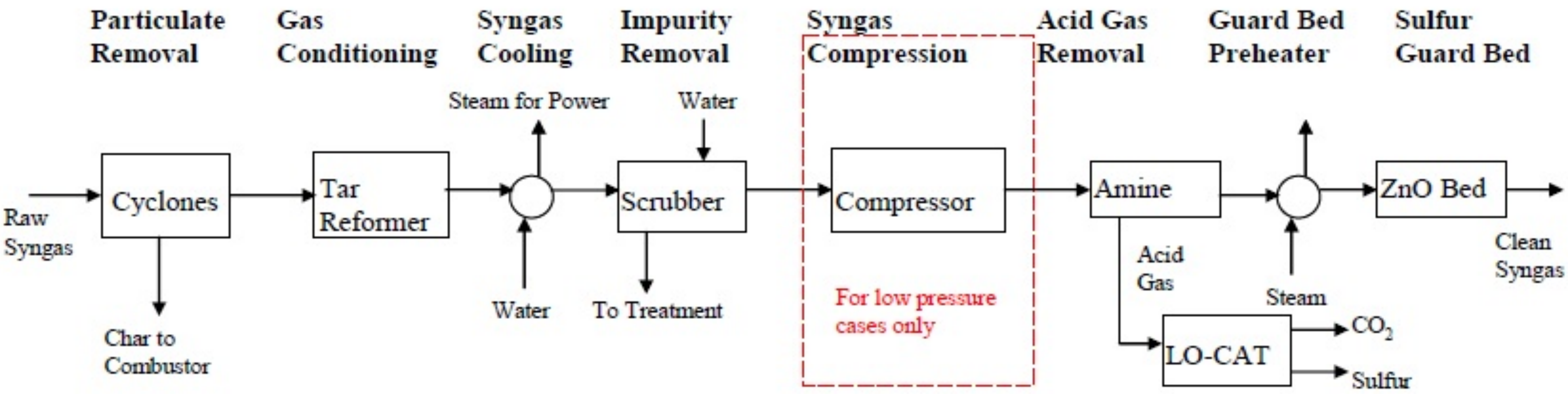
Acid Gas Removal I

Overlap with Silvagas Process



Acid Gas Removal II

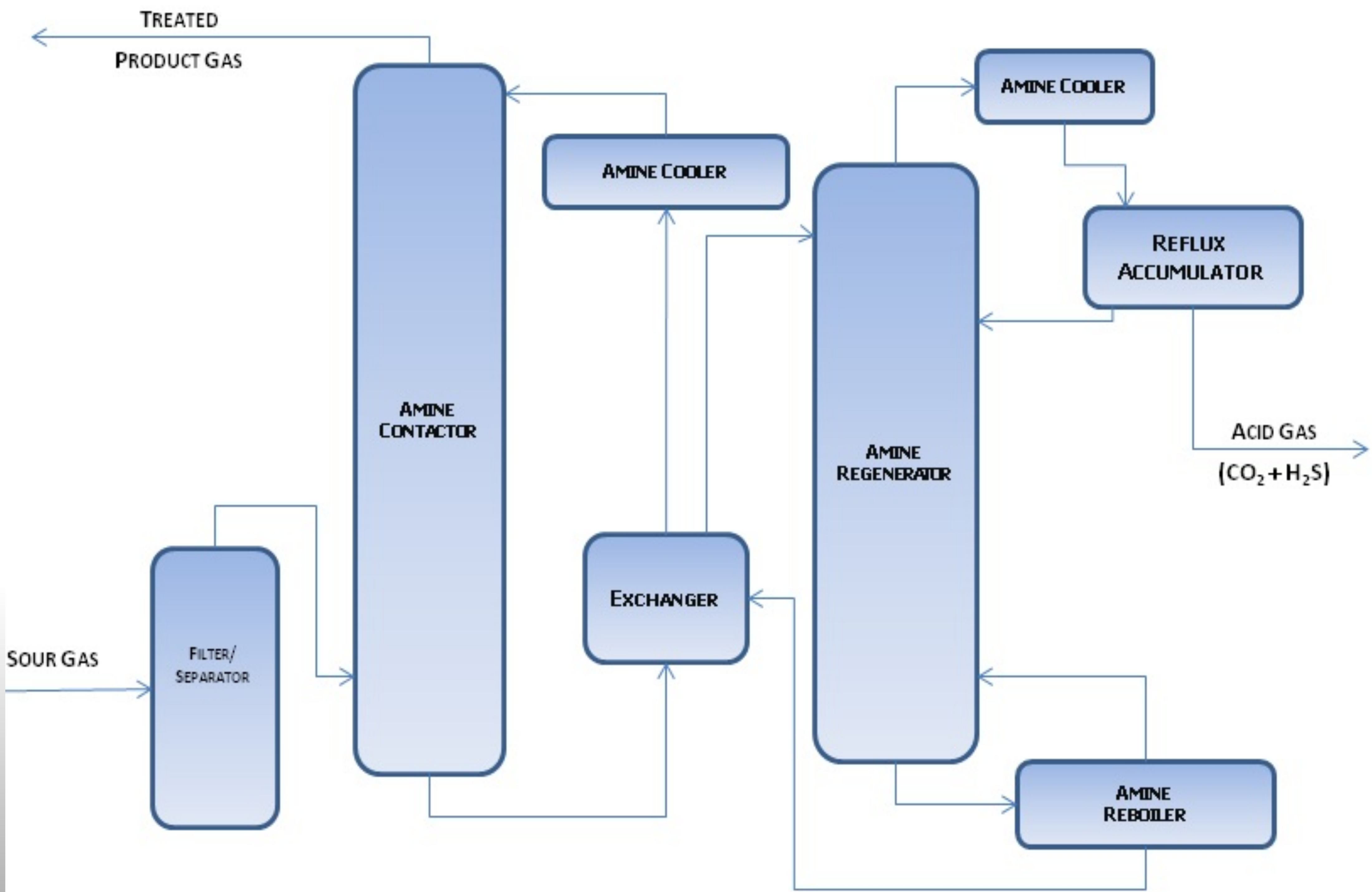
Overall Process



1. Particulate Removal (682°C, 1bar)
2. Cooling Syngas (682°C to 107°C)
3. Water Scrubber (107°C, 1bar)
4. Compressor (1bar to 30.7bar)
5. Acid Gas Removal (Diethanolamine $HN(CH_2CH_2OH)_2$)
6. LO-CAT (CO2, H2S Removal)

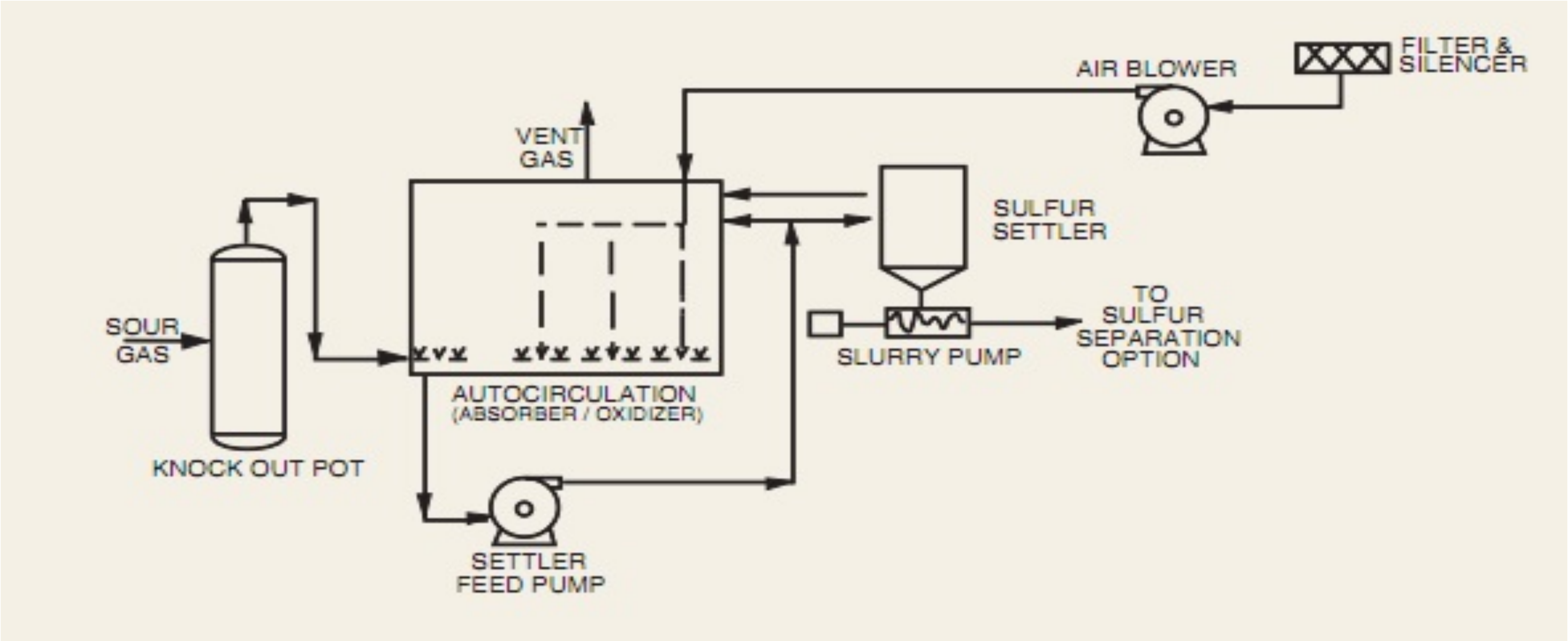
Acid Gas Removal III

Amine Plant



Acid Gas Removal IV

LO-CAT process

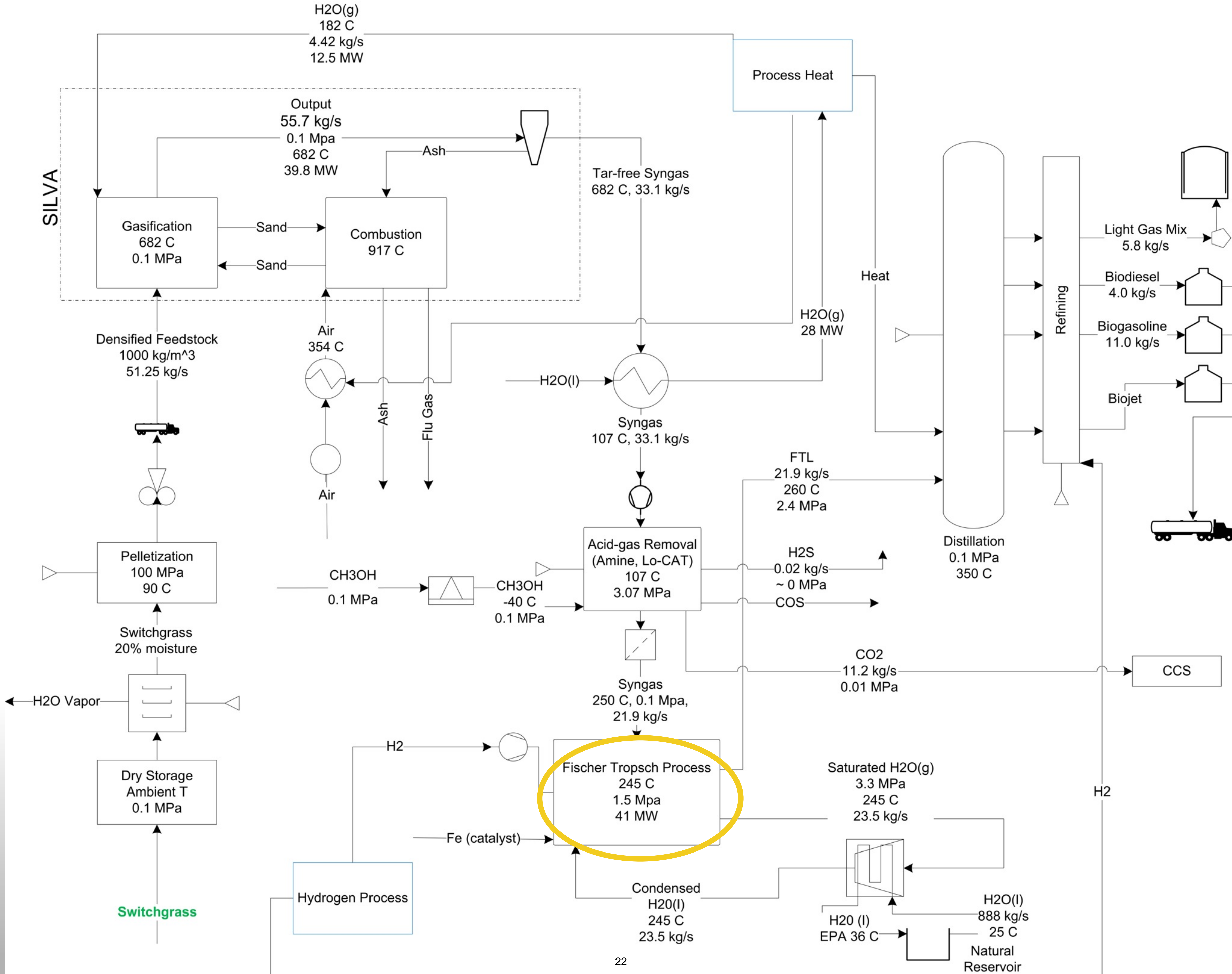


- Removes all remaining CO_2
- Converts H_2S to an innocuous, elemental sulfur
- Uses a dual chelated iron catalyst - environmentally safe.

Acid Gas Removal V

Composition of Input to F-T Reactor

Compound	Mass Flow (kg/s)
CO	18.4
H2	0.34
CO2	0.00
CH4	3.71
C2H4	2.12
C2H6	0.31
Total	25.0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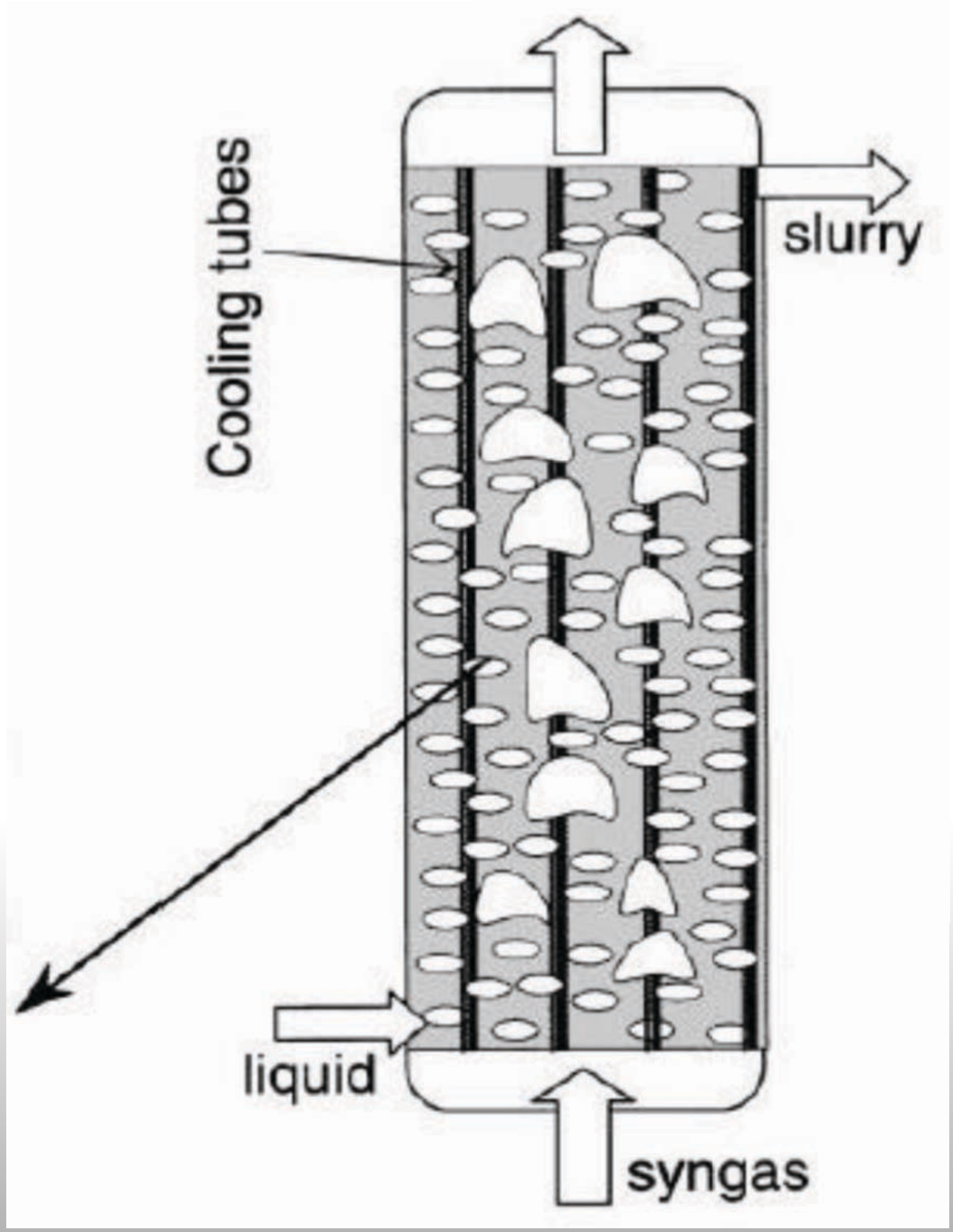
Fischer Tropsch Reactor I

Slurry Phase Bubble Column Design



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- Churn turbulent 2 phase flow
- Fe catalyst

  Catalyst activity:
  Ru > Fe > Ni > Co > Rh

Fischer Tropsch Reactor II

Reactions, Heat transfer

$CO+2H_2$ --> $-(CH_2)-$ + H_2O+170kJ

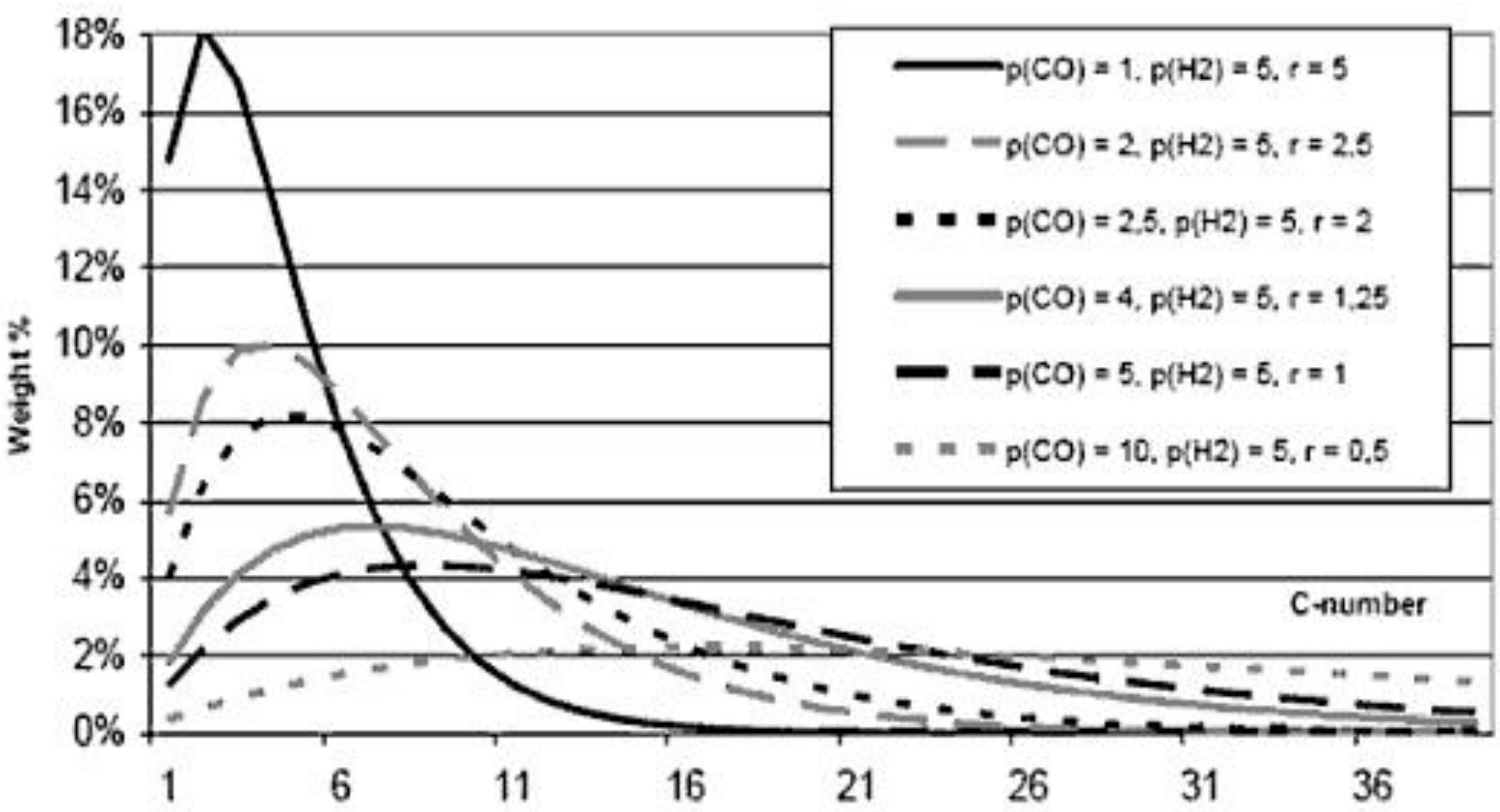
H_2O+CO --> CO_2+H_2 (water shift reaction)

Heat generated in FT reactor:
Q = 0.25kg/s*1mol/0.002kg*170kJ/mol = 21.8 MW

Intake water flow rate (using EPA limit of 11°C)
m = Q/(C*(Ta-Ti)) = 470 kg/s

Fischer Tropsch Reactor III

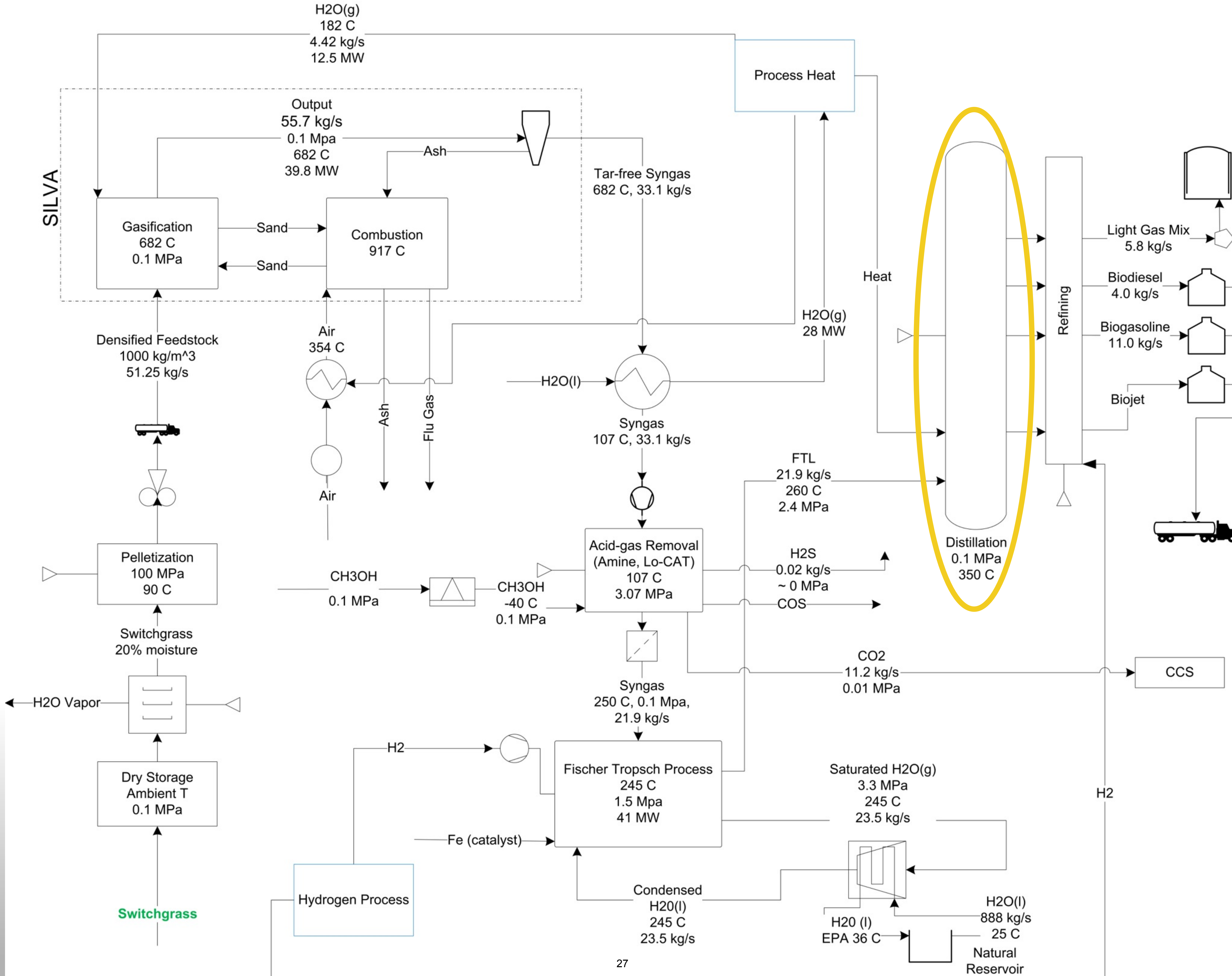
Product Selectivity



Fischer Tropsch Reactor IV

Reactor Outputs

Carbon Content	Product Classification	Mass Flow (kg/s)
C1 - C5	Light Gas	3.19
C5 - C12	Naphtha (Gasoline)	9.70
C12 - C20	Distillate (Biodiesel)	7.08
C20+	Heavy wax	4.70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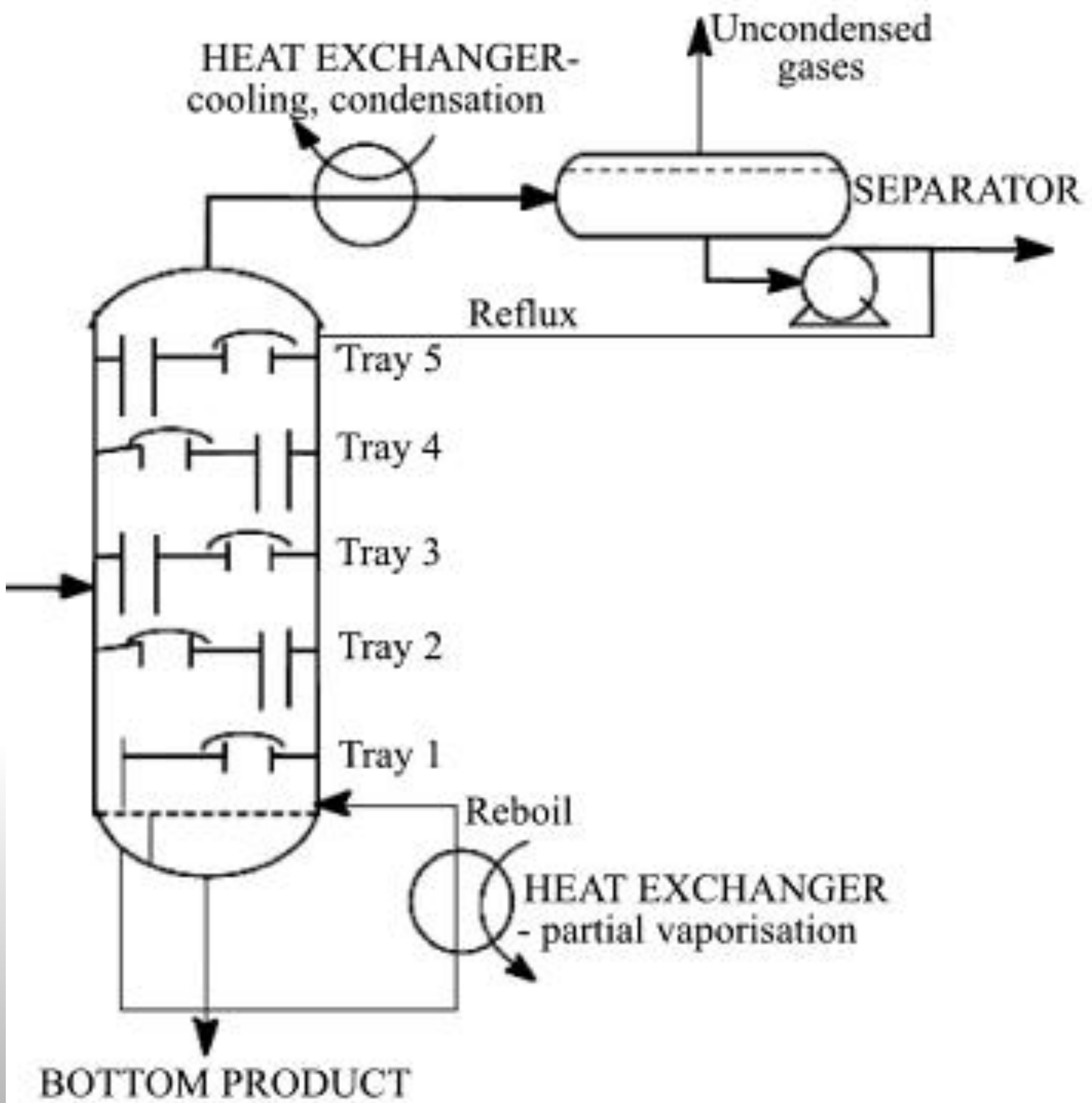
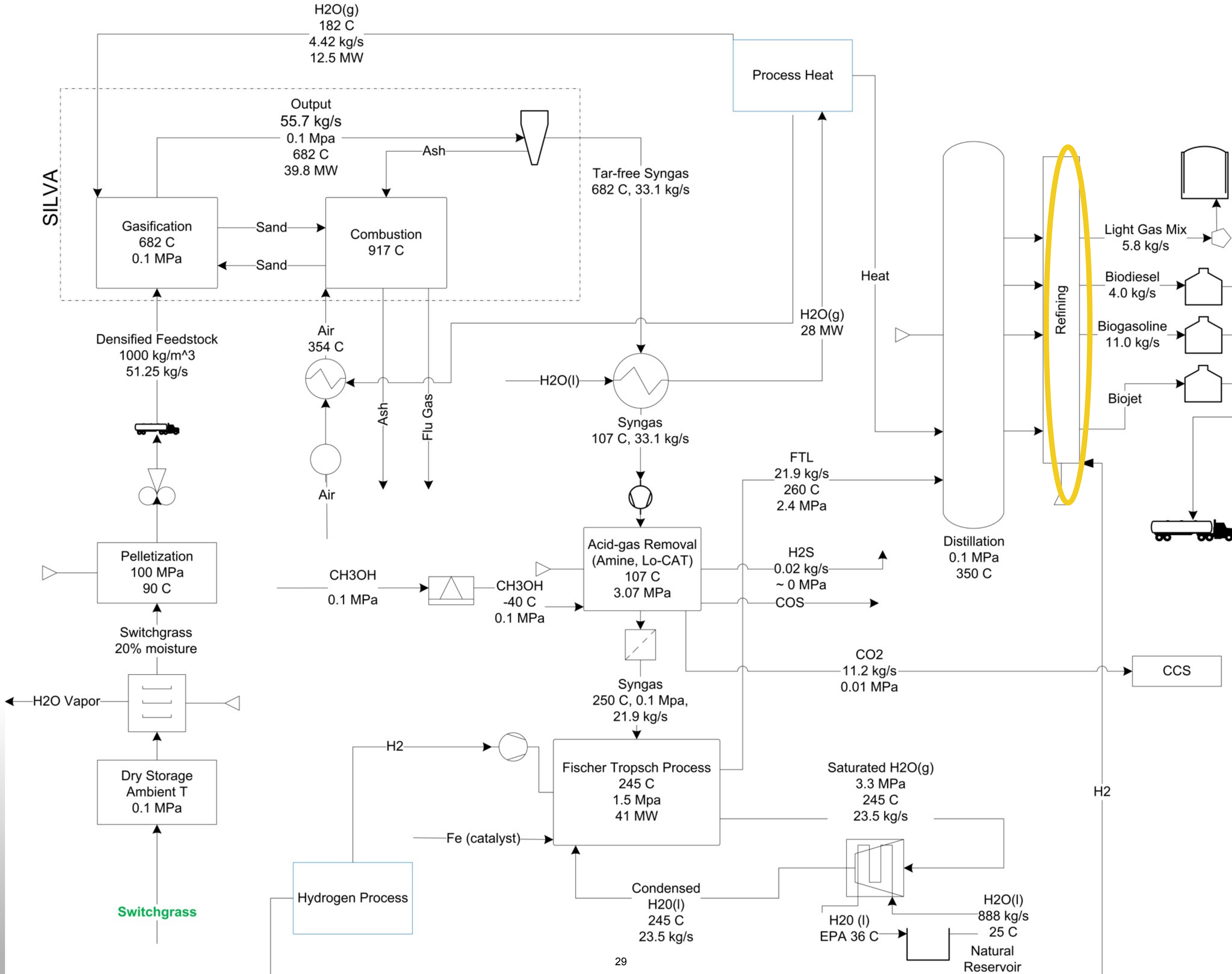


Fraction	Boiling Point (°C)
Liquid Petroleum Gas	< 40
Light Naptha	30-90
Heavy Naptha	90-200
Distillate	200-300
Heavy Wax	300-350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245 C
1.5 Mpa
41 MW
Saturated H2O(g)
3.3 MPa
245 C
23.5 kg/s
H2
Fe (catalyst)
Switchgrass
Hydrogen Process
Condensed
H20(l)
245 C
23.5 kg/s
H2O(l)
888 kg/s
25 C
H20 (l)
EPA 36 C
Natural
Reservoir

Refining I

Composition of Distillation Output

Compound Class	LFTF Syncrude
Linear Paraffins	> 60%
Naphthenes	< 1%
Olefins	**> 20%**
Aromatics	none
Oxygenates	**5-15%**
Sulfur Compounds	none
Nitrogen Compounds	none
Metal Containing Compounds	carboxylates
Water	major by-product

Sasol Technology R&D, FTR and C1 Chemistry Research, HCC 19 August 2010

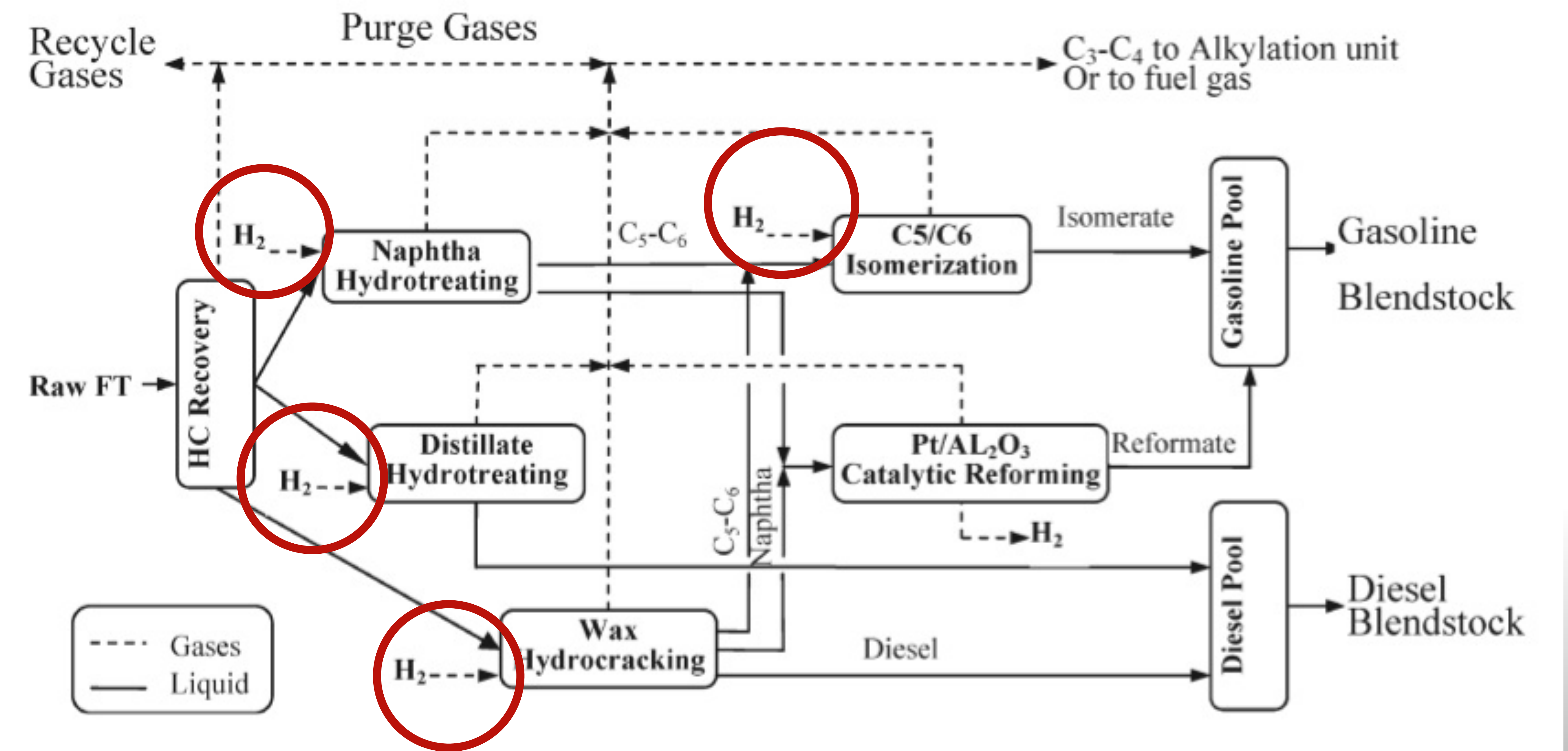
Refining II

Purposes

1. Hydrogenation of olefins
2. Removal of oxygen-containing compounds
3. Desulfurization to < 20microgram/gram
4. Hydroisomerization
    - Increases branched isomers
    - Better octane rating
5. Hydrocracking of n-paraffins to isoparaffins

Refining III

Hydrogen Inputs



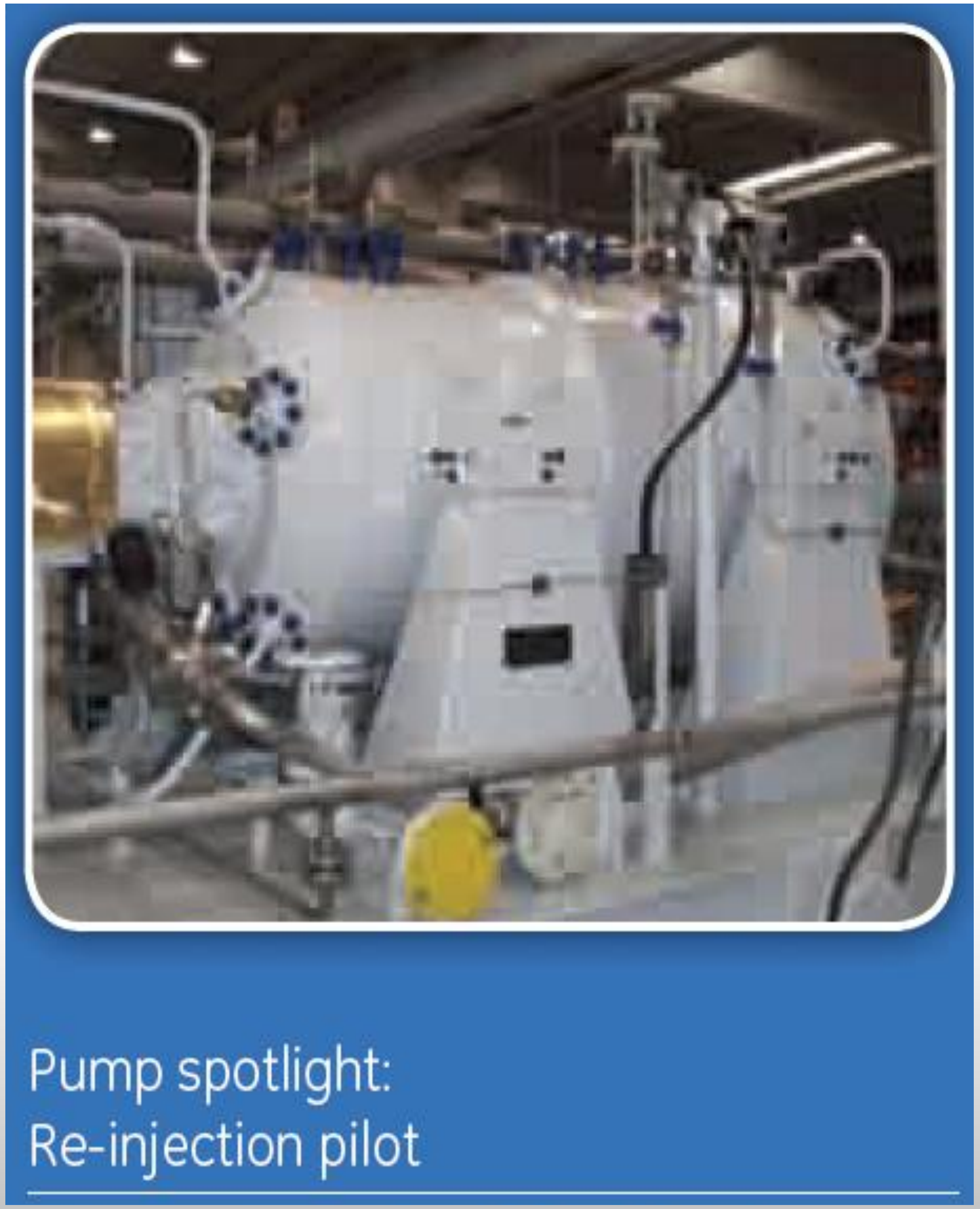
Final Products

Product Classification	Mass Flow (ton/day)
Light Gas	276
Diesel	612
Gasoline	838
Total Gasoline + Diesel	1450

- Assuming 10 gal/tank, this amount of gasoline and diesel can fill about 53,000 cars/day

Carbon Sequestration

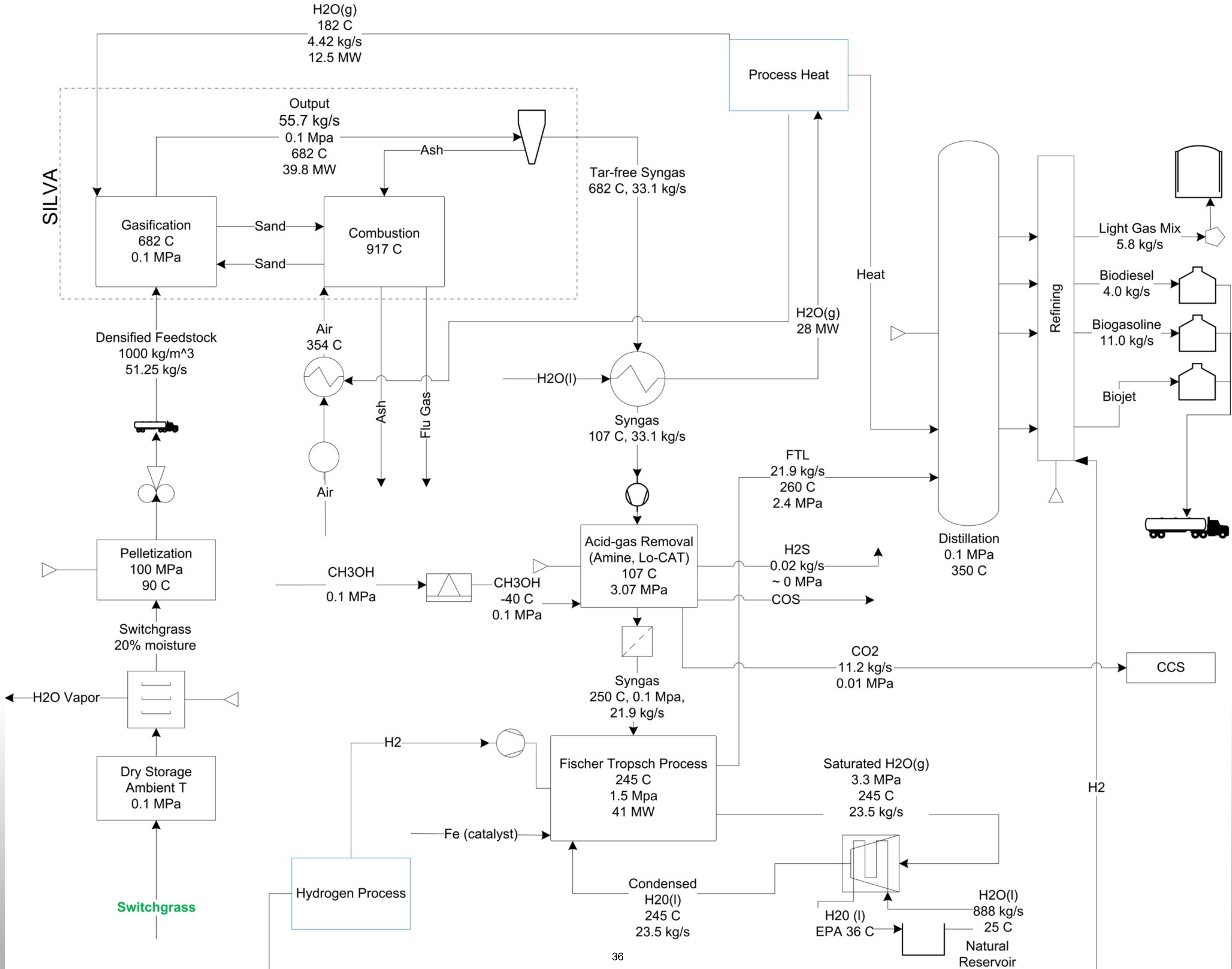
GE CO2 management system



- CO_2 sources: acid gas removal, distillation
- Options: Sell, inject to underground storage, send to deep ocean dissolution
- CO_2 liquidifies at density 300kg/m^3
- Compress to 200 bar with in-line integrally geared compressor and DDHF multistage barrel pump

Concluding Thoughts

- Research Continues
- Possible Electric Inputs
- Possible Heat Inputs and Outputs
- Hydrogen Inputs
- EES, Aspen modeling
- Questions


H2O(g)
182 C
4.42 kg/s
12.5 MW
Process Heat
SILVA
Output
55.7 kg/s
0.1 Mpa
682 C
39.8 MW
Ash
Tar-free Syngas
682 C, 33.1 kg/s
Gasification
682 C
0.1 MPa
Sand
Sand
Combustion
917 C
Heat
H2O(g)
28 MW
Densified Feedstock
1000 kg/m^3
51.25 kg/s
Air
354 C
H2O(l)
Ash
Flu Gas
Air
Syngas
107 C, 33.1 kg/s
Light Gas Mix
5.8 kg/s
Biodiesel
4.0 kg/s
Biogasoline
11.0 kg/s
Biojet
Refining
FTL
21.9 kg/s
260 C
2.4 MPa
Distillation
0.1 MPa
350 C
Pelletization
100 MPa
90 C
CH3OH
0.1 MPa
CH3OH
-40 C
0.1 MPa
Acid-gas Removal
(Amine, Lo-CAT)
107 C
3.07 MPa
H2S
0.02 kg/s
~ 0 MPa
COS
Switchgrass
20% moisture
CO2
11.2 kg/s
0.01 MPa
CCS
H2O Vapor
Syngas
250 C, 0.1 Mpa,
21.9 kg/s
H2
Fischer Tropsch Process
245 C
1.5 Mpa
41 MW
Saturated H2O(g)
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