

Process Calculation with TS diagrams

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MODIFICATIONS RECORDING

ISSUE OFMODIF	DATE	WRITTEN BY	CHECKED BY	EVOLUTION OF THE DOCUMENT (Updated pages)	JUSTIFICATION OF THE MODIFICATION
(0)	01/22/2016	S.Bigeard	A. Machefel	Initial	
(1)	02/11/2016	M.Roig	G.Zick	LPL compressors fully loaded in all modes: <ul style="list-style-type: none"> - Mode 2: Recirculation between LPR and LPL and 50g/s between MP to LPL - Modes 3 to 7: Recirculation between MP and LPL only 	Control of LPL stage with no VFD nor Slide Valve, extra flow is by-passed.
(2)	04/15/2016	M.Roig	G.Zick	<ul style="list-style-type: none"> - Mode 6 updated - Mode 8 added ("50% Standby") 	<p>Mode 6 : T1 and T3 efficiencies adjusted ; Carnot efficiency calculation taking into account all the compressors fully loaded</p> <p>Mode 8 : added during project execution</p>

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1. INTRODUCTION

1.1 OBJECTIVE OF THE NOTE

This note gathers process PFDs, TS diagrams and efficiency compared to Carnot for the 6 Operating modes described in the Technical Specification for the Procurement of CHL 4.5K Cold Box System.

In addition, a 7th mode named "50% Mode" and a 8th mode named "50% Standby" given by JLAB during project execution are also integrated in this note.

1.2 REFERENCE DOCUMENTS

- [1] Technical Specification for the Procurement of CHL 4.5K Cold Box System
- [2] Mode 7, 50% Turn-Down Operating Mode for the Cryoplant, (Dt:10/16/2015)
- [3] Mode 8, 50% of Mode 6-Standby, (Dt:03/16/2016)

2. MODE 1 – MAX CAPACITY

2.1 PROCESS INPUTS

Load	w [g/s]	Supply		Return		q [kW]
		p [atm]	T [K]	p [atm]	T [K]	
Warm Shield	≤146	Note 1	≤35	≥2.5	≤55	≥15.2
Cold Intercept	≤37	≥3.25	5.5	1.29	7.50	≥1.3
4-K Refrigeration						
4-K Liquefaction	≥15	≥3.2	4.5	1.10	300.0	
Sub-Atmospheric	≥200	≥3.2	4.5	1.20	30.0	

Max. Capacity: Mode1						
Loads:	w [g/s]	Supply		Return		q [kW]
		p [atm]	T [K]	p [atm]	T [K]	
C. Shield	36.4	3.000	5.10	1.277	7.50	1.30

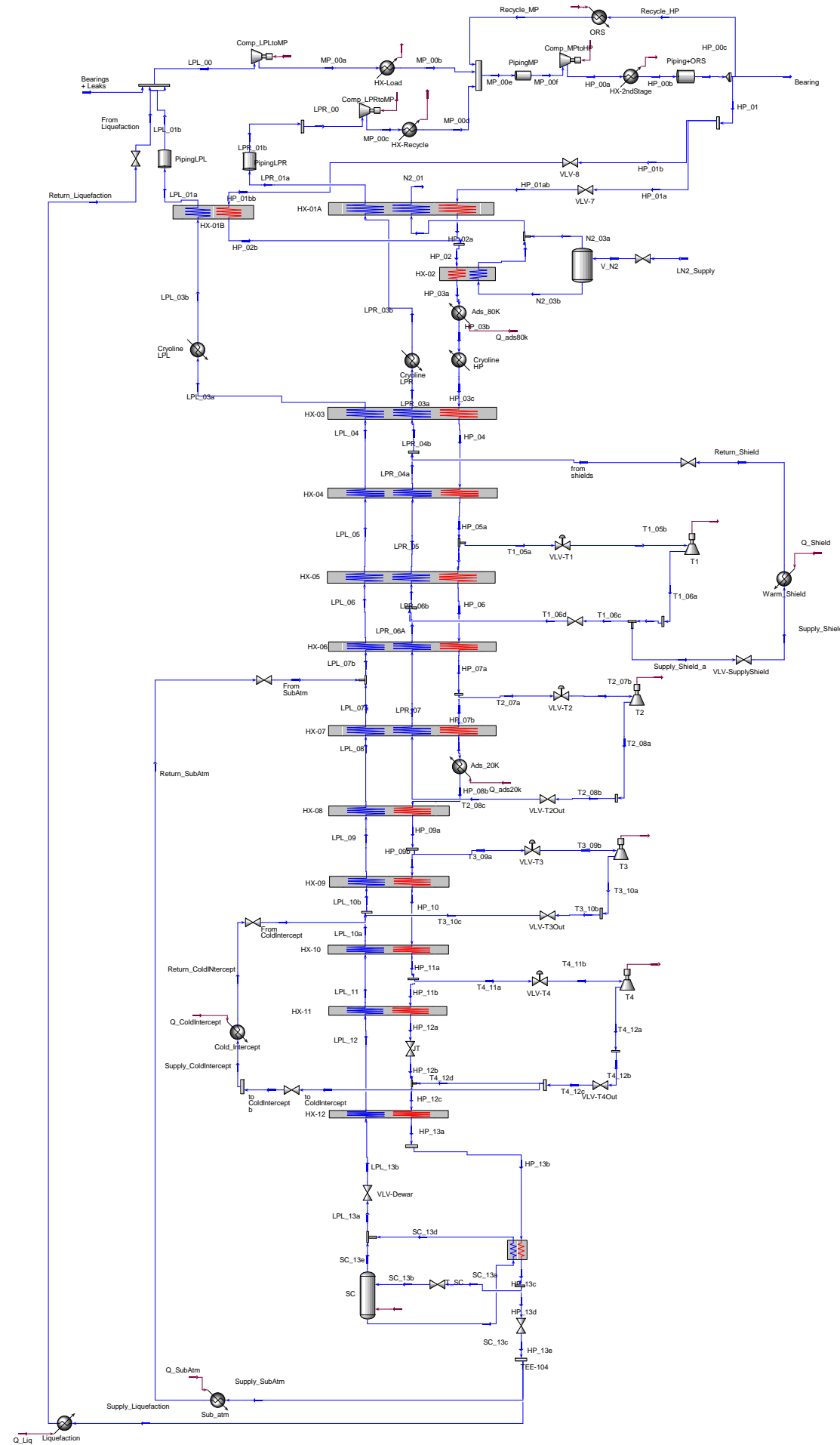
2.2 MAIN RESULTS AND REMARKS

- SHe supply for 4-K Liquefaction and Sub-Atmospheric at 3.2 atm and 4.55K
- Sub-Atmospheric Return pressure at 1.236 atm.

Load	w [g/s]	Supply		Return		q [kW]
		P (atm)	T (K)	P (atm)	T (K)	
Warm Shield	145.5	3.56	35	2.56	55	15.2
Cold Shield	40.59	3.0	5.43	1.277	7.5	1.3
4-K Refrigeration						
4-K Liquefaction	15	3.2	4.55	1.10	300	23.4
Sub-Atmospheric	200	3.2	4.55	1.236	30	31.8

2.3 PROCESS PFD

Mode 1: Max Capacity



Heat Loads						
	Warm_Shield	Cold_Intercept	Refrigeration	Liquefaction	Sub_atm	
DUTY	W*	15200	1300	0	23420	31754
Feed Temperature	K	35.00	5.43	4.55	4.55	4.55
Feed Pressure	atm	3.558	3.000	3.200	3.200	3.200
Product Temperature	K	55.00	7.50	4.47	300.00	30.00
Product Pressure	atm	2.558	1.277	1.250	1.100	1.236
Mass Flow	g/s	145.5	40.6	0.0	15.0	200.0

Warm Compression Station				
	ACT_m3/h	Comp_LPLtoMP	Comp_LPRtoMP	Comp_MPtoHP
Capacity (act feed vol flow)		15701	5579	5042
Feed Pressure	atm	1.050	2.350	6.000
Feed Temperature	K	306.1	306.3	310.0
Product Pressure	atm	6.150	6.150	19.000
Mass Flow	g/s	729.5	579.4	1318.9

Cryogenic Expanders					
	T1	T2	T3	T4	
Power	kW	28.62	20.96	14.05	2.94
Feed Temperature	K	55.48	29.94	16.48	6.90
Feed Pressure	atm	18.054	17.974	17.882	17.871
Product Temperature	K	35.00	17.19	7.49	5.49
Product Pressure	atm	3.603	2.609	1.260	3.242
Mass Flow	g/s	261.4	318.6	367.5	344.3
Adiabatic Fluid Head	kJ/kg	140.4	84.4	49.6	11.5
Adiabatic Efficiency		78	78	77	74

Heat Exchange								
	HX-01A	HX-01B	HX-02	HX-03	HX-04	HX-05	HX-06	
UA (Calculated)	W/C	203302	234542	9814	151549	4249	146507	58807
Minimum Approach	K	3.34	3.31	0.80	0.79	1.40	0.35	0.35
Heat Leak	W*	203	234	10	152	5	147	59
	HX-07	HX-08	HX-09	HX-10	HX-11	HX-12	HX-SC	
UA (Calculated)	W/C	76304	5878	26772	2034	0	1722	3948
Minimum Approach	K	0.56	0.61	0.10	0.10	0.52	0.10	0.08
Heat Leak	W*	76	6	27	5	5	5	0

Streams HP												
	HP_00a	HP_00b	HP_00c	HP_01	HP_01a	HP_01ab	HP_01b	HP_01bb	HP_02	HP_02a	HP_02b	HP_03a
Temperature	K	552.30	310.00	310.03	310.03	310.03	310.03	310.03	82.36	82.36	82.36	79.75
Pressure	atm	19.000	19.000	18.500	18.500	18.500	18.480	18.500	18.480	18.348	18.348	18.344
Mass Flow	g/s	1318.9	1318.9	1318.9	1291.8	598.7	598.7	693.0	693.0	1291.8	598.7	1291.8
	HP_03b	HP_03c	HP_04	HP_05a	HP_05b	HP_06	HP_07a	HP_07b	HP_08a	HP_08b	HP_09a	HP_09b
Temperature	K	79.78	79.78	56.40	55.48	55.48	35.34	29.94	17.78	17.80	16.48	16.48
Pressure	atm	18.186	18.176	18.117	18.115	18.115	18.058	18.035	18.035	18.005	17.945	17.943
Mass Flow	g/s	1291.8	1291.8	1291.8	1030.4	1030.4	1030.4	711.8	711.8	711.8	344.3	344.3
	HP_10	HP_11a	HP_11b	HP_12a	HP_12b	HP_12c	HP_13a	HP_13b	HP_13c	HP_13d	HP_13e	
Temperature	K	7.59	6.89	6.89	5.91	5.70	5.49	5.30	4.55	4.55	4.55	
Pressure	atm	17.933	17.932	17.932	17.932	3.234	3.234	3.233	3.233	3.231	3.200	
Mass Flow	g/s	344.3	344.3	0.0	0.0	0.0	302.9	302.9	302.9	215.0	215.0	

Streams LPR											
	LPR_00	LPR_01a	LPR_01b	LPR_03a	LPR_03b	LPR_04a	LPR_04b	LPR_05	LPR_06a	LPR_06b	LPR_07
Temperature	K	306.3	306.3	306.3	78.99	79.01	55.00	55.00	53.93	34.99	28.99
Pressure	atm	2.350	2.400	2.350	2.498	2.491	2.533	2.533	2.534	2.568	2.582
Mass Flow	g/s	579.4	579.4	579.4	579.4	579.4	433.8	579.4	433.8	318.2	433.8

Streams MP							
	MP_00b	MP_00d	MP_00e	MP_00f	MP_01b	MP_01a	MP_01ab
Temperature	K	310.0	310.0	310.0	310.0	310.0	310.0
Pressure	atm	6.150	6.150	6.150	6.000	18.500	18.500
Mass Flow	g/s	729.5	579.4	1319	1319	693.0	598.7

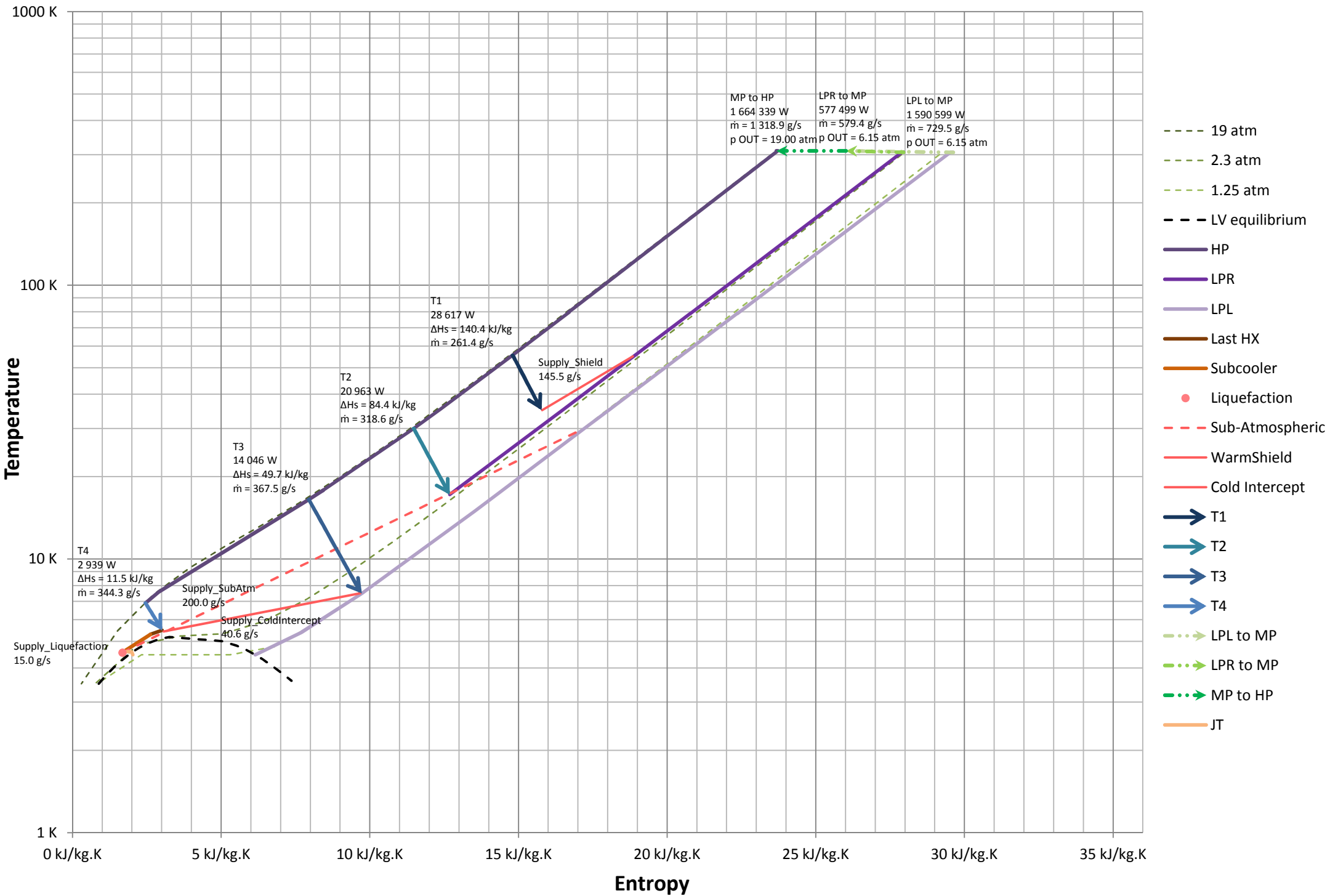
Streams LPL									
	LPL_00	LPL_01a	LPL_01b	LPL_03a	LPL_03b	LPL_04	LPL_05	LPL_06	LPL_07a
Temperature	K	306.10	306.20	306.21	78.99	79.00	55.00	53.93	34.99
Pressure	atm	1.050	1.100	1.050	1.168	1.163	1.193	1.194	1.228
Mass Flow	g/s	729.5	695.5	695.5	695.5	695.5	695.5	695.5	495.5
	LPL_07b	LPL_08	LPL_09	LPL_10a	LPL_10b	LPL_11	LPL_12	LPL_13a	LPL_13b
Temperature	K	29.28	17.19	14.93	7.49	7.49	5.40	5.39	4.47
Pressure	atm	1.228	1.240	1.241	1.245	1.245	1.245	1.250	1.245
Mass Flow	g/s	695.5	495.5	495.5	87.9	495.5	87.9	87.9	87.9

Streams Subcooler					
	SC_13a	SC_13b	SC_13c	SC_13d	SC_13e
Vapour Fraction		0.0000	0.0334	0.0000	0.9980
Temperature	K	4.55	4.47	4.47	4.47
Pressure	atm	3.231	1.250	1.250	1.250
Mass Flow	g/s	87.9	87.9	74.4	13.4

Streams Nitrogen							
	N2_01	N2_02a	N2_02b	N2_02c	N2_03a	N2_03b	LN2_Supply
Temperature	K	306.32	78.95	78.95	78.95	78.95	91.41
Pressure	atm	1.050	1.200	1.200	1.200	1.200	4.000
Mass Flow	g/s	104.0	13.9	90.0	104.0	104.0	90.0
Vapour Fraction		1.0000	1.0000	1.0000	0.1341	0.0000	0.0000

2.4 TS DIAGRAM

Mode 1 : Max Capacity



2.5 PROCESS DESIGN PERFORMANCE EVALUATION

Mode 1 - MaxCapacity : Carnot efficiency

Heat loads	Mass Flow g/s	q kW	Supply					Return					EL kW
			T K	P atm	h J/g	s J/g-K	ε kJ/g	T K	P atm	h J/g	s J/g-K	ε kJ/g	
Shield	145.5	15.20	35.00	3.56	196.83	17.77	2.769	55.00	2.56	301.28	20.82	1.96	118.1
Cold intercept	40.6	1.30	5.43	3.00	18.93	5.03	6.411	7.50	1.28	50.97	11.65	4.46	79.3
Refrigeration	0.0	0.00	4.55	3.20	12.08	3.65	6.820	4.47	1.25	30.53	8.12	5.50	0.0
Liquefaction	15.0	23.42	4.55	3.20	12.08	3.65	6.820	300.00	1.10	1573.55	31.39	0.06	101.4
Sub Atm	200.0	31.76	4.55	3.20	12.08	3.65	6.820	30.00	1.24	170.86	19.17	2.32	899.9
Total													1198.7

Compressors	Mass Flow g/s	Supply		Return	Ideal input power compressor kW	P2/P1	Isothermal Efficiency	Compressor Mechanical Power		Number of Motors ON	Motors rated power hp	Motors power margin	Motor efficiency	Electrical Power at Motors kW
		T K	P atm	P atm				kW	hp					
MP/HP	1318.9	300.00	6.00	19.00	947.3	3.17	53.1%	1785	2393	1	2500	4.3%	96.0%	1859.1
LPR/MP	579.4	300.00	2.35	6.15	347.3	2.62	55.8%	623	835	1	1000	16.5%	94.0%	662.5
LPL/MP	729.5	300.00	1.05	6.15	803.5	5.86	48.5%	1656	2220	3	800	7.5%	94.0%	1761.2
Total														4282.9

N2	Mass Flow g/s	Supply					Return					Ideal input power N2 kW	LN equivalent efficiency	Input power N2 kW
		T K	P atm	h J/g	s J/gK	ε kJ/g	T K	P atm	h J/g	s J/gK	ε kJ/g			
N2	104.2	91.41	4.00	-92.51	3.18	-1.05	306.27	1.05	317.72	6.85	-1.74	71.9	0.35	205.5
Total														205.5

Total Carnot Efficiency 26.7%
<i>Total Carnot efficiency without motors efficiencies</i> <i>28.1%</i>

3. MODE 2 – NOMINAL TURN DOWN

3.1 PROCESS INPUTS

Load	w [g/s]	Supply		Return		q [kW]
		p [atm]	T [K]	p [atm]	T [K]	
Warm Shield	≤96.7	Note 1	≤35	≥2.5	≤55	≥10.10
Cold Intercept	≤27	≥3.2	5.5	1.29	7.50	≥0.9
4-K Refrigeration						
4-K Liquefaction						
Sub-Atmospheric	≥157	≥3.2	4.5	1.20	30.0	

Normal Capacity: Mode 2						
Loads:	w [g/s]	Supply		Return		q [kW]
		p [atm]	T [K]	p [atm]	T [K]	
C. Shield	24.6	3.000	5.20	1.257	7.80	0.9

3.2 MAIN RESULTS AND REMARKS

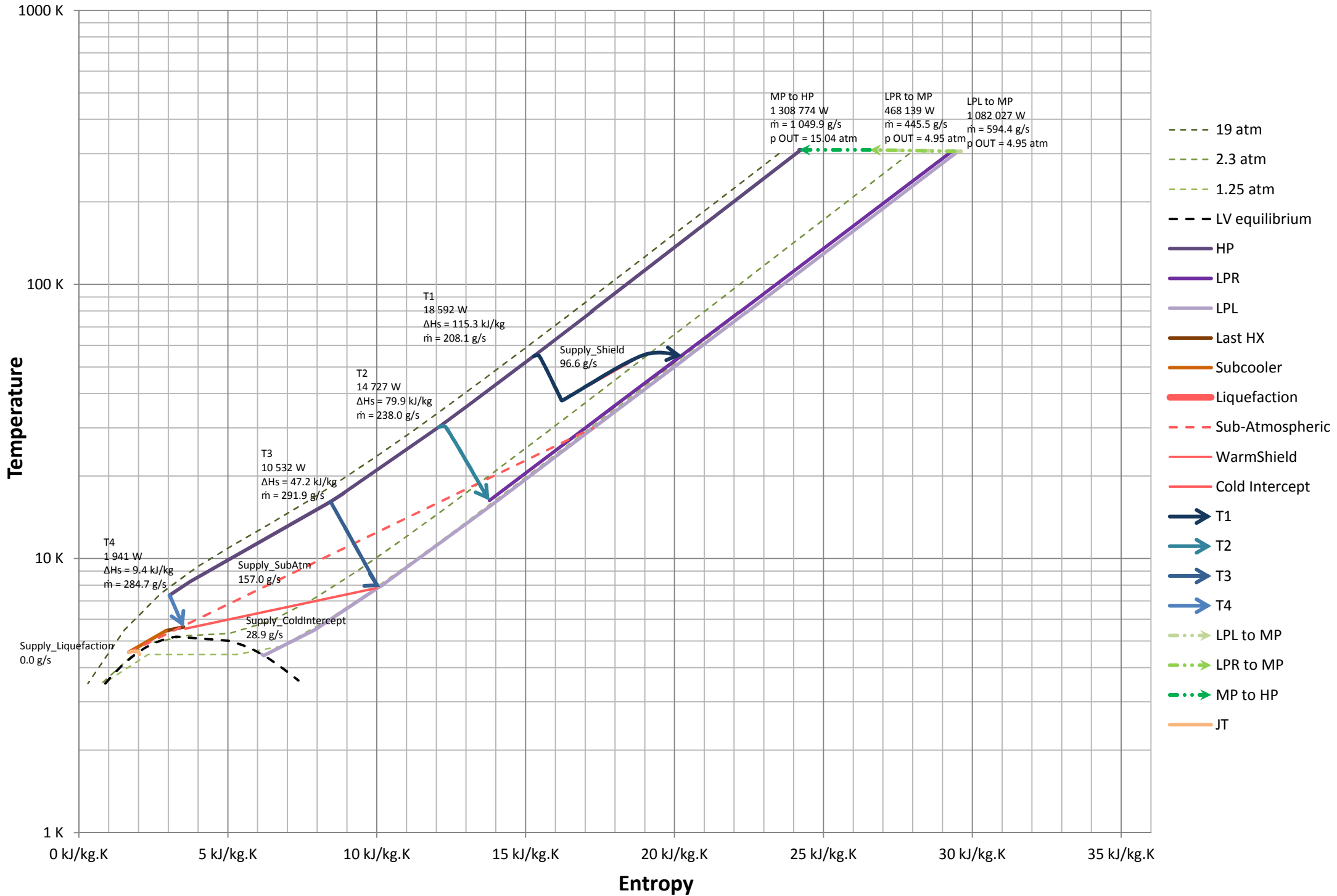
- SHe supply for Sub-Atmospheric at 3.2 atm and 4.55K

Load	w [g/s]	Supply		Return		q [kW]
		P (atm)	T (K)	P (atm)	T (K)	
Warm Shield	112.3	3.5	37.5	2.5	55	10.1
Cold Shield	28.9	3.000	5.5	1.234	7.8	0.9
4-K Refrigeration						
4-K Liquefaction						
Sub-Atmospheric	157	3.2	4.55	1.20	30	24.9

3.3 PROCESS PFD

3.4 TS DIAGRAM

Mode 2 : Nominal



3.5 PROCESS DESIGN PERFORMANCE EVALUATION

Mode 2 - Nominal : Carnot efficiency

Heat loads	Mass Flow g/s	q kW	Supply					Return					EL kW
			T K	P atm	h J/g	s J/g-K	ε kJ/g	T K	P atm	h J/g	s J/g-K	ε kJ/g	
Shield	112.3	10.10	37.76	3.50	211.31	18.20	2.654	55.00	2.50	301.28	20.87	1.94	79.7
Cold intercept	28.9	0.90	5.55	3.00	21.66	5.53	6.265	7.80	1.23	52.81	11.96	4.37	54.8
Refrigeration	0.0	0.00	4.55	3.20	12.08	3.65	6.820	4.47	1.25	30.53	8.12	5.50	0.0
Liquefaction	0.0	0.00	4.55	3.20	12.08	3.65	6.820	300.00	1.10	1573.55	31.39	0.06	0.0
Sub Atm	157.0	24.93	4.55	3.20	12.08	3.65	6.820	30.00	1.20	170.87	19.24	2.30	709.4
Total													843.9

Compressors	Mass Flow g/s	Supply		Return	Ideal input power compressor kW	P2/P1	Isothermal Efficiency	Compressor Mechanical Power		Number of Motors ON	Motors rated power hp	Motors power margin	Motor efficiency	Electrical Power at Motors kW
		T K	P atm	P atm				kW	hp					
MP/HP	1011.1	300.00	4.59	14.85	739.6	3.23	53.1%	1393	1868	1	2500	25.3%	96.0%	1451.4
LPR/MP	283.1	300.00	1.17	4.74	247.4	4.07	52.3%	473	634	1	1000	36.6%	94.0%	502.8
LPL/MP	768.1	300.00	1.05	4.74	721.5	4.52	49.9%	1447	1940	3	800	19.2%	94.0%	1539.0
Total														3493.2

N2	Mass Flow g/s	Supply					Return					Ideal input power N2 kW	LN equivalent efficiency	Input power N2 kW
		T K	P atm	h J/g	s J/gK	ε kJ/g	T K	P atm	h J/g	s J/gK	ε kJ/g			
N2	51.5	91.41	4.00	-92.51	3.18	-1.05	306.08	1.1622995	317.49	6.82	-1.73	35.1	0.35	100.3
Total														100.3

Total Carnot Efficiency 23.5%
<i>Total Carnot efficiency without motors efficiencies 24.7%</i>

4. MODE 3 – MAX LIQUEFACTION

4.1 PROCESS INPUTS

Load	w [g/s]	Supply		Return		q [kW]
		p [atm]	T [K]	p [atm]	T [K]	
Warm Shield	≤155	Note 1	≤44	≥2.3	≤56.5	≥10.1
Cold Intercept	≤20	≥3.2	≤5.8	≥1.23	≤10.8	≥0.9
4-K Refrigeration						
4-K Liquefaction	≥140	≥3.2	4.5	1.10	300.0	
Sub-Atmospheric						

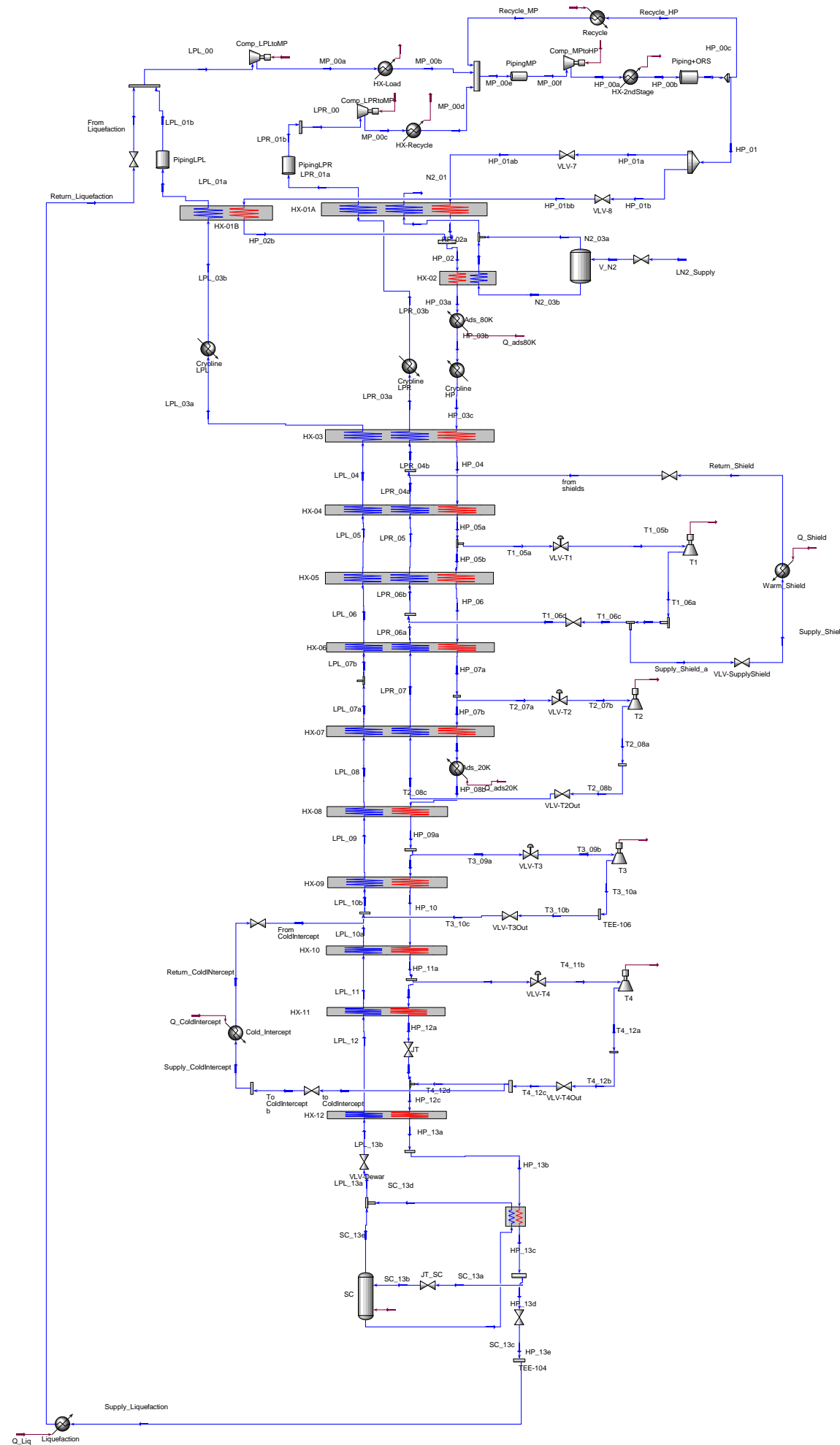
4.2 MAIN RESULTS AND REMARKS

- SHe supply for 4-K Liquefaction at 3.2 atm and 4.55K

Load	w [g/s]	Supply		Return		q [kW]
		P (atm)	T (K)	P (atm)	T (K)	
Warm Shield	141.4	3.3	42.8	2.3	56.5	10.1
Cold Shield	19.9	3.2	5.7	1.23	10.8	0.9
4-K Refrigeration						
4-K Liquefaction	140	3.2	4.55	1.10	300	218.6
Sub-Atmospheric						

4.3 PROCESS PFD

Mode 3 : Max Liquefaction



Heat Loads					
	Warm_Shield	Cold_Intercept	Refrigeration	Liquefaction	Sub_atm
DUTY	W*	10100	900	0	2.1859e+05
Feed Temperature	K	42.78	5.71	4.55	4.55
Feed Pressure	atm	3.300	3.200	3.200	3.200
Product Temperature	K	56.50	10.80	4.47	300.00
Product Pressure	atm	2.300	1.230	1.250	1.100
Mass Flow	g/s	141.4	19.9	0.0	140.0

Warm Compression Station			
	Comp_LPLtoMP	Comp_LPRtoMP	Comp_MPtoHP
Capacity (act feed vol flow)	ACT_m3/h	13757	5574
Feed Pressure	atm	1.050	2.080
Feed Temperature	K	307.5	309.5
Product Pressure	atm	5.420	5.420
Mass Flow	g/s	636.3	507.2

Cryogenic Expanders					
	T1	T2	T3	T4	
Power	kW	32.58	25.36	15.98	2.26
Feed Temperature	K	68.40	42.54	19.70	7.96
Feed Pressure	atm	18.209	18.142	18.047	14.500
Product Temperature	K	42.78	24.79	9.31	5.73
Product Pressure	atm	3.345	2.335	1.212	3.243
Mass Flow	g/s	238.1	269.7	333.6	284.9
Adiabatic Fluid Head	kJ/kg	178.8	126.2	63.4	10.9
Adiabatic Efficiency		77	75	76	73

Heat Exchange						
	HX-01A	HX-01B	HX-02	HX-03	HX-04	HX-05
UA (Calculated)	W/C	185657	179812	16406	108152	3462
Minimum Approach	K	0.55	0.30	0.80	0.10	0.18
Heat Leak	W*	203	234	10	152	5

	HX-07	HX-08	HX-09	HX-10	HX-11	HX-SC
UA (Calculated)	W/C	71940	5725	24479	2590	0
Minimum Approach	K	0.33	1.36	0.10	0.27	0.30
Heat Leak	W*	76	6	27	5	5

Streams: HP											
Temperature	K	588.81	310.00	310.03	310.03	310.03	310.03	310.03	310.03	91.90	68.51
Pressure	atm	19.110	19.110	18.610	18.610	18.610	18.590	18.610	18.590	18.495	18.228
Mass Flow	g/s	1153.4	1153.4	1153.4	1126.2	623.7	623.7	502.5	502.5	1126.2	888.1

Temperature	K	9.43	91.90	91.90	79.75	79.78	68.39	68.39	42.54	42.54	22.79	22.81
Pressure	atm	18.100	18.495	18.495	18.492	18.334	18.279	18.279	18.203	18.203	18.171	18.111
Mass Flow	g/s	284.9	623.7	502.5	1126.2	1126.2	888.1	888.1	618.4	618.4	618.4	618.4

Temperature	K	19.71	19.71	7.87	7.87	5.89	5.70	5.73	5.55	4.55	4.55
Pressure	atm	18.108	18.108	18.099	18.098	18.098	3.235	3.235	3.233	3.231	3.200
Mass Flow	g/s	618.4	284.9	284.9	0.0	0.0	0.0	264.1	264.1	140.0	140.0

Streams: LPR								
Temperature	K	309.5	309.5	309.5	79.68	68.33	65.03	68.17
Pressure	atm	2.080	2.130	2.080	2.216	2.251	2.251	2.252
Mass Flow	g/s	507.2	507.2	507.2	507.2	365.8	507.2	365.8

Streams: MP					
Temperature	K	310.0	310.0	310.0	310.0
Pressure	atm	5.420	5.420	5.420	5.270
Mass Flow	g/s	636.3	507.2	1153	1153

Streams: LPL							
Temperature	K	307.51	309.74	309.74	79.68	79.70	68.33
Pressure	atm	1.050	1.100	1.050	1.136	1.131	1.151
Mass Flow	g/s	636.3	477.1	477.1	477.1	477.1	477.1

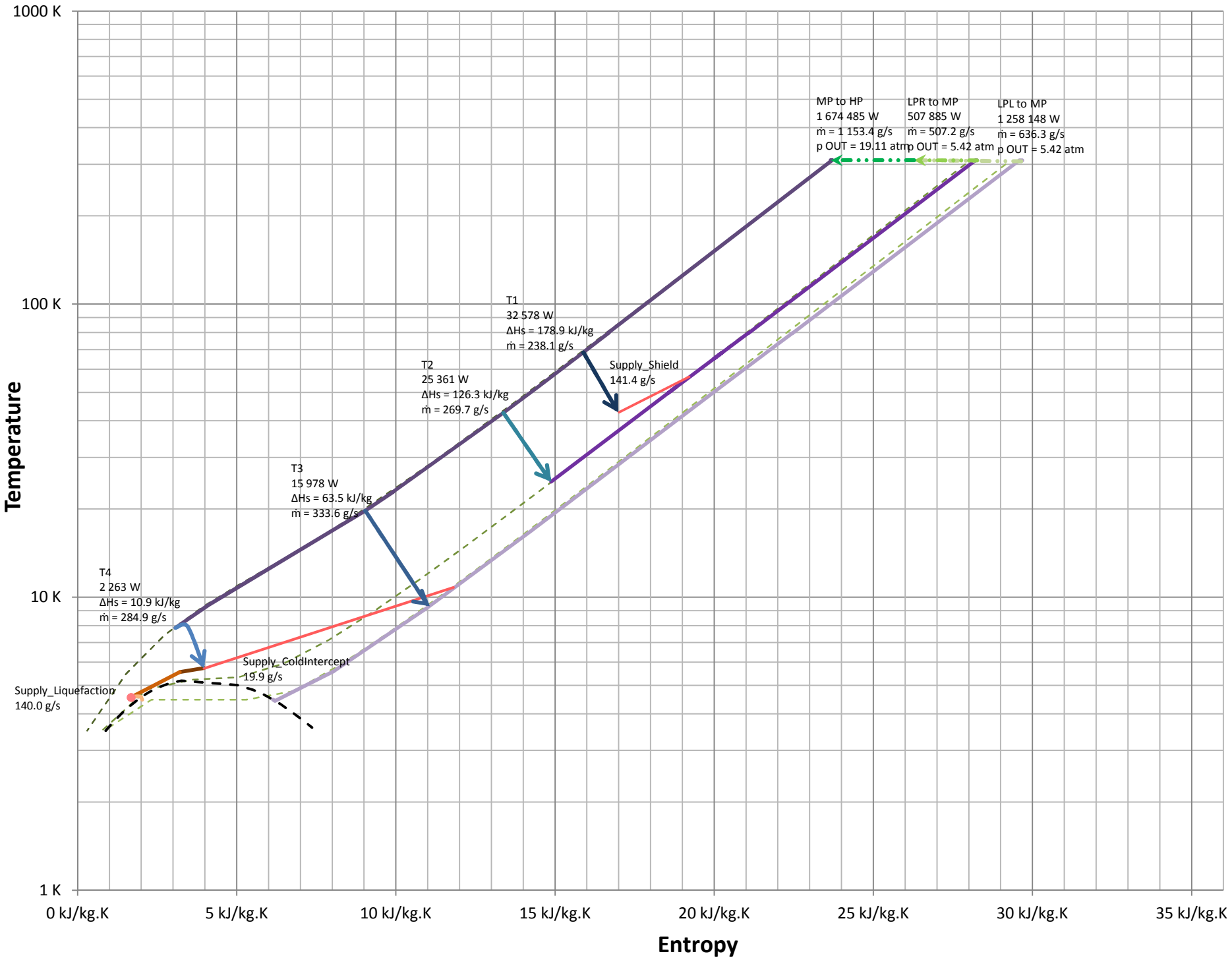
Temperature	K	40.05	21.44	16.89	9.16	9.33	5.59
Pressure	atm	1.176	1.191	1.192	1.197	1.197	1.197
Mass Flow	g/s	477.1	477.1	477.1	124.1	477.1	124.1

Streams: Subcooler					
Vapour Fraction		0.0000	0.0334	0.0000	0.9980
Temperature	K	4.55	4.47	4.47	4.47
Pressure	atm	3.231	1.250	1.250	1.250
Mass Flow	g/s	124.1	124.1	109.5	14.6

Streams: Nitrogen						
Temperature	K	309.48	78.95	78.95	78.95	78.95
Pressure	atm	1.050	1.200	1.200	1.200	1.200
Mass Flow	g/s	420.5	56.4	364.1	420.5	364.1
Vapour Fraction		1.0000	1.0000	1.0000	0.1341	0.0000

4.4 TS DIAGRAM

Mode 3 : Max Liq



- 19 atm
- 2.3 atm
- 1.25 atm
- - - - LV equilibrium
- HP
- LPR
- LPL
- Last HX
- Subcooler
- Liquefaction
- WarmShield
- Cold Intercept
- ➔ T1
- ➔ T2
- ➔ T3
- ➔ T4
- ➔ LPL to MP
- ➔ LPR to MP
- ➔ MP to HP
- JT

4.5 PROCESS DESIGN PERFORMANCE EVALUATION

Mode 3 - MaxLiq : Carnot efficiency

Heat loads	Mass Flow g/s	q kW	Supply					Return					EL kW
			T K	P atm	h J/g	s J/g-K	ε kJ/g	T K	P atm	h J/g	s J/g-K	ε kJ/g	
Shield	141.4	10.10	42.78	3.30	237.61	18.98	2.447	56.50	2.30	309.05	21.18	1.86	83.4
Cold intercept	19.9	0.90	5.71	3.20	24.25	5.94	6.144	10.80	1.23	69.47	13.77	3.84	45.9
Refrigeration	0.0	0.00	4.55	3.20	12.08	3.65	6.820	4.47	1.25	30.53	8.12	5.50	0.0
Liquefaction	140.0	218.61	4.55	3.20	12.08	3.65	6.820	300.00	1.10	1573.55	31.39	0.06	946.5
Sub Atm	0.0	0.00	4.55	3.20	12.08	3.65	6.820	30.00	1.22	170.86	19.20	2.31	0.0
Total												1075.7	

Compressors	Mass Flow g/s	Supply		Return	Ideal input power compressor kW	P2/P1	Isothermal Efficiency	Compressor Mechanical Power		Number of Motors ON	Motors rated power hp	Motors power margin	Motor efficiency	Electrical Power at Motors kW
		T K	P atm	P atm				kW	hp					
MP/HP	1153.4	300.00	5.27	19.11	925.9	3.63	52.9%	1749	2346	1	2500	6.2%	96.0%	1821.9
LPR/MP	507.2	300.00	2.08	5.42	302.7	2.61	55.8%	543	728	1	1000	27.2%	94.0%	577.3
LPL/MP	765.0 *	300.00	1.05	5.42	782.4	5.16	49.2%	1590	2132	3	800	11.2%	94.0%	1691.5
Total													4090.7	

* LPL compressors fully loaded and extra flow is by passed

N2	Mass Flow g/s	Supply					Return					Ideal input power N2 kW	LN equivalent efficiency	Input power N2 kW
		T K	P atm	h J/g	s J/gK	ε kJ/g	T K	P atm	h J/g	s J/gK	ε kJ/g			
N2	420.5	91.41	4.00	-92.51	3.18	-1.05	309.48	1.05	321.06	6.86	-1.74	290.3	0.35	829.5
Total													829.5	

Total Carnot Efficiency 21.9%
<i>Total Carnot efficiency without motors efficiencies 22.8%</i>

5. MODE 4 – MAX REFRIGERATION

5.1 PROCESS INPUTS

Load	w [g/s]	Supply		Return		q [kW]
		p [atm]	T [K]	p [atm]	T [K]	
Warm Shield	≤146	Note 1	≤35	≥2.5	≤55	≥15.2
Cold Intercept	≤31	≥3.2	≤5.3	≥1.23	≤9.0	≥1.3
4-K Refrigeration	≤481	≥3.2	≤4.5	≥1.23	≤4.45	≥9.0
4-K Liquefaction						
Sub-Atmospheric						

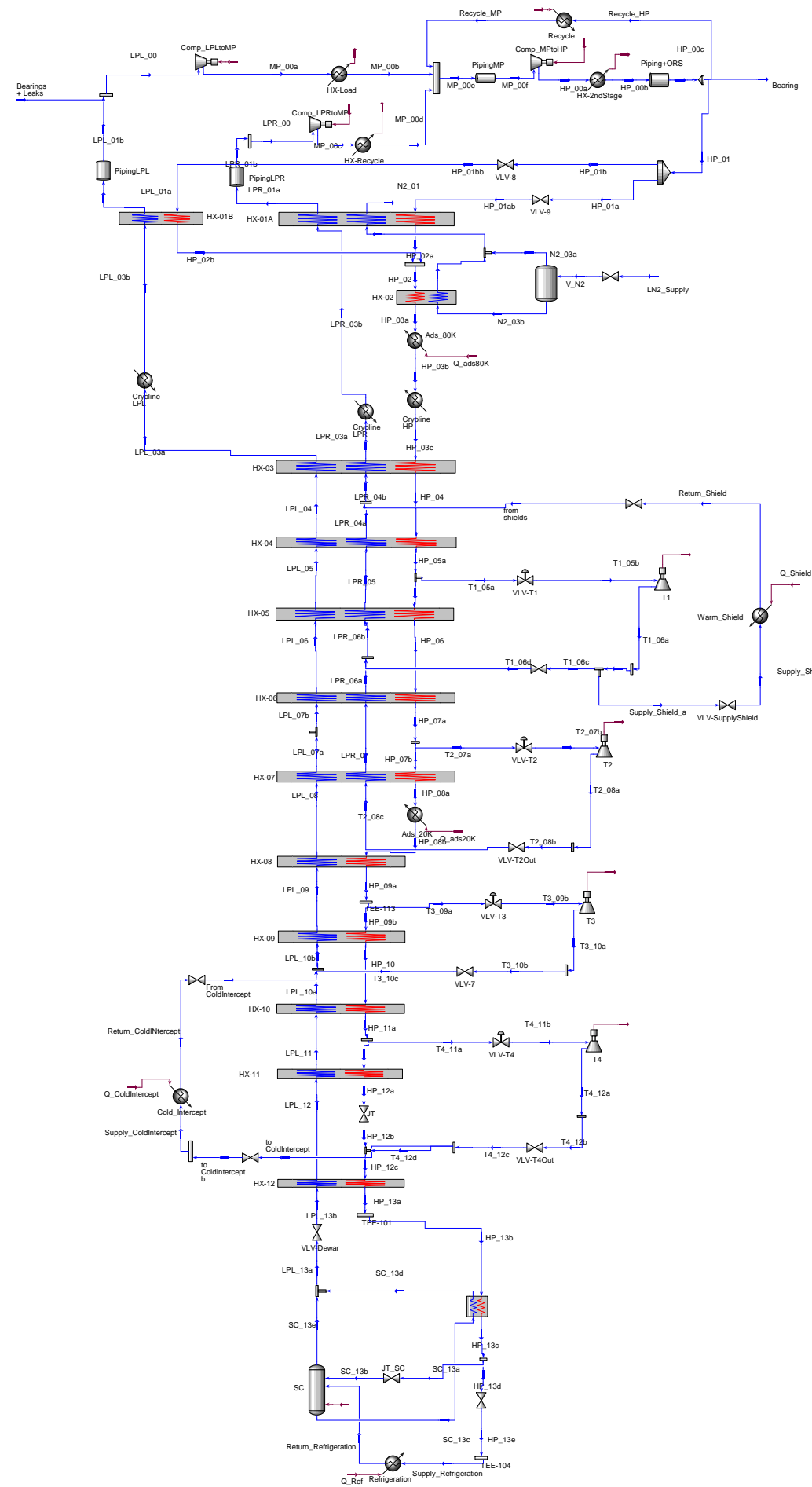
5.2 MAIN RESULTS AND REMARKS

- SHe supply for 4-K Refrigeration at 3.2 atm and 4.6K
- Pressure in LHe phase separator regulated at 1.25 atm → Temperature at 4.5K

Load	w [g/s]	Supply		Return		q [kW]
		P (atm)	T (K)	P (atm)	T (K)	
Warm Shield	145.5	3.5	35	2.5	55	15.2
Cold Shield	31.2	3.2	5.4	1.23	9.0	1.3
4-K Refrigeration	487.5	3.2	4.6	1.25	4.5	9.0
4-K Liquefaction						
Sub-Atmospheric						

5.3 PROCESS PFD

Mode 4 : Max Refrigeration



Heat Loads						
		Warm_Shield	Cold_Intercept	Refrigeration	Liquefaction	Sub_atm
DUTY	W*	15200	1300	8996	0	0
Feed Temperature	K	34.99	5.40	4.55	4.55	4.55
Feed Pressure	atm	3.500	3.200	3.200	3.200	3.200
Product Temperature	K	55.00	9.00	4.47	300.00	30.00
Product Pressure	atm	2.500	1.230	1.250	1.100	1.220
Mass Flow	g/s	145.5	31.2	487.5	0.0	0.0

Warm Compression Station				
		Comp_LPLtoMP	Comp_LPRtoMP	Comp_MPtoHP
Capacity (act feed vol flow)	ACT_m3/h	12554	5550	5037
Feed Pressure	atm	1.050	1.990	4.930
Feed Temperature	K	305.7	305.7	310.0
Product Pressure	atm	5.080	5.080	17.300
Mass Flow	g/s	584.0	489.1	1083.1

Cryogenic Expanders					
		T1	T2	T3	T4
Power	kW	23.13	10.22	0.00	2.43
Feed Temperature	K	53.62	20.87	12.77	6.53
Feed Pressure	atm	15.786	11.867	16.192	16.255
Product Temperature	K	34.99	12.69	5.69	5.41
Product Pressure	atm	3.545	2.202	1.205	3.248
Mass Flow	g/s	233.0	256.7	0.0	328.9
Adiabatic Fluid Head	kJ/kg	128.1	51.7	33.4	10.1
Adiabatic Efficiency		78	77	75	73

Heat Exchange								
		HX-01A	HX-01B	HX-02	HX-03	HX-04	HX-05	HX-06
UA (Calculated)	W/C	179889	204096	6290	132969	3661	126345	50985
Minimum Approach	K	2.54	2.55	0.80	0.91	1.51	0.33	0.66
Heat Leak	W*	203	234	10	152	5	147	59
		HX-07	HX-08	HX-09	HX-10	HX-11	HX-12	HX-SC
UA (Calculated)	W/C	69744	1929	29495	7232	2736	6125	3909
Minimum Approach	K	0.10	0.10	0.12	1.13	0.10	0.39	0.08
Heat Leak	W*	76	6	27	5	5	5	0

Streams: HP													
	HP_00a	HP_00b	HP_00c	HP_01a	HP_01ab	HP_01b	HP_01bb	HP_01	HP_02	HP_02a	HP_02b	HP_03a	
Temperature	K	579.77	310.00	310.03	310.03	310.03	310.03	310.03	310.03	81.43	81.43	81.43	79.75
Pressure	atm	17.300	17.300	16.800	16.800	16.780	16.800	16.780	16.800	16.687	16.687	16.687	16.684
Mass Flow	g/s	1083.1	1083.1	1083.1	495.8	495.8	564.3	564.3	1060.1	1060.1	495.8	564.3	1060.1
	HP_03b	HP_04	HP_05a	HP_05b	HP_06	HP_07a	HP_07b	HP_08a	HP_08b	HP_09a	HP_09b	HP_10	
Temperature	K	79.78	54.65	53.60	53.60	31.93	21.14	21.14	12.82	12.84	12.78	12.78	9.45
Pressure	atm	16.526	16.472	16.471	16.471	16.432	16.417	16.417	16.403	16.343	16.342	16.342	16.320
Mass Flow	g/s	1060.1	1060.1	1060.1	827.1	827.1	570.4	570.4	570.4	570.4	570.4	570.4	570.4
	HP_11a	HP_11b	HP_12a	HP_12b	HP_12c	HP_13a	HP_13b	HP_13c	HP_13d	HP_13e			
Temperature	K	6.53	6.53	5.17	5.56	5.49	4.82	4.82	4.55	4.55			
Pressure	atm	16.316	16.316	16.312	3.240	3.240	3.237	3.237	3.231	3.200			
Mass Flow	g/s	570.4	241.6	241.6	241.6	538.4	538.4	538.4	487.5	487.5			

Streams: LPR										
	LPR_00	LPR_01a	LPR_01b	LPR_03a	LPR_04a	LPR_04b	LPR_05	LPR_06a	LPR_06b	LPR_07
Temperature	K	305.7	305.7	305.7	78.87	53.14	53.70	51.90	31.27	19.58
Pressure	atm	1.990	2.040	1.990	2.123	2.152	2.152	2.152	2.175	2.183
Mass Flow	g/s	489.1	489.1	489.1	489.1	343.6	489.1	343.6	256.4	256.4

Streams: MP						
	MP_00a	MP_00b	MP_00c	MP_00d	MP_00e	MP_00f
Temperature	K	663.9	310.0	491.1	310.0	310.0
Pressure	atm	5.080	5.080	5.080	5.080	4.930
Mass Flow	g/s	584.0	584.0	489.1	489.1	1083

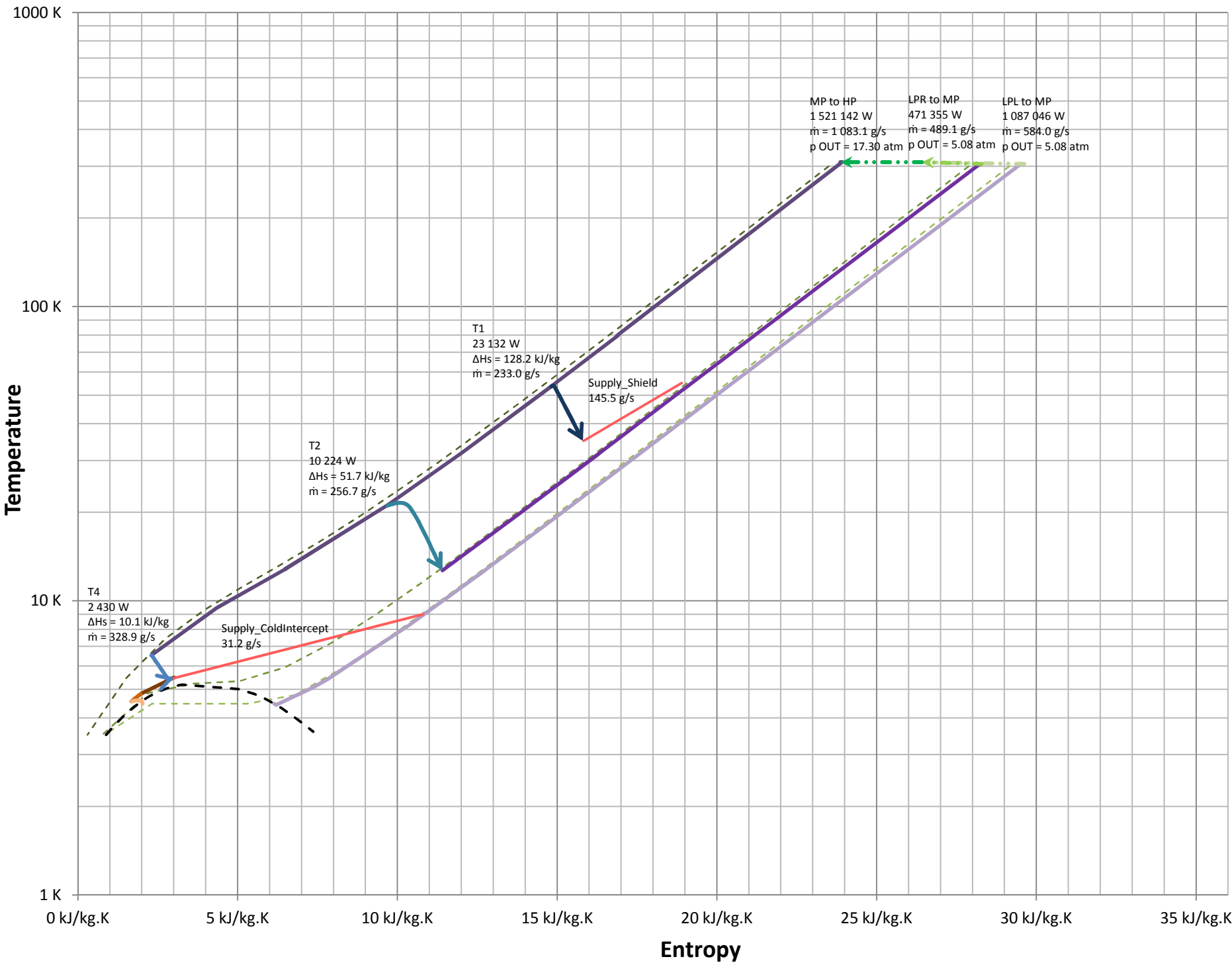
Streams: LPL																		
	LPL_00	LPL_01a	LPL_01b	LPL_03a	LPL_03b	LPL_04	LPL_05	LPL_06	LPL_07a	LPL_07b	LPL_08	LPL_09	LPL_10a	LPL_10b	LPL_11	LPL_12	LPL_13a	LPL_13b
Temperature	K	305.69	305.66	305.66	78.87	78.89	53.14	51.90	31.27	19.58								
Pressure	atm	1.050	1.100	1.050	1.148	1.143	1.165	1.165	1.180	1.185								
Mass Flow	g/s	584.0	569.6	569.6	569.6	569.6	569.6	569.6	569.6	569.6								
	LPL_13c	LPL_13d	LPL_13e	LPL_13f	LPL_13g	LPL_13h	LPL_13i	LPL_13j	LPL_13k	LPL_13l	LPL_13m	LPL_13n	LPL_13o	LPL_13p	LPL_13q	LPL_13r	LPL_13s	LPL_13t
Temperature	K	19.58	12.74	12.66	8.29	8.33	5.40	5.07	4.47	4.43								
Pressure	atm	1.185	1.197	1.198	1.205	1.205	1.205	1.205	1.205	1.205								
Mass Flow	g/s	569.6	569.6	569.6	538.4	569.6	538.4	538.4	538.4	538.4								

Streams: Subcooler						
	SC_13a	SC_13b	SC_13c	SC_13d	SC_13e	
Vapour Fraction		0.0000	0.0335	0.0000	0.9980	1.0000
Temperature	K	4.55	4.47	4.47	4.47	4.47
Pressure	atm	3.231	1.250	1.250	1.250	1.250
Mass Flow	g/s	50.9	50.9	38.4	38.4	500.0

Streams: Nitrogen							
	N2_01	N2_02a	N2_02b	N2_02c	N2_03a	N2_03b	LN2_Supply
Temperature	K	305.71	78.95	78.95	78.95	78.95	91.41
Pressure	atm	1.050	1.200	1.200	1.200	1.200	4.000
Mass Flow	g/s	55.1	7.4	47.7	55.1	55.1	47.7
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	0.1341	0.0000

5.4 TS DIAGRAM

Mode 4 : Max Ref



- 19 atm
- - - - 2.3 atm
- - - - 1.25 atm
- - - - LV equilibrium
- HP
- LPR
- LPL
- Last HX
- Subcooler
- WarmShield
- Cold Intercept
- T1
- T2
- T4
- LPL to MP
- LPR to MP
- MP to HP
- JT

5.5 PROCESS DESIGN PERFORMANCE EVALUATION

Mode 4 - MaxRef : Carnot efficiency

Heat loads	Mass Flow g/s	q kW	Supply					Return					EL kW
			T K	P atm	h J/g	s J/g-K	ε kJ/g	T K	P atm	h J/g	s J/g-K	ε kJ/g	
Shield	145.5	15.20	34.99	3.50	196.78	17.80	2.759	55.00	2.50	301.28	20.87	1.94	118.6
Cold intercept	31.2	1.30	5.40	3.20	17.89	4.80	6.479	9.00	1.23	59.57	12.77	4.13	73.3
Refrigeration	487.5	9.00	4.55	3.20	12.08	3.65	6.820	4.47	1.25	30.53	8.12	5.50	645.2
Liquefaction	0.0	0.00	4.55	3.20	12.08	3.65	6.820	300.00	1.10	1573.55	31.39	0.06	0.0
Sub Atm	0.0	0.00	4.55	3.20	12.08	3.65	6.820	30.00	1.22	170.86	19.20	2.31	0.0
Total												837.1	

Compressors	Mass Flow g/s	Supply		Return	Ideal input power compressor kW	P2/P1	Isothermal Efficiency	Compressor Mechanical Power		Number of Motors ON	Motors rated power hp	Motors power margin	Motor efficiency	Electrical Power at Motors kW
		T K	P atm	P atm				kW	hp					
MP/HP	1083.1	300.00	4.93	17.30	847.3	3.51	53.0%	1598	2143	1	2500	14.3%	96.0%	1664.9
LPR/MP	489.1	300.00	1.99	5.08	285.6	2.55	55.8%	512	687	1	1000	31.3%	94.0%	544.8
LPL/MP	772.0 *	300.00	1.05	5.08	758.4	4.84	49.5%	1532	2054	3	800	14.4%	94.0%	1629.3
Total													3839.0	

* LPL compressors fully loaded and extra flow is by passed

N2	Mass Flow g/s	Supply					Return					Ideal input power N2 kW	LN equivalent efficiency	Input power N2 kW
		T K	P atm	h J/g	s J/gK	ε kJ/g	T K	P atm	h J/g	s J/gK	ε kJ/g			
N2	55.1	91.41	4.00	-92.51	3.18	-1.05	305.71	1.05	317.13	6.85	-1.74	38.0	0.35	108.7
Total													108.7	

Total Carnot Efficiency 21.2%
<i>Total Carnot efficiency without motors efficiencies 22.3%</i>

6. MODE 5 – MAX FILL

6.1 PROCESS INPUTS

Load	w [g/s]	Supply		Return		q [kW]
		p [atm]	T [K]	p [atm]	T [K]	
Warm Shield	≤146	Note 1	≤35	≥2.7	≤55	≥15.2
Cold Intercept	≤35	≥3.2	≤5.3	≥1.23	≤7.8	≥1.3
4-K Refrigeration						
4-K Liquefaction	≥45	≥3.2	4.5	1.10	300.0	
Sub-Atmospheric	≥157	≥3.2	4.5	1.20	30.0	

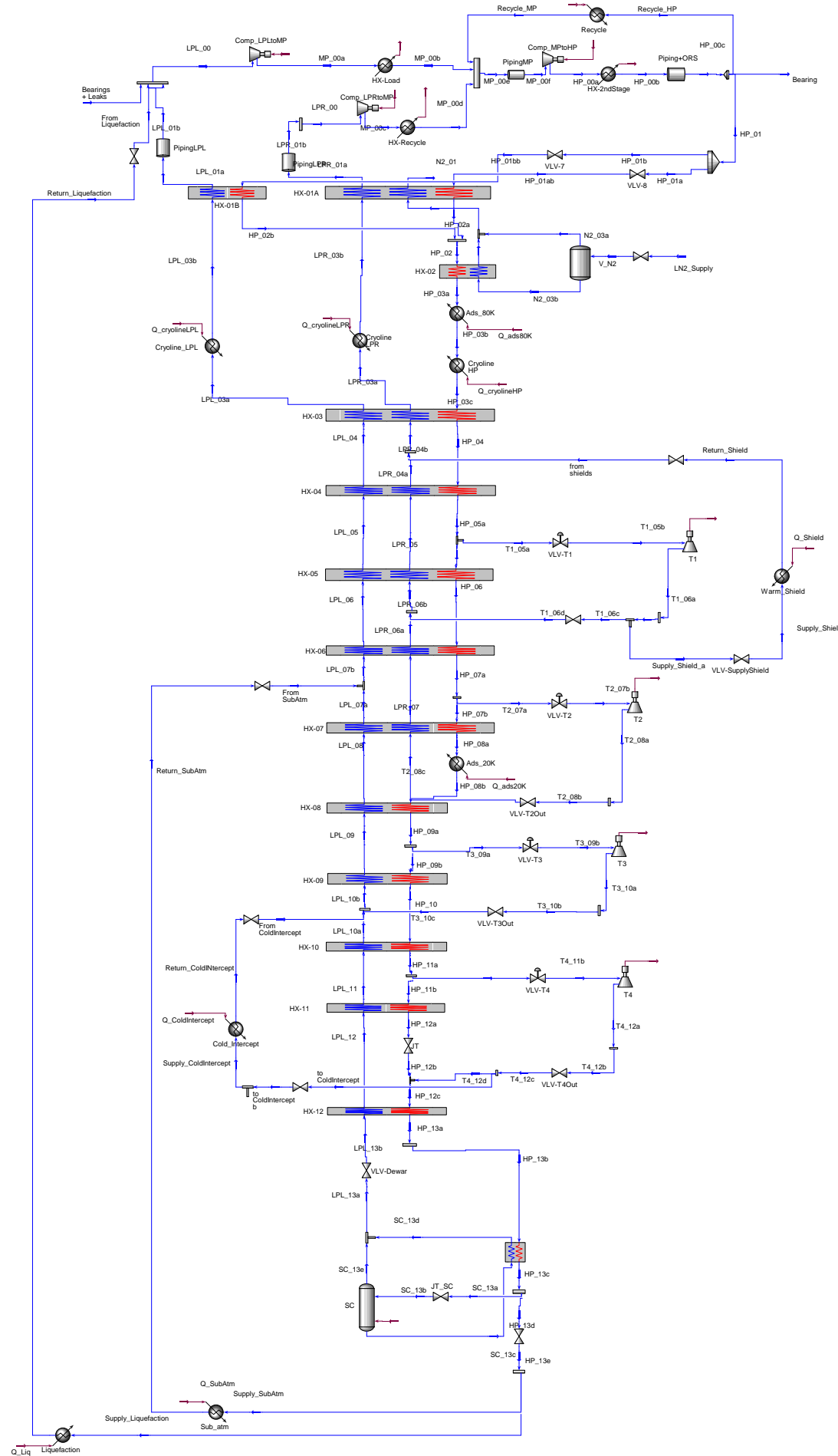
6.2 MAIN RESULTS AND REMARKS

- SHe supply for 4-K Liquefaction at 3.2 atm and 4.6K
- Sub-Atmospheric Return pressure at 1.236 atm.

Load	w [g/s]	Supply		Return		q [kW]
		P (atm)	T (K)	P (atm)	T (K)	
Warm Shield	190.5	3.7	37.4	2.7	52.7	15.2
Cold Shield	39.5	3.2	5.5	1.27	7.8	1.3
4-K Refrigeration						
4-K Liquefaction	45	3.2	4.6	1.1	300	
Sub-Atmospheric	157	3.2	4.6	1.236	30	

6.3 PROCESS PFD

Mode 5 : Max Fill



Heat Loads					
	Warm_Shield	Cold_Intercept	Refrigeration	Liquefaction	Sub_atm
DUTY	W*	15200	1300	0	24927
Feed Temperature	K	37.37	5.53	4.55	4.55
Feed Pressure	atm	3.700	3.200	3.200	3.200
Product Temperature	K	52.65	7.80	4.47	300.00
Product Pressure	atm	2.700	1.273	1.250	1.100
Mass Flow	g/s	190.5	39.5	0.0	45.0

Warm Compression Station				
	ACT_m3/h	Comp_LPLtoMP	Comp_LPRtoMP	Comp_MPtoHP
Capacity (act feed vol flow)		15622	5552	5039
Feed Pressure	atm	1.050	2.346	5.950
Feed Temperature	K	307.1	307.4	310.0
Product Pressure	atm	6.100	6.100	19.450
Mass Flow	g/s	723.5	573.5	1307.0

Cryogenic Expanders						
	T1	T2	T3	T4		
Power	kW	30.10	22.61	14.82	2.84	
Feed Temperature	K	59.01	32.30	17.03	7.09	
Feed Pressure	atm	18.513	18.429	18.336	17.443	
Product Temperature	K	37.37	18.47	7.73	5.54	
Product Pressure	atm	3.745	2.602	1.256	3.242	
Mass Flow	g/s	260.0	314.1	369.1	336.5	
Adiabatic Fluid Head	kJ/kg	148.4	92.3	52.1	11.5	
Adiabatic Efficiency		78	78	77	74	

Heat Exchange							
	HX-01A	HX-01B	HX-02	HX-03	HX-04	HX-05	HX-06
UA (Calculated)	W/C	200725	226053	12570	148373	4017	139204
Minimum Approach	K	2.59	2.46	0.80	0.51	0.59	0.67
Heat Leak	W*	203	234	10	152	5	147
		HX-07	HX-08	HX-09	HX-10	HX-11	HX-12
UA (Calculated)	W/C	76554	5937	25408	2137	0	1817
Minimum Approach	K	0.54	0.77	0.10	0.12	0.42	0.10
Heat Leak	W*	76	6	27	5	5	0

Streams HP												
	HP_00a	HP_00b	HP_00c	HP_01a	HP_01ab	HP_01b	HP_01bb	HP_01	HP_02	HP_02a	HP_02b	HP_03a
Temperature	K	560.69	310.00	310.03	310.03	310.03	310.03	310.03	84.17	84.17	84.17	79.75
Pressure	atm	19.450	19.450	18.950	18.950	18.950	18.950	18.950	18.804	18.804	18.804	18.800
Mass Flow	g/s	1307.0	1307.0	1307.0	614.3	614.3	665.5	665.5	1279.8	1279.8	614.3	1279.8
		HP_03b	HP_03c	HP_04	HP_05a	HP_05b	HP_06	HP_07a	HP_07b	HP_08a	HP_08b	HP_09a
Temperature	K	79.78	79.78	59.39	59.01	59.01	41.27	32.30	32.30	18.67	18.69	17.03
Pressure	atm	18.642	18.632	18.576	18.574	18.574	18.516	18.490	18.490	18.459	18.399	18.397
Mass Flow	g/s	1279.8	1279.8	1279.8	1279.8	1019.8	1019.8	705.7	705.7	705.7	705.7	336.5
		HP_10	HP_11a	HP_11b	HP_12a	HP_12b	HP_12c	HP_13a	HP_13b	HP_13c	HP_13d	HP_13e
Temperature	K	7.82	7.02	7.02	5.86	5.70	5.54	5.35	5.35	4.55	4.55	4.55
Pressure	atm	18.387	18.387	18.387	18.386	3.234	3.234	3.233	3.233	3.231	3.231	3.200
Mass Flow	g/s	336.5	336.5	0.0	0.0	0.0	296.2	296.2	296.2	296.2	202.0	202.0

Streams LPR											
	LPR_00	LPR_01a	LPR_01b	LPR_03a	LPR_03b	LPR_04a	LPR_04b	LPR_05	LPR_06a	LPR_06b	LPR_07
Temperature	K	307.4	307.4	307.4	79.27	79.29	58.79	56.75	58.32	40.75	40.14
Pressure	atm	2.346	2.396	2.346	2.493	2.486	2.528	2.528	2.529	2.559	2.574
Mass Flow	g/s	573.5	573.5	573.5	573.5	573.5	383.0	573.5	383.0	313.8	313.8

Streams MP					
	MP_00b	MP_00d	MP_00e	MP_00f	
Temperature	K	310.0	310.0	310.0	310.0
Pressure	atm	6.100	6.100	6.100	5.950
Mass Flow	g/s	723.5	573.5	1307	1307

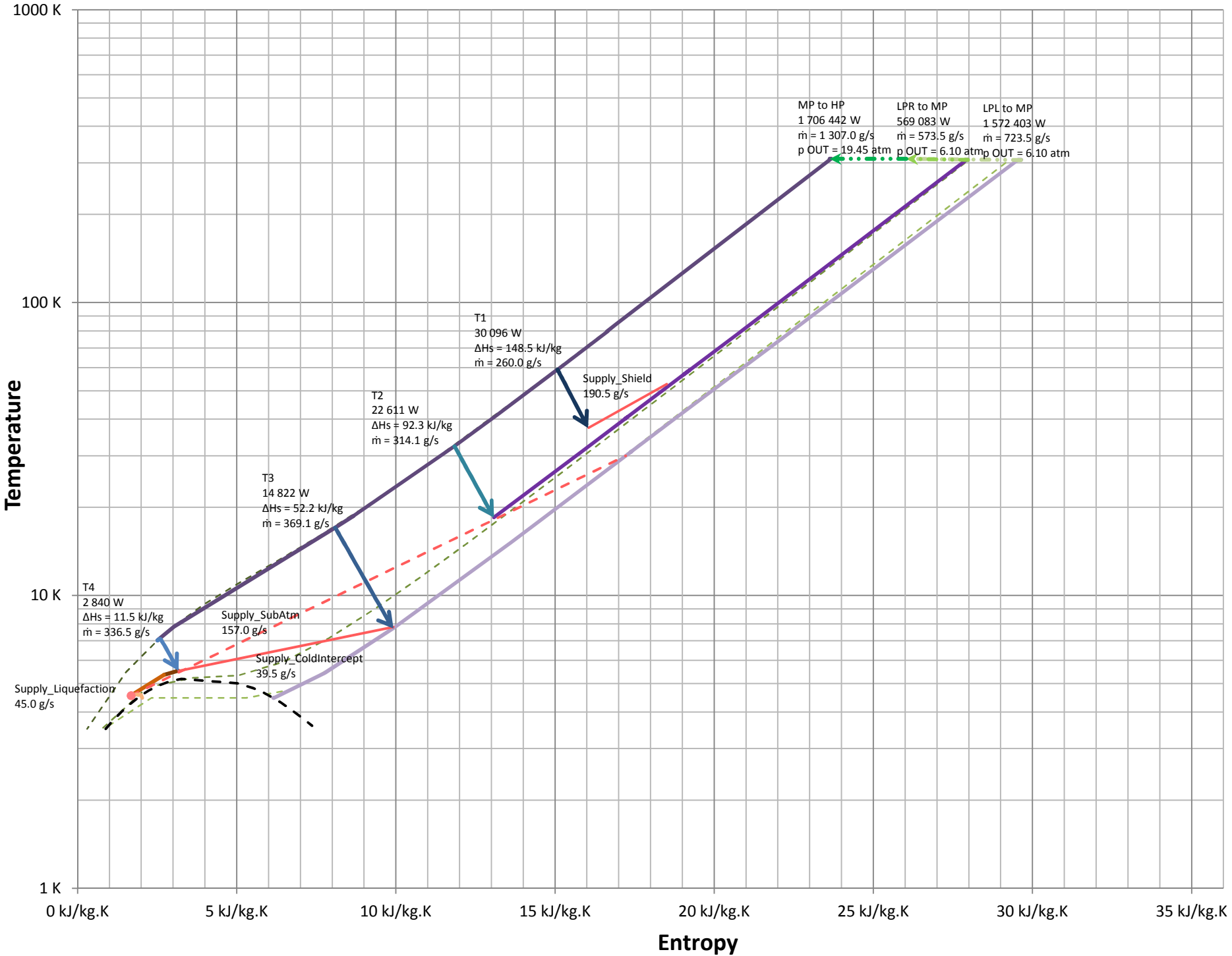
Streams LPL												
	LPL_00	LPL_01a	LPL_01b	LPL_03a	LPL_03b	LPL_04	LPL_05	LPL_06	LPL_07a	LPL_07b	LPL_08	LPL_09
Temperature	K	307.09	307.57	307.57	79.27	79.29	58.79	58.32	40.75	31.09	30.83	17.92
Pressure	atm	1.050	1.100	1.050	1.162	1.157	1.187	1.188	1.213	1.222	1.222	1.235
Mass Flow	g/s	723.5	659.3	659.3	659.3	659.3	659.3	659.3	502.3	659.3	502.3	602.3
		LPL_10a	LPL_10b	LPL_11	LPL_12	LPL_13a	LPL_13b	HP_01a	HP_01b	HP_02a	HP_02b	HP_01bb
Temperature	K	7.70	7.72	5.44	5.44	4.47	4.46	310.03	310.03	84.17	84.17	310.03
Pressure	atm	1.241	1.241	1.241	1.241	1.250	1.241	18.950	18.950	18.804	18.804	18.930
Mass Flow	g/s	94.2	502.3	94.2	94.2	94.2	94.2	614.3	665.5	614.3	665.5	614.3

Streams Subcooler										
	HP_01a	HP_01ab	HP_01b	HP_01bb	HP_02a	HP_02b	SC_13a	SC_13b	SC_13c	SC_13d
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0335	0.0000
Temperature	K	310.03	310.03	310.03	310.03	84.17	84.17	4.55	4.47	4.47
Pressure	atm	18.950	18.930	18.950	18.930	18.804	18.804	3.231	1.250	1.250
Mass Flow	g/s	614.3	614.3	665.5	665.5	614.3	665.5	94.2	94.2	80.6

Streams Nitrogen						
	N2_01	N2_02a	N2_02b	N2_02c	N2_03a	N2_03b
Temperature	K	307.44	78.95	78.95	78.95	78.95
Pressure	atm	1.050	1.200	1.200	1.200	1.200
Mass Flow	g/s	174.1	23.3	150.8	174.1	150.8
Vapour Fraction		1.0000	1.0000	1.0000	0.1341	0.0000

6.4 TS DIAGRAM

Mode 5 : Max Fill



- 19 atm
- 2.3 atm
- 1.25 atm
- - - LV equilibrium
- HP
- LPR
- LPL
- Last HX
- Subcooler
- Liquefaction
- - - Sub-Atmospheric
- WarmShield
- Cold Intercept
- ➔ T1
- ➔ T2
- ➔ T3
- ➔ T4
- ➔ LPL to MP
- ➔ LPR to MP
- ➔ MP to HP
- JT

6.5 PROCESS DESIGN PERFORMANCE EVALUATION

Mode 5 - MaxFill : Carnot efficiency

Heat loads	Mass Flow g/s	q kW	Supply					Return					EL kW
			T K	P atm	h J/g	s J/g-K	ε kJ/g	T K	P atm	h J/g	s J/g-K	ε kJ/g	
Shield	190.5	15.20	37.37	3.70	209.26	18.03	2.703	52.65	2.70	289.06	20.48	2.05	124.8
Cold intercept	39.5	1.30	5.53	3.20	19.75	5.14	6.379	7.80	1.27	52.71	11.88	4.39	78.5
Refrigeration	0.0	0.00	4.55	3.20	12.08	3.65	6.820	4.47	1.25	30.53	8.12	5.50	0.0
Liquefaction	45.0	70.27	4.55	3.20	12.08	3.65	6.820	300.00	1.10	1573.55	31.39	0.06	304.2
Sub Atm	157.0	24.93	4.55	3.20	12.08	3.65	6.820	30.00	1.23	170.86	19.19	2.31	707.3
Total												1214.9	

Compressors	Mass Flow g/s	Supply		Return	Ideal input power compressor kW	P2/P1	Isothermal Efficiency	Compressor Mechanical Power		Number of Motors ON	Motors rated power hp	Motors power margin	Motor efficiency	Electrical Power at Motors kW
		T K	P atm	P atm				kW	hp					
MP/HP	1307.0	300.00	5.95	19.45	964.7	3.27	53.1%	1817	2437	1	2500	2.5%	96.0%	1892.9
LPR/MP	573.5	300.00	2.35	6.10	341.5	2.60	55.8%	612	821	1	1000	17.9%	94.0%	651.3
LPL/MP	757.0 *	300.00	1.05	6.10	830.0	5.81	48.6%	1708	2291	3	800	4.6%	94.0%	1817.3
Total													4361.4	

* LPL compressors fully loaded and extra flow is by passed

N2	Mass Flow g/s	Supply					Return					Ideal input power N2 kW	LN equivalent efficiency	Input power N2 kW
		T K	P atm	h J/g	s J/gK	ε kJ/g	T K	P atm	h J/g	s J/gK	ε kJ/g			
N2	174.1	91.41	4.00	-92.51	3.18	-1.05	307.44	1.05	318.93	6.85	-1.74	120.2	0.35	343.5
Total													343.5	

Total Carnot Efficiency 25.8%
<i>Total Carnot efficiency without motors efficiencies 27.1%</i>

7. MODE 6 – STANDBY

7.1 PROCESS INPUTS

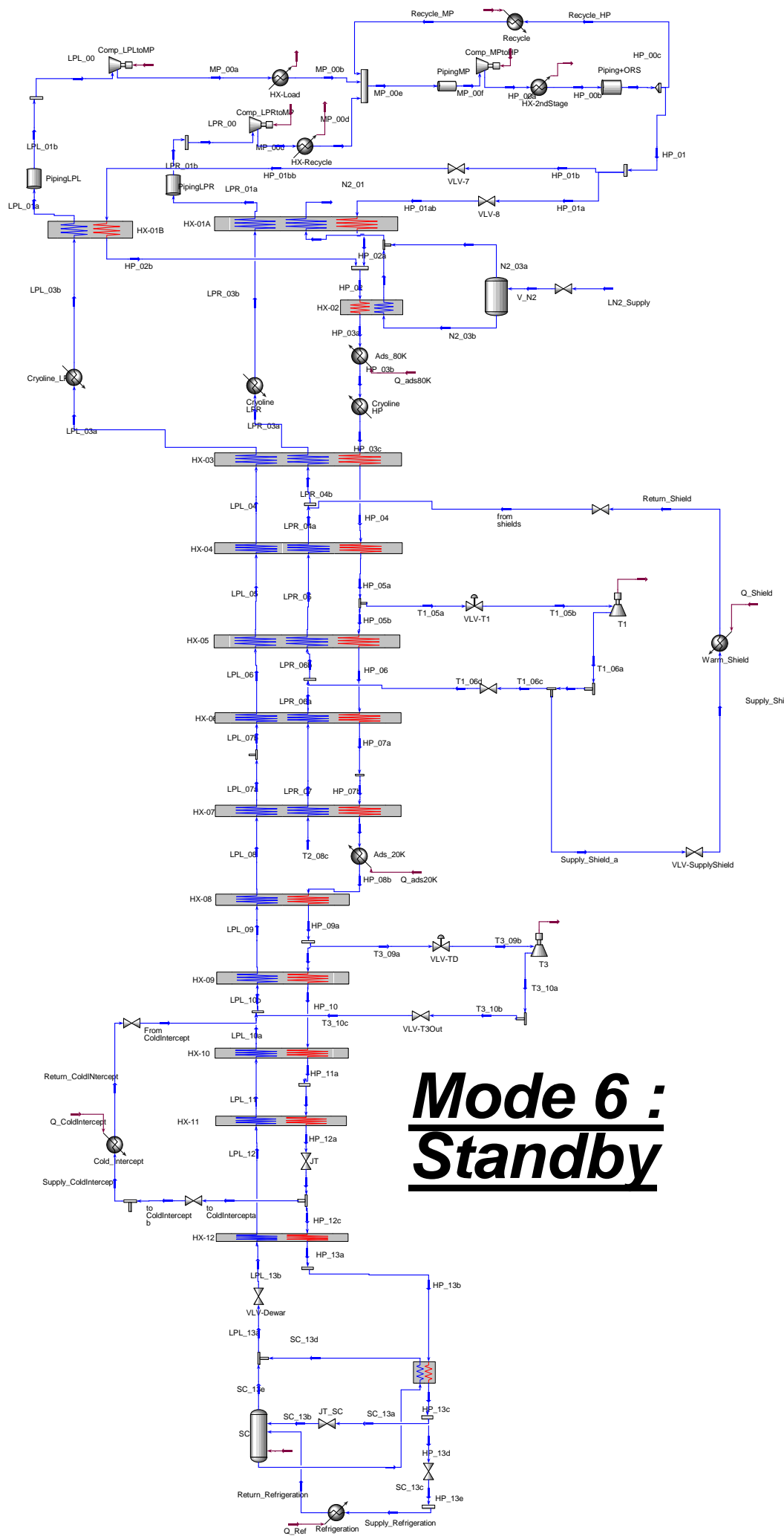
Load	w [g/s]	Supply		Return		q [kW]
		p [atm]	T [K]	p [atm]	T [K]	
Warm Shield	≤96.7	Note 1	≤35	≥2.7	≤55	≥10.1
Cold Intercept	≤25	≥3.2	≤5.3	≥1.23	≤7.5	≥0.9
4-K Refrigeration	≤27	≥3.2	≤4.5	≥1.23	≤4.5	≥0.5
4-K Liquefaction						
Sub-Atmospheric						

7.2 MAIN RESULTS AND REMARKS

- Cold Shields supplied at 3.0 atm
- SHe supply for 4-K Refrigeration at 3.2 atm and 4.55K

Load	w [g/s]	Supply		Return		q [kW]
		P (atm)	T (K)	P (atm)	T (K)	
Warm Shield	85.9	3.7	32.5	2.7	55	10.1
Cold Shield	35.7	3.0	5.68	1.23	7.5	0.9
4-K Refrigeration	27.1	3.2	4.55	1.25	4.47	0.5
4-K Liquefaction						
Sub-Atmospheric						

7.3 PROCESS PFD



Heat Loads						
		Warm_Shield	Cold_Intercept	Refrigeration	Liquefaction	Sub_atm
DUTY	W*	10100	900	500	0	0
Feed Temperature	K	34.80	5.52	4.55	4.55	4.55
Feed Pressure	atm	3.700	3.000	3.200	3.200	3.200
Product Temperature	K	55.00	7.50	4.47	300.00	30.00
Product Pressure	atm	2.700	1.230	1.250	1.100	1.220
Mass Flow	g/s	95.7	29.7	27.1	0.0	0.0

Warm Compression Station				
		Comp_LPLtoMP	Comp_LPRtoMP	Comp_MPtoHP
Capacity (act feed vol flow)	ACT_m3/h	4784	3925	4030
Feed Pressure	atm	1.050	1.050	2.350
Feed Temperature	K	306.9	307.0	310.0
Product Pressure	atm	2.500	2.500	12.450
Mass Flow	g/s	221.7	181.8	413.5

Cryogenic Expanders					
		T1	T2	T3	T4
Power	kW	13.11	0.00	1.95	0.00
Feed Temperature	K	48.38	30.00	9.96	6.35
Feed Pressure	atm	11.667	3.939	5.129	11.605
Product Temperature	K	34.80	23.04	6.31	5.43
Product Pressure	atm	3.745	1.500	1.132	3.239
Mass Flow	g/s	182.1	0.0	144.9	0.0
Adiabatic Fluid Head	kJ/kg	93.5	50.1	19.5	6.9
Adiabatic Efficiency		77	72	69	70

Heat Exchange								
		HX-01A	HX-01B	HX-02	HX-03	HX-04	HX-05	HX-06
UA (Calculated)	W/C	90216	102301	2055	66491	1675	15738	18940
Minimum Approach	K	1.96	1.96	0.80	0.73	2.77	0.10	0.10
Heat Leak	W*	203	234	10	152	5	147	59
		HX-07	HX-08	HX-09	HX-10	HX-11	HX-12	HX-SC
UA (Calculated)	W/C	29826	3248	2272	486	428	1100	24
Minimum Approach	K	0.26	1.70	0.10	0.10	0.24	0.10	0.08
Heat Leak	W*	76	6	27	5	5	5	0

Streams HP												
	HP_00a	HP_00b	HP_00c	HP_01	HP_01a	HP_01b	HP_01bb	HP_01ab	HP_02	HP_02a	HP_02b	HP_03a
Temperature	K	702.08	310.00	310.03	310.03	310.03	310.03	310.03	81.12	81.12	81.12	79.75
Pressure	atm	12.45	12.45	11.95	11.95	11.95	11.95	11.93	11.93	11.91	11.91	11.91
Mass Flow	g/s	413.5	413.5	413.5	394.8	184.0	210.8	184.0	394.8	184.0	210.8	394.8
	HP_03b	HP_03c	HP_04	HP_05a	HP_05b	HP_06	HP_07a	HP_08a	HP_07b	HP_08b	HP_09a	HP_09b
Temperature	K	79.83	79.84	50.94	48.37	48.37	34.86	32.04	16.21	32.04	16.27	11.25
Pressure	atm	11.76	11.75	11.74	11.74	11.74	11.73	11.73	11.73	11.73	11.67	11.67
Mass Flow	g/s	394.8	394.8	394.8	394.8	212.7	212.7	212.7	212.7	212.7	212.7	67.8
	HP_10	HP_11a	HP_11b	HP_12a	HP_12b	HP_12c	HP_13a	HP_13b	HP_13d	HP_13e		
Temperature	K	6.59	6.35	6.35	5.89	5.59	5.59	4.56	4.56	4.55	4.55	
Pressure	atm	11.67	11.67	11.67	11.67	3.231	3.231	3.231	3.231	3.231	3.200	
Mass Flow	g/s	67.8	67.8	67.8	67.8	67.8	38.1	38.1	38.1	27.1	27.1	

Streams LPR											
	LPR_00	LPR_01a	LPR_01b	LPR_03b	LPR_03a	LPR_04a	LPR_04b	LPR_05	LPR_06a	LPR_06b	LPR_07
Temperature	K	307.0	307.0	307.0	79.16	79.11	48.17	51.79	44.72	34.76	34.77
Pressure	atm	1.050	1.100	1.050	1.129	1.136	1.143	1.143	1.143	1.146	1.146
Mass Flow	g/s	181.8	181.8	181.8	181.8	181.8	86.13	181.8	86.13	1.000e-006	86.13

Streams MP				
	MP_00b	MP_00d	MP_00e	MP_00f
Temperature	K	310.0	310.0	310.0
Pressure	atm	2.500	2.500	2.500
Mass Flow	g/s	221.7	181.8	413.5

Streams LPL									
	LPL_00	LPL_01a	LPL_01b	LPL_03a	LPL_03b	LPL_04	LPL_05	LPL_06	LPL_07a
Temperature	K	306.89	306.88	306.88	79.11	79.16	48.17	44.72	34.76
Pressure	atm	1.050	1.100	1.050	1.110	1.105	1.112	1.112	1.114
Mass Flow	g/s	221.7	212.2	212.2	212.2	212.2	212.2	212.2	212.2
	LPL_07b	LPL_08	LPL_09	LPL_10a	LPL_10b	LPL_11	LPL_12	LPL_13a	LPL_13b
Temperature	K	31.77	14.57	8.39	6.49	6.49	6.11	5.49	4.47
Pressure	atm	1.115	1.117	1.117	1.117	1.117	1.117	1.250	1.117
Mass Flow	g/s	212.2	212.2	212.2	38.1	212.2	38.1	38.1	38.1

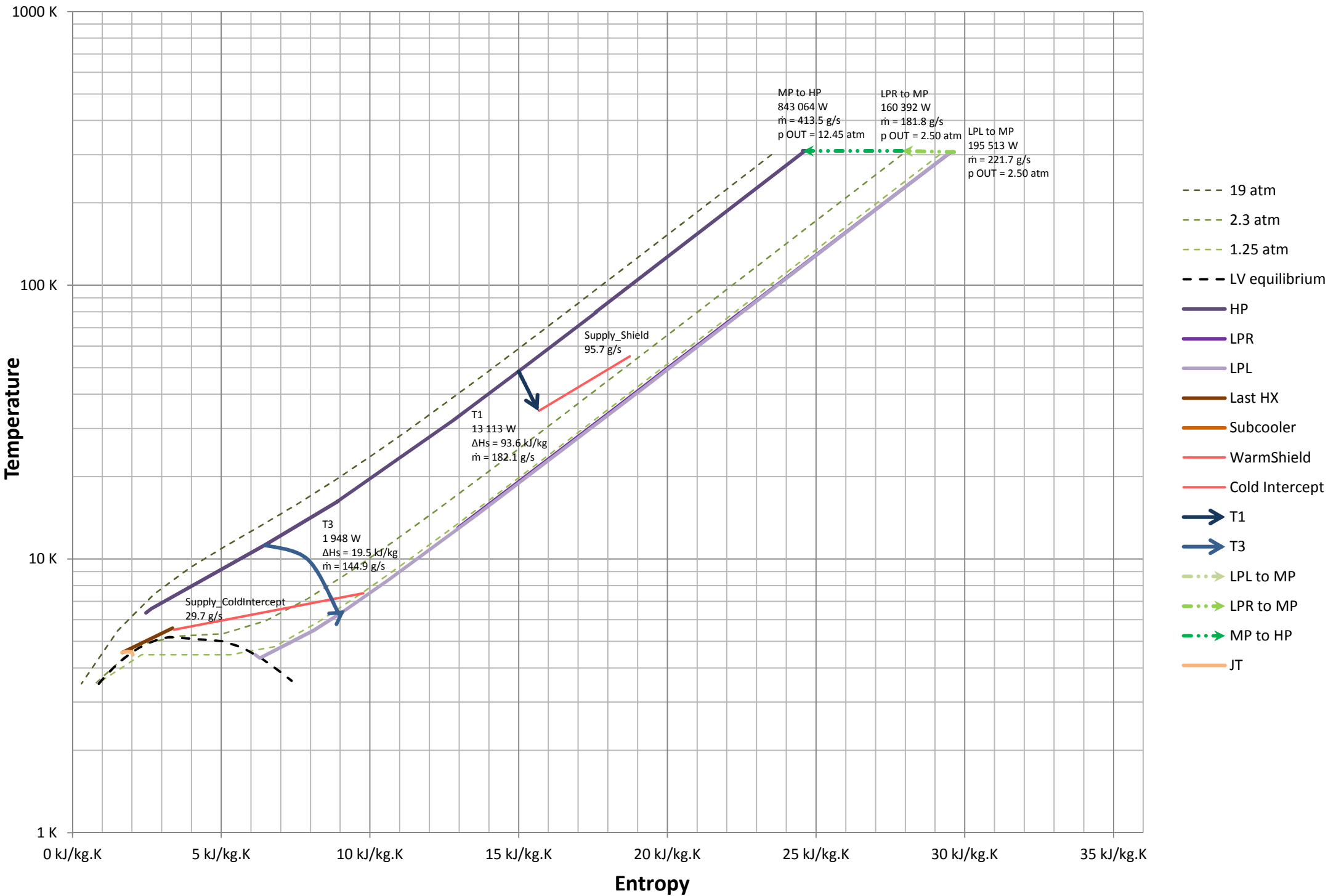
Streams Subcooler					
	SC_13a	SC_13b	SC_13c	SC_13d	SC_13e
Vapour Fraction		0.0000	0.0334	0.0000	0.9980
Temperature	K	4.55	4.47	4.47	4.47
Pressure	atm	3.231	1.250	1.250	1.250
Mass Flow	g/s	11.0	11.0	0.1	0.1

Streams Nitrogen							
	N2_01	N2_02a	N2_02b	N2_02c	N2_03a	N2_03b	LN2_Supply
Temperature	K	306.97	78.95	78.95	78.95	78.95	91.41
Pressure	atm	1.050	1.200	1.200	1.200	1.200	4.000
Mass Flow	g/s	16.7	2.2	14.5	16.7	16.7	16.7
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	0.1341	0.0000

**Mode 6 :
Standby**

7.4 TS DIAGRAM

Mode 6 : Standby



7.5 PROCESS DESIGN PERFORMANCE EVALUATION

Mode 6 - Standby : Carnot efficiency

Heat loads	Mass Flow g/s	q kW	Supply					Return					EL kW
			T K	P atm	h J/g	s J/g-K	ε kJ/g	T K	P atm	h J/g	s J/g-K	ε kJ/g	
Shield	95.7	10.10	34.80	3.70	195.75	17.65	2.802	55.00	2.70	301.31	20.71	1.99	77.5
Cold intercept	29.7	0.90	5.52	3.00	20.82	5.38	6.310	7.50	1.23	51.09	11.74	4.43	55.8
Refrigeration	27.1	0.50	4.55	3.20	12.08	3.65	6.820	4.47	1.25	30.53	8.12	5.50	35.9
Liquefaction	0.0	0.00	4.55	3.20	12.08	3.65	6.820	300.00	1.10	1573.55	31.39	0.06	0.0
Sub Atm	0.0	0.00	4.55	3.20	12.08	3.65	6.820	30.00	1.22	170.86	19.20	2.31	0.0
Total												169.2	

Compressors	Mass Flow g/s	Supply		Return	Ideal input power compressor kW	P2/P1	Isothermal Efficiency	Compressor Mechanical Power		Number of Motors ON	Motors rated power hp	Motors power margin	Motor efficiency	Electrical Power at Motors kW
		T K	P atm	P atm				kW	hp					
MP/HP	510*	300.00	2.35	12.45	529.9	5.30	50.0%	1060	1422	1	2500	43.1%	96.0%	1104.3
LPR/MP	260*	300.00	1.05	2.50	140.6	2.38	55.6%	253	339	1	1000	66.1%	94.0%	269.0
LPL/MP	260*	300.00	1.05	2.50	140.6	2.38	48.4%	290	389	3	800	83.8%	94.0%	308.8
Total													1682.1	

* compressors fully loaded (with 2 LPL compressors stopped), extra-flow is by passed

N2	Mass Flow g/s	Supply					Return					Ideal input power N2 kW	LN equivalent efficiency	Input power N2 kW
		T K	P atm	h J/g	s J/gK	ε kJ/g	T K	P atm	h J/g	s J/gK	ε kJ/g			
N2	16.7	91.41	4.00	-92.51	3.18	-1.05	306.97	1.05	318.44	6.85	-1.74	11.5	0.35	32.9
Total														32.9

Total Carnot Efficiency 9.9%
<i>Total Carnot efficiency without motors efficiencies 10.3%</i>

8. MODE 7 – 50% TURN-DOWN

8.1 PROCESS INPUTS

Table 7: Mode 7, 50% turn down

Load	Supply			Return		q [kW]
	w [g/s]	p [atm]	T [K]	p [atm]	T [K]	
Warm Shield		[Note 1]	35 ± 5 [Note 3]	≥ 2.5	55 ± 5 [Note 3]	7.5 [Note 1]
Cold Intercept		≥ 3.2	5 ± 0.5 [Note 3]	≥ 1.29 [Note 4]	8 ± 0.5 [Note 3]	0.7 [Note 1]
4-K Liq.	-					
Sub-Atm.	100	≥ 3.2	4.5	1.2	30	1.9 [Note 1]

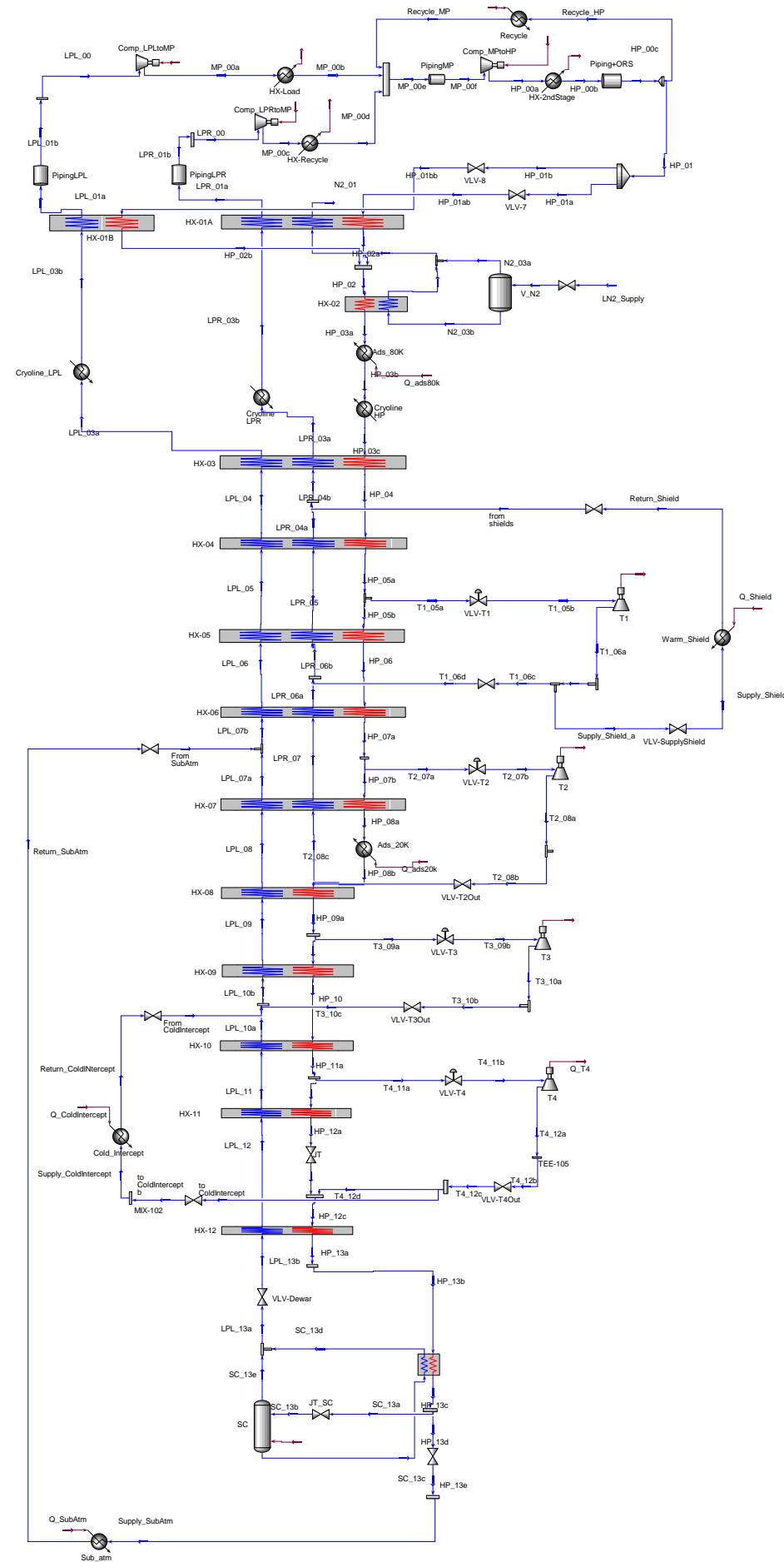
8.2 MAIN RESULTS AND REMARKS

- SHe supply for 4-K Refrigeration at 3.2 atm and 4.55K

Load	w [g/s]	Supply		Return		q [kW]
		P (atm)	T (K)	P (atm)	T (K)	
Warm Shield	77.8	3.5	36.5	2.5	55	7.5
Cold Shield	22.1	3.2	5.5	1.29	7.5	0.7
4-K Refrigeration						
4-K Liquefaction						
Sub-Atmospheric	100	3.2	4.55	1.2	30	

8.3 PROCESS PFD

Mode 7 : 50% Turndown



Heat Loads					
	Warm_Shield	Cold_Intercept	Refrigeration	Liquefaction	Sub_atm
DUTY	W*	7500	700	0	15877
Feed Temperature	K	36.53	5.50	4.55	4.55
Feed Pressure	atm	3.500	3.200	3.200	3.200
Product Temperature	K	55.00	7.50	4.47	300.00
Product Pressure	atm	2.500	1.290	1.250	1.100
Mass Flow	g/s	77.8	22.1	0.0	100.0

Warm Compression Station			
	Comp_LPLtoMP	Comp_LPRtoMP	Comp_MPtoHP
Capacity (act feed vol flow)	ACT_m3/h	10301	5534
Feed Pressure	atm	1.050	1.580
Feed Temperature	K	306.1	306.2
Product Pressure	atm	4.155	4.155
Mass Flow	g/s	478.6	386.7

Cryogenic Expanders					
	T1	T2	T3	T4	
Power	kW	13.39	11.97	6.28	0.16
Feed Temperature	K	51.16	26.69	11.83	5.92
Feed Pressure	atm	11.364	11.314	11.236	5.526
Product Temperature	K	36.53	15.74	5.76	5.51
Product Pressure	atm	3.545	1.771	1.181	3.240
Mass Flow	g/s	172.6	214.7	290.1	170.7
Adiabatic Fluid Head	kJ/kg	100.8	72.4	28.6	2.2
Adiabatic Efficiency		77	77	76	45

Heat Exchange														
	HX-01A	HX-01B	HX-02	HX-03	HX-04	HX-05	HX-06	HX-07	HX-08	HX-09	HX-10	HX-11	HX-12	HX-SC
UA (Calculated)	W/C	153098	175757	4815	113992	3245	111918	44203						
Minimum Approach	K	2.44	2.44	0.80	0.93	1.64	0.11	0.44						
Heat Leak	W*	203	234	10	152	5	147	59						
UA (Calculated)	W/C	59808	4694	6717	629	0	921	1912						
Minimum Approach	K	0.21	1.05	0.10	0.10	0.15	0.10	0.08						
Heat Leak	W*	76	6	27	5	5	5	0						

Streams HP												
	HP_00a	HP_00b	HP_00c	HP_01	HP_01a	HP_01ab	HP_01b	HP_01bb	HP_02b	HP_02	HP_02a	HP_03a
Temperature	K	542.99	310.00	310.03	310.03	310.03	310.03	310.03	310.03	81.32	81.32	81.32
Pressure	atm	12.240	12.240	11.740	11.740	11.740	11.720	11.740	11.720	11.637	11.637	11.637
Mass Flow	g/s	875.2	875.2	875.2	848.1	392.2	392.2	456.0	456.0	456.0	848.1	392.2
Temperature	K	79.79	79.79	52.40	51.16	51.16	33.82	26.69	14.36	14.38	11.83	11.83
Pressure	atm	11.476	11.466	11.426	11.425	11.425	11.390	11.375	11.358	11.298	11.297	11.297
Mass Flow	g/s	848.1	848.1	848.1	848.1	675.6	675.6	460.9	460.9	460.9	170.7	170.7
Temperature	K	HP_11a	HP_11b	HP_12a	HP_12b	HP_12c	HP_13a	HP_13b	HP_13c	HP_13d	HP_13e	
Pressure	atm	11.295	11.295	11.293	3.232	3.232	3.231	3.231	3.231	3.231	3.200	
Mass Flow	g/s	170.7	0.0	0.0	0.0	147.8	147.8	147.8	147.8	100.0	100.0	

Streams LPR									
	LPR_00	LPR_01a	LPR_01b	LPR_03b	LPR_04a	LPR_04b	LPR_05	LPR_06a	LPR_07
Temperature	K	306.2	306.2	306.2	78.88	50.77	51.62	49.37	33.38
Pressure	atm	1.580	1.630	1.580	1.689	1.718	1.718	1.743	1.743
Mass Flow	g/s	386.7	386.7	386.7	386.7	308.9	386.7	308.9	214.4

Streams MP				
	MP_00b	MP_00d	MP_00e	MP_00f
Temperature	K	310.0	310.0	310.0
Pressure	atm	4.155	4.155	4.005
Mass Flow	g/s	478.6	386.7	875.2

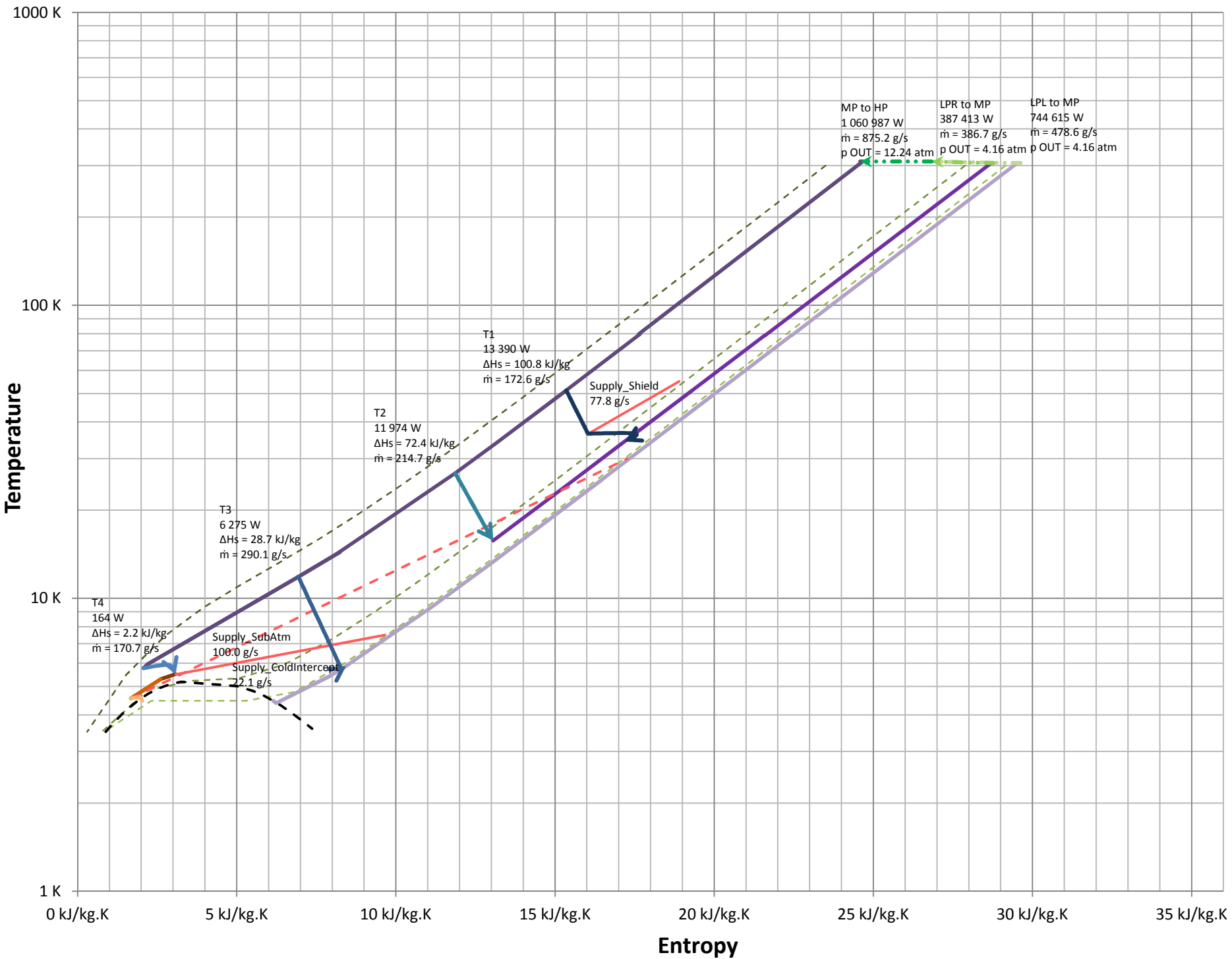
Streams LPL									
	LPL_00	LPL_01a	LPL_01b	LPL_03a	LPL_03b	LPL_04	LPL_05	LPL_06	LPL_07a
Temperature	K	306.11	306.07	306.07	78.86	78.88	50.77	49.37	33.38
Pressure	atm	1.050	1.100	1.050	1.134	1.129	1.144	1.145	1.159
Mass Flow	g/s	478.6	459.5	459.5	459.5	459.5	459.5	459.5	359.5
Temperature	K	LPL_07b	LPL_08	LPL_09	LPL_10a	LPL_10b	LPL_11	LPL_12	LPL_13a
Pressure	atm	26.24	1.164	1.165	1.166	1.166	1.166	1.166	1.250
Mass Flow	g/s	459.5	359.5	359.5	47.8	359.5	47.8	47.8	47.8

Streams Subcooler				
	SC_13a	SC_13b	SC_13c	SC_13e
Vapour Fraction		0.0000	0.0331	0.0000
Temperature	K	4.55	4.47	4.47
Pressure	atm	3.231	1.250	1.250
Mass Flow	g/s	47.8	47.8	35.7

Streams Nitrogen						
	N2_01	N2_02a	N2_02b	N2_02c	N2_03a	N2_03b
Temperature	K	306.20	78.95	78.95	78.95	78.95
Pressure	atm	1.050	1.200	1.200	1.200	1.200
Mass Flow	g/s	41.1	5.5	35.5	41.1	35.5
Vapour Fraction		1.0000	1.0000	1.0000	0.1341	0.0000

8.4 TS DIAGRAM

Mode 7 : 50% Turndown



- 19 atm
- 2.3 atm
- 1.25 atm
- LV equilibrium
- HP
- LPR
- LPL
- Last HX
- Subcooler
- Sub-Atmospheric
- WarmShield
- Cold Intercept
- ➔ T1
- ➔ T2
- ➔ T3
- ➔ T4
- ➔ LPL to MP
- ➔ LPR to MP
- ➔ MP to HP
- JT

8.5 PROCESS DESIGN PERFORMANCE EVALUATION

Mode 7 - 50% Turndown: Carnot efficiency

Heat loads	Mass Flow g/s	q kW	Supply					Return					EL kW
			T K	P atm	h J/g	s J/g-K	ε kJ/g	T K	P atm	h J/g	s J/g-K	ε kJ/g	
Shield	77.8	7.50	36.53	3.50	204.84	18.02	2.699	55.00	2.50	301.28	20.87	1.94	58.8
Cold intercept	22.1	0.70	5.50	3.20	19.25	5.05	6.406	7.50	1.29	50.93	11.63	4.47	42.9
Refrigeration	0.0	0.00	4.55	3.20	12.08	3.65	6.820	4.47	1.25	30.53	8.12	5.50	0.0
Liquefaction	0.0	0.00	4.55	3.20	12.08	3.65	6.820	300.00	1.10	1573.55	31.39	0.06	0.0
Sub Atm	100.0	15.88	4.55	3.20	12.08	3.65	6.820	30.00	1.20	170.87	19.24	2.30	451.8
Total												553.5	

Compressors	Mass Flow g/s	Supply		Return	Ideal input power compressor kW	P2/P1	Isothermal Efficiency	Compressor Mechanical Power		Number of Motors ON	Motors rated power hp	Motors power margin	Motor efficiency	Electrical Power at Motors kW
		T K	P atm	P atm				kW	hp					
MP/HP	875.2	300.00	4.01	12.24	609.3	3.06	53.0%	1149	1540	1	2500	38.4%	96.0%	1196.5
LPR/MP	386.7	300.00	1.58	4.16	233.0	2.63	55.8%	418	560	1	1000	44.0%	94.0%	444.4
LPL/MP	519.0 *	300.00	1.05	4.16	444.9	3.96	50.6%	879	1179	2	800	26.3%	94.0%	935.2
Total													2576.1	

* 2 LPL Compressors fully loaded, 1 stopped, and extra flow is by passed

N2	Mass Flow g/s	Supply					Return					Ideal input power N2 kW	LN equivalent efficiency	Input power N2 kW
		T K	P atm	h J/g	s J/gK	ε kJ/g	T K	P atm	h J/g	s J/gK	ε kJ/g			
N2	41.1	91.41	4.00	-92.51	3.18	-1.05	306.20	1.05	317.64	6.85	-1.74	28.3	0.35	81.0
Total														81.0

Total Carnot Efficiency 20.8%
<i>Total Carnot efficiency without motors efficiencies</i> <i>21.9%</i>

9. MODE 8 – 50%STANDBY

9.1 PROCESS INPUTS

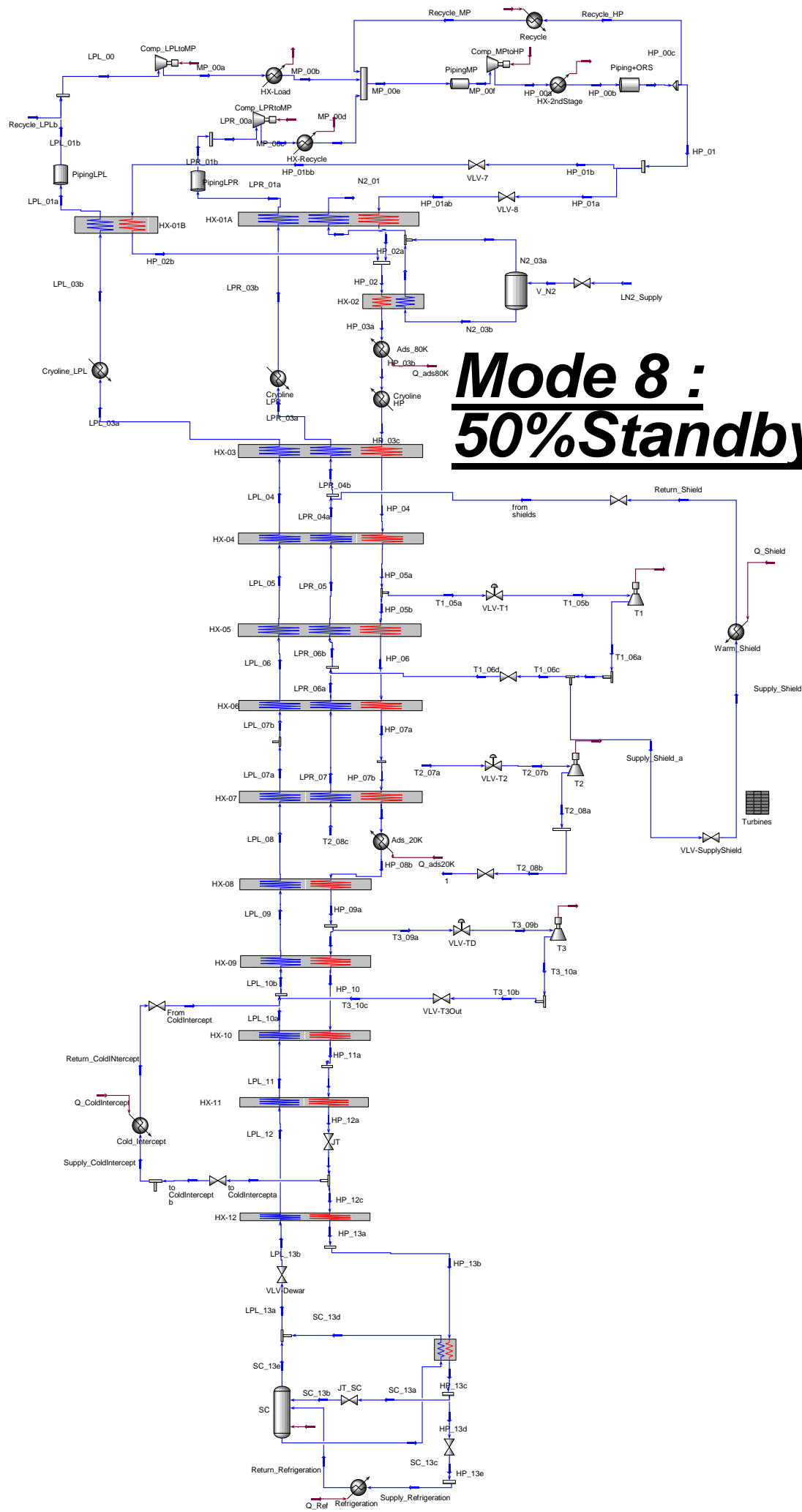
LOAD	Supply	Return	Q [kW]
Warm Shield	Same as in mode 6	Same as in mode 6	≥ 5
Cold Intercept			≥ 0.45
4-K Ref			≥ 0.25

9.2 MAIN RESULTS AND REMARKS

- Cold Shields supplied at 3.0 atm
- SHe supply for 4-K Refrigeration at 3.2 atm and 4.55K

Load	w [g/s]	Supply		Return		q [kW]
		P (atm)	T (K)	P (atm)	T (K)	
Warm Shield	46.58	3.7	34.45	2.7	55	5
Cold Shield	14.83	3.0	5.51	1.23	7.5	0.45
4-K Refrigeration	13.55	3.2	4.55	1.25	4.47	0.25
4-K Liquefaction						
Sub-Atmospheric						

9.3 PROCESS PFD



Mode 8 : 50% Standby

Heat Loads					
	Warm_Shield	Cold_Intercept	Refrigeration	Liquefaction	Sub_atm
DUTY	W*	5000	450	250	0
Feed Temperature	K	34.30	5.51	4.55	4.55
Feed Pressure	atm	3.700	3.000	3.200	3.200
Product Temperature	K	55.00	7.50	4.47	300.00
Product Pressure	atm	2.700	1.230	1.250	1.100
Mass Flow	g/s	46.2	14.8	13.5	0.0

Warm Compression Station				
	ACT_m3/h	Comp_LPLtoMP	Comp_LPRtoMP	Comp_MPtoHP
Capacity (act feed vol flow)		3517	3110	3086
Feed Pressure	atm	1.050	1.050	2.350
Feed Temperature	K	307.5	307.3	310.0
Product Pressure	atm	2.500	2.500	11.400
Mass Flow	g/s	162.7	143.9	316.6

Cryogenic Expanders					
	T1	T2	T3	T4	
Power	kW	7.34	0.00	1.24	0.00
Feed Temperature	K	43.94	30.00	9.49	6.56
Feed Pressure	atm	8.779	3.939	3.980	10.562
Product Temperature	K	34.30	23.04	6.60	5.51
Product Pressure	atm	3.745	1.500	1.129	3.239
Mass Flow	g/s	144.2	0.0	114.4	0.0
Adiabatic Fluid Head	kJ/kg	66.9	50.1	16.6	6.4
Adiabatic Efficiency		76	72	65	70

Heat Exchange								
		HX-01A	HX-01B	HX-02	HX-03	HX-04	HX-05	HX-06
UA (Calculated)	W/C	76811	81536	1509	54957	1481	8058	8861
Minimum Approach	K	1.87	1.87	0.80	0.73	2.91	0.10	0.10
Heat Leak	W*	203	234	10	152	5	147	59
		HX-07	HX-08	HX-09	HX-10	HX-11	HX-12	HX-SC
UA (Calculated)	W/C	23715	2585	1327	282	314	697	16
Minimum Approach	K	0.24	1.64	0.10	0.10	0.26	0.10	0.08
Heat Leak	W*	76	6	27	5	5	5	0

Streams HP												
	HP_00a	HP_00b	HP_00c	HP_01	HP_01a	HP_01b	HP_01bb	HP_01ab	HP_02	HP_02a	HP_02b	HP_03a
Temperature	K	674.18	310.00	310.03	310.03	310.03	310.03	310.03	310.03	81.07	81.07	81.07
Pressure	atm	11.40	11.40	10.90	10.90	10.90	10.88	10.88	10.86	10.86	10.86	10.86
Mass Flow	g/s	316.6	316.6	316.6	297.9	145.6	152.4	145.6	297.9	145.6	145.6	297.9
		HP_03b	HP_03c	HP_04	HP_05a	HP_05b	HP_06	HP_07a	HP_08a	HP_07b	HP_08b	HP_09a
Temperature	K	79.85	79.87	46.93	43.91	43.91	34.37	32.61	16.32	32.61	16.41	10.98
Pressure	atm	10.71	10.70	10.69	10.69	10.69	10.69	10.68	10.68	10.69	10.62	10.62
Mass Flow	g/s	297.9	297.9	297.9	297.9	153.7	153.7	153.7	153.7	153.7	153.7	153.7
		HP_10	HP_11a	HP_11b	HP_12a	HP_12b	HP_12c	HP_13a	HP_13b	HP_13c	HP_13d	Recycle_LPLb
Temperature	K	6.79	6.56	6.56	5.95	5.59	5.59	4.56	4.56	4.55	4.55	310.00
Pressure	atm	10.62	10.62	10.62	10.62	3.231	3.231	3.231	3.231	3.231	3.200	1.050
Mass Flow	g/s	39.3	39.3	39.3	39.3	39.3	24.5	24.5	24.5	13.5	13.5	9.5

Streams LPR												
	LPR_00a	LPR_01a	LPR_01b	LPR_03b	LPR_03a	LPR_04a	LPR_04b	LPR_05	LPR_06a	LPR_06b	LPR_07	Recycle_LPLb
Temperature	K	307.3	307.3	307.3	79.20	79.13	44.02	47.56	40.36	34.27	34.27	310.0
Pressure	atm	1.050	1.100	1.050	1.129	1.136	1.140	1.140	1.140	1.144	1.144	1.050
Mass Flow	g/s	143.9	143.9	143.9	143.9	143.9	97.70	143.9	97.70	1.000e-008	97.70	9.460

Streams MP					
	MP_00b	MP_00d	MP_00e	MP_00f	Recycle_LPLb
Temperature	K	310.0	310.0	310.0	310.0
Pressure	atm	2.500	2.500	2.500	1.050
Mass Flow	g/s	162.7	143.9	316.6	9.460

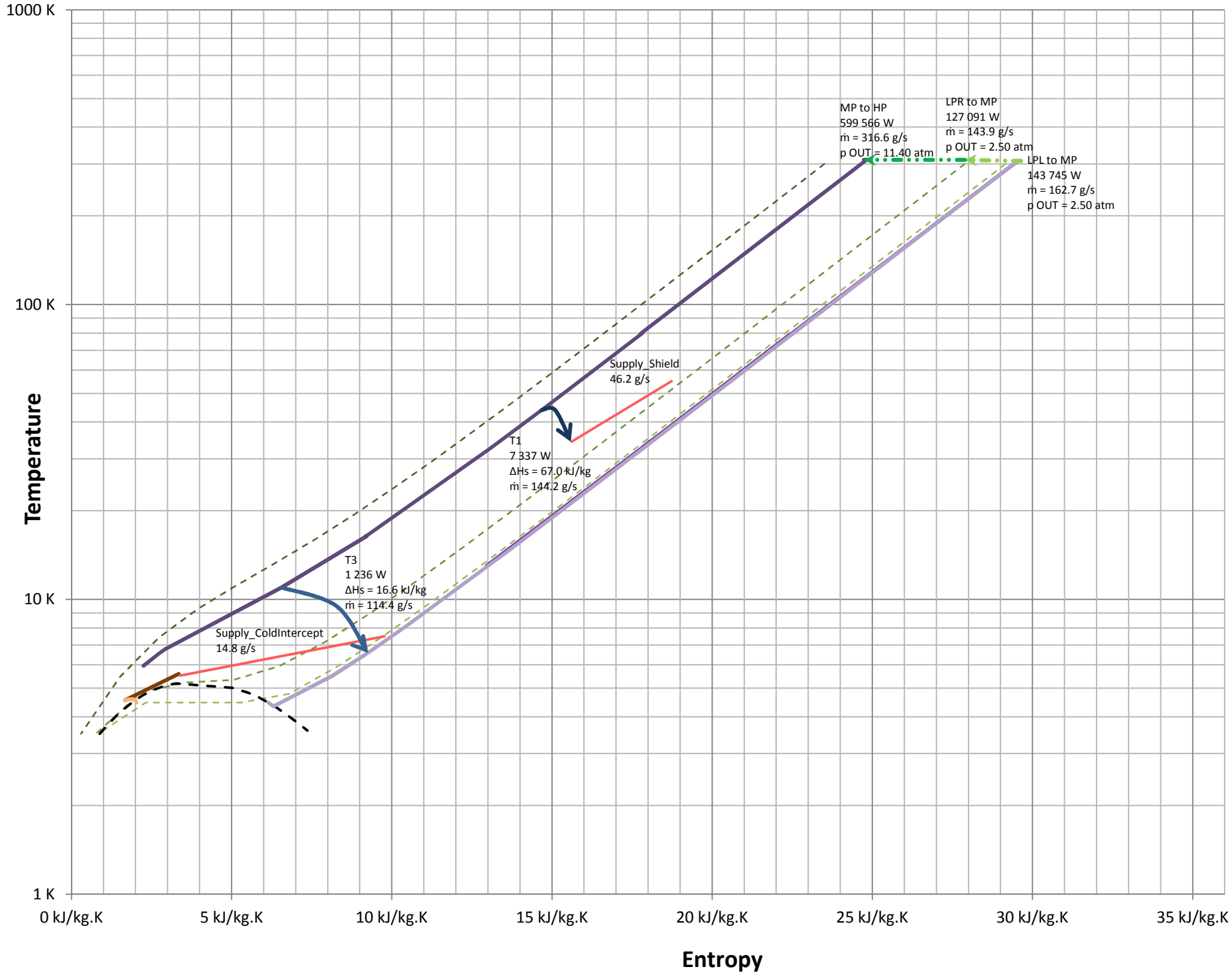
Streams LPL										
	LPL_00	LPL_01a	LPL_01b	LPL_03a	LPL_03b	LPL_04	LPL_05	LPL_06	LPL_07a	LPL_07b
Temperature	K	307.46	307.30	307.30	79.13	79.19	44.02	40.36	34.27	32.37
Pressure	atm	1.050	1.100	1.050	1.110	1.105	1.111	1.111	1.112	1.113
Mass Flow	g/s	162.7	153.2	153.2	153.2	153.2	153.2	153.2	153.2	153.2
		LPL_08	LPL_09	LPL_10a	LPL_10b	LPL_11	LPL_12	LPL_13a	LPL_13b	Recycle_LPLb
Temperature	K	14.77	8.15	6.69	6.69	6.30	5.49	4.47	4.34	310.00
Pressure	atm	1.114	1.114	1.114	1.114	1.114	1.114	1.250	1.114	1.050
Mass Flow	g/s	153.2	153.2	24.5	153.2	24.5	24.5	24.5	24.5	9.5

Streams Subcooler						
	SC_13a	SC_13b	SC_13c	SC_13d	SC_13e	Recycle_LPLb
Vapour Fraction		0.0000	0.0332	0.0000	0.9980	1.0000
Temperature	K	4.55	4.47	4.47	4.47	310.00
Pressure	atm	3.231	1.250	1.250	1.250	1.050
Mass Flow	g/s	10.9	10.9	0.1	0.1	24.4

Streams Nitrogen								
	N2_01	N2_02a	N2_02b	N2_02c	N2_03a	N2_03b	LN2_Supply	Recycle_LPLb
Temperature	K	307.26	78.95	78.95	78.95	78.95	78.95	310.00
Pressure	atm	1.050	1.200	1.200	1.200	1.200	4.000	1.050
Mass Flow	g/s	12.1	1.6	10.5	12.1	12.1	10.5	9.5
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	0.1341	0.0000	1.0000

9.4 TS DIAGRAM

Mode 8 : 50%Standby



- - - 19 atm
- - - 2.3 atm
- - - 1.25 atm
- - - LV equilibrium
- HP
- LPR
- LPL
- Last HX
- Subcooler
- WarmShield
- Cold Intercept
- ➔ T1
- ➔ T3
- ➔ LPL to MP
- ➔ LPR to MP
- ➔ MP to HP
- JT

9.5 PROCESS DESIGN PERFORMANCE EVALUATION

Mode 8 - 50% Standby : Carnot efficiency

Heat loads	Mass Flow g/s	q kW	Supply					Return					EL kW
			T K	P atm	h J/g	s J/g-K	ε kJ/g	T K	P atm	h J/g	s J/g-K	ε kJ/g	
Shield	46.2	5.00	34.30	3.70	193.14	17.58	2.822	55.00	2.70	301.31	20.71	1.99	38.4
Cold intercept	14.8	0.45	5.51	3.00	20.74	5.36	6.314	7.50	1.23	51.09	11.74	4.43	27.9
Refrigeration	13.5	0.25	4.55	3.20	12.08	3.65	6.820	4.47	1.25	30.53	8.12	5.50	17.9
Liquefaction	0.0	0.00	4.55	3.20	12.08	3.65	6.820	300.00	1.10	1573.55	31.39	0.06	0.0
Sub Atm	0.0	0.00	4.55	3.20	12.08	3.65	6.820	30.00	1.22	170.86	19.20	2.31	0.0
Total												84.2	

Compressors	Mass Flow g/s	Supply		Return	Ideal input power compressor kW	P2/P1	Isothermal Efficiency	Compressor Mechanical Power		Number of Motors ON	Motors rated power hp	Motors power margin	Motor efficiency	Electrical Power at Motors kW
		T K	P atm	P atm				kW	hp					
MP/HP	510*	300.00	2.35	11.40	501.9	4.85	50.9%	986	1322	1	2500	47.1%	96.0%	1026.9
LPR/MP	260*	300.00	1.05	2.50	140.6	2.38	55.6%	253	339	1	1000	66.1%	94.0%	269.0
LPL/MP	260*	300.00	1.05	2.50	140.6	2.38	48.4%	290	389	1	800	51.3%	94.0%	308.8
Total													1604.7	

* compressors fully loaded (with 2 LPL compressors stopped), extra-flow is by passed

N2	Mass Flow g/s	Supply					Return					Ideal input power N2 kW	LN equivalent efficiency	Input power N2 kW
		T K	P atm	h J/g	s J/gK	ε kJ/g	T K	P atm	h J/g	s J/gK	ε kJ/g			
N2	12.1	91.41	4.00	-92.51	3.18	-1.05	307.26	1.05	318.74	6.85	-1.74	8.4	0.35	23.9
Total														23.9

Total Carnot Efficiency 5.2%
<i>Total Carnot efficiency without motors efficiencies</i> 5.4%