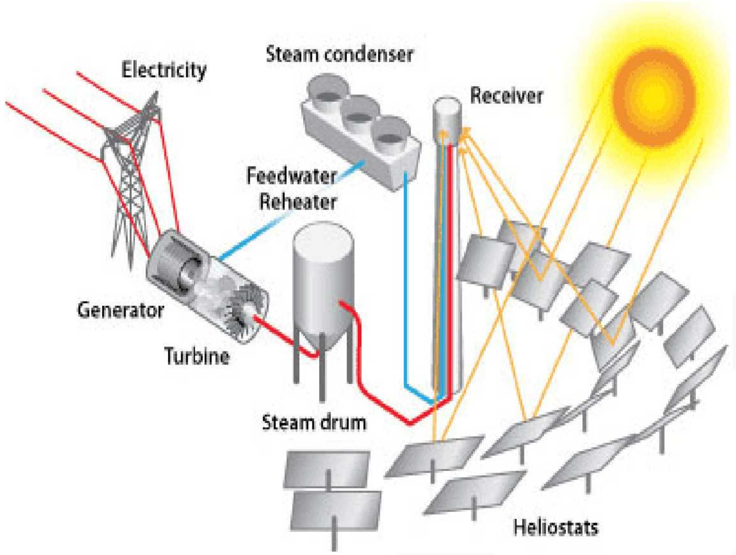
SAND2019-2947PE

SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy



Gen 3 Liquid-Pathway Molten Salt Chemistry Workshop – Process Overview

Ken Armijo (SNL)

2-22-2019

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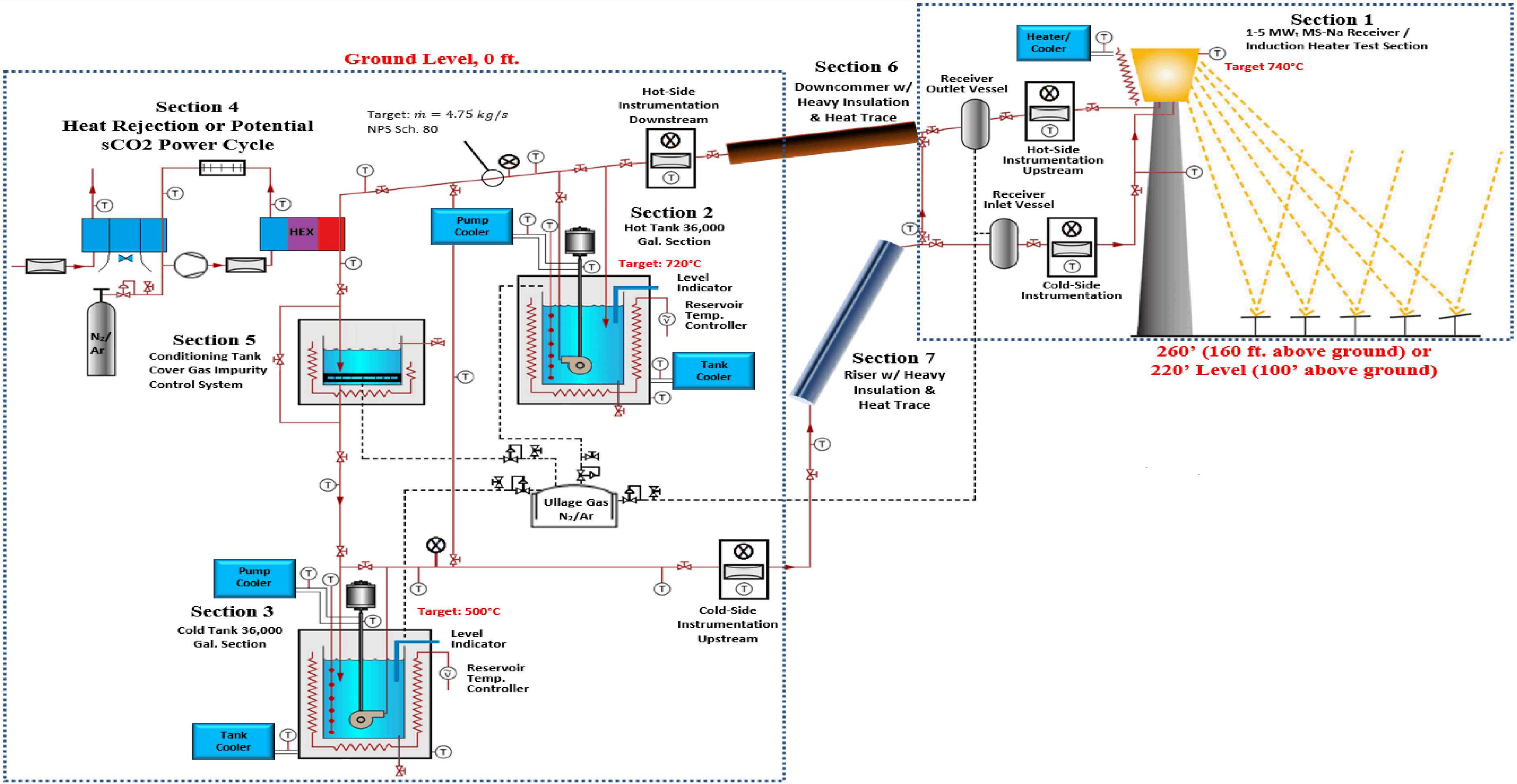
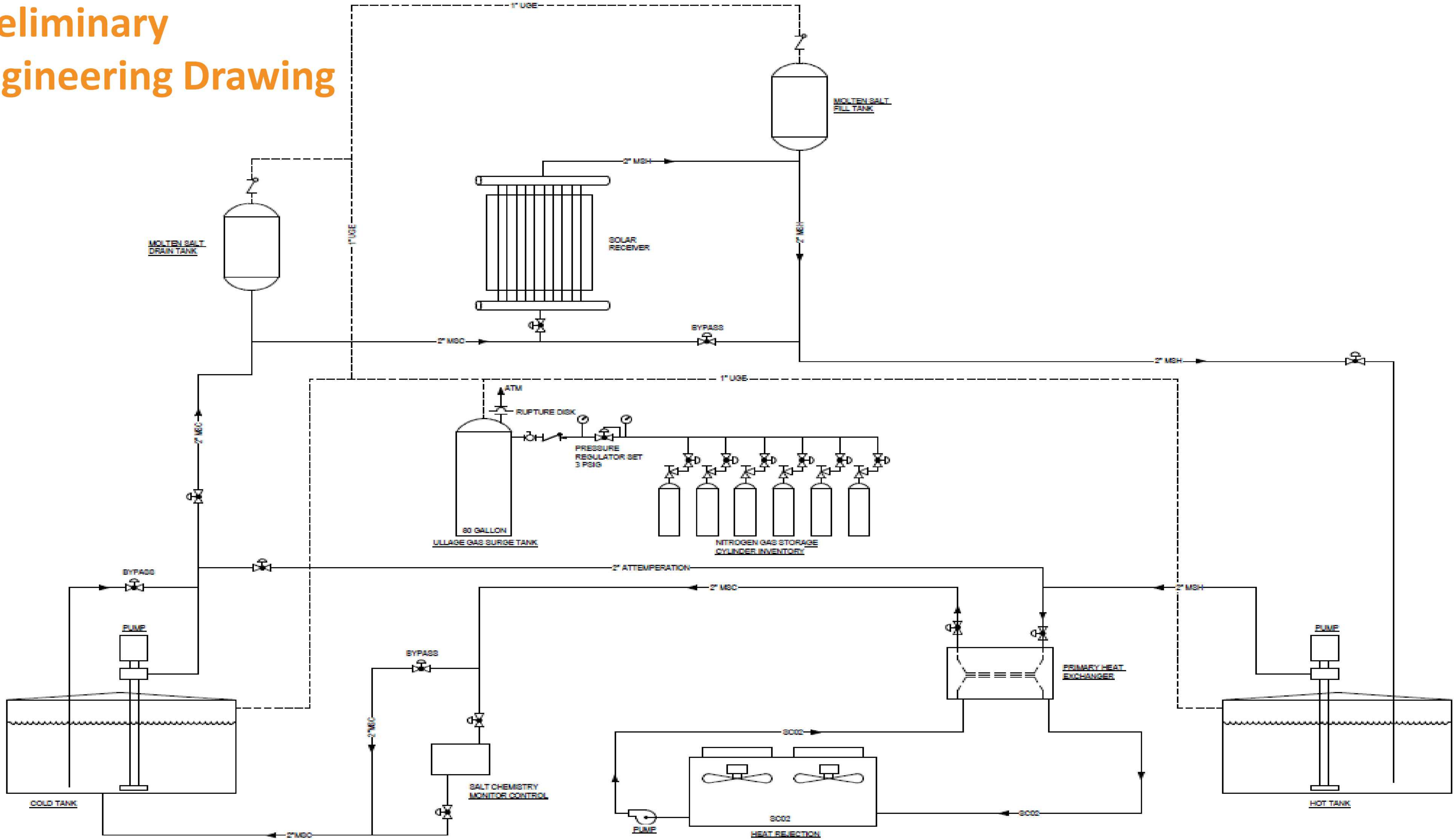
Design Review & Discussion

- Preliminary System Layout Design Overview



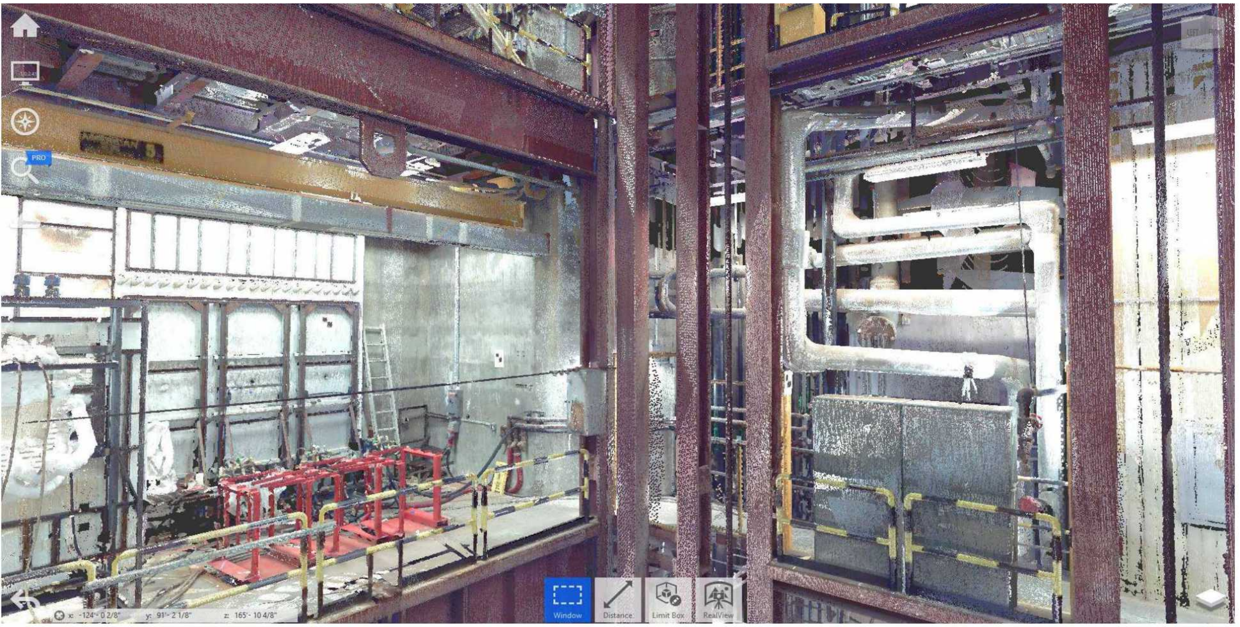
Preliminary Engineering Drawing



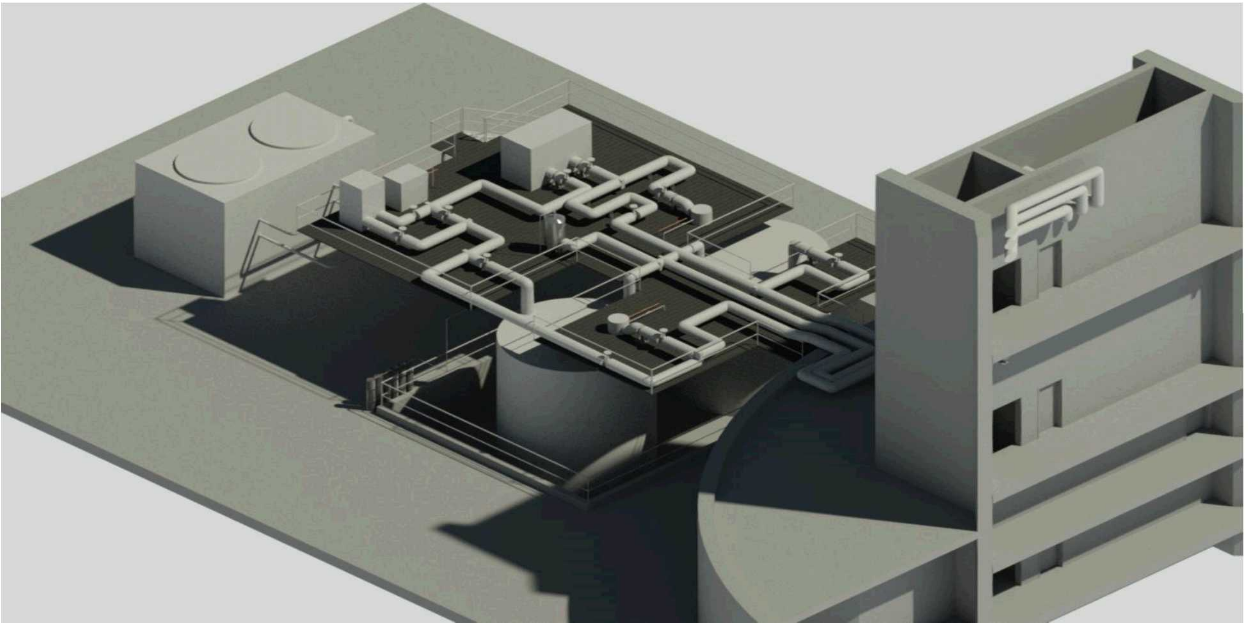
Design Review & Discussion

- Preliminary Piping Layout drawings within the Solar Tower.
  - Solar Tower 3-D scan with Cloud Point files for areas necessary for Gen 3 pipe routing have been converted to AutoCad REVIT 3-D files.
  - Preliminary piping layout within Tower is completed. Piping enters the Tower from the south through existing pipe penetrations at Level 140, is routed up the mechanical piping shaft on the east side of tower to Level 220 where the Solar Receiver will be located.
  - We currently have 58 CAD drawings under development. The number of drawings in the Phase I 30% submittal is expected to increase.
- Preliminary Equipment Layout drawings including interconnecting pipe layout.
  - Preliminary piping layout is completed for the south exterior side of the Tower which locates the two-36,379 gal tanks, heat exchanger, pumps, and piping. The secondary containment pit is sized and located along with structural platform over the tanks for piping support and positive drainage into tanks.
- Preliminary I&C Diagram with preliminary Operating Sequence.
  - Awaiting updated pipe stress analysis in the next 2 weeks. Once our piping is updated we will begin locating the ceramic heaters on the drawings which will reflect where thermocouples will be located.

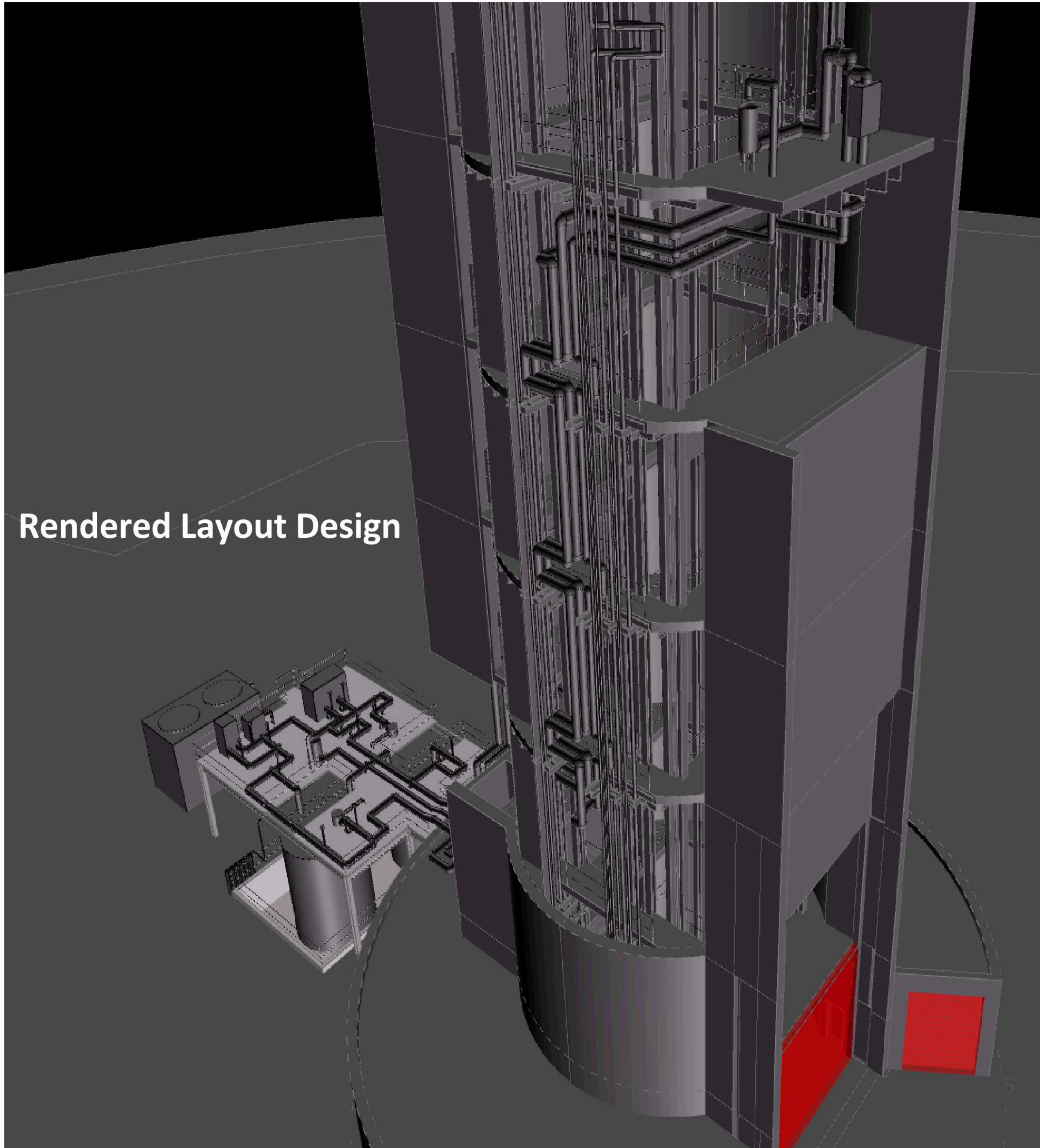
220 ft Point Cloud Tower Level

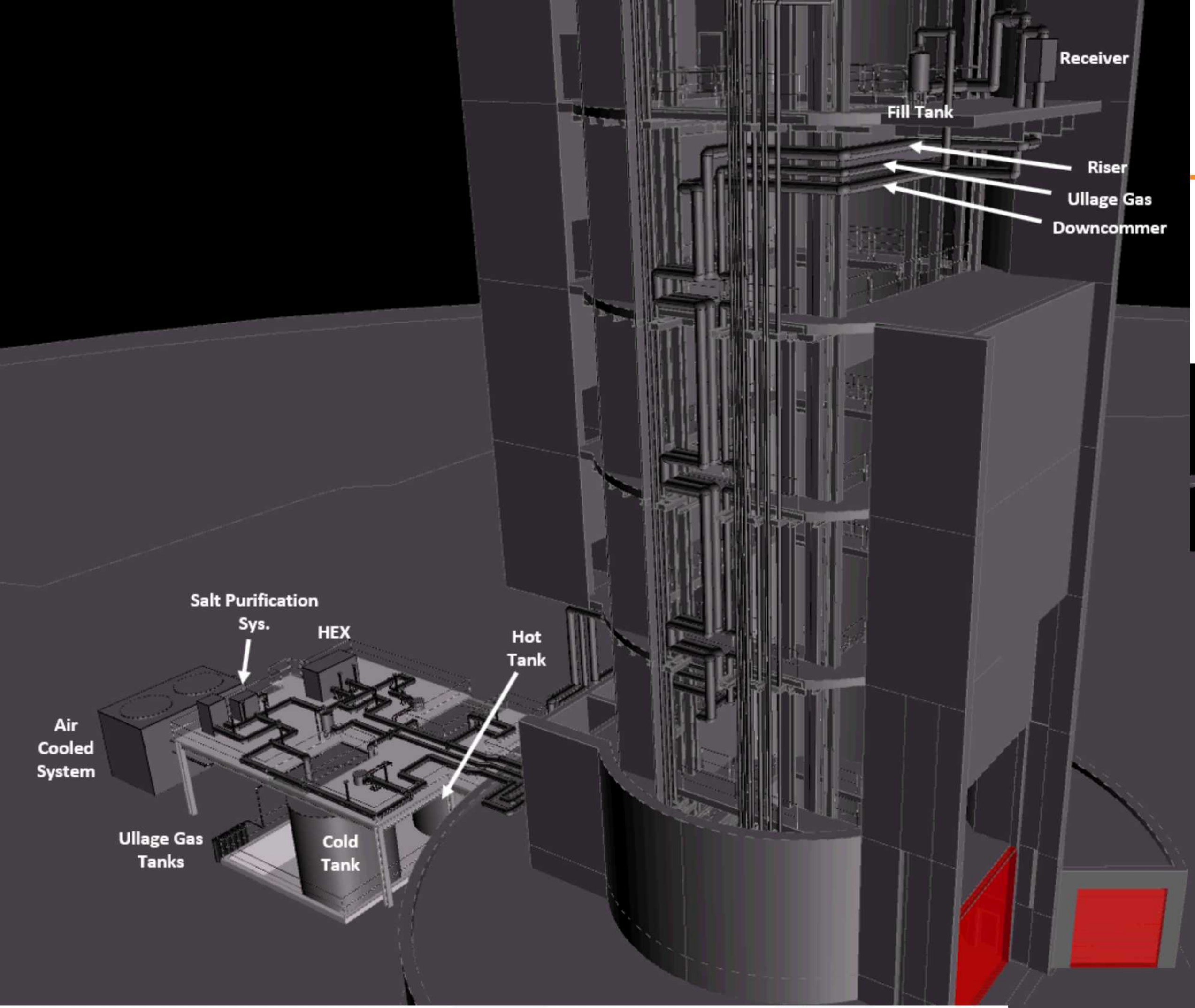


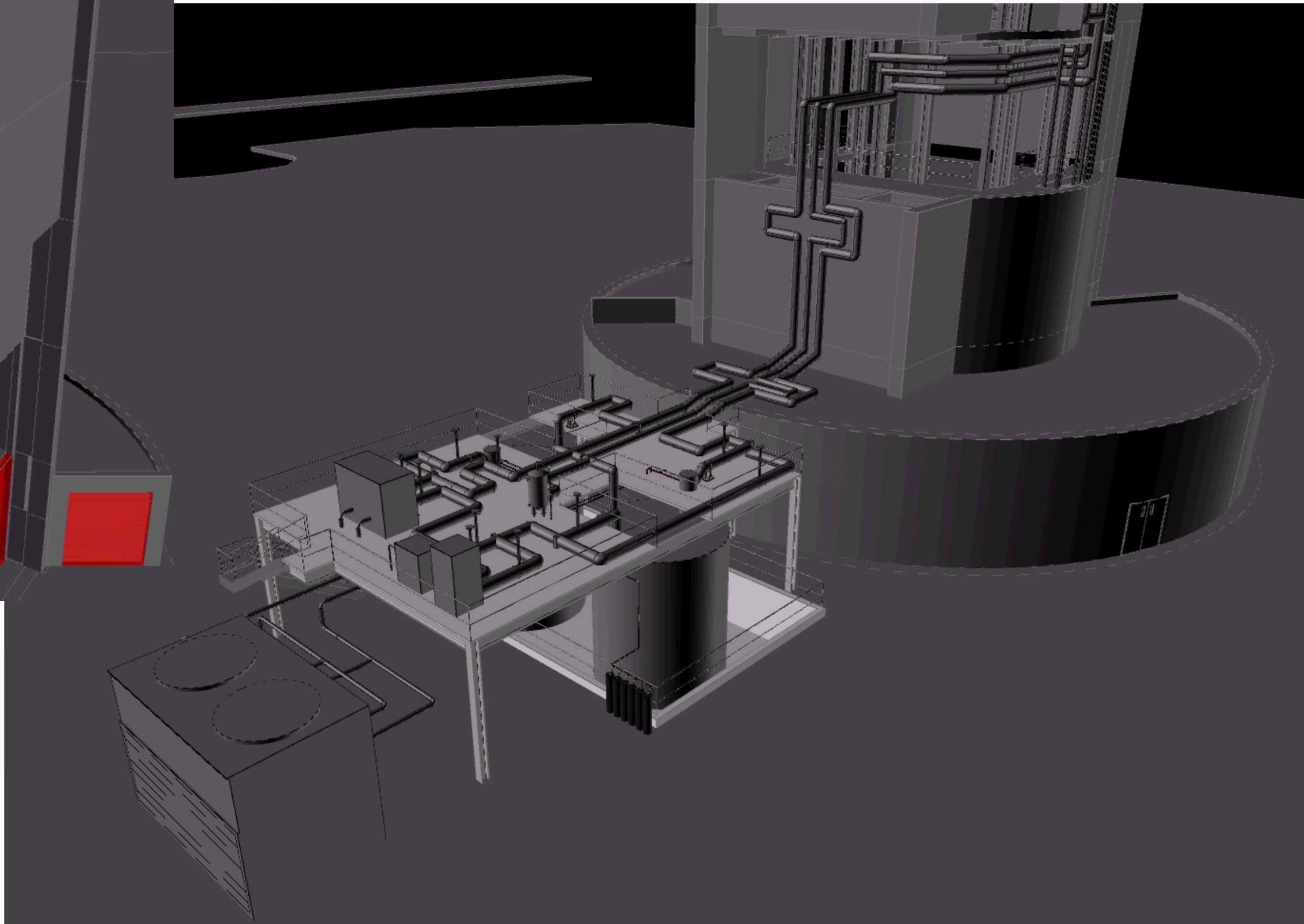
Rendered Revit 3D Model



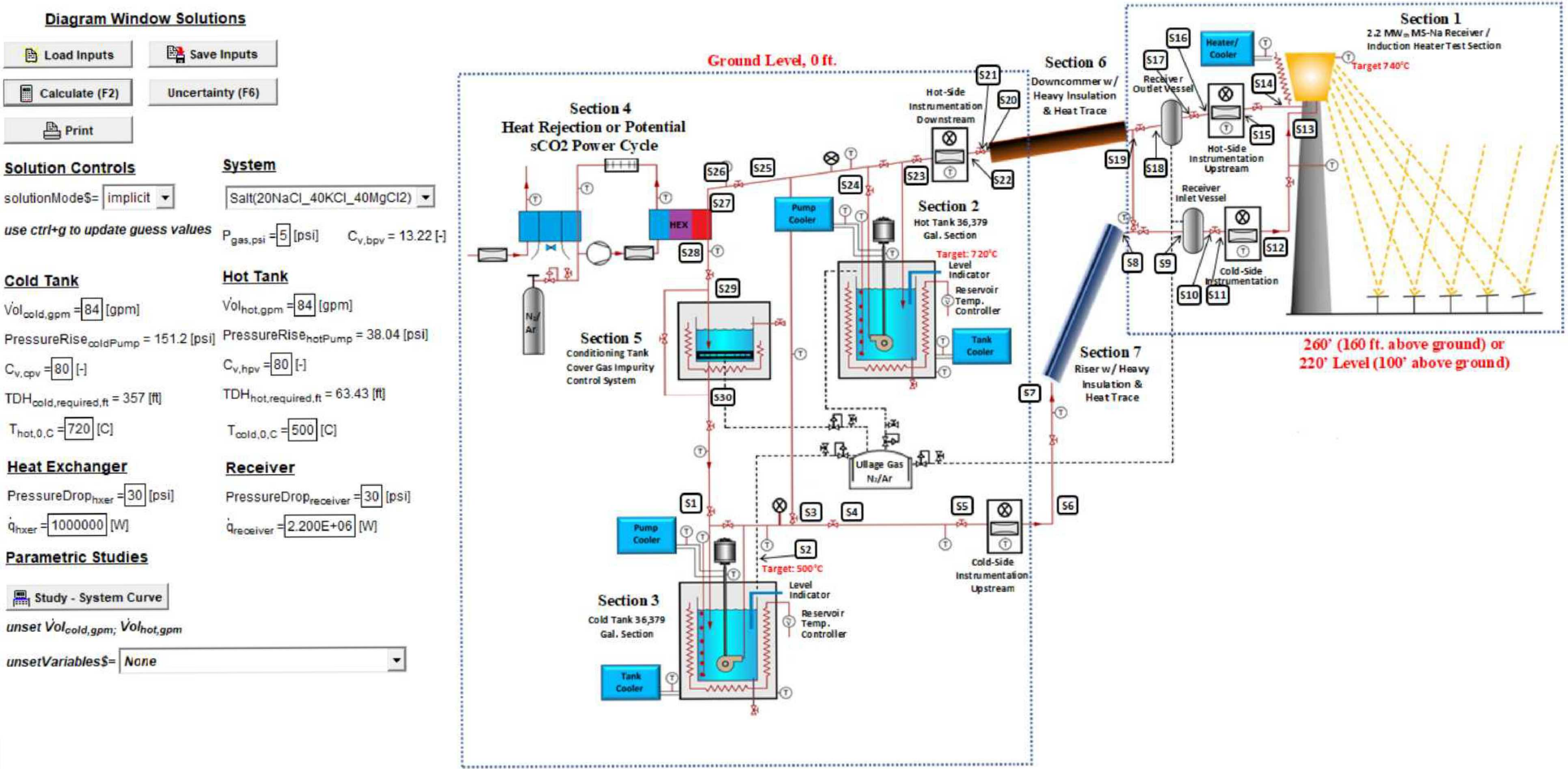
Rendered Layout Design



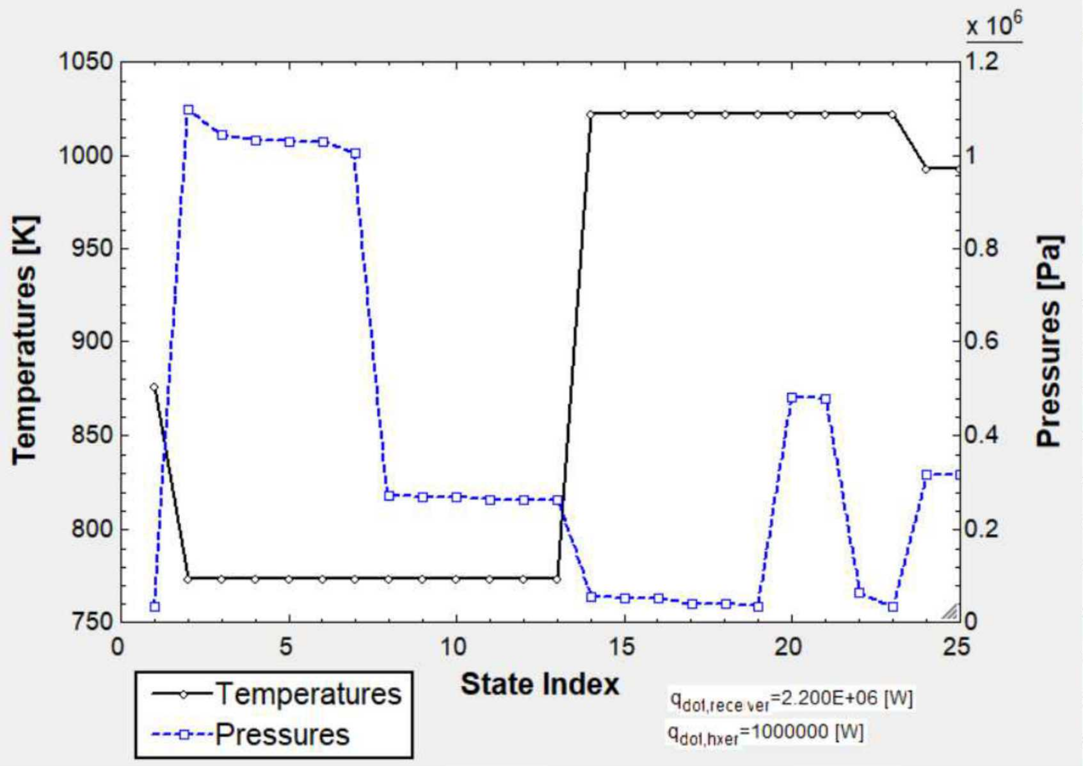

Receiver
Fill Tank
Riser
Ullage Gas
Downcommer
Salt Purification Sys.
HEX
Hot Tank
Air Cooled System
Ullage Gas Tanks
Cold Tank



EES System Model



System States



Sort	description$_i$	$dP_{\psi,i}$ [psi]	dP_i [Pa] {[psi]}	$\dot{q}_{in,i}$ [W]	$\dot{q}_{heat,i}$ [W]	T_i [K] {[C]}	P_i [Pa] {[psi]}
[1]	Component - cold tank	-151.2	-1.042E+06 {-151.2}			876 {602.9}	34474 {5}
[2]	Piping - cold tank to cold throttle valve		53916 {7.82}	0	3090	773.2 {500}	1.097E+06 {159.2}
[3]	Component - cold pump throttle valve		11942 {1.732}			773.2 {500}	1.043E+06 {151.3}
[4]	Piping - cold throttle valve to instrument panel		1658 {0.2405}	0	206	773.2 {500}	1.031E+06 {149.6}
[5]	Component - not modeled					773.2 {500}	1.030E+06 {149.4}
[6]	Piping - instrument panel to riser		25754 {3.735}	0	3090	773.2 {500}	1.030E+06 {149.4}
[7]	Component - riser		734067 {106.5}	0	11690	773.2 {500}	1.004E+06 {145.6}
[8]	Piping - riser to receiver inlet vessel		1658 {0.2405}	0	206	773.2 {500}	269987 {39.16}
[9]	Component - not modeled					773.2 {500}	268329 {38.92}
[10]	Piping - receiver inlet vessel to instrument panel		6346 {0.9203}	0	206	773.2 {500}	268329 {38.92}
[11]	Component - not modeled					773.2 {500}	261983 {38}
[12]	Piping - instrument panel to receiver		1658 {0.2405}	0	206	773.2 {500}	261983 {38}
[13]	Component - receiver	30	206843 {30}	2.200E+06		773.2 {500}	260326 {37.76}
[14]	Piping - receiver to instrument panel		2127 {0.3085}	0	455	1022 {749.2}	53483 {7.757}
[15]	Component - not modeled					1022 {749.2}	51356 {7.448}
[16]	Piping - instrument panel to receiver outlet vessel		10898 {1.581}	0	455	1022 {749.2}	51356 {7.448}
[17]	Component - not modeled					1022 {749.2}	40458 {5.868}
[18]	Piping - receiver outlet vessel to downcomer		5984 {0.8679}	0	455	1022 {749.2}	40458 {5.868}
[19]	Component - downcomer		-445649 {-64.64}	0	25821	1022 {749.2}	34474 {5}
[20]	Piping - downcomer to backpressure valve		1599 {0.2319}	0	455	1022 {749.2}	480123 {69.64}
[21]	Component - backpressure valve		415595 {60.28}			1022 {749.2}	478524 {69.4}
[22]	Piping - backpressure valve to hot tank		28455 {4.127}	0	6825	1022 {749.2}	62929 {9.127}
[23]	Component - hot tank	-38.04	-262294 {-38.04}			1022 {749.2}	34474 {5}
[24]	Piping - hot tank to hot throttle valve		1434 {0.208}	0	417.3	993.2 {720}	316185 {45.86}
[25]	Component - hot pump throttle valve		11262 {1.633}			993.2 {720}	314751 {45.65}
[26]	Piping - hot throttle valve to heat exchanger		19548 {2.835}	0	6259	993.2 {720}	303489 {44.02}
[27]	Component - hxer	30	206843 {30}	-1000000		993.2 {720}	283941 {41.18}
[28]	Piping - heat exchanger to conditioning tank		19766 {2.867}	0	4392	876 {602.9}	77098 {11.18}
[29]	Component - not modeled					876 {602.9}	57332 {8.315}
[30]	Piping - conditioning tank to cold tank		22858 {3.315}	0	4026	876 {602.9}	57332 {8.315}

Thermodynamic System Prediction Model

- EES System Model
  - This model will continue to be used and developed as the project progresses, but preliminary results assuming 4 NPS SCH80 pipe with 2 inches of insulation blanket
  - Preliminary model for assessing performance of preliminary design is complete and is being calibrated with B&P Pipe flow model.
- Parametric Analysis
  - Assessment of Pump Curves for tanks to provide proper TDH values for both hot- and cold-leg pumps.

piping | Tube&Pipe | profile

	1 descriptions	2 index	3 pipeSize	4 L_{ft} [ft]	5 RR [-]	6 $\Delta elevation_{ft}$ [ft]	7 N_{bends} [-]	8 N_{elbows} [-]	9 N_{tees} [-]	10 $T_{amb,F}$ [F]	11 $P_{amb,\psi}$ [psi]	12 $u_{inf,mph}$ [mph]	13 orientation
Row 1	Piping - cold tank to cold throttle valve	2	2.5 NPS Pipe SCH80	60	0.0007	6	0	2	0	70	12.2	5	horizontal
Row 2	Piping - cold throttle valve to instrument panel	4	2.5 NPS Pipe SCH80	4	0.0007	0	0	0	0	70	12.2	5	horizontal
Row 3	Piping - instrument panel to riser	6	2.5 NPS Pipe SCH80	60	0.0007	0	1	1	1	70	12.2	5	horizontal
Row 4	Component - riser	7	2.5 NPS Pipe SCH80	227	0.0007	130	8	22	1	70	12.2	5	vertical
Row 5	Piping - riser to receiver inlet vessel	8	2.5 NPS Pipe SCH80	4	0.0007	0	0	0	0	70	12.2	5	horizontal
Row 6	Piping - receiver inlet vessel to instrument panel	10	2.5 NPS Pipe SCH80	4	0.0007	1	0	0	0	70	12.2	5	horizontal
Row 7	Piping - instrument panel to receiver	12	2.5 NPS Pipe SCH80	4	0.0007	0	0	0	0	70	12.2	5	horizontal
Row 8	Piping - receiver to instrument panel	14	2.5 NPS Pipe SCH80	4	0.0007	0	1	0	0	70	12.2	5	horizontal
Row 9	Piping - instrument panel to receiver outlet vessel	16	2.5 NPS Pipe SCH80	4	0.0007	2	1	0	0	70	12.2	5	horizontal
Row 10	Piping - receiver outlet vessel to downcomer	18	2.5 NPS Pipe SCH80	4	0.0007	1	0	0	0	70	12.2	5	horizontal
Row 11	Component - downcomer	19	2.5 NPS Pipe SCH80	227	0.0007	-130	8	22	1	70	12.2	5	vertical
Row 12	Piping - downcomer to backpressure valve	20	2.5 NPS Pipe SCH80	4	0.0007	0	0	0	0	70	12.2	5	horizontal
Row 13	Piping - backpressure valve to hot tank	22	2.5 NPS Pipe SCH80	60	0.0007	0	4	2	1	70	12.2	5	horizontal
Row 14	Piping - hot tank to hot throttle valve	24	2.5 NPS Pipe SCH80	4	0.0007	0	0	0	0	70	12.2	5	horizontal
Row 15	Piping - hot throttle valve to heat exchanger	26	2.5 NPS Pipe SCH80	60	0.0007	0	0	0	0	70	12.2	5	horizontal
Row 16	Piping - heat exchanger to conditioning tank	28	2.5 NPS Pipe SCH80	60	0.0007	0	0	0	0	70	12.2	5	horizontal
Row 17	Piping - conditioning tank to cold tank	30	2.5 NPS Pipe SCH80	55	0.0007	0	4	2	0	70	12.2	5	horizontal

Pump Calculated TDH Based on 2.5” ID Pipe

- Design pump flow for 84 GPM, based on 2.2 MWth, ΔT=220 °C, 40MgCl2/20NaCl/40KCl Salt
- Models are being calibrated with B&P Pipe flow models
- 2.5 in. ID pipe size with over 833 ft of total pipe length, 120 ft. of elevation.

Parametric Table: Study - System Curve

	$\dot{Vol}_{cold,gpm}$ [gpm]	$\dot{Vol}_{hot,gpm}$ [gpm]	$TDH_{cold,required}$ [m]	$TDH_{hot,required}$ [m]	$C_{v,bpv}$ [-]	dP_{21} [Pa] {[psi]}
Run 1	40	40	99.17	15.55	5.724	517225 {75.02}
Run 2	48.89	48.89	100.6	16.11	7.115	500202 {72.55}
Run 3	57.78	57.78	102.3	16.77	8.582	480081 {69.63}
Run 4	66.67	66.67	104.3	17.54	10.15	456878 {66.26}
Run 5	75.56	75.56	106.4	18.41	11.77	434071 {62.96}
Run 6	84.44	84.44	108.9	19.38	13.5	409263 {59.36}
Run 7	93.33	93.33	111.6	20.45	15.42	380873 {55.24}
Run 8	102.2	102.2	114.5	21.62	17.6	349071 {50.63}
Run 9	111.1	111.1	117.7	22.89	20.13	313979 {45.54}
Run 10	120	120	121.1	24.26	23.16	275688 {39.99}

Piping Material Costs

- Sandia team conducted a materials trade study of 12 materials for both hot and cold legs of the 2.2 MWth system.
  - SS316, SS304, Inc800H, Inc625, Inc617, Inc740/740H, Inc600, Haynes 230, Hastelloy C-276, SS347H, SS310H, SS347
- Have received costs from 2 companies out of 10 over the last 2 weeks.
- For 100’ quantities lead times are around 4-5 weeks.
- The 500’ quantities minimum 14-16 week lead times.
- Lead times for Inconel 617, Inconel 740 and Haynes 230 could run out to 30 weeks.

Piping Material Costs

(Arch City Steel & Alloy)

2.5" SCH 80 PIPE (Averaged between 2" and 3" Pipe Costs)

100'	Stainless Steel	304	$ 42.00	/FT
100'	Stainless Steel	316	$ 53.00	/FT
100'	Inconel	800H	$ 327.00	/FT
100'	Inconel	625	$ 281.00	/FT
500'	Inconel	617	$ 525.50	/FT
500'	Inconel	740	$ 570.00	/FT
100'	Inconel	600	$ 201.00	/FT
500'	Haynes	230	$ 611.00	/FT
100'	Hastelloy	C-276	$ 403.50	/FT
100'	Stainless Steel	347H	$ 68.00	/FT
100'	Stainless Steel	310H	$ 114.00	/FT

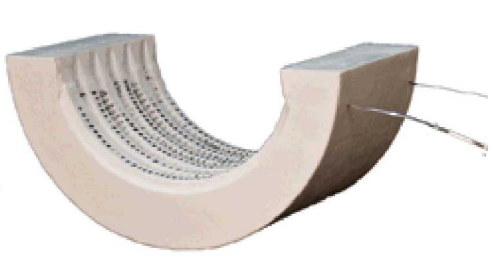
2" SCH 80 PIPE (2.375"OD X .218" WALL)

100'	304 Stainless Steel	@ $ 27.00 / FT
100'	316 Stainless Steel	@ $ 35.00 / FT
100'	Inconel 800H	@ $ 215.00 / FT
100'	Inconel 625	@ $ 185.00 / FT
500'	Inconel 617	@ $ 346.00 / FT
500'	Inconel 740	@ $ 375.00 / FT
100'	Inconel 600	@ $ 117.00 / FT
500'	Haynes 230	@ $ 402.00 / FT
100'	Hastelloy C-276	@ $ 265.00 / FT
100'	347H Stainless Steel	@ $ 43.00 / FT
100'	310H Stainless Steel	@ $ 74.00 / FT

3" SCH 80 PIPE (3.500"OD X .300" WALL) NOMINAL ID (2.900")

100'	304 Stainless Steel	@ $ 57.00 / FT	500' -2%	1000' -5%
100'	316 Stainless Steel	@ $ 71.00 / FT	500' -2%	1000' -5%
500'	Inconel 800H	@ $ 439.00 / FT	1000' -5%	
500'	Inconel 625	@ $ 377.00 / FT	1000' -5%	
500'	Inconel 617	@ $ 705.00 / FT	1000' -5%	
500'	Inconel 740	@ $ 765.00 / FT	1000' -5%	
500'	Inconel 600	@ $ 285.00 / FT	1000' -5%	
500'	Haynes 230	@ $ 820.00 / FT	1000' -5%	
100'	Hastelloy C-276	@ $ 542.00 / FT	500' -2%	1000' -5%
100'	347H Stainless Steel	@ $ 93.00 / FT	500' -2%	1000' -5%
100'	310H Stainless Steel	@ $ 154.00 / FT	500' -2%	1000' -5%

Task 1.3: Piping, Heat Trace & System Layout – Heat Trace Options Report



- Due March 30st
- Team reviewed three possible pipe pre-heating systems and had discussions with multiple manufacturers on system limitations and possibilities of manufacturers developing higher-temperature rated systems.
- MI cable is capable of pre-heating the pipe to 450°C however the cable has a maximum temperature exposure of 590°C.
- Impedance heating system is capable for preheating pipe to 450°C and can be exposed to temperatures exceeding 750°C.
  - Valves and flowmeters must be completely isolated from the electrically energized piping; otherwise valves and flowmeters will not function.
  - Isolation requires flanged connections on valve and flowmeters with an electrical insulator between the flanges and flange bolts.
  - However, flanged fittings are not possible due to salt wicking effects.

Task 1.3: Piping, Heat Trace & System Layout – Heat Trace Options Report (cont'd)

- Ceramic fiber heaters (from Thermcraft) operate off of radiant heat principle
  - Heater contains multiple electrical heating elements at the internal surface of the heater with a small air gap (~1") between the pipe OD and heater ID.
  - Heaters are capable of preheating pipe to 1200°C and could be utilized to raise salt fluid temperature or offset temperature loss if desired.
  - With an operating temperature of 704°C, the outer surface of the ceramic heater would be 173°F.
- SNL and B&P team are developing Heat Trace Report with target completion by early March.
  - Testing through Phase 1B work is likely considering challenges with ceramic fiber heating system, which includes: A. formed geometries at bends, B. Pre-conditioning challenges, C. Expansion geometry issues with respect to consistent gap, C. Thermal performance & reliability
  - Testing at SNL during Phase 1B could provide input for tests later at ORNL FASTR loop with flowing salt.

Extra Slides

Design Review & Discussion

- Preliminary Electrical One-Line Drawings.
  - Research existing electrical system @ solar tower & develop base one-line diagram (existing one-line diagram in SNL drawings is not directly useable for our project).
  - Apply ceramic heating information received to developing the system of control cabinets, transformers, and panelboards for inclusion in one-line diagram
- Preliminary Electrical Plan Drawings.
  - Work with preliminary piping layout drawings to develop zoning for heating system and include on plan drawings.
  - Work on loading calculations to determine required electrical infrastructure to presently known loads
  - Develop plans for source of power to heating system and other loads to include on power drawings.
- Preliminary concept Structural framing plans to support piping.
  - Beginning structural analysis and design of equipment platform south of the tower. Structural loads are based on conservative anticipated live load ranges (150 psf) in addition to the code analysis for dead loads, snow loads, lateral wind and seismic loads.

Design Review & Discussion

- Preliminary Site Plan.
  - On-going development.
- Preliminary calculation for piping heat loss for various pipe materials and insulation types.
  - The spreadsheets have been developed which are currently setup for analyzing 6 types of suitable insulation. Spreadsheets are setup for analyzing pre-heat pipe, cold salt pipe and hot salt pipe for both indoors and outdoors. Included for each system is insulation surface temperature, power usage per foot and total power usage for the heating system. The report is currently under development.
- Heat Trace / Impedance Heating Options Report.
  - The report is under development, we are currently awaiting additional information from 2-MI cable manufacturers and 1-ceramic fiber manufacturer. We expect to submit the report by late February.
- ASME Piping Code Determination Report.
  - Piping code determined to be ASME BPVC Section VIII Div. 2. Beginning work on report.

Pump Calculated TDH Curves w.r.t. System Design

- Design pump flow for 84 GPM, based on 2.2 MWth, ΔT=220 °C, 40MgCl2/20NaCl/40KCl Salt
- Models are being calibrated with B&P Pipe flow models
- Varying ID pipe size with over 833 ft of total pipe length, 120 ft. of elevation.