MOLTEN SALT

Concept Definition & Capital Cost Estimate

B&V PROJECT NO. 042839

B&V FILE NO. 40.1200

PREPARED FOR

SunShot
U.S. Department of Energy

U.S. Department of Energy

30 JUNE 2016

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1.0 Executive Summary

The Department of Energy's (DOE's) Office of Renewable Power (ORP) has been tasked to provide effective program management and strategic direction for all of the DOE's Energy Efficiency & Renewable Energy's (EERE's) renewable power programs. The ORP's efforts to accomplish this mission are aligned with national energy policies, DOE strategic planning, EERE's strategic planning, Congressional appropriation, and stakeholder advice. ORP is supported by three renewable energy offices, of which one is the Solar Energy Technology Office (SETO) whose SunShot Initiative has a mission to accelerate research, development and large scale deployment of solar technologies in the United States. SETO has a goal of reducing the cost of Concentrating Solar Power (CSP) by 75 percent of 2010 costs by 2020 to reach parity with base-load energy rates, and to reduce costs 30 percent further by 2030. The SunShot Initiative is promoting the implementation of high temperature CSP with thermal energy storage allowing generation during high demand hours. The SunShot Initiative has funded significant research and development work on component testing, with attention to high temperature molten salts, heliostats, receiver designs, and high efficiency high temperature supercritical CO_2 (sCO2) cycles.

DOE retained Black & Veatch to support SETO's SunShot Initiative for CSP solar power tower technology in the following areas:

1. Concept definition, including costs and schedule, of a flexible test facility to be used to test and prove components in part to support financing.
2. Concept definition, including costs and schedule, of an integrated high temperature molten salt (MS) facility with thermal energy storage and with a supercritical CO_2 cycle generating approximately 10MWe.
3. Concept definition, including costs and schedule, of an integrated high temperature falling particle facility with thermal energy storage and with a supercritical CO_2 cycle generating approximately 10MWe.

This report addresses the concept definition of the MS/sCO2 integrated 10MWe facility, Item No. 2 above. Other reports address Items No. 1 and No. 3 above.

Section 2 of the report presents the plant design basis. In summary, the plant design is based on the use of a magnesium chloride/potassium chloride molten salt circulated from a cold (540 °C) tank to a solar receiver irradiated by a solar heliostat field, providing hot (750 °C) molten salt to a hot tank. The hot salt is pumped to a MS/sCO2 heat exchanger providing heat to a sCO2 turbine generator with motor driven compressors. The site is assumed to be Daggett, California. Export power is assumed to be at 33kV.

Section 3 of the report presents the conceptual design. Highlights of the design include a solar field with 57,600m^2 of heliostat mirror area surrounding the solar receiver, a steel lattice tower with a platform at 50m elevation to support the solar receiver, single hot and cold MS storage tanks each with a diameter of approximately 14m, extensive use of Haynes 230 corrosion-resistant material, and an SCO2 cycle achieving less than the desired 50 percent efficiency to minimize costs. Site arrangement, plant arrangement, process flow diagrams, a heat/mass balance diagram for the sCO2 cycle and other details are provided in appendices. A number of risk areas requiring future research and development are summarized at the end of pertinent subsections.

Section 4 of the report provides details on the net output of the plant. Despite the 14.9MW gross output of the turbine generator system, auxiliary loads for the sCO2 compressors require 5.5 MW and other operating auxiliary loads require 2.1MW, resulting in a net generation of 8.6 MW on a 22.5 C dry bulb ambient temperature day with 25 percent relative humidity. Projections of plant availability have not been made at this time.

Section 5 of the report presents a potential implementation schedule. Allowing for permitting and financing, the start of construction is anticipated to be in April 2018, subject to some assumptions. At that time, research and development should be essentially completed. The schedule for design, procurement, construction and commissioning of the plant is driven by the sCO2 turbine-generator/compressor. Substantial completion of the project is expected in February 2021.

The capital cost of the facility was developed in Section 6 of the report, based on numerous supplier budget quotes and on Black & Veatch in-house data, using bills of quantity developed specifically for the project. The cost does not include EPC contractor profit as it is assumed that EPC contractors will not take normal EPC risks with the advanced technology nature of the project. A contingency has not been included at this time. The estimated capital cost of the project is $174,700,000. This cost could be reduced at least $10M by relocating the primary sCO2 heat exchangers directly above the turbine; other optimizations may also be possible.

The O&M cost of the facility, developed in Section 7, is $3,170,000/yr, in 2016$. Note that there is uncertainty in this figure with the unknown failure rates at this time of high temperature unproven equipment.

There are several major observations:

- Capital costs are extremely high. In particular, the cost of Haynes 230 material for the molten salt service and high pressure/high temperature sCO2 primary heaters and piping to the sCO2 turbine is surprisingly high.
- Suppliers of high temperature/high-to-moderate pressure equipment, such as pumps, valves, piping and heat exchangers, may be providing excessively high pricing reflecting technical uncertainties and use of unfamiliar materials. Significant future research is required.
- Corrosion remains a major concern. Costs above generally reflect minimal corrosion rates from the molten salt and the sCO2. A program to develop sCO2 corrosion rates should be initiated. Impacts of impurities in the salt need characterization.

- Plant efficiency is low when heat and pressure losses are included. However, relatively high approach temperatures were used to reduce heat exchanger costs and future turbine/compressor/generator optimization may be possible. Some studies could be undertaken to optimize the cycle based on overall system parameters, such as approaches, air cooler range, etc.
- Ramp rates for startup and shutdown in Section 3 of the report need careful characterization. These will affect operation but could influence expensive start-up systems, heat tracing and other design features.
- A clear plan of development activities for systems described in this report is required for commercialization. Besides the items above, Haynes 230 material needs further characterization both in terms of its properties and in terms of ways to reduce its costs.

2.0 Study Objective

2.1 SYSTEM DESIGN DESCRIPTION

This report addresses the design, cost, and construction schedule of a nominal 10MWe integrated molten salt/sCO2 concentrated solar power (CSP) facility using technology under development in the SunShot program.

Key elements of the project are as follows:

1. The CSP technology uses a power tower with a heliostat field.
2. The CSP technology uses an advanced molten salt. In this case, the molten salt will be a 33/67 molar mixture of magnesium chloride ($MgCl_2$) and potassium chloride (KCl). The chloride molten salt (MS) composition will be referred to as $MgCl_2$-KCl.
3. The molten salt will be pumped from a cold MS tank to a receiver system at the top of the power tower and will flow to a hot MS tank. The MS in the hot tank will be pumped to a supercritical CO_2 (sCO2) heat exchanger system to which it will transfer heat to sCO2, before flowing back to the cold MS tank. The sCO2 heat exchange may be concurrent with receiver heat absorption or non-concurrent, i.e. in night-time hours.
4. The sCO2 system will use the STEP design under SunShot development. In this design, cold sCO2 is compressed by motor-driven compressors, heated in recuperators, heated in the primary MS/sCO2 heat exchanger system, expanded in the sCO2 turbine, cooled in the recuperators and finally cooled in an air cooler before starting the compression cycle again.
5. An arbitrary site near Daggett, California, has been assumed for the new facility.

2.2 DESIGN BASIS

2.2.1 Power Capacity

Without knowledge of auxiliary loads, a plant net output near 10MWe was desired. Assuming a 2 MW auxiliary load, this would result in a turbine generator/compressor gross output of 12MWG. Given the goals of achieving a 50 percent sCO2 gross cycle efficiency, the heat transferred by the primary MS/sCO2 heat exchanger system was selected to be 24MW-thermal.

As presented to CSP workshop attendees and agreed with DOE, net output would be developed based on calculated auxiliary loads using the 24 MW thermal MS/sCO2 duty as fixed quantity.

2.2.2 Thermal Storage

The molten salt storage was agreed with DOE to be 4 hours of storage at full turbine load. This translates to 96 MWh of thermal storage.

2.2.3 Solar Multiple

The solar multiple (SM) is a key design variable for the receiver and solar field. As discussed in Section 3.2.4 of this report, the SM was selected to be 1.3, with agreement from DOE and following presentation to the CSP 2016 workshop attendees.

2.2.4 Molten Salt Properties

MS properties were provided to Black & Veatch under a Non-Disclosure Agreement with Savannah River National Laboratory. Those properties are omitted from this report.

2.2.5 Supplier Submittals

Black & Veatch solicited and received a number of quotes with design features from equipment suppliers. Details of the suppliers and quotes have generally been withheld from this report.

3.0 Conceptual Plant Design

3.1 SITE LAYOUT

The project site layout was driven by the tower and heliostat locations. A site arrangement drawing is included in Appendix A. An interior loop road diameter was set based on the diameter of the innermost ring of heliostats which itself was set to accommodate the layout of the major power block equipment. The area inside the interior loop road is detailed on the Plant Arrangement drawing included in Appendix B. Due to the constricted space inside the interior loop road, less critical equipment was located to the south of the solar field, clustered around the main access road, near the entrance gate. The heliostat assembly building and laydown area are expected to be converted to maintenance facilities after initial construction of the plant. The water treatment building and associated tanks and pumps will also be located near the plant entrance. An evaporation pond that is associated with the water treatment facility is shown in the southeast corner of the site arrangement. The main access road will be designed as a 24 foot wide aggregate surfaced road with the loop roads being reduced to a 20 foot width. A perimeter fence is shown around the site.

From the site arrangement drawing, the site will require approximately 126 acres.

3.2 SOLAR FIELD SYSTEM

3.2.1 Heliostats

Heliostats are mirror assemblies which track the sun on two axes (elevation and azimuth) to redirect the sun's rays to a solar receiver atop a tall tower. Historically, heliostats have been the most important part of a solar power tower plant because they have been the most significant contributor to the capital cost of plants.

Typically, heliostat fields have been configured as surround fields, where the heliostat field is completely around the tower, or as a partial arc around the tower. In the northern hemisphere, the partial arc is typically a north field, forming an arc of about 120 degrees north of the tower.

The design of individual heliostats has evolved significantly over the years as various organizations have attempted to develop designs that reduce the cost. Most of today's heliostats are of a single pedestal design, with the azimuth and elevation drives located at pivot point at the top of the pedestal. eSolar has developed a significantly different design, using ganged 2.2 m^2 mirror facets which are field-mounted on easily-shipped, preassembled racks.

Heliostat sizes have varied significantly in the past and continue to be varied. The eSolar design, with its 2.2 m^2 mirror facets, comes in as the smallest mirror size. BrightSource has tested single pedestal, single mirror facet heliostats at 7 m^2, and then a single pedestal, double mirror facet heliostat at 15 m^2, which was used at their Ivanpah Solar Plant.

Heliostats at the National Solar Thermal Test Facility at Sandia Laboratories in Albuquerque use heliostats that comprise 25 mirror facets totaling 37 m^2 of reflective area. These heliostats are unique in that they have a single base with an azimuth drive which sits atop the foundation. The mirror facets are mounted on structures supported by two vertical beams, which in turn are connected to a horizontal beams mounted on the azimuth drive assembly. Black & Veatch is not aware of any heliostat provider using the NSTTF heliostat design. The heliostat, with individual mirror facets focused and canted, appears to be a very effective design; however, it is more costly than a single pedestal design.

Heliostats at the 10 MWe Solar One/Solar Two Pilot Plant in Daggett, California, were single pedestal units with 39.13 m^2 of reflective area. SolarOne/Solar Two operated in the late 1980s through the late 1990s.

Abengoa heliostats at their PS-10 and PS-20 Power Tower Solar Plants in Spain used single pedestal heliostats with 120 m^2 of reflective area.

At the SolarReserve Crescent Dunes plant, which went commercial in early 2016, the heliostats were provided by the EPC Contractor, ACS Cobra. These heliostats had a reflective area of 115.7 m^2.

The SunShot program is aiming to reduce heliostat costs to $\$75/m^2$. However, DOE directed Black & Veatch to base the conceptual designs in this study on commercial heliostat offerings rather than the heliostats under development in the SunShot program.

3.2.2 Proxy Heliostats

The extremely fast pace of this project necessitated the early selection of a proxy heliostat to allow solar field design to establish the tower height. Setting the tower height was necessary not only for developing the tower design, but also establishing design criteria such as pump heads and pressures for pipes and valves.

In general, there are no "commercially offered" heliostats, because heliostats are being developed by companies who are developing power tower plants, with the heliostat an integral part of their intellectual property. Black & Veatch, in consultation with personnel from the National Renewable Energy Laboratory, decided on a representative heliostat with the characteristics shown in Figure 3-1.

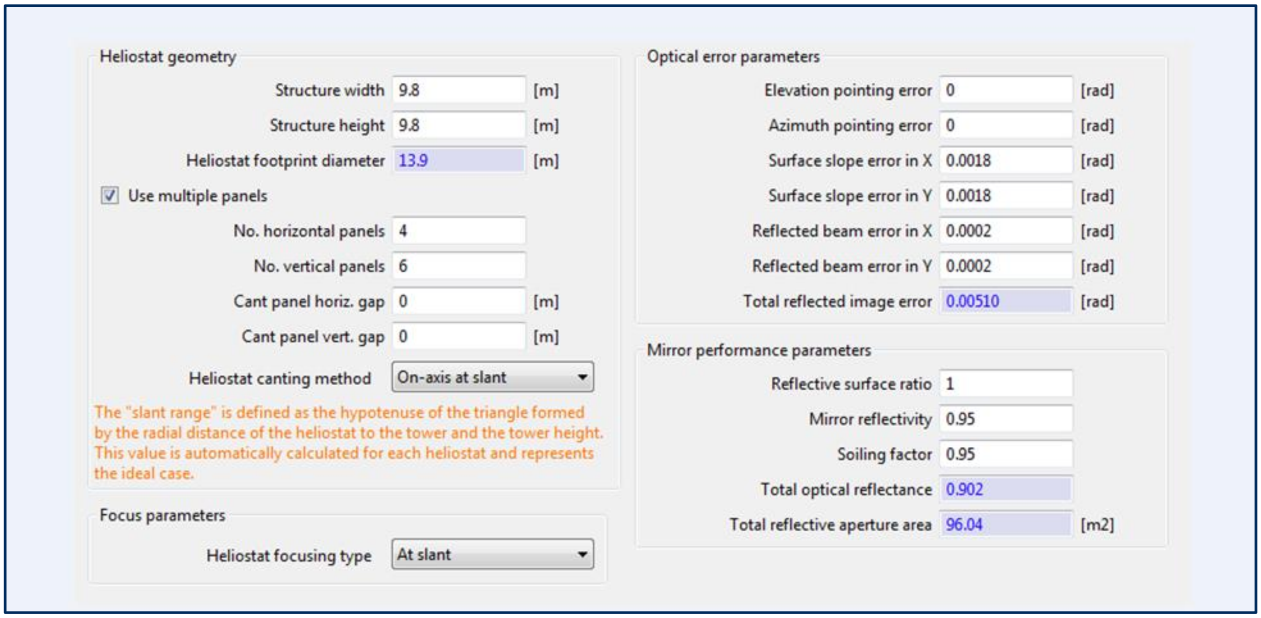


Figure 3-1 Proxy Heliostat Characteristics As Modeled in SolarPILOT and the System Advisor Model

The 96 m^2 heliostat was chosen as being representative of a single pedestal, large total mirror area, relatively small-mirror-facet heliostat. Black & Veatch is unable to verify if a heliostat with these characteristics will be commercially available at the time the molten chloride salt power tower plant would be built; however, heliostats with different mirror areas are likely to result in similar total mirror areas and layouts as for the proxy heliostat. For example, a 140 m^2 heliostat, if modeled in SAM or SolarPILOT, would likely end up with the same total mirror area, although placement of individual heliostats in the field layout would differ.

Heliostats for which individual facets are not focused would result in larger spillage (that amount of reflected sunlight missing the receiver), and therefore would require more heliostats.

3.2.3 System Advisor Model (SAM)

In laying out the heliostat field and identifying the proper tower height, Black & Veatch used the System Advisor Model (SAM). SAM is a software tool developed by the National Renewable Energy Laboratory (NREL) to model grid connected renewable energy systems. It has a module for surround field molten salt solar power tower plants that can be used for heliostat field layout, tower height optimization, solar multiple optimization, modeling thermal storage, and estimating annual system and plant electric output. SAM has hourly weather and solar insolation data for a large number of locations, including Daggett, California, the proxy site for this study.

SAM is populated with default design data and cost data for many of the plant systems, and allows the user to input alternate data that more closely represents the system the user is modeling.

At present SAM does not have standard algorithms for modeling north field power tower plants. Black & Veatch requested and was provided assistance by NREL in using the newly developed SolarPILOT model to provide tower heights and heliostat field layouts for the Falling Particle Power Tower Plant and the Flexible Use Test Facility, both which have north heliostat fields.

The Solar Power tower Integrated Layout and Optimization Tool, SolarPILOT, was recently developed by NREL to use the analytical flux image techniques implemented in the DELSOL3 software. DELSOL3 was developed by Sandia national laboratory in the early 1980's. SolarPILOT has improved the DELSOL3 analytical model, and has been incorporated into the newest releases of SAM. SolarPILOT can be used to model a variety of heliostat field configurations, including surround fields and north fields (which cannot be modeled in SAM). It can also be used to model heliostat fields using the eSolar heliostat, a capability not currently in SAM.

3.2.4 Solar Multiple/Hours of Storage

The solar multiple (SM) of a solar thermal plant is the ratio of the thermal power available from the solar receiver at the design point divided by the design point thermal input to the power cycle. If, for example, the design point power to the power cycle were 20 MWt, a SM of 2 would require 40 MWt from the solar receiver.

Solar thermal systems are generally designed with SMs greater than 1.0. Designing the system with a SM of 1.0 would result in the inability to produce rated thermal power from the receiver at all times other than solar noon, resulting in the underutilization of much of the system's equipment. Furthermore, a SM greater than 1.0, coupled with thermal storage, allows systems to operate into the evening, outside of normal solar hours.

In determining the SM for the 10 MWe molten salt integrated demonstration plant, Black & Veatch made use of SAM, making multiple runs of SAM to observe the thermal output of the receiver, filling of storage, discharge of storage, and generation of electricity for various solar multiples and various storage capacities. Runs were based on Typical Meteorological Year solar data for Daggett, California. The plant performance data were observed for three clear days, one near the spring equinox, one near the summer solstice, and one near the winter solstice. The assumptions for this exercise was that the net output of the plant was 10 MWe, the gross output 12 MWe, and with the cycle efficiency assumed to be 50 percent, the thermal input to the turbine at the design point was 24 MWt.

A fundamental understanding of this exercise was that there is no economic optimum for solar multiple and storage for a 10 MWe demonstration plant. Furthermore, there were no accurate cost data in SAM in parametric form that fit a 10 MWe demonstration plant using equipment that, in many cases, had never been designed or used. Therefore, the goal of this exercise was to find a reasonable solar multiple, that provided sufficient operating hours in a day, in winter, spring, summer, to have meaningful testing, without having an expensive, oversized field and oversized thermal storage.

Upon reviewing pertinent daily curves from SAM, consultation with DOE and with people from the solar community, Black & Veatch selected a solar multiple of 1.3 and a thermal storage capacity of 4 hours. With the 24 MWt design input power to the power cycle, this resulted in a power from the receiver of 31.2 MWt.

3.2.5 Tower Height and Field Layout

Having determined the SM, and therefore the design point power from the receiver, Black & Veatch was ready to determine the optimum tower height and heliostat field layout. Black & Veatch configured the preliminary solar receiver dimensions included in SAM to be equivalent to those of the Solar Two molten salt receiver. Preliminary runs were made with SAM as well as runs of SolarPILOT by NREL to determine the optimum tower optical height, where the optical height is the difference in elevation between the center of the receiver active area and the pivot point of the heliostats (assuming level ground). Several iterations of the field layout occurred, with a final iteration with SAM conducted when it was found that the molten salt receiver for the 10 MWe system, because of its small size and inefficiencies related to its size, was going to have a design point efficiency of 82 percent, rather than the initially assumed 90 percent. Fortunately, it was found that the tower height was not highly dependent on the change in efficiency, and the final tower height and field layout were set.

- Optical tower height: 53.6 m.
- Design height for top of tower: 50 m
- Heliostats number: 600
- Heliostat field mirror area: 57,600 m^2

The heliostat layout for the molten salt plant is shown in Figure 3-2. As noted earlier, a site arrangement drawing with tower, roads, facilities, and fencing is provided in Appendix A.

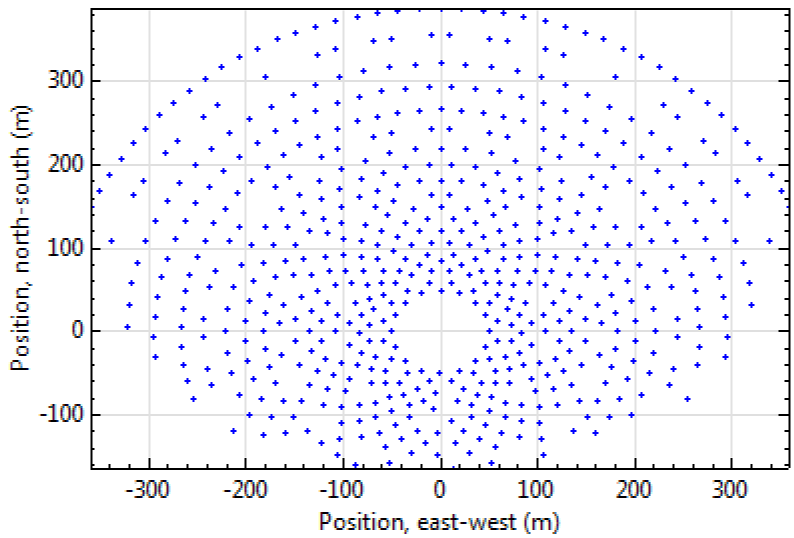


Figure 3-2 Heliostat Layout for 10 MWe Integrated Molten Salt Plant

3.2.6 Heliostat Assembly

The approach for the assembly of heliostat parts into a complete heliostat depends on the size and configuration of the heliostat. eSolar, with its rack configuration, has designed its heliostats with pre-tested parts and assemblies manufactured in high volume, quality controlled factories. The assemblies are shipped to the plant site, where unskilled labor is able to manually complete the assembly and install the heliostats without heavy equipment.

The approach for BrightSource, with its 15 m^2 heliostats, is to perform assembly of complete heliostats in an assembly building adjacent to the collector field, and to haul completed heliostats to their position in the field with a specialized transport vehicle.

For larger heliostats, the heliostat torque tube, support structure, and mirror facets are assembled in an assembly building. Facets are canted, and the assembly is transported to the field, where it is attached to the pedestal, which was previously installed in the field. The drive unit may be attached to the torque tube in the assembly building or on the pedestal in the field, depending on the heliostat design. Transportation and installation may affect the canting, so that a certain amount of field canting could be necessary.

3.2.7 Heliostat I/C

Controls for the heliostats consist of the heliostat controllers (HCs), a heliostat array controller (HAC), and a redundant communications link between the HCs and the HAC. Each heliostat is provided with an HC and control sensors. The HAC, located in the Central Control Room (CCR), executes master control over the entire collector system and includes (1) a Beam Characterization System (BCS), (2) Static Aim Processing System (SAPS), and (3) Dynamic Aim Processing System

(DAPS) software. The HAC includes redundant HAC processors, data historian, BCS hardware and software, DAPS hardware and software, SAPS software, and special instruments. The BCS includes a BCS target, cameras, and required automatic software.

The operator interface and interaction will be through the Distributed Control System (DCS). The DCS includes a Human Machine Interface (HMI), consisting of operator console containing LCD operator work stations, and operations printers.

A Master Control System (MCS) program controls and monitors all Solar Power Tower process functions for all system equipment through all stages and transitions in response to operator commands. The MCS consists of the following major subsystems, a DCS, HAC, and Administrative and Data Analysis System (ADAS).

3.2.8 Heliostat Washing

Heliostats will be washed on a two-week basis. The principal method will be a semi-automated high-pressure spray with deionized water. As necessary, heliostats may be washed manually with deionized water and a mild biodegradable detergent.

The semi-automatic washing approach requires a specialized vehicle with washing equipment and with the vehicle size to accommodate clearances between and under heliostats.

3.3 PLANT LAYOUT

Refer to the Plant Arrangement drawing DM-G2000 in Appendix B. The power producing plant sits in the interior loop area (approximately 300 foot diameter) within the heliostat field. Produced power will be fed via direct-buried 33kV cables from the power plant to a terminal riser pole near the south site boundary. The interior loop area is separated into the following primary areas:

- Concentrated Solar Power Tower.
- Molten Salt Melting area.
- Molten Salt Tanks area.
- sCO_2 turbine/compressor area.
- sCO_2 pre-cooler area.
- Admin/Control building.

The plant arrangement drawing was used as the basis for quantity take-offs required for pricing.

3.4 CIVIL/STRUCTURAL CONCEPTUAL DESIGN

3.4.1 Concentrated Solar Power Tower

The tower for the Molten Salt Facility will be a steel lattice tower. The base of the tower will be 35 foot x 35 foot. The height of the tower will be 164 foot (50m) with a working platform located 10 foot below the top level. The solar receiver will sit at the top of the tower on a 15 foot x 15 foot platform. A model of the tower was created in RISA 3D to accommodate the appropriate loads and to determine the quantity of steel in the tower design for cost estimating purposes. The tower will accommodate BCS plates near the 50m elevation on each of the 4 sides of the lattice steel tower. Figure 3-3 shows a detail of the molten salt tower as it was modeled.

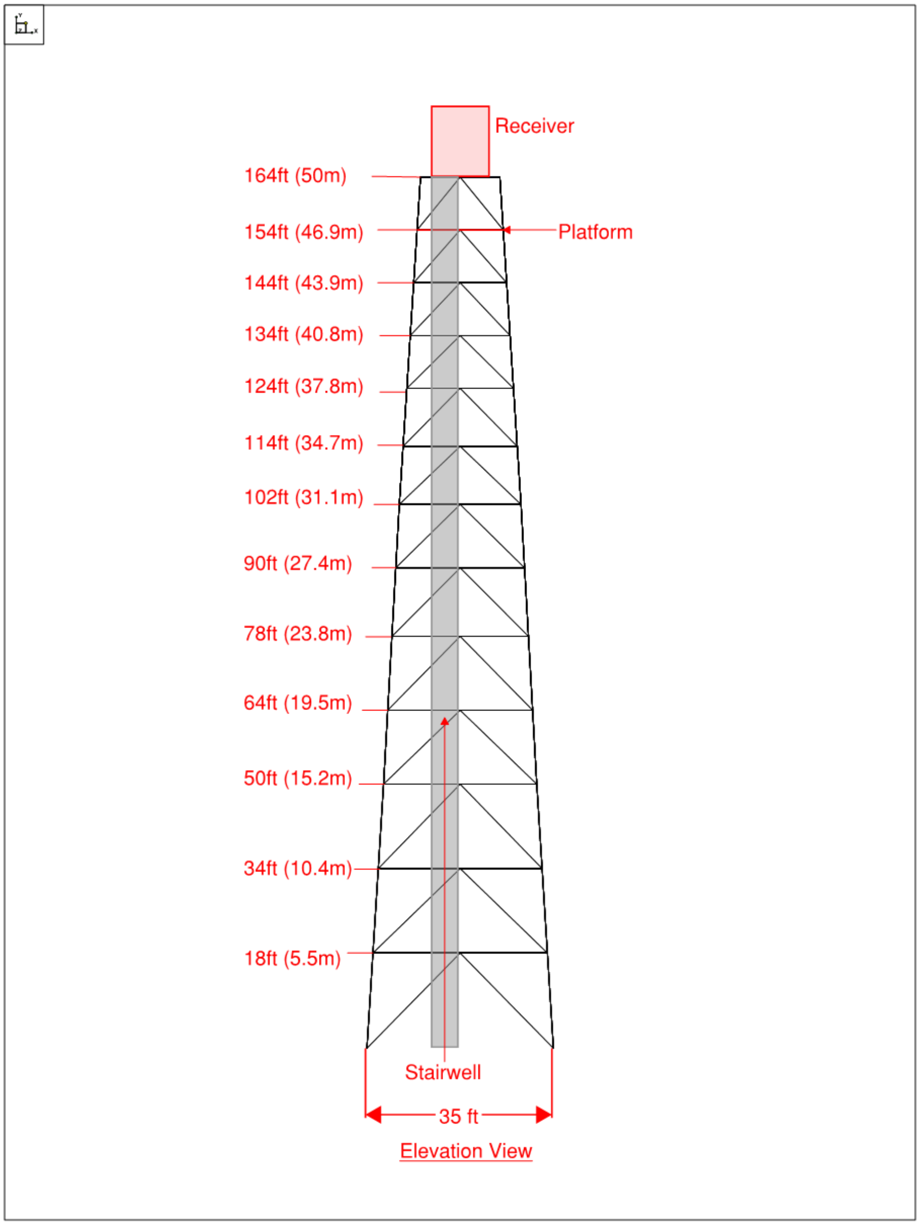


Figure 3-3 Molten Salt Tower (with Elevator Inside the Tower Steel)

3.4.2 Structural Design

All designs will meet federal, state and municipal building code requirements, including IBC 2012. The following Table 3-1 shows the parameters used for the conceptual design of the on-site structures:

Table 3-1 Structural Design Basis

General Design Data:	
Building Code	IBC 2012
Risk Category	II
Site Elevation (Mean Sea Level), ft (m)	2100 FT.
Wind Design Data:	
Ultimate Design Wind Speed, V_{ult}, Nominal 3 second gust wind speed at 33 ft. (10 m) above ground for Exposure C category, mph (m/s)	110 MPH
Exposure Category	C
Topographic Factor, Kzt	1.0
Snow Design Data:	
Ground Snow Load, P_g, lb/ft^2 (kN/m^2)	5 PSF
Importance Factor (Snow Loads), I	1.0
Ice Design Data:	
Nominal Ice Thickness, t, Due to freezing rain at a height of 33 ft (10 m), inches (mm)	0 IN.
Concurrent Wind Speed, V_c, mph (m/s)	30 MPH
Importance Factor (Ice Loads – Ice Thickness), I_i	1.0
Importance Factor (Ice Loads – Concurrent Wind), I_w	1.0
Seismic Design Data:	
Short Period Mapped Spectral Acceleration, S_s	1.423g
One Second Period Mapped Spectral Acceleration, S_1	0.538g
Site Class	D (Stiff Soil)
Importance Factor (Seismic Loads), I	1.0

3.4.3 Subsurface Conditions and Foundations

From historical reports, the soil conditions in the assumed Daggett, California, site area are predominantly sandy soils. Groundwater does not appear to be an issue at this location.

Foundations for all equipment and structures will be either individual drilled piers, drilled piers with a pile cap, or mat type foundations.

Foundations were sized for the heliostats assuming 96m^2 surface area. Foundations were sized for the tower based on loads provided from the tower model in RISA. For the molten salt tanks, foundations were sized assuming the top of the concrete was at 50C, as determined by heat transfer calculations using insulating refractory bricks and water cooling below each molten salt tank. Slab-on-grade foundations were approximated for the remaining equipment, for purposes of the cost estimate.

3.4.4 Site Preparation

The area of the proposed project is relatively arid and flat. Therefore, there should not be significant expenses for clearing or earthmoving. It was assumed that excess spoils from foundation excavation and topsoil removal can be used or stored on-site.

3.4.5 Paving and Roads

The main entrance road will be designed as a 24 foot wide aggregate surfaced road with the loop roads being reduced to a 20 foot width. Both road widths will allow enough room for vehicles to pass, but the 24 foot road will allow better traffic flow on the main access road. An aggregate base thickness of 8 inches was assumed for the purpose of this study. It was assumed that 6 inches of topsoil will be removed to allow for the compaction of the road subgrade and installation of the road base material. is assumed for the road subgrade.

3.4.6 Storm Water Drainage

An on-site detention basin will be located on the site for drainage control. Culverts will be located in appropriate locations along the access roads. Ditches will be used to route storm water to the detention system.

3.4.7 Secondary Containment Structures

Secondary containment for the molten salt tanks will be provided by an earth mound around the tanks, as shown on Drawing DM-6200 in Appendix B.

3.4.8 Buildings and Pipe Racks

All buildings on the site except for the tower and pipe rack are assumed to be pre-engineered metal buildings.

Pipe racks will be made constructed out of galvanized hot rolled steel shapes and will be galvanized. The pipe rack design basis will be according to Table 3-1.

3.4.9 Painting and Coatings

All exterior structural steel will be galvanized. Pre-engineered metal building structural steel will be shop primed. Metal wall panels for the buildings will have a standard Galvalum® coating.

3.4.10 Cranes and Hoists

An allowance for crane pads has been made on the site. The tower will be designed with hot rolled steel shapes to allow for the addition of hoists as necessary. It has been assumed that a personnel elevator will be placed alongside the tower.

3.4.11 Security Fence

A security fence will be installed around the site. The fence was squared off to allow for construction laydown as needed and storm water conveyance and detention. The security fence will be a 6' tall galvanized chain link fence with three strand barbed wire at the top of the chain link fence, with the assumption that no slats will be required.

3.5 ELECTRICAL CONCEPTUAL DESIGN

3.5.1 Electrical One Line Drawing

Electrical One Line Diagram Sheet SE-E1000 illustrates the 33 kV and 4.16 kV distribution and backup generation for the Molten Salt Facility. See Appendix D for Electrical One Line Diagram. Refer to Table 4-1 for a listing of motor loads.

3.5.2 Power Distribution

The Facility is a self-contained power generating facility utilizing solar energy and mechanical heat transfer systems to spin two generators, rated 12 MVA and 6 MVA, providing electric power at 13.8 kV, 3-phase, 60 Hz. Each generator is connected to a 13.8-33 kV generator step-up transformer (GSU) and then connected to the primary 33 kV switchgear line-up.

3.5.3 Site 33 kV Substation

The primary 33 kV switchgear is indoor metal-clad type switchgear with vacuum circuit breakers and digital multi-function protective relays. The switchgear will be housed in a prefabricated, weather-tight, industrial power assembly (IPA) enclosure. The switchgear will feed a 4.16 kV metal-clad switchgear lineup (also housed in the IPA) serving heaters, two large compressors, and heat tracing loads.

The 33kV switchgear will have an underground feeder connected to an overhead distribution line routed off site on wood poles. The feeder will be sized for exporting approximately 10 MVA of power to a commercial utility system at 33kV. The terminal point of the underground 33kV feeder will be at a riser pole shown on the site arrangement drawing near the site entrance.

3.5.4 Auxiliary Power System

The 33kV switchgear will feed a 480V secondary unit substation (SUS), which will supply low voltage power to pumps, auxiliary loads and the control building. Medium voltage loads (sCO2 compressor motors and sCO2 start-up electric heater - see Table 4-1) will be served at 4160V.

3.5.5 Raceway Design Materials

Distribution at 4.16, 13.8 and 33 kV will consist of single-conductor, medium voltage, copper conductors routed in direct-buried fiberglass conduits. [PVC conduit will not be used because of its brittleness, low impact and crush strength, low resistance to sunlight. In addition, when pulling power cables into underground conduits, PVC elbows are easily scored and damaged by pulling ropes, even at low pulling tensions.] Distribution at 480 volts will consist of single copper conductors routed in direct buried fiberglass conduits, or armored 3-conductor copper cables route in above-ground fiberglass cable trays.

3.5.6 Motors

All medium voltage motors and all low voltage motors 200 HP and above will be controlled by variable frequency drive units.

3.5.7 Grounding Design

Switchgear lineups, outdoor transformers, buildings and mechanical equipment structures will be connected by a direct-buried ground grid consisting of copper conductors and ground rods. All below-grade connections will be exothermically welded.

3.5.8 Lighting Design

All indoor lighting, equipment lighting and area lighting will consist of energy efficient LED fixtures. Outdoor lighting may use photoelectric sensors to minimize auxiliary load. CCTV, with its potential lighting requirements in alarmed areas, has not been included in the current design.

3.5.9 Power Control and Instrument Cable

Power cable and control cable will be conventional, sized to meet code requirements.

3.6 INSTRUMENTATION AND CONTROLS CONCEPTUAL DESIGN

The plant control system will consist of a Distributed Control System (DCS), Solar Collector System controls, field instrumentation, sCO2 Turbine Generator controllers, and other local controllers (e.g. air compressors, Raw Water Treatment, and Demineralized Water Production). The DCS provides the operator interface functions and will be designed for daily startups, shutdowns, and transitional functions.

3.6.1 Distributed Control System (DCS)

The DCS will be a microprocessor-based system composed of functionally distributed (modular) processors, input/output modules, field cable termination facilities, and operator interface devices, all connected via a redundant communications network.

Input/output (I/O) modules will be used for interfacing via termination cabinets, with transmitters, sensors, final control elements, motor starters, breakers, and other equipment located throughout the unit. The I/O modules will normally be connected directly to the redundant control processors via redundant datalinks such that a single failure of the communications network will not affect the availability of the control functions of the system.

PC-based work stations will be provided for operation of the Project control systems as well as providing alarm and data acquisition functions. The work stations will include keyboards and cursor control devices for entering operator-initiated control commands. "Hard-wired" devices such as push buttons, switches, and indicators will be limited to those required by Laws and Codes, and those provided for hard-wired emergency shutdown.

The DCS will include an overall minimum of 25 percent installed spare I/O capacity and equipment, after DCS factory acceptance testing, in each DCS I/O cabinet grouping. Spare capacity will also be included for functional control within each processing unit. Spare equipment will include I/O cabinet field cable termination terminal blocks and active I/O points. Space will be included to allow an additional 10 percent increase in I/O in each DCS I/O and termination cabinet grouping.

The DCS will be equipped with a diagnostic package that includes both hardware and software to detect system malfunction and equipment failure. The occurrence of any malfunction or equipment failure will be alarmed instantly. The diagnostic package will be capable of pinpointing the defective component down to the card level.

The DCS will be designed to react in a predictable manner to certain failures. Upon system logic failure, as detected by system diagnostics, a controller will transfer to its backup. If the backup is unavailable, the controller outputs will fail to a predictable state and will enable any manual shutdown facilities which are appropriate to provide orderly shutdown of equipment.

Upon system logic power supply failure, the controller will transfer to its backup. If the backup is unavailable, the system outputs will fail to a predetermined state.

Upon power failure to an active or running controlled device or equipment, the system will react in a predetermined manner, either to command a restart of the equipment upon power resumption, or to cycle the logic to a status requiring equipment shutdown.

3.6.2 Processor I/O Cabinets

The DCS will include control processor cabinets and remote I/O cabinets where it is advantageous to have the DCS I/O terminations at a remote location. The processor cabinets and remote I/O cabinets will house the I/O modules to which field instrumentation, open/close valves, modulating valves and control/monitoring signals will be wired. The DCS utilizes five main types of I/O module cards. Included are the following:

- Analog Inputs (AI) – Primarily 4-20 mAdc signals for transmitters. These are powered by the DCS with 24 Vdc. Also included are 4-20 mAdc signals from packaged system control cabinets.
- Analog Outputs (AO) – Primarily 4-20 mAdc, DCS-powered, signals that are wired to modulating control valves.
- Digital Inputs (DI) – Primarily 120 Vac or 24 Vdc, interrogation signals from field switches and motor control panels.
- Digital Outputs – Will be used to provide control commands/intelligence to motor control panels, open/close valves and miscellaneous control cabinets. Digital outputs will be via either mechanical or solid-state contacts (depending on the required output rating).
- Sequence of Events (SOE) – Basically digital inputs that are time-stamped with a resolution of approximately 1 msec.

3.6.3 Operator /Machine Interface

The Central Control Room (CCR) will house the following major operator/machine interface equipment:

- Five, dual-screen DCS operator stations.
- One, alarm/event printer.
- One, report printer.
- One, color printer.
- A separate DCS Historian station. This allows the operator/engineer to access historical data.
- sCO2 Turbine Generator Operator Work Station and associated printer.

The Engineering room will house the following major engineer/machine interface equipment:

- One, single-screen DCS engineer station.
- One, single-screen Turbine Generator engineer station.
- One, single-screen HAC engineer station.

3.6.4 Redundancy

The DCS design will incorporate functional redundancy to ensure maximum reliability during system operation. Redundant processing units with redundant power supplies will be provided as required to ensure that a single point of failure will not result in loss of generation capacity. In the event of a failure of the active processor, the other processor will maintain the system functions without disturbing the operation of the unit. Processor failure will be alarmed.

Redundant power supplies will be provided for all control processors in the system. Peripheral devices such as work stations and printers will each be powered from a single feed of the 120 volt AC uninterruptible power supply (UPS).

Assignment of inputs and outputs to specific cards will be carefully made for reliability. Redundant inputs and outputs to redundant control devices will be placed on modules that are separate from their redundant counterpart. In the event of a card failure, it will only affect one of the redundant signals, leaving the other one intact for continued, seamless control.

Each DCS processor cabinet will have two redundant power feeds and redundant power supplies. The main power feed will be from battery-backed UPS source. The secondary feed will be from a house power source. The processor will be fully redundant with automatic failover capabilities.

3.6.5 Data Highway

The DCS controller network will be connected by a redundant data highway. The DCS data highway will have automatic failover capability. In the event of a communications failure, or data highway cable that has been cut, the redundant cable/equipment will instantaneously and automatically be engaged, giving a seamless transfer, which will not be transparent to the operator, save for an alarm that will register on the DCS alarm page.

3.6.6 Datalink Communications and hard wired Signals

DCS datalink communications will be provided for the turbine generators, HAC and possibly other local programmable logic controllers (PLC). This will be accomplished by use of redundant Ethernet communications links or redundant proprietary interfaces. The communication links will have automatic failover capability. In general, I/O that is critical for coordination of control between stand-alone controllers and the DCS will be accomplished using hardwired signals. Datalink information will primarily be used to provide the operator with alarm and monitoring information. While the DCS operator stations will be the primary location for operators to control the plant, a TG operator station will be provided in the CCR to supplement the DCS screens accessible to the operators.

3.6.7 Major Control Functions

The following control functions will be provided through the DCS:

- Overall control of the Collector System, Receiver System, sCO2 cycle, electric power generation system, auxiliary electric system, and Balance-of-Plant (BOP).
- Overall control of unit startups and shutdowns initiated by the unit operators.
- Control of the balance-of-plant process equipment.
- Operator interface for the auxiliary electric system.

- Visual and discernable audible alarms for abnormal events based on process signals or software generated signals (including out-of-limit parameters) from the systems, processes, and equipment, or discrete alarms from equipment control systems.
- Sequence-of-events (SOE) recording to assist with diagnostic evaluation of unit upsets, trips, and unit operation.
- Operator interface through work stations consisting of color graphic flat panel displays, keyboards, cursor control mouse, and printers.
- On-line programming, graphics and logic changes.

3.6.8 Instrumentation Racks

Instrumentation will be installed on open instrument racks. Instruments will be grouped for ease of wiring and maintenance. Each instrument on the rack will have its own blowdown valve and instrument valve manifold, where applicable. Instruments on the racks will be wired directly to the DCS I/O cabinets.

3.6.9 Modulating Control Valves

Modulating control valves will typically be air powered and modulated via 4-20 mAdc signals from the DCS, or other controller. Modulating control valves generally will have 4-20 mAdc demand signals from the DCS (or separate controller), and no position feedback. In general, modulating control valves will be sized to pass normal operating flow when the valves are between 65 percent and 85 percent open. Motor or electric operated modulating valves will not be generally used.

3.6.10 Open/Close Valves

Automatic valves for open/close applications will either be air-operated block valves (ABVs) or motor operated block valves (MBVs).

3.7 MOLTEN SALT SYSTEMS

3.7.1 Molten Salt Receiver

3.7.1.1 Molten Salt Receiver System Description

The SunShot goal of 90 percent receiver efficiency (and 10,000 cycles) will not be met with the small size of the conventional surround receiver for the 10MWe integrated facility, whereas it may be met with a larger one-sided panel and north facing solar field. Because of the financial difficulties of the north facing field receiver supplier, a decision was made to proceed with a surround field multi-panel receiver to prove capability for future financing reasons with compatible receiver suppliers.

The molten salt (MS) receiver will be installed on the power tower steel. As noted earlier, it will be supplied with cold MS by pumps mounted in the cold MS tank, receive solar irradiation from the heliostat field and provide hot molten salt that will flow to the hot MS tank. The tower, MS pumps, heliostats and MS piping system to the hot MS tank are described in other sections of this report. The MS receiver system as described in this section includes all equipment installed above the tower steel, i.e. above the 50m elevation of the tower. The equipment, described in drawing 042839-DM-M2600 in Appendix C, includes:

- A receiver inlet vessel with an inert (nitrogen) pressure blanket. The vessel will be connected to the riser piping and to the nitrogen supply, with piping routed inside the steel tower frame work.
- The receiver itself. The receiver may be of a two flow loop design with a MS flow as shown in the above referenced drawing through each loop or of an alternative design, as proposed by a qualified supplier. It will include appropriate inlet headers, outlet headers, U-tubes, tube clips and instrumentation. Instrumentation will include flux meters, as well as flow, pressure and temperature elements. There will be multiple absorber panels to absorb the surround solar field irradiation, with the final number of panels left to the qualified supplier to select and design. The use of oven boxes to protect headers and manifolds from excessive heat exposure to heliostat irradiation or an alternative design will be left to the qualified supplier. It is likely that the tubes will be coated to increase absorptivity; the coating material will be per supplier recommendations to meet SunShot receiver efficiency.
- A receiver outlet vessel. This vessel will receive hot MS from the receiver and feed the down-comer to the hot MS tank. It will also receive vents and drains from the receiver and be an important start up and shutdown component.
- A receiver bypass valve in cross-over piping. This valve will be used for start-up and to de-superheat the hot MS as appropriate.
- Structural steel to support the receiver panel frame, vessels and appropriate platforms above the 50m elevation.

The control system controlling the heliostats and receiver operation will be provided either by the heliostat supplier or by the receiver supplier.

For the selected surround field, the receiver will be in the general form of a cylinder with vertical panels making up the side of the cylinder. The diameter of the cylinder and height of the panels will be determined by the suppliers based on the maximum receiver flux in MW/m^2 on the panels for the receiver material under consideration and on cost-effective aspect ratios. The tubes will be subject to high thermal stresses which are expected to dictate multiple small diameter tubes in the panels. The tube diameter will be determined by the suppliers based on rates of change of temperature reflecting allowable stresses during start-up and during cloud passage, with suitable allowances for cyclic fatigue strain with the tube material in the creep range.

Supplier costs received assume relatively insignificant corrosion allowances. This is an important assumption relative to wall thickness and thermal stress.

The receiver will be supported by panel support frames. The panel support frames typically support the colder top headers with unrestrained downward thermal expansion of the tubes and bottom headers. Tube clips may be used to line up the tubes with increasing temperature. The design of the panel support frames and tube guides will be the receiver supplier's proven standard. There will be a number of valves provided with the receiver, for flow balancing, bypass, and venting. Compressed air will be supplied to the receiver system for pneumatic valve service.

The high points of the receiver will be vented and the low points drained to the outlet vessel and then to the MS tanks, to allow drainage of the MS from the receiver system during daily shutdown and to remove air during daily start-up.

Nitrogen will be supplied to the receiver inlet vessel as noted above and to the outlet vessel. With the chloride MS, the nitrogen will need to be nearly free of moisture and oxygen.

A head loss for the receiver system, including the inlet vessel head, has been included in the calculation of the cold MS pump head.

The receiver system including the inlet vessel, receiver, outlet vessel and associated piping will be heat traced and insulated.

Design details for mitigation of thermal stress will be the qualified supplier's proven standard. The receiver supplier's scope will include cutting and welding equipment for night-time maintenance of receiver tubes.

Design conditions will be based on the following:

- Receiver heat absorption = 31.2 MWth
- Receiver cold MS inlet temperature = 540C less riser heat losses plus allowance (e.g. 20C).
- Receiver outlet MS temperature = 750C plus down comer heat losses plus allowance (e.g. 10C).
- Receiver tube temperature (steady state) = supplier recommended maximum.
- Receiver trip temperature = supplier recommendation.

Black & Veatch adds an allowance to steady state conditions for pipe design. For the receiver piping design with flow distributions less uniform, the design temperature will be agreed with the supplier.

3.7.1.2 Materials of Construction

At this time, it is assumed that Haynes 230 will be the material of construction of the following:

- Inlet vessel (use of a lower grade material may be considered in the future).
- Headers, tubes and tube clips.
- Outlet vessel.

- Receiver cold and hot valves and piping (lower grade material may be considered in the future on cold piping and valves).
- Interconnecting piping (cross-over, U tubes, vent and drain piping to the outlet vessel).

Nitrogen piping to the inlet control valve to the inlet and outlet vessel would be lower grade material. The motor-operated valve and piping connecting to each vessel would be Haynes 230 as MS could contact those valves.

3.7.1.3 Issues/Concerns

Black & Veatch has assumed that DOE is currently focusing on receiver issues dealing with efficiency. At the April 2016 workshop, for example, work on coatings was evident. Work with receiver suppliers should continue to characterize performance, hot spots, allowable temperature ramp rates and start-up times, materials, flow distribution, etc. Presumably, under existing DOE funding, receiver suppliers will develop suitable designs of the inlet vessel, outlet vessel, and other components of the receiver system to meet SunShot project lifetime and cycle goals.

Other issues and concerns relating to the receiver include:

- Corrosion from MS. Oxygen and moisture control in the MS are being investigated as noted in the April 2016 workshop. However, effects of other impurities in industrial MS $MgCl_2$ and KCl on corrosion rates also need some investigation for long term operation. Performance of Haynes 230 at temperatures above 750 °C. Local hot spots on the receiver may reach significantly higher temperatures (e.g. 850 °C). Tube replacement criteria will need to be developed, to cut out and replace failing tubes without introduction of air. Trip temperature limits will need to be developed.
- Performance of valves and instrumentation in the high temperature MS environment.
- Purge gas. Alternatives to nitrogen may be appropriate to consider and develop.
- Mill scale control. It has been assumed that mill scale will be removed after construction using air blows followed by air removal. After initial fill of the MS tanks, this will be more difficult and procedures should be developed.
- Expected replacement rates for tubes, for O&M cost allowances.

3.7.2 Molten Salt Storage Tanks

3.7.2.1 Hot & Cold Storage Tank Descriptions

The hot and cold molten salt storage tanks conceptual design information illustrated in Table 3-2 is based on a 4 hour inventory of 750 °C molten salt for power generation.

Table 3-2 Molten Salt Tanks

DATA – ITEM	HOT SALT TANK	COLD SALT TANK
Operating temp + 10 °C	750°C + 10°C = 760 °C	540°C + 10°C = 550 °C
Operating vapor space pressure (N2 blanket)	0.2 bar	0.2 bar
Diameter of shell	14.2 meters	13.8 meters
Height of shell (1)	10 meters	10 meters
Tracing maintenance temp- electric (2)	750 °C shell & 540 °C roof	540 °C roof and shell
Insulation (3)	Multi layer-SS cladding	Multi layer-SS cladding
Foundation TOC elevated to allow access to cooling system piping (4)	Per codes and standards	Per codes and standards
Roof - Self-supporting dome	Provide PVRV nozzles	Provide PVRV nozzles
Number of pumps (estimated weights)	2 @ 3000 Kg each	2 @ 4000 Kg each
Corrosion allowance (5)	3 mm	3 mm

1. Includes allowance of 2 meters for liquid sloshing due to earth quake + 1 meters for pump suction above the base of the tank - to be confirmed during detailed design.
2. Tracing to be placed on the roof and top meter of the side wall. Include thermocouples on the shell at 3 levels; near floor joint, at mid height and 2 meters down from roof joint 60° intervals and for every 8 square meters of the roof wired to central terminal box.
3. Insulation for minimize heat loss design basis for the MS tanks is assumed to be 1% delta T/day on the coldest day with max wind. The delta T is the difference between tank temperature and ambient temperature– insulation and electric heat tracing to be supplied and installed by tank vendor.
4. Foundation heat barrier design to be based on minimum thermal loss necessary.
5. Corrosion allowance is based on preliminary available testing data of < 0.1 mm/yr and 25 year life.

The roof of the tank is electric traced to maintain 550 °C to avoid possible formation of solid salt on the underside of the roof and its supporting structures. The top 1 meter of the shell is electric traced to 550 °C to reduce the thermal induced stresses at the critical roof to shell junction.
The conceptual design eliminates side wall penetrations in the 750 °C tank due to concerns for local increased stress and creep. This same practice is applied to the 550 °C tank although it may be possible to utilize shell penetrations at this temperature.

3.7.2.2 Tank Immersion Heaters

The tank heaters conceptual data is based on the electric tracing on the tank roofs and top one meter of shell to maintain metal temperatures above salt melting temperature and maintaining the salt temperature but not to quickly recover the salt temperature if allowed to decay significantly.

Table 3-3 Tank Immersion Heater Design

ITEM[1.]	UNTRACED SIDE WALL	BOTTOM HEAT LOSS	TOTALS OPERATING FOR TANK HEATER DUTY W
Hot tank to maintain 750 °C salt temp	92730 W	48050 W	140780 W
Hot tank to maintain 550 °C salt temp alternate	64800 W	33630 W	98430 W
Cold tank to maintain 550 °C salt temp	64800 W	33630 W	98430 W

1. External immersed heater in pump return to the tank, 2 piped and 2 installed spares for each tank, duty for exchangers is to replace side wall and bottom loss, it is assumed that the roof and upper side wall tracing duty will be available if exchangers are placed in service. Hot tank exchanger duty to be capable of maintaining 550 °C minimum and 750 °C if necessary, cold tank exchanger duty to be capable of maintaining 550 °C. Heater duty does not include tank top tracing duty as this tracing is expected to be in continuous service and the tank heater is intermittent service only as necessary.

The external immersion heater conceptual arrangement selection is based on the hot salt tank 760 °C design temperature and local stress and permanent strain concerns of a large side wall nozzle near the bottom of the tank and adjacent to the side wall to bottom plate junction. The cold salt tank 560 °C design temperature conceptual design includes a similar external immersion heater arrangement although it may present less of a concern for the local stress and permanent strain concerns.

3.7.2.3 Molten Salt Foundations

The molten salt tank foundation conceptual design utilizes an insulating brick section from the bottom of the tank to the top of the concrete foundation pile cap. At the top of the concrete a closed circuit circulating water system is used to remove the necessary heat to maintain a suitable concrete temperature. The piping in the concrete is to be redundant to allow maintenance and repairs with the tank in service. The closed circuit loop includes the use of redundant air coolers and pumps to provide a reasonable reliability level.

3.7.2.4 Materials of Construction

The molten salt tanks utilize a high temperature service nickel alloy, N06230 commonly known as Haynes 230, which DOE has qualified for this service by corrosion testing. The ASME Boiler and Pressure Vessel code section II D 2013 provides design stress values for the service molten salt service design temperatures as do the ASME B 31.1 & 31.3 piping codes. At the hot salt temperature of 750 °C, it is recommended that the N06230 material be evaluated for creep rupture considerations as creep is expected to be the controlling factor in design. Some suggested considerations:

- Establish creep life expectancy..
  - Establish design stress for > 100,000 hour.
- Thermal cycle definition.
  - Number of cycles.
  - Rates of temperature change.
- Establish acceptable strain limit.
  - Determine acceptable dimensional changes due to creep permanent strain.
- Establish creep/fatigue interaction limits.

Design involves evaluation of time dependent effects of creep and stress rupture and it is recommended that the design utilize methodology and procedures per ASME Section III including Paragraph W-4400 and Subsection NH.

3.7.2.5 Issues/Concerns

The following issues and concerns are recognized for the salt tanks:

- The corrosion rate for the N06230 nickel alloy and the necessary associated controlling parameters need to be verified as the resulting corrosion allowance is a significant design and cost issue for the KCl-MgCl2 salt services. The concerns for the purity of the available industrial grade salt and the effect of these impurities on the corrosion rate along with the velocity and stagnate conditions impact on corrosion rates need to be confirmed to assure acceptable service for both the hot and cold tank services.
- The design and service experience for molten salt tanks at 550 °C is very limited and at 750 °F apparently no design and service experience is available. There is some design and service experience for ~ 500 °C applications that can be extrapolated to the 550 °C service; however, the extrapolation of the ~500°C experience to the 750 °C service is not considered to be reasonable.
- Apparently, there is no design or service experience for the use of N06230 materials for molten salt tank service.
- The necessary design methodology for time dependent effects of creep and stress rupture, utilizing methodology and procedures per ASME Section III including Paragraph W-4400 and Subsection NH, is not a common tank design practice.
- There is a concern for the methodology of heating up the tank from ambient to ~ 550 °C to ready it for receiving molten salt form the salt melting system. Maximum ramp rates require investigation.
- No concept has been developed or provision provided for de-inventorying of one or both tanks.
  - The inventory of one tank can be pumped to the other tank. The difficulty will be to remove the MS inventory below the suction of the MS pumps in either tank.
- The large amount of the N06230 alloy material for the tanks may present delivery problems for maintaining the project schedule.
  - May consider advanced commitment for producing these materials on a bulk tonnage basis.

3.7.3 Molten Salt Pumps

3.7.3.1 Hot & Cold Molten Salt Pump Descriptions

The hot and cold molten salt pumps data for the conceptual design are listed in Table 3-4.

Table 3-4 Molten Salt Pump Design Data

DATA/ITEM	HOT SALT PUMP	COLD SALT PUMP
Quantity (2 installed + complete spare = 3)	3	3
Operating/design temp	750 °C/760 °C	540 °C/570 °C
Head operating/design/max curve limited	42/46/50 meters	107/118/128 meters
Flow rate operating cubic meters per hr /GPM	235 m^3/1037 gpm	283 m^3/1246 gpm
Height of shell[1.]/pump length	11/12 meters	11/12 meters
Hydraulic power/motor power	(4)	(4)
Tracing maintenance temp- electric[2.]	750°C	550°C
Insulation	Multi layer-SS cladding	Multi layer-SS cladding
Corrosion allowance	3 mm	3 mm

1. Allowance of 1 meter from bottom for pump suction and 2 meters from top of shell for pump mounting.
2. Tracing to be placed on the pump outlet nozzle extension and mounting plate with two thermocouples per location (boxed arrangement is acceptable) please provide concept of the tracing and insulation system with offering.

The molten salt pumps are to be vertical single or multi-stage sump type, roof mounted on the molten salt tanks. The salt is $MgCl_2$-KCl and the pump seals must be nitrogen purged to prevent oxygen and moisture ingress. The tank nitrogen purge operating pressure is ± 0.15 bar. The Tanks will have internal pump columns, in which the pumps will be inserted, that facilitate the maintenance removal and replacement of a pump while maintaining the inert gas purge of the tank vapor space.

Pumps will be supplied with variable speed drive (VFD) systems, vibration monitoring systems, and purge control systems.

Pump mounting plate will be insulated and electric heat traced to maintain same operating temperature as the salt tank.

The site location is assumed to be near Barstow, CA, for ambient and earthquake considerations. Design life of pumps is 20 years in tank exposure and 12 years in operating service.

Due the operating temperature being in the creep rupture design temperature range, the expected maximum design life of the pumps for operating and non-operating conditions is uncertain.

Pumps will require simulated performance testing at the manufacturing site. At this time, none of the multiple pump suppliers contacted have experience with Haynes 230 or with the high temperatures involved.

3.7.3.2 Materials of Construction

The specified material for wetted parts of both the hot and cold pumps is Haynes 230 SB 435 (UNS N06230) with design operating temperature stress for 100,000 hours from ASME Section II D allowable values.

The materials used in the sealing of the vertical shaft will need to be selected for the following conditions;

- High temperature exposure from the shafting and mounting plate.
- Possible corrosion conditions from the salt atmosphere.
- N06230 or other suitable alloy may be acceptable.

The long vertical pump shaft will require steading bearings and the lower bearings will typically be submerged in the molten salt. There is little information to support the selection of bearing materials and their design. These bearing must be suitable to maintain suitable contact conditions including lubrication when immersed in the molten salt and when not immersed in the salt and possible lubrication supply using the pumped fluid.

Additionally, corrosion and salt freezing at the seals at the motor end must be avoided and the inert gas tank vapor space must also be protected; this is accomplished by nitrogen purged shaft seals.

3.7.3.3 Issues/Concerns

- The design and service experience for molten salt pumps at 550 °C is very limited and at 750 °C apparently no design and service experience is available. There is some design and service experience for ~ 550 °C applications that may be extrapolated to the 750 °C service but there are many technical areas of concern and related unknowns at this higher temperature.
- Apparently there is no design or service experience for the use of N06230 materials for molten salt pump service.
- The effect of creep induced permanent strain on the pump internal parts which require fixed dimensions and tolerances is a critical issue to be addressed.
- The design corrosion allowance is critical for the pump internal parts and there apparently are no available data for velocity effects on the corrosion rate flow. This flow affected corrosion (FAC) data is an important aspect that must be addressed.
- There is apparently no experience with the selected salt and the high operating temperatures to guide the selection for materials and design for the shaft steady bearings and this aspect must be addressed.
- The responding pump vendors indicated the lack of this specific molten salt service, service temperature and use of alloy N06230 experience was a significant issue and several of the

vendors stated that basic research and development required to extrapolate their service experience which would be time consuming and costly. When asked if they would be open to participating with DOE for this research and development some raised the issue of confidentially of joint developed information versus public disclosure.

- The maintenance and overall life aspects for both the cold and hot service pumps is expected to result in removal of the pumps from the tanks at some regular intervals perhaps more than once a year.

3.7.4 Primary Heat Exchanger – Molten Salt/sCO2 System

3.7.4.1 Primary Heat Exchanger Description

The Primary Heat Exchanger will transfer heat from the molten salt system to the sCO2 system. For this conceptual phase of investigation of the molten salt system, design verification was solicited from Brayton Energy, Heatric, and Thar Energy. The conceptual Primary Heat Exchanger may consist of a shell and tube or printed circuit arrangement depending on availability and constructability of the Haynes 230 and equivalent material. In each arrangement, molten salt flow through the vessels transfers its heat to the sCO2 fluid in the tubes or circuit. Three (3) 100 percent heat exchangers will be installed for the plant system for redundancy. One (1) heat exchanger will normally be in operation. Table 3-5 provides each supplier's heat exchanger type.

Table 3-5 Primary Heat Exchanger Type and Materials of Construction

SUPPLIER	TYPE
Brayton Energy	Shell and Tube (Vessel)
Heatric	Printed Circuit
Thar	Shell and Tube (Serpentine)

The Primary Heat Exchanger will supply 100 percent of the design heat load to the sCO2 Power Generation System, heating the sCO2 to approximately 716 °C. The maximum design heat load and conditions provided in the Table 3-6 as follows are consistent with the plant rated load heat balance. All heat exchanger designs will be specified with 10 percent excess surface area installed to account for molten salt fouling. The pressure drop across the molten salt side will be limited to 36 psi maximum; pressure drop across the sCO2 side will be limited to 20 psi maximum per heat exchanger. (The use of more expensive multiple smaller heat exchangers may be desirable for availability reasons.)

Table 3-6 Primary Heat Exchangers Design Data

CONDITION	VALUE
Overall Heat Transfer	31.2 MWt
Molten Salt Inlet Temperature	748.1 °C
Molten Salt Outlet Temperature	540 °C
Molten Salt Pressure inlet	3.48 Bar
Molten Salt Pressure Outlet	2.13 Bar
Molten Salt Flow rate	100.3 kg/s
sCO2 Pressure inlet	252.7 Bar
sCO2 Pressure outlet	250.2 Bar
sCO2 Inlet Temperature	514.8 °C
sCO2 Outlet Temperature	715.9 °C
sCO2 Flow rate	93.4 kg/s

A line supplied by the cold MS tank pumps will feed a desuperheater to control the temperature of the hot MS tank flow entering the MS/sCO2 heat exchanger during start-up. The use of VFDs on the cold MS pumps will enable establishment of a suitable, to be determined, maximum temperature ramp rate in the piping, valves and MS/sCO2 heat exchanger system.

The design and fabrication of the heat exchanger will be in accordance with the latest ASME Boiler and Pressure Vessel Code, Section VIII, Division 1; additional standards will be identified during detailed design for the thermal and mechanical design. The supplier will also be responsible for determining the requirement for providing vibration supports at the inlet and outlet sections of the bundle to avoid vibration due to excessive cross flow velocities.

The Primary Heat Exchanger will be shipped with tubes installed and as a complete unit. sCO2 inlet and discharge nozzles will be combined into a single header by the supplier. Nozzles and connections on the units will be arranged to allow unit covers to be removed without dismantling piping connections for easy access.

3.7.4.2 Materials of Construction

The Primary Heat Exchanger vessel, tubes, plates and all internal components subject to the Minimum Design Metal Temperature (MDMT) of 750 °C will be constructed of Haynes 230 material.

3.7.4.3 Issues/Concerns

Black & Veatch is proposing use of a sCO2 heater for start-up, to minimize thermal stresses in the sCO2 piping and primary sCO2 heat exchanger system. Coordinated use of this heater with trace heating and cold MS desuperheating will be important in establishing the ramp rates and start up times for the sCO2 system. The high pressure of the sCO2 combined with primary heater high thermal stresses at elevated temperatures need additional study.

3.7.5 Molten Salt Piping and Supports

3.7.5.1 Molten Salt Piping

The conceptual design data for the molten salt piping applications is shown in Table 3-7.

Table 3-7 Molten Salt Piping Design Data

ITEM NOTE MATERIALS ARE HAYNES 230 UNS N06230	DESIGN TEMP °C[1.]	FLOW RATE KG/HR//GPM	DESIGN PRESSURE PSI	VELOCITY FT/SEC	PIPE SIZE & WALL THICKNESS WITH NO CORROSION ALLOWANCE
Cold salt piping	550+20=570 °C 1058 °F	460705 Kg/hr 283 meter^3/hr 1246 GPM	Design 300 psi[2.]	7.3 Ft/sec for no corrosion allowance (CA) 8.8 Ft/Sec	8 inch 0.147 inch no CA ~Schedule 10
Hot salt down comer piping[5.]	750+10=760 °C 1400 °F	460705 Kg/hr 300 meter^3/hr 1320 GPM	Design 220 psi[4.]	9.1 Ft/sec for no corrosion allowance 11.1 Ft/Sec	8 inch 0.436 inch no CA ~Schedule 60/80
Hot salt to exchanger piping	750+10=760 °C 1400 °F	354389 Kg/hr 231 meter^3/hour 1070 GPM	Design 110 psi[3.]	6.2 Ft/sec for no corrosion allowance 7.3 Ft/Sec	8 inch 0.22 inch no CA ~Schedule 20

1. Based on preliminary heat & material balance and on creep rupture design stress from B31.3.
2. Based on assumed 100psi pressure drop for receiver system.
3. At a salt temperature, a 50psi pressure drop allowance for salt to sCO2 exchanger; design to include 20% discharge pressure rise from operating pressure to maximum pressure at shutoff with reduced flow rate.
4. Downcomer can have less wall thickness at the upper end.
5. Downcomer design concern for mitigation of pulsation, surging and syphon effects has not been evaluated at this conceptual stage but remains a concern for the detailed design stage.

The molten salt piping is to be configured to self-drain to the appropriate cold or hot salt tank. Special considerations will be required for any obstruction to self-draining, such as check valves, and flow loops in the receiver are to be addressed during detailed engineering.

To reduce the concerns for transient thermal induced stresses during refilling of the salt piping the piping is electrically traced to approximately the cold salt temperature expected during filling. This same electric heating approach is utilized for the primary exchanger which exchanges the energy from the salt to the sCO_2 and the sCO_2 piping from this exchanger to the turbine inlet.

3.7.5.2 Materials of Construction

The specified material for the hot and cold salt piping is Haynes 230 SB 435 (UNS N06230) with design operating temperature stress for 100,000 hours from ASME Section II D allowable values.

3.7.5.3 Down-comer Piping

A conceptual design for the solar tower down-comer was evaluated using the computer program CAESAR II in accordance with the latest B31.1 Code for Power Piping. The molten salt tower which is approximately 140 feet high will need to have a vertical run of pipe in the tower and some horizontal offset at the top and bottom of the tower to absorb vertical thermal expansion. The following is a summary of the piping system design conditions.

- 8 inch Schedule 120 (0.719" Wall) pipe.
- Electric traced.
- Insulation system composed of:
  - Inner layer of 2 inch thick ceramic blanket.
  - Middle multi-layers to 4 inch total thickness E-glass needled-mat not water repellent formed insulation
  - Outside multi-layers to 4 inch total thickness E-glass needled-mat water repellent formed insulation
  - Stainless steel lagging.
- Design pressure of 200 PSI and design temperature of 1,300 °F.
- Salt solution specific gravity of 1.6.
- Piping material Haynes 230 Alloy.
- B31.1 Cold Allowable Stress (Sc) of 20,000 psi at ambient.
- B31.1 Hot Allowable Stress (Sh) of 8500 psi at 1300 °F.

Two conceptual approaches for the piping and support arrangement were investigated for the preliminary conceptual design as follows:

- Option 1. Single straight vertical run with a rigid support near the top and spring supported horizontal run below to absorb about 15 inches of thermal expansion.
- Option 2. Vertical run with three expansion loops rigidly supported within the tower to absorb the thermal expansion.

Option 1 and Option 2 are illustrated in Figure 3-4 and Figure 3.5, respectively.

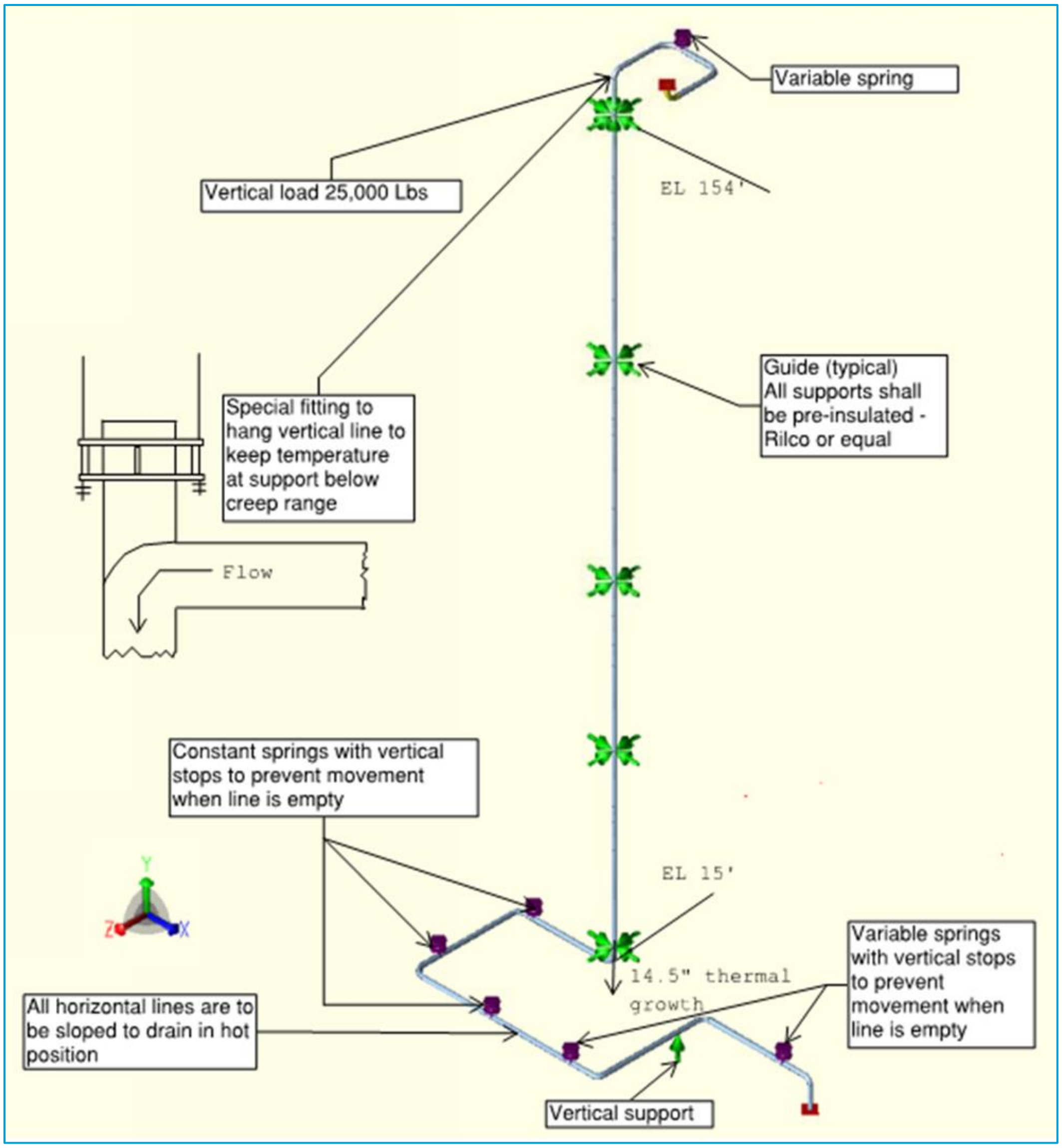


Figure 3-4 Option 1 – Straight Run Down-comer

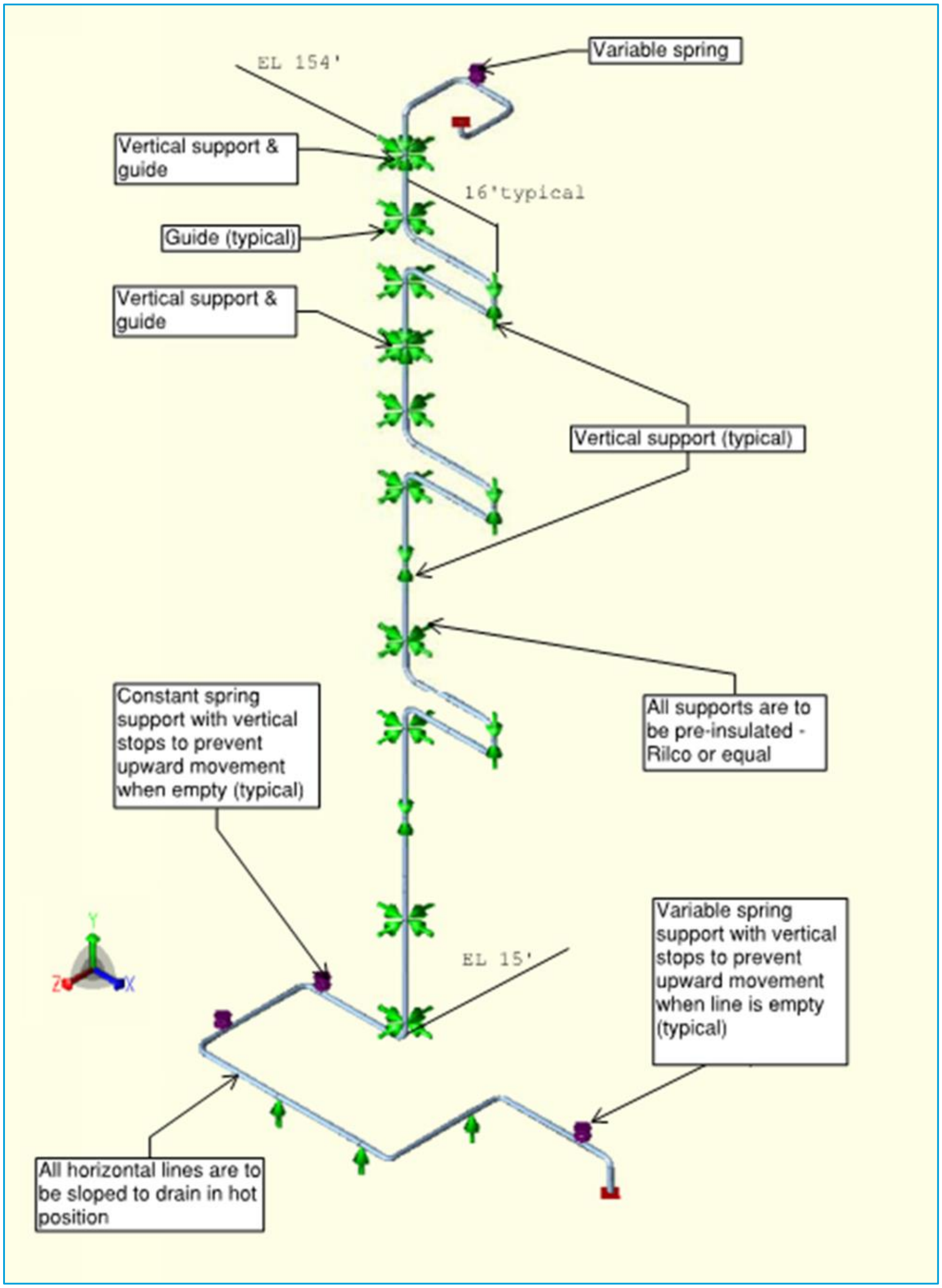


Figure 3-5 Option 2 – Down-comer with Expansion Loops

Both arrangements resulted in acceptable solutions from a routing and support stand point. Option 1 has less linear feet of pipe and bends. However, Option 1 requires more spring supports including the use of constant support and variable support springs in the lower horizontal offset run. Option 1 design was used for the cost estimate basis.

3.7.5.4 Issues/Concerns

The piping design for the cold and hot salt services will require significant engineering effort including the use of standard industry practice pipe design software and more rigorous analysis methodologies to address transient thermal conditions, local stress conditions, and creep rupture, fatigue, and ratcheting considerations.

The initial design corrosion allowance was very tight. Later corrosion information obtained indicated a corrosion rate of <0.1 mm/yr may be achievable and this would reduce the pipe wall thickness significantly; however, there is no available data for velocity effects on the corrosion rate flow. This flow affected corrosion (FAC) data is an important aspect that must be addressed.

Salt piping design temperatures are is in the creep rupture temperature range. Although the 570 °C service is at the lower end of the creep rupture range such items as the potential cycling temperature, localized stress conditions at supports and other areas should be fully evaluated. The 760°C service is a creep rupture consideration and must be further evaluated as creep is expected to be the controlling factor in design. Some suggested considerations for further piping design development:

- Establish creep life expectancy and corresponding data.
- Thermal cycle definition.
  - Number of cycles.
  - Rates of temperature change.
- Establish acceptable strain limit.
  - Determine acceptable dimensional changes due to creep permanent strain .

Design involves evaluation of time dependent effects of creep and stress rupture and it is recommended that the design utilize methodology and procedures per ASME Section III including Paragraph W-4400 and Subsection NH.

3.7.5.5 Molten Salt Piping Supports

For this conceptual design the pipe supports and anchors design was reviewed for the hot molten salt down comer as it has a significant gravity (weight) force that must be addressed by specialized anchors and supports. Due to the amount of thermal expansion some supports will have to address considerable movement and also accommodate the change in pipe weight from the operating conditions to the self-drained condition when not operating. It was concluded from this review that sufficient industry technology is available for the selection and design of anchor, normal supports and high movement supports.

3.7.6 Molten Salt Valves

The design and service experience for molten salt valves at 550 °C is very limited and at 750 °F apparently no significant design and service experience is available. The design for valves in the

750 °C service presents many technical areas of concern and related unknowns for this higher temperature. For this conceptual design the valves would be butt weld ended and be a top entry design for maintenance. The piping forces and moments that are imposed on flanged connections combined with the concern for bolting and gasket relaxation at these temperatures provide significant concerns for maintaining the leak tightness of flanged bolting. Several valve vendors have responded with these concerns and continue working to determine suitable valves for the salt services.

3.7.6.1 Molten Salt Vents and Drain Systems

Molten salt vents and drains on the receiver will be important for the startup and shutdown of the receiver. During startup, the high point vents will need to be opened to ensure no N2 is trapped in any receiver circuit, which would cause overheating and failure of the affected tubes. Therefore, the receiver vents to the hot receiver vessel will need to be opened during startup to clear the N2. Likewise, during shutdown, the receiver drains to the hot receiver vessel will need to be opened for drainage of MS to the hot tank, and avoidance of solid salt in the receiver.

There are only a few areas in the piping systems that are expected to require these systems as the intent is to eliminate as many drains and vents as possible.

The size of the vents and drains, including the valves, will need to be coordinated with the allowable ramp rates. This will clearly depend on the final materials of construction and final wall thickness details.

3.7.7 Molten Salt Melting Plant

3.7.7.1 Molten Salt Melting Plant Description

The molten salt melting plant is designed to melt salt delivered in solid form, temporarily store a molten salt and transfer the molten salt to the cold salt tank. The entire 4h molten salt ($MgCl_2$-KCl) capacity for this facility is estimated at approximately 1,500 metric tons. When compared to existing operating molten salt plants using nitrate salts for higher thermal storage capacities, the molten salt plant for this facility will be relatively small. Once the molten salt is melted and transferred to the cold molten salt tank, the molten salt melting plant is shut-down, and may never be used again for the life of the plant. It is estimated that the melting plant will take approximately two weeks to melt the entire product.

The molten salt melting plant consists of three main modules; the filling module, the dosing module and the melting furnace. The melting plant process flow diagram is shown on 042839-DM-M2025 in Appendix C.

The filling mode begins with the delivery of two separate salts, magnesium chloride ($MgCl_2$) and potassium chloride (KCl) in super sacks. The super sacks will have a capacity of 1,000 kg (1 metric ton). The capacity and the size of the super sacks will ultimately be determined by the salt supplier. The super sacks are transferred from the truck to the roller conveyor by forklift. The super sacks will be then hoisted and dumped into a feed bin where the salt product is temporarily stored. From the feed bins, the salt product will exit the feed bin through a de-lumper or roll crusher, and be transferred by a screw conveyor into a bucket elevator were the de-lumped salt product will be stored in a larger storage dosing bin.

From the dosing bin, the salt product will be fed by variable drive dosing screws to the melting furnace. The dosing screws control the feed ratio of the two salts in the melting furnace. The dosing ensures that magnesium chloride and potassium chloride are carried to the melting furnace in the correct ratio and that the furnace is constantly supplied with raw materials. The mixing proportion can be freely selected; however, the molar ratio will be at 33:67.

The melting furnace will be fired with a burner control system fueled by propane. Propane was chosen as a fuel source due to unknown site location and the availability of a natural gas source. If the ultimate site location has an existing natural gas source, natural gas could be used as a fuel source. The firing system will utilize multiple burners, a forced air system, and an exhaust stack.

The melting salt furnace/tank will contain two 100 percent vertical pumps for transporting molten product to the cold salt storage tank located on the top of the melting furnace. For a good and steady fused salt temperature the furnace will be provided with an agitator. The melting furnace will require a roof structure supported from shell to provide access for roof supported vertical pumps and provide support/access for related piping.

The melting furnace will require a heat barrier type foundation and it is expected that the foundation system will require water cooling and the water cooling pipes should be dual circuits and serviceable for the life of the tank. The installation tank vendor will supply water flow rates and duty requirement of the tanks. The cool water supply would be ~ 50 °C. The tank location is assumed to be near Barstow, CA for ambient and earthquake considerations, soil bearing is not expected to be suitable and piling is expected to be required, and the furnace/tank vendor will design and install the foundation.

The furnace/tank design will be based on API 620 with the exception noted for the service temperature above 250 °F.

The specified material for the furnace/tank shell and roof is Haynes 230 SB 435 (UNS N06230) with design stress extrapolated for 170,000 hours versus 100,000 hours from ASME Section II D allowable values and Haynes 230 Alloy bulletin H-3000H.

Due to the creep rupture design requirement, alternative floor to shell and shell to roof junctions will require confirming rigorous analysis during the detailed design stage.

Table 3-8 Furnace/Tank Design Data

DATA ITEM	MELTING SALT PLANT
Operating temp + 10°C	550°C
Operating vapor space pressure	0.2 bar
Super Sacks Size	1000 kg
Super Sack Number (total)	1500
Melting rate	By vendor
Diameter of shell	By vendor
Height of shell[1.]	By vendor
Molten Salt Blend, MgCl2*KCl	0.33/0.66 molar ratio
Tracing maintenance temp- electric[3.]	540°C roof and shell
Insulation[4.]	Multi-layer-SS cladding
Foundation - TOC elevated to allow access to cooling system piping[5.]	Per code
Roof - Self-supporting dome	Provide PVRV nozzles
Number of pumps (estimated weights)	2@ Kg by vendor
Pump to Cold Salt Tank distance	50 m
Cold Salt Tank height	13 m (above grade)
Corrosion allowance	3 to 12 mm

1. Allowance of 2 meters for liquid sloshing due to earth quake + 1 meters for pump suction - to be confirmed
2. Tracing to be placed on the roof and top meter of the side wall. Include thermocouples on the shell at 3 levels; near floor joint, at mid height and 2 meters down from roof joint 60° intervals and for every 8 square meters of the roof wired to central terminal box
3. Insulation for minimize heat loss to Insulation design basis for the MS tanks: 1% delta T/day on the coldest day with max wind. The delta T is the difference between tank temperature and ambient temperature– insulation and electric heat tracing to be supplied and installed by tank vendor
4. Foundation heat barrier design to be based on minimum thermal loss necessary.

3.8 SCO2 POWER GENERATION SYSTEM

The sCO2 heat and mass balance is provided in Appendix F. The sCO2 system is described in a separate report to DOE.

3.9 BALANCE-OF-PLANT SYSTEM DESCRIPTIONS

3.9.1 Water Treatment Systems

3.9.1.1 Water Mass Balance

Refer to the Water Mass Balance Diagram 042839-WMB-0001 in Appendix D. The water mass balance characterizes the water usage on site and supports design of water and wastewater treatment equipment.

All water to the system will be obtained by well water. A small portion of the water will be drawn off as potable water and sent to the septic system. The remaining water enters the multimedia filters (MMF) where solids are removed. The backwash waste is sent to the wastewater sump.

The filter effluent is stored in the service/fire water tank. Service water is pumped to service water users, or in the event of a fire, can be pumped through the fire protection system. The service/fire water tank also provides makeup to the reverse osmosis (RO) system downstream.

The service water pumps will also be used to feed the Reverse Osmosis (RO) system. The RO feedwater first passes through cartridge filters that serve as the final filtration to remove suspended solids and protect RO membranes. The feedwater is then pumped through the double pass RO system with 75 percent recovery. RO product water is stored in the RO product water tank. A clean in place (CIP) skid is installed with the unit to allow for periodic cleaning. The waste and reject from the RO system is collected in the wastewater sump.

RO product water is pumped from the RO product water tank to mixed bed ion exchanger vessels which act as a “polishing” step to remove any remaining ionic impurities in the water. The mixed bed ion exchange unit will employ off-site regeneration.

Effluent from the mixed bed is demineralized quality water and is stored in the demineralized water storage tank. Demineralized water will be used for washing the heliostats. The wash water storage capacity will be designed for one cleaning every three months. The demineralized storage tank capacity will be 134,000 gallons. The water treatment system is sized for an output flowrate of 55 gpm.

3.9.1.1.1 Water Treatment

The raw water treatment system will treat raw water provided from local wells for use as service water, fire water, and supply to the Demineralized Water Production System.

The Raw Water Treatment System includes the following:

- Two (2) 50 percent capacity multimedia filters A/B.
- Two (2) 100 percent capacity MMF backwash pumps.

This system removes any solids in the well water. The MMF backwash pumps supply backwash water to filters to provide adequate cleaning of the filters.

The Demineralized Water Production System will produce demineralized water to provide high purity water for the heliostat cleaning. The demineralized water system will have a capacity to produce 55 gpm (daily) of demineralized water.

The RO Treatment System includes the following:

- Two (2) 50 percent capacity cartridge filters.
- Three (3) 50 percent RO booster pumps.
- Two (2) 50 percent capacity double pass RO trains.
- One (1) RO cleaning skid including one (1) solution tank with an immersion heater, one (1) pump, and one (1) RO cleaning cartridge filter.
- Two (2) 100 percent capacity RO antiscalant feed pumps.
- Two (2) 100 percent capacity RO sodium bisulfite feed pumps.
- Three (3) 50 percent capacity RO caustic feed pumps.
- All necessary piping, valves, and instrumentation required for operating the system.

Service water is directed to two 50 percent capacity cartridge filters to further reduce suspended solids. Antiscalant is fed to prevent scaling of the RO membranes. Sodium bisulfite is fed to remove free chlorine residual and protect the RO membranes from oxidation. Two double pass RO trains will be provided. Decarbonation of the feed water, which improves RO rejection and mixed bed polishing, is achieved by feeding caustic to the second pass RO feed water. The RO reject flow is directed to the water treatment area wastewater sump.

The Mixed Bed Ion Exchange System includes the following:

- One (1) RO permeate tank.
- Two (2) 100 percent Demineralizer Supply Pumps.
- Three (3) 50 percent Mixed Bed Exchangers.
- One (1) analyzer skid, consisting of one pH analyzer, one (1) conductivity analyzer, one (1) silica analyzer, one (1) sodium analyzer, and one (1) total organic carbon analyzer.

A fiberglass permeate tank is provided for RO product (permeate) water. The RO Product water tank allows for a control break point between the RO equipment and deionization equipment. The permeate water tank effluent is directed to the deionization units. The mixed bed ion exchangers remove remaining ions in the water. Analyzers will be used to confirm the water quality. The demineralized water is delivered to the demineralized water storage tank.

The Demineralized Water Storage and Supply System include the following:

- One (1) Demineralized Water Storage Tank.
- Two (2) 100 percent capacity Demineralized Water Transfer Pumps.

The demineralized water storage tank will receive demineralized water from the demineralized water production system. The demineralized water transfer pumps will take suction from the demineralized water storage tank and provide water, via a truck filling connection, for the heliostat cleaning.

3.9.1.1.2 Waste Treatment

The wastewater sump collects water from the multimedia filter backwash, RO reject, and all water treatment drains. This sump is rated to hold all waste for up to an hour resulting in a capacity of approximately 960 gallons.

The Wastewater Collection System includes the following:

- One (1) Common Wastewater Collection Sump.
- Two (2) 100 percent capacity Common Wastewater Sump Pumps.

Sanitary wastewater is directed to an on-site septic system.

The wastewater collection sump will serve as a central collection point for all Facility non-oily and non-chemical wastewaters including plant drains, cooling tower blowdown, and other miscellaneous drains.

The wastewater collection sump will be a below grade concrete structure with capacity as required for disposal at a rate that meets the requirements of the Facility Permit. Additionally, the sump will be sized such that any pump will cycle no more than three times per hour.

The wastewater collection sump will be equipped with two full-capacity submersible wastewater pumps. The wastewater discharge pumps will be controlled by sump level. The pumps will discharge to the evaporation pond.

The wastewater collection system will be designed and have adequate controls provided such that maximum discharge flows are not exceeded as stated in the Facility Permit under all operating and shutdown modes.

Equipment and instruments required for monitoring the effluent discharge as required by the Facility Permit will be provided.

3.9.2 Compressed Air

The Compressed Air System will be furnished to provide compressed air for instruments and controls, hose stations, air motor drives, and miscellaneous plant uses.

The compressed air system will consist of the following:

- Two (2) full capacity oil-free air compressors.
- One (1) full capacity service air receiver.
- Two (2) full capacity twin tower heat reactivated or heatless air dryers.
- One (1) full capacity instrument air receiver.
- Distribution piping, valves, instruments and accessories.
- PLC based control system.

The compressors will be sized for the maximum continuous service air and instrument air requirement of the Facility during startup and normal operation. Air receivers will be sized to be compatible with the load-unload cycle of the air compressors, and will also provide sufficient instrument air for safety shutdown requirement in case of Facility trip.

The service air system will furnish service air in quantities and at pressures required to ensure proper functioning of the Facility through all modes of plant operation. A station air header will be furnished around the turbine area with hose connections. Connections will be located near major equipment for maintenance.

Service air headers with hose connections at approximately 50 foot intervals will be provided in the following areas:

- Around the turbine area with risers on two sides.
- In the molten salt tank areas with risers on each of the four corners supplying headers at grade level and at each platform elevation.
- On the pipe rack platform and underneath the pipe rack.
- At the receiver 50 m elevation level.
- Near all major equipment.
- Along platforms and walkways.

The service air hose connections will be located in close proximity to the service water hose connections and the electrical convenience outlets. Each hose connection will be capable of being isolated by a flow limiting check valve as a safety device to prevent hose whip should an air hose rupture while in use. Hose connections will be provided with isolation valves and quick disconnect fittings. Hose connections will be 3/4 inch size.

Large service air supply headers will be fabricated of carbon steel. Miscellaneous air supply piping from air supply headers to services requiring clean air will be stainless steel.

The service air system will provide air to the instrument air system. The instrument air system will be furnished with two (2) full capacity instrument air dryer units to satisfy the ISA dry air requirements. Each unit will consist of twin tower heat reactivated or heatless air dryers with prefilter and after-filter. Controls will automatically alternate the dryer trains between their operating and regenerating cycles. Instrument air supply piping will be welded stainless steel. Provisions will be made to cutoff non-essential service air users on low system pressure.

Interconnecting piping and valves will be furnished such that any combination of air compressor, station air receiver, instrument air dryer, and instrument air receiver can be in service at any one time. Air loop distribution headers will be provided with isolating valves to permit isolation of selected areas of headers without loss of air to the entire loop. Air piping distributed to major areas within the project site will have isolation valves to isolate one area without taking the remaining areas out of service.

A complete factory installed programmable microcontroller based control system will be furnished for the compressors and dryers. The air compressors will be capable of being started, stopped, and monitored from the DCS.

3.9.3 Nitrogen System

A nitrogen supply system will be furnished to supply nitrogen gas for isolation to the Molten Salt system, for MS system purge and for receiver vessel pressurization.

The nitrogen supply system will consist of the following:

- Nitrogen storage tank.
- Nitrogen vaporizer.
- Interconnecting manifolds and pressure control stations.
- Distribution piping, valves, instruments and accessories.
- A concrete pad for the storage tank.
- An open frame roof structure over the storage tank area.

Liquid nitrogen will be stored in a pressurized and refrigerated tank. A conditioning system consisting of a vaporizer and any required compression system will be provided. The total storage volume of the tank will be capable of continuously replenishing the system loss for 10 days. The nitrogen supply system will be furnished with safety valves, pressure regulators, pressure indication and alarm devices, and flow control valves.

The concrete pads and piping arrangement will accommodate truck delivery of nitrogen for initial filling and make-up.

A sun shade open sided roof structure will be provided over the nitrogen storage system to protect the equipment from direct effects of sunlight and weather.

3.9.4 Carbon Dioxide System

A carbon dioxide supply system will be furnished to supply carbon dioxide gas to the sCO2 turbine.

The carbon dioxide supply system will consist of the following:

- Carbon dioxide storage tank.
- Carbon dioxide vaporizer.
- Interconnecting manifolds and pressure control stations.
- Distribution piping, valves, instruments and accessories.
- A concrete pad for storage tank.
- An open frame roof structure over the storage tank area.

Liquid carbon dioxide will be stored in a pressurized and refrigerated tank. A conditioning system consisting of a vaporizer and any required compression system will be provided. The total storage volume of the tank will be capable of continuously replenishing the system loss for 10 days. The carbon dioxide supply system will be furnished with safety valves, pressure regulators, pressure indication and alarm devices, and flow control valves.

The concrete pads and piping arrangement will accommodate truck delivery of carbon dioxide for initial filling and make-up.

A sun shade open sided roof structure will be provided over the carbon dioxide storage system to protect the equipment from direct effects of sunlight and weather.

3.9.5 Fire Protection

The primary function of the Fire Protection System is to provide fire suppression and detection throughout the power plant to support personnel safety and minimize equipment damage and outage duration for repairs.

The Fire Protection system will consist of the following:

- Water supply system.
- Fire mains.
- Area/Equipment Protection System.
- One 100 percent horizontal diesel driven main fire water pump.
- One 100 percent electric driven main fire water pump.
- One 100 percent main pressure maintenance pump.
- Fire pump controller with associated mechanical and electrical components.
- Fire water pump enclosure with associated heating and ventilation system along with an associated piping and instrumentation system for fire water pump testing (if required).
- Fire water recirculation line with flow meter for fire water pump testing.
- Full flow relief valve and supporting components.
- Interconnecting piping, valves, instrumentation, and accessories.

The Fire Protection System will provide fire suppression and detection systems throughout the plant except at the receiver level, to support personnel safety and minimize equipment damage and outage duration for repairs. The systems will be a combination of automatic and manual systems that provide alarm, detection, and suppression that are in accordance with local building code requirements, NFPA codes and standards, NFPA 850 and typical industrial engineering practices, as applicable.

The fire water supply system will be designed in accordance with NFPA 850 recommendations. Fire water supply system will be configured to ensure that no single failure or maintenance occurrence will keep the system from providing water to the plant fire protection system.

The fire protection water supply system will be designed to provide a minimum 2-hour supply for the demands described below but not less than 1,000 gpm:

- The largest fixed fire suppression system demand that could be expected to operate simultaneously during a single event (e.g. turbine bearings), plus a simultaneous hose stream demand of not less than 500 gpm.

A minimum of 120,000 gallons of storage capacity in the service/fire water tank, dedicated to fire water, is required.

To ensure the availability of the water, water level and temperature switches monitor the tanks and annunciate a trouble on the main fire alarm panel when necessary. The firewater connections will be below any service water connections to ensure a dedicated, retained, two hour volume of water for fire protection use.

The site fire mains are provided to supply fire protection water throughout the plant. The distribution piping system includes a loop(s) around the generation block as well as piping in the remote areas needing protection. The system supports the fire hydrants, hose stations, buildings and fixed water suppression systems, as required, in the event of fire.

The mains include a loop for the generation area as well as the remote areas. Sectional valves are furnished on the piping network for isolation purposes. The valves are located to minimize loss of protection to the protected areas due to a break or maintenance activity. The location of isolation valves also addresses the potential for a loss of both the automatic and manual suppression systems serving a given area. Sectional isolation valves are furnished with post indicators and tamper switches to provide visible conformation the valve remains open. Hydrants will include an isolation valves at each location for ease of repairs and maintenance. All shutoff valves will be electrically supervised using tamper switches.

The piping will be sized to supply the required fire water demands to any point in the yard with the most direct path of piping valved out of service.

A fire protection system will be furnished and include both automatic and manual features to provide alarm, detection, and suppression capability (if required). Design will be consistent with local building code requirements, NFPA guidance, and typical industrial engineering practices, as judged applicable.

Automatic fire suppression systems will be furnished for all buildings, structures, and specific hazards requiring such protection in accordance with NFPA requirements and the local code requirements. Protection of equipment and areas will include NFPA 850 recommendations. Additionally, specific hazards will be protected with automatic fire suppression systems, as noted below. The fire suppression systems will be designed in accordance with the more stringent of NFPA or local code requirements. General areas requiring protection are:

- Lube oil equipment areas.
- Oil-filled main, station service, and startup transformers (not meeting the separation or fire barrier recommendations in NFPA850).
- Fire pump rooms.
- Maintenance area/warehouse.
- Water Treatment.
- Electrical cable vaults.
- Facility Control Room.
- Electrical Equipment and Control Electrical Rooms.
- Turbine/generator bearings will be furnished with fire detection alarms and automatic fire spray system.

A complement of portable fire extinguishers rated for Class A and Class B fires will be furnished and located throughout the plant areas requiring manual suppression capability in accordance with local building code and NFPA 10 requirements. Additionally, portable CO_2 extinguishers should be located in areas containing sensitive electrical equipment, such as the main control room, DCS and the electrical switchgear rooms. Dry Chemical extinguishers are recommended for remaining areas.

An NFPA Class III standpipe system will be furnished, if required, for all buildings requiring such protection in accordance with the local building or fire code, NFPA recommendations, and standard industry practice. The system will include both 2-1/2 inch hose valve and 1-1/2 inch hose valve connections for occupant use. The 1-1/2 inch hose connections will be provided with a hose reel, complete with 100 feet of industrial grade fire hose and industrial fog nozzle. Hose racks or reels will be provided with a Class C electrical fog nozzle (non-brass) where required. Standpipes and hose stations will be furnished on main walkways of every floor, adjacent to elevator platforms, and adjacent to stair landings. Locations for fixed fire suppression system valve stations will be selected to meet code requirements and recommendations, including criteria for accessibility and protection from freezing and physical damage.

Detection systems are located in electrical equipment areas and other areas where required for suppression system actuation or areas where required by the building code. Detectors consist of smoke, linear, thermal, methane, and carbon monoxide and are designed in accordance with NFPA 72. Manual pull stations are provided in the hazardous areas for actuation of fire alarms and for manual actuation of preaction or deluge systems where applicable. The systems are supervised by the main fire alarm panel located in the control room.

The fire protection signaling system is provided to monitor the various fixed fire protection systems throughout the power plant and annunciates to the main fire alarm panel located in the main control room. The system includes local supervisory panels at strategic local locations to monitor, control, and annunciate all protection systems. The local panels are networked together to bring that information back to the main fire alarm panel in the control room. Local and remote audible fire and trouble alarms are provided as required by NPFA and local codes and standards.

3.9.6 Service Water

The Service Water Supply System will distribute service water at the required flows and pressures to various plant users, such as flushing, wash down, and other water users throughout the Plant.

The treated water with suitable quality as required by service water and fire water systems is stored in the service/fire water storage tank.

The Service Water Supply System will consist of the following major components:

- One (1) service/fire water storage basin/tank – approximately 125,000 gallons.
- Two (2) 100 percent capacity service water supply pumps.
- Interconnecting piping, valves, instrumentation and accessories.

Treated water from the raw water treatment plant will be stored in the service/fire water storage tank. The capacity of the tank will be adequate to meet all the service water consumption plus fire water minimum requirement for two hours.

The service water pumps will draw water from the service/fire water storage tank and supply it through service water header to various plant users for flushing, wash down, and other water uses throughout the Plant. The pumps will be provided with a minimum flow recirculation line discharging water back to the storage tank.

The Service Water Supply System will provide service water for the following Facility users (as a minimum):

- Supply to the Demineralized Water Production System.
- Fire protection water.
- Wastewater sump washdown.
- Pretreatment filter backwash.
- General facility use.

Service water headers with hose connections at approximately 50 feet intervals will be provided in the following areas (as a minimum) for washdown and housekeeping:

- Around the generation area and chemical storage area, at all operating floor and platform elevations.
- Chemical storage areas.
- Wastewater sump.
- On the pipe rack platform and underneath the pipe rack.
- Near all major materials and equipment.
- Along platforms and walkways.

Each service water drop for hose connections will be provided with minimum two (2) connections (tee-branch), same size as line drop, with associated isolation valves and hose connectors.

The service water hose connections will be located in close proximity to the service air hose connections and electrical convenience outlets.

Hose connections will 3/4 inch NPS provided with isolation valves and quick disconnect fittings.

All vent, drain, instrumentation, and hose connections will be furnished with a single ball valve for isolation.

3.10 MOLTEN SALT OPERATION

3.10.1 Operating Philosophy

The conceptual design is based on the ability to generate power at the design rate for 4 hours utilizing stored hot salt energy. The operational basis is to store solar energy in hot molten salt and then to use the stored energy to generate power.

3.10.2 Start-up and Shutdown

This section addresses the sequence for a normal starting of the power tower salt system to store energy in the hot salt tank. The shutdown sequence is for a normal stopping of the power tower salt system. The startup sequence for the primary heat exchanger to transfer the energy to the sCO2 power generation system is included.

Beginning Status:

- Facility has been in normal operation and has been normally shut down the previous day
- All salt is self-drained and drained to the appropriate salt tank.
- Cold storage tank at ~540 °C and normal high level.
- Hot storage tank at ~750 °C and normal low level.
- Salt tanks are allowed to cool down slightly during shutdown period.
  - Individual electric heating system for the hot and cold tanks is available for prolonged shutdowns.
- Salt piping and equipment at ~ 540 °C maintained as necessary by electric tracing system.
- Low pressure nitrogen blanket/purge is maintained in the receiver system.

Startup Sequence:

- The cold salt pump is lined up to recirculate to the cold tank using minimum flow circuit.
  - Flow is initiated by VFD control .
- Recirculation by minimum flow circuit to the cold tank continues, flow circuit for initiation of salt riser flow is lined up using the low cross over and the diversion line to return the salt flow to the cold tank and flow is established and increased sufficiently for the minimum flow circuit control to reduce and stop flow.
  - Circulation established by increasing pump speed by VFD control.
- Cold salt flow circuit is lined up to establish riser flow to the Receiver inlet vessel, flow through the high cross over circuit, flow through the down comer and diversion return to cold tank.
  - Circulation established by increasing pump speed by VFD control and closing the low cross over circuit.
  - Significant pump discharge pressure increase is required.
- This status continues as the cold salt flow rate increases to initial receiver flow conditions.
  - Status is maintained as ready to initiate flow through the receiver when the receiver is sufficiently heated by heat tracing (and solar energy as appropriate) to a temperature above the salt freezing temperature.
- The down comer circuit is lined up to the hot salt – cold salt continues to return to the cold salt tank.
- When receiver conditions are acceptable cold salt flow is initiated to the receiver and is returned to the cold tank.
  - During this step, the receiver vent valves are open to the receiver outlet vessel to assure nitrogen blanketing gas is removed from the receiver.
  - Receiver vent valve system is closed.
  - Level is maintained in receiver inlet vessel by controlling the nitrogen blanket pressure.

- As receiver and down comer salt temperature quickly increases the salt flow circuit to the hot salt storage tank and flow is established.
  - The flow circuit to the cold storage tank is closed.
- Receiver down comer temperature rises to and is maintained at 750 °C and design flow rates are established.
- Status remains constant as energy is stored in the hot storage tank.

Shutdown Sequence:

- Receiver solar energy is sharply reduced and eliminated.
  - The high cross over circuit is opened.
  - Receiver vent and drain system valves are opened.
  - Nitrogen blanket pressure in receiver inlet vessel is sharply reduced.
- Down comer temperature drops to 540 °C at a design ramp rate and cold salt flow rate is sharply reduced.
  - The diversion line circuit is opened and the circuit to the hot salt tank is closed.
- Cold salt pump is stopped and all drain system valves are opened
  - Self-drain status is achieved.
- Returned to original beginning status

Initiation of Salt to Primary Exchanger for Energy Recovery:

- The hot salt pump is lined up to recirculate to the hot tank using minimum flow circuit
  - Flow is established by VFD control.
  - Hot tank pump is lined up to the mixing chamber and the exchanger bypass is opened to the cold tank.
  - Cold salt flow is lined up to minimum flow circuit and to the mixing chamber circuit. Cold salt flow is initiated through the primary exchanger bypass back to the cold salt tank.
  - At this time the sCO2 system is to be warmed up and ready to initiate CO_2 flow through the primary exchanger at ~ 550 °C simultaneously with the initiation of molten salt flow.
  - Initiate hot salt flow to mixing chamber. Establish control of temperature of salt out of mix chamber to accommodate the exchanger temperature to initial salt temperature limits set by exchanger design.
  - Initiate salt flow through the primary exchanger.
  - Initiate sCO2 flow through the primary exchanger.
  - Close by pass circuit around primary exchangers. Rate of temperature change in the primary exchanger is the controlling parameter for ramping up the salt and CO_2 flow rates.

3.10.3 Issues/Concerns

Several issues such as emergency shutdowns, power outages and similar impacts on the operability of the systems have not been addressed.

Initial startup and maintenance issues such as how to warm up the salt tanks prior to bringing molten salt into the tanks and removal and replacement of the hot salt pumps and other tank equipment have not been addressed. Removal of MS valves, receiver tubes, and any other MS equipment will request attention to minimize ingress of moist air and to subsequently remove oxygen and moisture; procedures will need to be developed to satisfactorily restore the oxygen and moisture free atmosphere in the MS loop.

Acceptable ramp rates need to be established for the entire molten salt system. With the use of VDFs on pump drives and control valves, the current design should accommodate any reasonable ramp rates. However, the startup duration is currently unknown.

4.0 PERFORMANCE ASSESSMENT

4.1 GENERATION AND AUXILIARY LOADS

The plant generation and auxiliary loads are summarized below.

Table 4-1 Plant Generation and Auxiliary Loads

				CHARGING			DISCHARGING			
			VOLTAGE SERVING LOAD	IN-SERVICE	OPERATIN G FACTOR	OPERATIN G KW	IN-SERVIC E	OPERATI NG FACTOR	OPERATIN G KW	
Gross Power Generation	14902	kW				-			14,902.0	
Auxiliary Loads:										
Molten Salt Electrical Component	Load	Units								
Main sCO2 Compressor VFD	2,785	kW	4,160				x	100%	2,785.4	
Recycle sCO2 Compressor VFD	2,702	kW	4,160				x	100%	2,702.1	
sCO2 Start-up Heater	1,750	kW	4,160							
sCO2 Pre-Cooler Fan Cell A	40	HP	480				x	100%	33.1	
sCO2 Pre-Cooler Fan Cell B	40	HP	480				x	100%	33.1	
sCO2 Pre-Cooler Fan Cell C	40	HP	480				x	100%	33.1	
sCO2 Pre-Cooler Fan Cell D	40	HP	480				x	100%	33.1	
sCO2 Pre-Cooler Fan Cell E	40	HP	480				x	100%	33.1	
sCO2 Pre-Cooler Fan Cell F	40	HP	480				x	100%		

				CHARGING			DISCHARGING			
			VOLTAGE SERVING LOAD	IN-SERVICE	OPERATING FACTOR	OPERATING KW	IN-SERVICE	OPERATING FACTOR	OPERATING KW	
									33.1	
sCO2 Pre-Cooler Fan Cell G	40	HP	480				x	100%	33.1	
sCO2 Pre-Cooler Fan Cell H	40	HP	480				x	100%	33.1	
sCO2 Pre-Cooler Fan Cell I (spare)	40	HP	480							
MS Cold Tank Pump A (VFD)	300	kW	480?	x	100%	300.0				
MS Cold Tank Pump B (VFD) (backup)	300	kW	480?							
MS Hot Tank Pump A (VFD)	90	kW	480				x	100%	90.0	
MS Hot Tank Pump B (VFD) (backup)	90	kW	480							
MS Foundation MU Cooling Water Pump A	5	HP	480	x	5%	0.2	x	5%	0.2	
MS Foundation MU Cooling Water Pump B	5	HP	480	x	5%	0.2	x	5%	0.2	
MS Foundation MU Cooling Water Pump C	5	HP	480	x	5%	0.2	x	5%	0.2	
MS Foundation Fin Fan Cooler Fan A	1.5	HP	480	x	100%	0.1	x	100%	0.1	
MS Foundation Fin Fan Cooler Fan B	1.5	HP	480	x	100%	0.1	x	100%	0.1	
MS Melting Plant Supersack Feeder A	5	HP	480							

				CHARGING			DISCHARGING			
			VOLTAGE SERVING LOAD	IN-SERVICE	OPERATIN G FACTOR	OPERATIN G KW	IN-SERVIC E	OPERATI NG FACTOR	OPERATIN G KW	
MS Melting Plant Supersack Feeder B	5	HP	480							
MS Melting Plant Supersack Hoist A	20	HP	480							
MS Melting Plant Supersack Hoist B	20	HP	480							
MS Melting Plant Feed Bin Delumper A	10	HP	480							
MS Melting Plant Feed Bin Delumper B	10	HP	480							
MS Melting Plant Feed Bin Screw Feeder A	10	HP	480							
MS Melting Plant Feed Bin Screw Feeder B	10	HP	480							
MS Melting Plant Pipe Elevator A	25	HP	480							
MS Melting Plant Pipe Elevator B	25	HP	480							
MS Melting Plant Dosing Feeder A (VFD)	15	HP	480							
MS Melting Plant Dosing Feeder B (VFD)	15	HP	480							
MS Melting Plant Furnace Fan	200	HP	480							
MS Melting Plant Furnace Mixer	25	HP	480							
MS Melting Plant Furnace Immersion Heater		kW	480							

				CHARGING			DISCHARGING			
			VOLTAGE SERVING LOAD	IN-SERVICE	OPERATIN G FACTOR	OPERATIN G KW	IN-SERVIC E	OPERATI NG FACTOR	OPERATIN G KW	
MS Melting Plant Transfer Pump A	200	HP	480							
MS Melting Plant Transfer Pump B (backup)	200	HP	480							
Air Compressor A	125	HP	480	x	100%	103.6	x	100%	103.6	
Air Compressor B	125	HP	480							
Water Well Pump	5	HP	480	x	100%	4.1	x	100%	4.1	
Service Water Pump A	10	HP	480	x	50%	4.1	x	50%	4.1	
Service Water Pump B	10	HP	480	x	50%	4.1	x	50%	4.1	
RO Forwarding Pump A	2	HP	480	x	50%	0.8	x	50%	0.8	
RO Forwarding Pump B	2	HP	480	x	50%	0.8	x	50%	0.8	
RO Booster Pump A	5	HP	480	x	50%	2.1	x	50%	2.1	
RO Booster Pump B	5	HP	480	x	50%	2.1	x	50%	2.1	
RO Booster Pump C	5	HP	480	x	50%	2.1	x	50%	2.1	
RO Chemical Cleaning Pump A	5	HP	480	x	50%	2.1	x	50%	2.1	
RO Chemical Cleaning Pump B	5	HP	480	x	50%	2.1	x	50%	2.1	

				CHARGING			DISCHARGING			
			VOLTAGE SERVING LOAD	IN-SERVICE	OPERATIN G FACTOR	OPERATIN G KW	IN-SERVIC E	OPERATI NG FACTOR	OPERATIN G KW	
Caustic Feed Pump A	1/2	HP	120	x	50%	0.2	x	50%	0.2	
Caustic Feed Pump B	1/2	HP	120	x	50%	0.2	x	50%	0.2	
Caustic Feed Pump C	1/2	HP	120	x	50%	0.2	x	50%	0.2	
RO Antiscalant Pump A	1/2	HP	120	x	50%	0.2	x	50%	0.2	
RO Antiscalant Pump B	1/2	HP	120	x	50%	0.2	x	50%	0.2	
Sodium Bisulfite Feed Pump A	1/2	HP	120	x	50%	0.2	x	50%	0.2	
Sodium Bisulfite Feed Pump B	1/2	HP	120	x	50%	0.2	x	50%	0.2	
Demineralizer Supply Pump A	15	HP	480	x	50%	6.2	x	50%	6.2	
Demineralizer Supply Pump B	15	HP	480	x	50%	6.2	x	50%	6.2	
MMF Backwash Pump A	25	HP	480	x	50%	10.4	x	50%	10.4	
MMF Backwash Pump B	25	HP	480	x	50%	10.4	x	50%	10.4	
Waste Water Sump Pump A	5	HP	480	x	50%	2.1	x	50%	2.1	
Waste Water Sump Pump B	5	HP	480	x	50%	2.1	x	50%	2.1	
Fire Water Pump	35	HP	480							

				CHARGING			DISCHARGING			
			VOLTAGE SERVING LOAD	IN-SERVICE	OPERATIN G FACTOR	OPERATIN G KW	IN-SERVIC E	OPERATI NG FACTOR	OPERATIN G KW	
Fire Water Pressure Maintenance Pump	5	HP	480	x	100%	4.1	x	100%	4.1	
Demineralizer Water Pump A	5	HP	480	x	100%	4.1	x	100%	4.1	
Demineralizer Water Pump B	5	HP	480	x	100%	4.1	x	100%	4.1	
Potable Water Pump A	1	HP	480	x	100%	0.8	x	100%	0.8	
Potable Water Pump B	1	HP	480	x	100%	0.8	x	100%	0.8	
MS Heat Tracing Tracing (when MS operating)	747.862	kW	480	x	100%	747.9	x	100%	747.9	
MS Hot & Cold Tank Top Heat Tracing (24/7)	55.990	kW	480	x	100%	56.0	x	100%	56.0	
MS Hot Tank Imersion Heater (via pump)	140.780	kW	480							
MS Cold Tank Imersion Heater (via pump)	98.430	kW	480							
Closed Cycle Cooling Water (MS fndt cooling, etc.?)				x	100%	-	x	100%	-	
HVAC				x	100%	-	x	100%	-	
Lighting				x	100%	-	x	100%	-	
DCS				x	100%	-	x	100%	-	
Site Security				x	100%	-	x	100%	-	
Turbine Generator Loads	29.8	kW					x	100%	29.8	

				CHARGING			DISCHARGING			
			VOLTAGE SERVING LOAD	IN-SERVICE	OPERATING FACTOR	OPERATING KW	IN-SERVICE	OPERATING FACTOR	OPERATING KW	
Compressor Train Loads	11.0	kW					x	100%	11.0	
Battery Chargers (UPS)										
Solar Field Loads from Aux Power System?										
Tower Loads										
Others??										
Operating Aux Load		kW				1,493.1			7,076.5	
Aux Electric System Losses @ 2.5%		kW				37.3			176.9	
Electrical Power to GSU		kW							7,648.6	
GSU Losses @ 0.3%		kW				-			22.9	
Net Generation		**kW**				**(1,530.4)**			**7,625.7**	
Net Efficiency		%							31.8	

4.2 AREAS OF CONCERN

The sCO2 cycle efficiency including heat losses and pressure losses is below the SunShot target of 50 percent. Additionally, the heat exchanger approaches were increased to reduce heat exchanger costs.

The compressor loads are very significant as noted above. The compressors are motor driven in the conceptual design.

Several of the auxiliary loads, e.g. MS heater and trace heating loads may or may not be required depending on insulation trade-offs. The high heat tracing load suggests studies of the right amount of insulation given typical winter/summer dry bulb temperatures and wind velocities affecting heat losses.

5.0 Project Schedule

The Molten Salt project schedule is provided in Appendix G. It is a logically driven schedule, developed with conceptual design and preliminary vendor information.

The initial phase of the project will involve permitting with parallel ongoing R&D by DOE and others.

The permit phase assumes that an Application for Certification will not be required as the facility will be below the 50MW threshold in California. An Environmental Impact Report (EIR) will need to be submitted to the authority having jurisdiction (AHJ, or San Bernardino County, California, for the assumed site) for a non-BLM land site. Typically, a new EIR will take on the order of 6 months to prepare and will cover biological resources assessments, botanical surveys, cultural resource surveys, paleontological surveys, flood and drainage evaluations, air quality, water quality, traffic and transportation, reviews of glare and reflectance, farmland conversion studies as appropriate, project descriptions, etc. Typically, it takes on the order of 12 months for County EIR approval, including public hearings and County Board approval. Until the EIR is approved, any parallel work is at risk in case the EIR is not approved. Typically, Limited Notice to Proceed (LNTP) starts around the time that the EIR is approved.

The LNTP will initiate preparation of the work needed to obtain critical permits and to start early design work for critical path equipment. In California, the EIR approval includes numerous Conditions of Approval (COAs) and Mitigation Measures (MMs). A MM binder addressing all MMs and COAs needs to be prepared prior to obtain building permit approvals for any construction drawings. The earliest construction drawings will relate to site access roads, erosion control, grading and drainage. Upon LNTP, a detailed hydrology study is normally initiated along with the work needed to generate the grading plans. The schedule assumes that the hydrology study will be completed in 2 months after LNTP, and that grading plans will be complete with retention basins defined, roads detailed, perimeter fencing detailed, and grading detailed for the entire site area, within 4 months after LNTP. The schedule assumes that the AHJ will approve the grading plans within 2 months. If there are difficulties with other permits, e.g. if there are streambed alterations, existing State Waters impacts, etc., the approval durations may increase by several months. As a condition for approval of the critical grading and drainage permit, a Storm Water Pollution Prevention Plan (SWPPP) must be prepared and approved. There are numerous other potential permits to obtain (e.g. encroachment permits, FAA permits, etc.) which will depend upon the site details. It has been assumed that those permits will be obtained in the 6-month period allocated to obtain the critical grading and drainage permit. That permit is critical to start construction and is commonly a pre-requisite for construction contractor site mobilization. (Some Counties in California take significantly longer than the durations listed above.)

The intent of the LNTP will also be to initiate design activities for long lead procurement items. In this case, the sCO2 turbine generator/compressor package is on the critical path. It has been assumed that a specification will be prepared and issued for bid at the start of the of the LNTP period to allow the selected supplier to undertake necessary engineering and procurement activities. It has been assumed that the turbine generator/compressor (TGC) supplier will only execute contracts for material orders at Full Notice to Proceed (FNTP) to minimize financial risk to the new concentrated solar power 'Facility' owners.

After LNTP, the project developer/owner will need to buy easements for the land for the project. Depending on the number of landowners, this can be a difficult and intense effort.
Financing activities have been assumed to take approximately 3 months, assuming a project financing approach with third party debt. Typically, developers seek project financing before FNTP. It has been assumed that all necessary R&D to satisfy lenders will be completed to satisfy financing parties by FNTP.

The schedule assumes FNTP will be given to the Contractor to complete detailed design and development of specifications of equipment and construction. An exception, as noted earlier, to developing equipment specifications after NTP is the specification for the turbine generator and CO_2 compressors; this specification is assumed to be developed during the Preliminary Engineering phase, due to long fabrication and delivery time as the entire series of activities for the turbine generator and the CO_2 compressors, from award to installation, are the longest (critical) path for the project.

Mobilization for Construction would happen at the same time as FNTP and commence with earthwork and foundation work. The entire construction duration is approximately 27 months to Mechanical Completion, followed by Startup/ Commissioning and Performance Testing.

The entire schedule has the following assumptions and qualifications:

- Based on a 5 day work week schedule with union labor.
- Equipment fabrication and delivery times given by the vendors on a conceptual design, i.e. subject to change.
- Construction durations and sequence predicated on conceptual design philosophy.
- All required permits, except building permits, will be approved on or before the Full Notice to Proceed date.

Engineering drawings and calculations will be submitted to the AHJ for building permit approval before any construction drawing can be used for construction. In California, a copy of the approved drawings will be given to discipline County inspectors who will monitor constructor per those drawings. (Significant engineering changes during the construction phase may require additional building permit approvals.)

The sequence of design, procurement, construction and commissioning is broken down by major equipment in the Level 2 schedule attached in Appendix G. For construction, a Level 3 schedule with several thousand activities is normally prepared and used to administer the project.

6.0 Capital Cost Estimate

6.1 GENERAL ASSUMPTIONS

6.1.1 Electrical Assumptions and Clarifications

- Grounding: Site area has a #4/0 bare copper cable ground grid in the power block facility which will have ground cable extensions from all electrical equipment, buildings and steel members interconnected to the main ground grid system.
- Grounding: #2/0 Insulated Copper cable extensions from all electrical equipment, buildings and steel members interconnected to the main Ground grid system are a average length of 25 foot.
- All Underground direct duct banks have a #2/0 bare ground cable installed and routed in the trench and connected at each end to the ground grid and structure where the trenching begins or ends.
- Miscellaneous lighting hardware, labor, and trenching.
- Control cables for the facility are accumulated in a line item for each site.
- All major electrical equipment quantities were accounted for in this estimate from the engineered one-line and the equipment load list. The majority of this equipment will be located inside the Power Distribution Center (PDC) enclosure building.
- The power distribution center building will be 55 foot x 20 foot split in 2 sections, and installed on site. The power distribution center building will be elevated above grade on steel members. Cable trays will be installed on the underside of power distribution center building to feed the power, control and instrument cables from site to the power distribution center building electrical equipment.
- The site area includes a cable tray system that will be installed for power, controls and instrumentation cables and routed on the site steel racks to tie the facility buildings and site equipment together for routing the required equipment electrical cables back to the PDC Building.
- The heat trace system bulk material items were taken from an engineered list indicating approximate quantities. Heat trace circuits are to be installed on site.
- Power cables to the heat trace control panels are routed and installed are included in this estimate. Cables for the heat trace panel loads were made from average lengths of 200 linear feet from each of the power distribution center building to the heat trace control panels.
- From the 480 SUS 2000A Switchgear, 8 - 400A, 3ph, outdoor rated power panels were added to the estimate to provide power in the field for power to the small motor loads as noted on the motor load list. Cables for the motor loads were made from average lengths of 100 linear feet from each of the power panels.
- Cable quantities were accrued by using the Equipment Load List. Cable quantities were based on average lengths of 200' from the power distribution center building to the 400A field power panels.

6.1.2 Civil/ Structural Assumptions and Clarifications

- The descriptive technical portion of the assumptions and clarifications are as given in Section 3.4 above.
- Cost for excavation and backfill is based on on-site disposal, with no haul off required.
- Costs for building enclosure are based on historical averages, and the scope of this effort did not include a study of state and local codes that might have impact.
- Costs for steel and concrete commodities are based on historical averages and do not include additional "design allowances", and only "neat" as designed commodities were considered.
- Steel costs are based on full shop coated hot dipped galvanized pricing.

6.1.3 Mechanical Assumptions and Clarifications

- Pipe quantities were provided in BOQs from the design engineers.
- Man-hours for the pipe were based on typical California Union estimates.
- Pricing was solicited for the Haynes 230 pipe, with 100 percent NDE testing on the entire pipe.
- Equipment was estimated based on PFDs and the GAs.
- Equipment man-hours were based on Black & Veatch standard rates.

6.1.5 I&C Qualifications and Clarification

- PFD BOQs were supplied by engineering.
- Hand stations for motor operation from the MCC at local locations.
- For process tubing, 40 linear feet is used for single users.
- Indicating devices are assumed mounted remote from process pipe.

6.1.4 CMCI Clarifications

- Role: CMCI included as management only.
- Base: 50-hr work week.
- Mobilization date: March 2018 (as per schedule and subject to change)
- Site security including security staff, guard houses, fence modifications, etc. is included.
- Environmental, Health and Safety Management is included.

6.2 COST ESTIMATE QUALIFICATIONS

The following are cost estimate clarifications and qualifications:

- The cost estimate is based upon the conceptual siting in Barstow, CA.
- Contingency is not included in cost estimate.
- The cost estimate contains no escalation.
- Insurance is not included in cost.
- The cost estimate does not include any profit margins.
- The subcontractor's markup has been included.
- The cost estimate does not contain any taxes.
- The cost estimate includes freight.

6.3 ORDERS OF MAGNITUDE COST ESTIMATE

Black & Veatch's judgment is that total costs are accurate to +/- 30%. Some cost reductions are possible, e.g. by reducing hottest sCO2 piping lengths, while other costs may rise, e.g. heliostat costs. Generally, Black & Veatch has used the lowest costs obtained if multiple suppliers provided quotes. Some costs are based on a single supplier quote and may therefore be high.

DESCRIPTION	LABOR TOTAL	MATERIAL TOTAL	SUB CONTRACT	CONSTRUCTION EQUIPMENT	TOTAL
Civil/Structural					
Site Work	$525,000	$224,000	$346,000	$0	$1,905,000
Foundations & Concrete	$802,000	$829,000	$1,531,000	$0	$3,162,000
Buildings	$0	$0	$1,815,000	$0	$1,815,000
Steel	$396,000	$677,000	$0	$0	$1,073,000
Mechanical					
Process & Mechanical Equipment	$1,214,000	$19,914,000	$37,171,000	$0	$58,299,000
Piping & Piping Specials	$2,054,000	$10,883,000	$250,000	$0	$13,187,000
Electrical & Control					
Electrical Equipment	$189,000	$5,515,000	$0	$0	$5,704,000
Electrical Bulks	$6,928,000	$4,118,000	$3,000	$0	$11,049,000
Instrument Equipment	$213,000	$1,010,000	$1,000	$0	$1,223,000
Instrument Bulks	$253,000	$134,000	$0	$23,000	$410,000
Insulation	$24,000	$693,000	$0	$0	$717,000
Solar					
Heliostats	$0	$0	$9,504,000	$0	$9,504,000
sCO2 Piping and Piping Specials	$1,019,000	$17,461,000	$0	$0	$18,480,000
sCo2 Mechanical Equipment	$681,000	$20,039,000	$0	$0	$20,720,000
Construction Management	$2,278,000	$930,000	$0	$0	$3,208,000
Construction	$0	$42,000	$0	$276,000	$318,000

DESCRIPTION	LABOR TOTAL	MATERIAL TOTAL	SUB CONTRACT	CONSTRUCTION EQUIPMENT	TOTAL
Indirects					
Head Office & Engineering Services	$4,410,000	$0	$0	$0	$4,410,000
CM Labor Burden	$912,000	$0	$0	$0	$912,000
US Payroll Burden	$3,108,000	$0	$0	$0	$3,108,000
Procurement Burden	$424,000	$0	$0	$0	$424,000
Subcontractor Markup	$15,882,000	$0	$0	$0	$15,882,000
				Total	**$174,700,000**

7.0 O&M Cost Estimate

The annual O&M costs for a new facility consist of the following elements:

- Fixed O&M costs. These consist of labor costs, routine maintenance and other annual recurring expenses, with the principal cost being permanent O&M staff.
- Variable costs. These include costs for outage maintenance, parts and materials, chemicals (water treatment chemicals, CO2, N2, etc.) and specialized equipment costs (mobile equipment).

The following assumptions were considered in developing the O&M Cost estimate provided below:

- Facility will operate 24 hours a day, 7 days a week, 365 days a year.
- Variable maintenance is estimate as a percentage of capital cost for each asset. The applied percent of capital was as such;
  - Convention Assets is 2 percent.
  - First-of-Kind Assets is 4 percent.
- Material Damage, Breakdown, and Business Interruption insurance costs based on equipment purchase and installation costs.
- Labor rates based on estimated labor rates defined by the Daggett, CA area.

7.1 OPERATION ORGANIZATION

O&M staff requirements were estimated to be higher than a generating facility of proven technologies. The O&M staff requirements for the 10MWe facility have been assumed to include the following:

- Administration.
  - Plant Manager. Will work 1 shift per day, 5 days per week and be on call. Responsible for reporting financials back to accounting staff in the Facility owner's home office, will approve work orders, etc., besides being responsible for all site staff.
  - Administrative Assistant. There will be 1 person, 1 shift per day, 5 days a week.
- Operations.
  - As noted above, the Plant Manager will double as Operations Supervisor.
  - Control Room Operators. There will be 2 per shift, covering 4 shifts per day, 24 hours a day and 7 days a week.
  - Field Operator. There will be 1 person, 1 shift per day, 5 days a week.
  - Mirror Wash Operator. There will be 1 operator, 1 shift per day, 5 days a week.
  - Water Treatment Operator. Control Room Operators will coordinate with Field Operator for operation of Water Treatment.
  - Security Guards. There will be 1 per shift, 5 shifts per day, 7 days a week.
- Maintenance.
  - Maintenance Manager. Maintenance manager will be responsible for daily approval of work orders, and will report to the Plant Manager regarding ongoing maintenance activities. The Maintenance manager will also double as Warehouse Supervisor.

- Maintenance Planner. There will be 1 per shift, 1 shift per day, 5 days a week.
- Mechanics. There will be 2 per shift, 1 shift per day, 5 days a week.
- Electricians. Electricians will be cross-trained to double as I&C technicians. There will be 1 per shift, 1 shift per day, 5 days a week.
- Welders. There will be 2 per shift, 1 shift per day, 5 days a week for replacement of tube sections. Welders are assumed to be night shift only.
- General Technologist. There will be 1 per shift, 1 shift per day, 5 days a week.

- Technical Services.
  - EH&S Services Manager. There will be 1 environmental health and safety manager per shift, 1 shift per day, 5 days a week.
  - Engineers. There will be 1 engineer available, 1 shift per day, 5 days a week. Additional engineering support is assumed to be provided through the head office engineering support.
  - Chemist. There will be 1 per shift, 1 shift per day, 5 days a week.
  - Controls/Data Acquisition/Heliostat Field Tech. There will be 1 per shift. 1 Per day. 5 days a week.

Table 7-1 Site Labor Estimate

RESPONSIBILITY	PER SHIFT	SHIFTS	TOTAL	ANNUAL BASE WAGES	TOTAL LOADED ANNUAL EXPENSE
Operations					
Shift Supervisor	1	1	1	$97,000	$140,000
Plant Operator	2	4	8	$76,000	$900,000
Field Operator	1	1	1	$49,000	$80,000
Mirror Wash Operators	1	1	1	$49,000	$80,000
Security Guards	1	5	5	$32,000	$230,000
				Operations Sub-Total	**$1,430,000**
Maintenance					
Maintenance Manager	1	1	1	$122,000	$180,000
Maintenance Planner	1	1	1	$89,000	$130,000
Mechanics	2	1	2	$72,000	$220,000
Electricians	1	1	1	$72,000	$110,000
Welder	2	1	2	$64,000	$190,000
General Technologist	1	1	1	$58,000	$90,000
				Maintenance Sub-Total	**$920,000**
Technical Services					
EH&S Services Mgr	1	1	1	$106,000	$150,000
Engineer	1	1	1	$81,000	$120,000

Chemist	1	1	1	$81,000	$120,000
Controls/Data Acquisition/Heliostat Field Tech	1	1	1	$106,000	$150,000
				Technical Services Sub-Total	**$540,000**
Administration					
Plant Manager	1	1	1	$145,000	$210,000
Admin. Asst.	1	1	1	$48,000	$70,000
				Administration Sub-Total	**$280,000**
				Total Cost	**$3,170,000**

7.2 O&M COST ESTIMATE

Fixed and Variable O&M cost estimate is provided below per $1000USD, and includes Site Specific labor and training, general site purchases, standard and outage maintenance, and insurance costs.

Table 7-2 Annual Fixed O&M Estimate

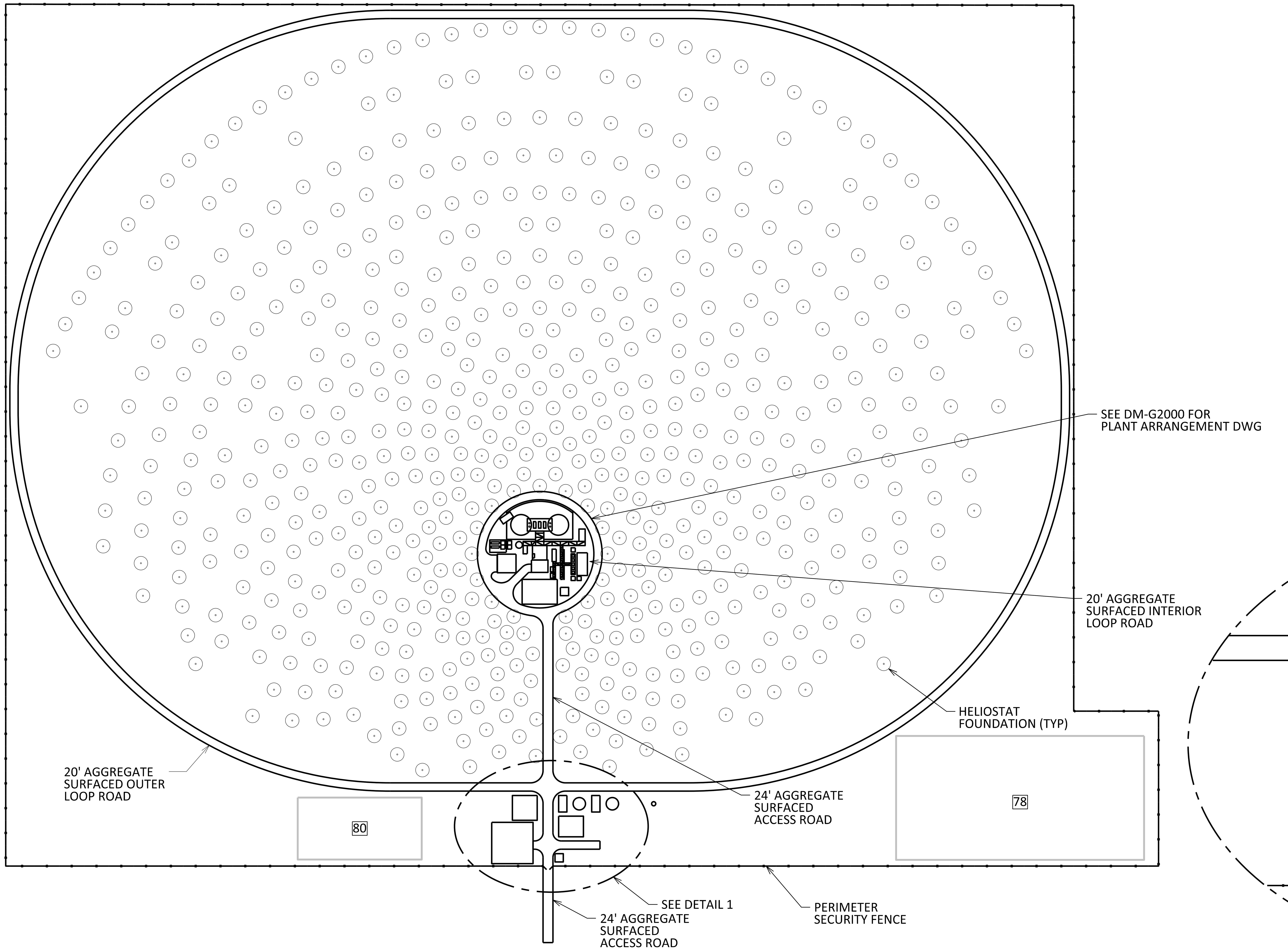
ANNUAL FIXED O&M COSTS	USD/1000
Site Labor	$3,170
Site Specific Training	$40
General Site Purchases	$250
Insurance	$1,090
Total	**$4,550**

Table 7-3 Annual Fixed O&M Estimate

ANNUAL VARIABLE O&M COSTS	USD/1000
Maintenance	$3,650
Total	**$3,650**

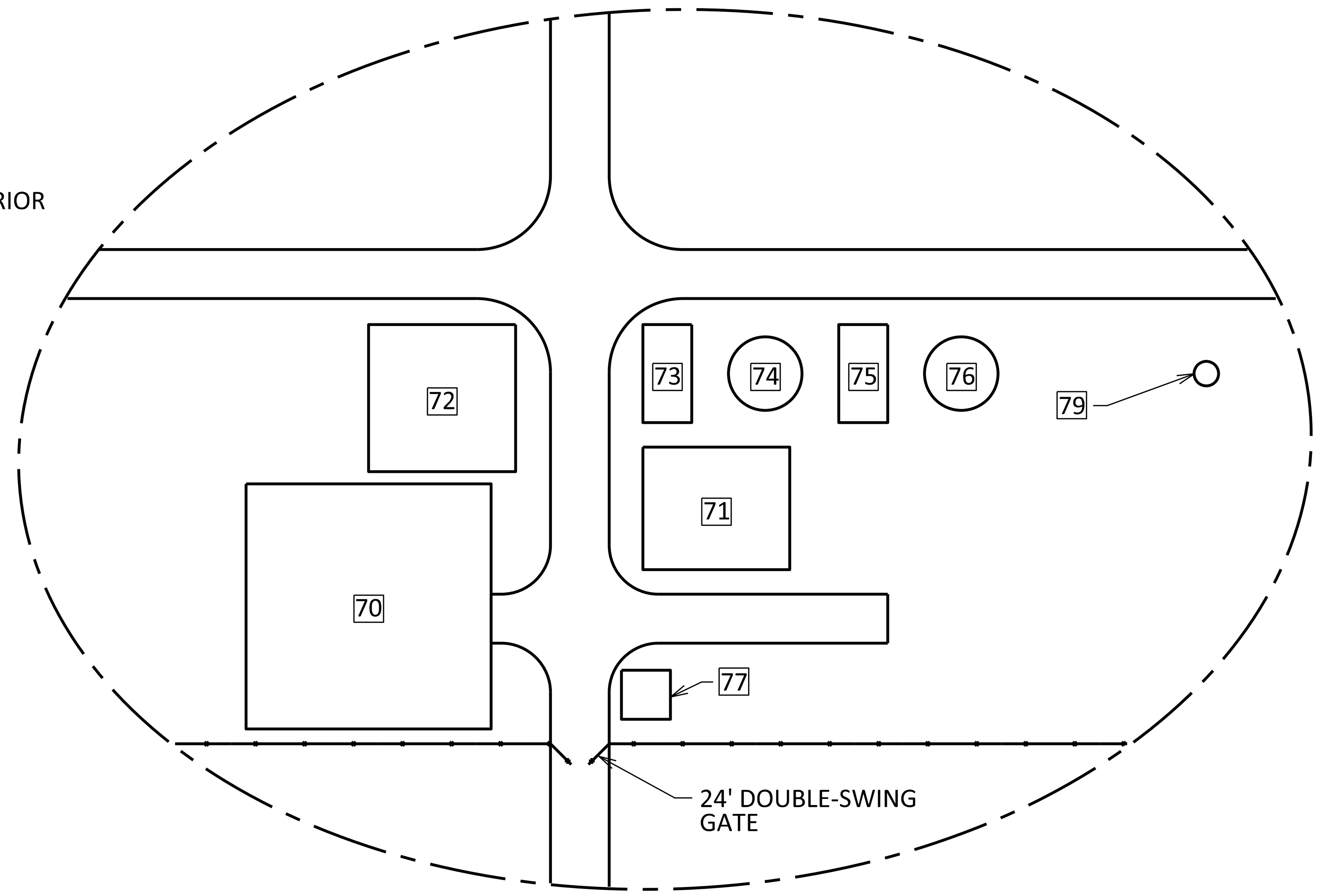
Appendix A. Site Arrangement

EQUIPMENT IDENTIFICATION LIST	
ID	MOLTEN SALT
70	HELIOSTAT ASSEMBLY BUILDING (100' X 100')
71	WATER TREATMENT BUILDING (50' X 60')
72	HELIOSTAT ASSEMBLY AREA (60' X 60')
73	DEMIN PUMP SKID AND SUNSHADE (20' X 40')
74	DEMIN TANK (30Ø)
75	SERVICE/FIRE WATER PUMP SKID AND SUNSHADE (20' X 40')
76	SERVICE/FIRE WATER TANK (30Ø)
77	SECURITY GATE HOUSE (20' X 20')
78	EVAPORATION POND (300' X 600')
79	TERMINAL 33kV RISER POLE
80	STORM WATER DETENTION AREA



MOLTEN SALT SITE ARRANGEMENT

SCALE: 1"=150'



DETAIL 1

SCALE: 1"=50'

150' 75' 0 150' 300'

1"=150'

N

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B	13/JUN/16	ISSUED FOR CLIENT REVIEW	MJP	MJP		JRB	
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DOE SUNSHOT

MOLTEN SALT
SITE ARRANGEMENT

PROJECT | DRAWING NUMBER 042839-DM-G1000 | REV C

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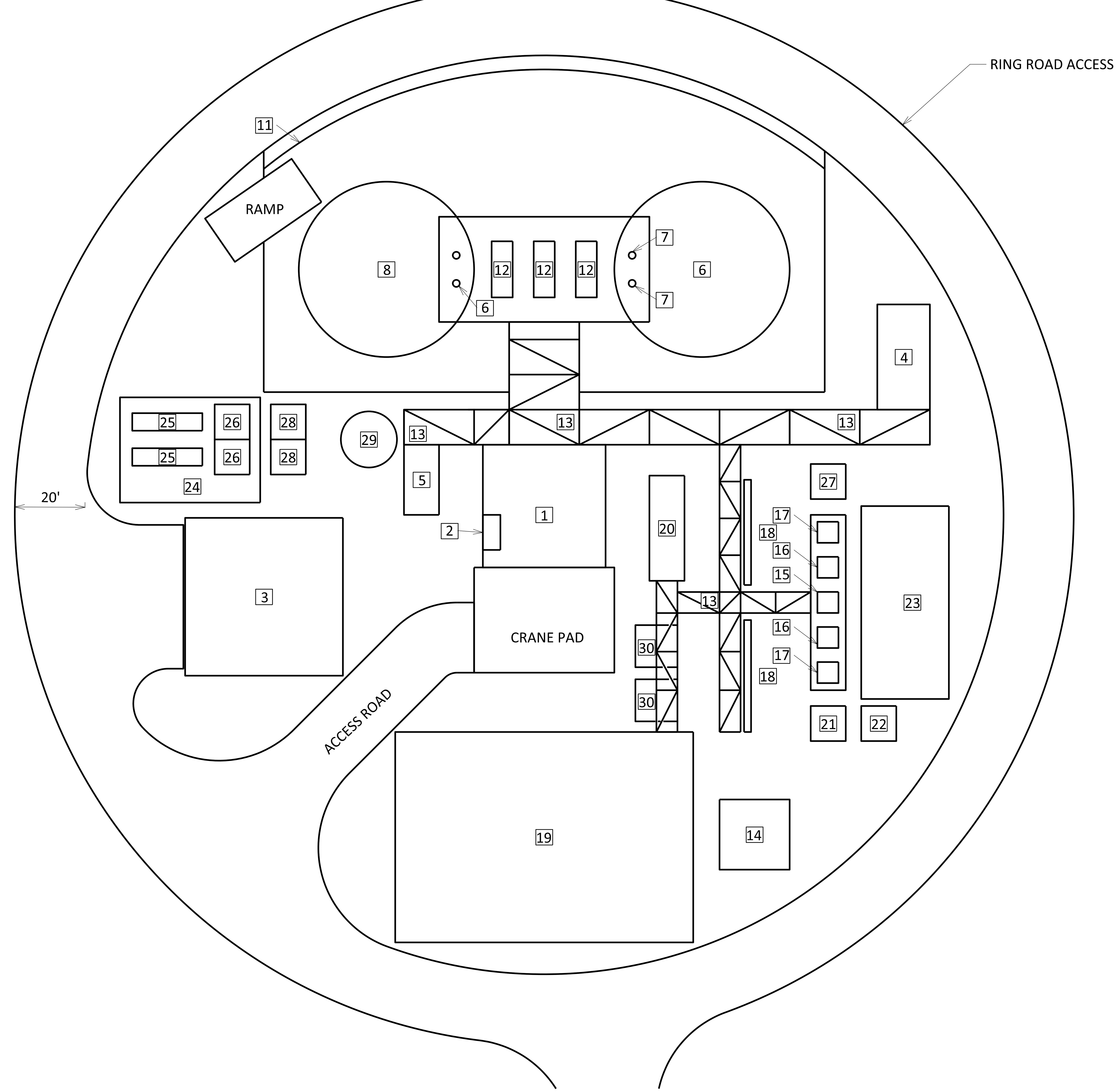
Appendix B. Plant Arrangement

ID	EQUIPMENT IDENTIFICATION LIST (MS MOLTEN SALT)
1	CONCENTRATED SOLAR POWER TOWER
2	ELEVATOR
3	ADMINISTRATION/CONTROL BUILDING
4	COMPRESSED AIR EQUIPMENT
5	NITROGEN STORAGE
6	MS HOT TANK
7	MS HOT PUMPS
8	MS COLD TANK
9	MS COLD PUMPS
10	NOT USED
11	MS CONTAINMENT BERM
12	MS/SCO2 HEAT EXCHANGERS
13	PIPE RACK
14	CO2 STORAGE
15	SCO2 TURBINE
16	SCO2 GEAR
17	SCO2 GENERATOR
18	SC02 RECOUPERATORS
19	SC02 PRECOOLER
20	SC02 COMPRESSORS
21	GENERATOR STEP UP TRANSFORMER 1
22	AUXILIARY TRANSFORMER
23	POWER DISTRIBUTION
24	MS MELTING BUILDING
25	MS BAG CONVEYOR
26	MS FILLING BAG BIN/DELUMPER
27	GENERATOR STEP UP TRANSFORMER 2
28	MS DOSING BIN
29	MS MELTING FURNACE
30	SC02 COMPRESSOR VFD



MOLTEN SALT PLANT ARRANGEMENT

SCALE: 1"=20'

20' 10' 0 20' 40'
1"=20'

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MOLTEN SALT
PLANT ARRANGEMENT

PROJECT DRAWING NUMBER 042839-DM-G2000 | REV C

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Appendix C. Process Flow Diagrams

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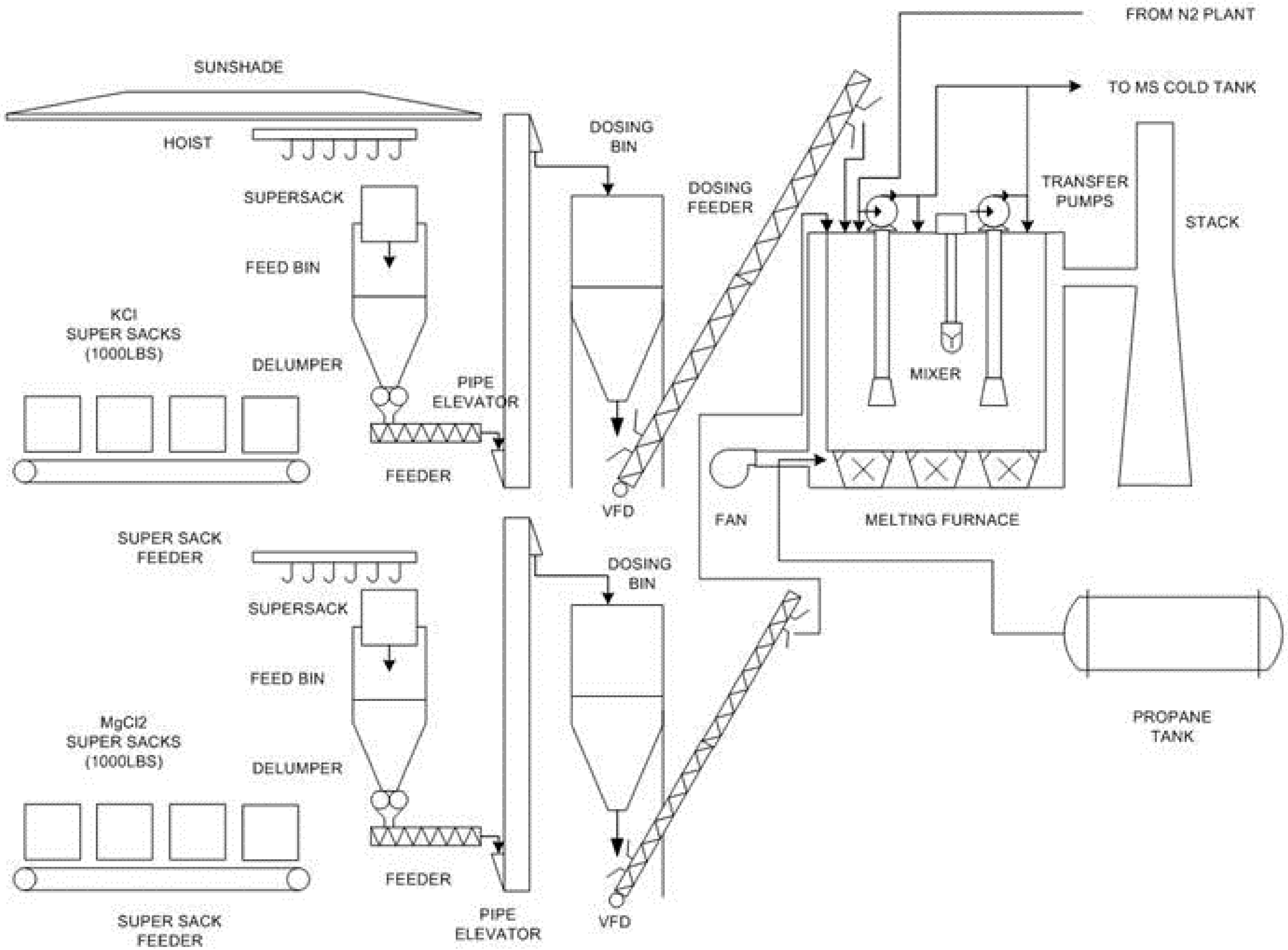

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MOLTEN SALT

PROCESS FLOW DIAGRAM
MOLTEN SALT MELTING PLANT

PROJECT 042839 DRAWING NUMBER DM-M2025 REV B

CODE

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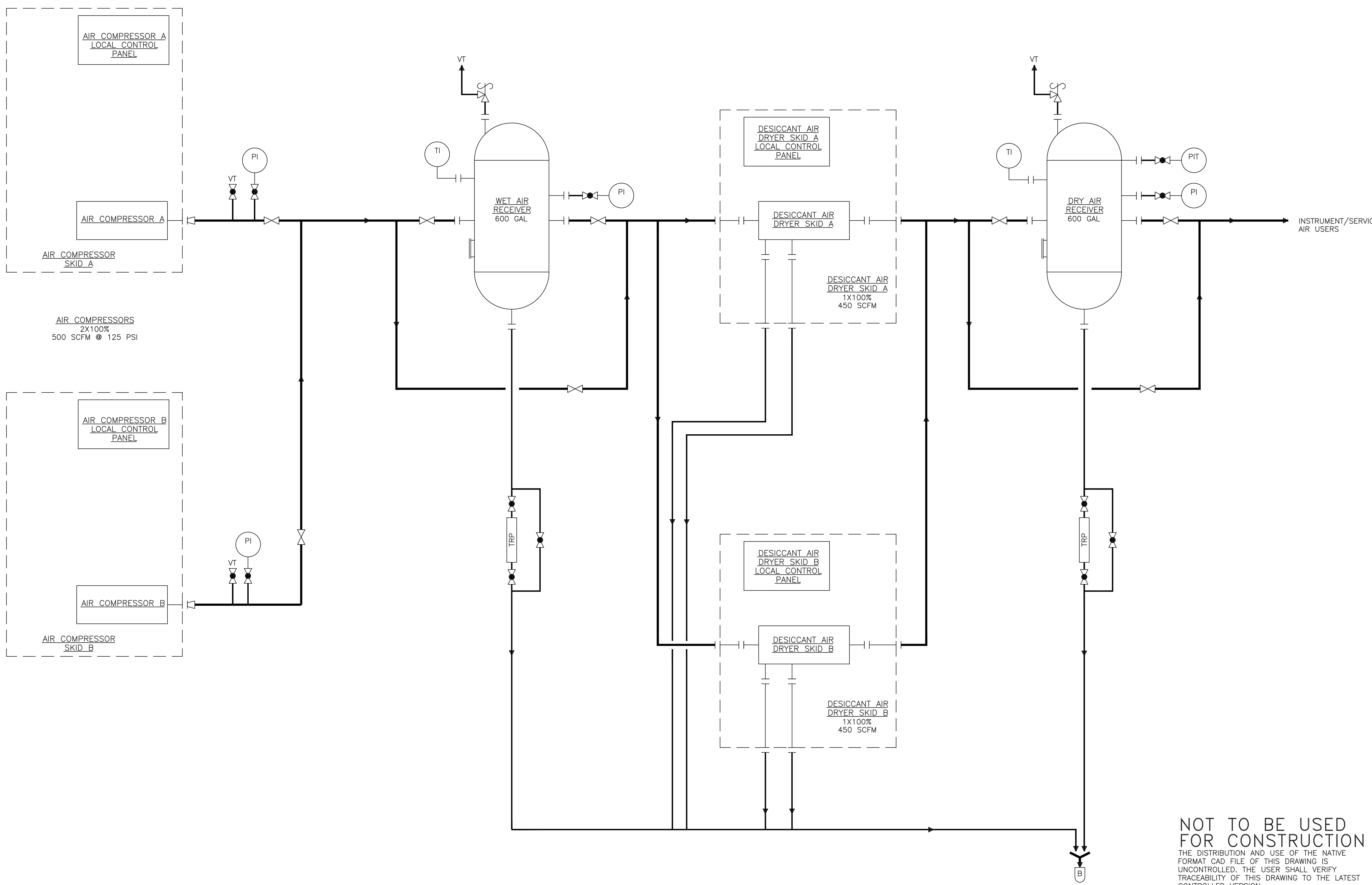

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DOE SUNSHOT
MOLTEN SALT

PROCESS FLOW DIAGRAM
COMPRESSED AIR

PROJECT | DRAWING NUMBER | REV
042839-DM-M2181 | B

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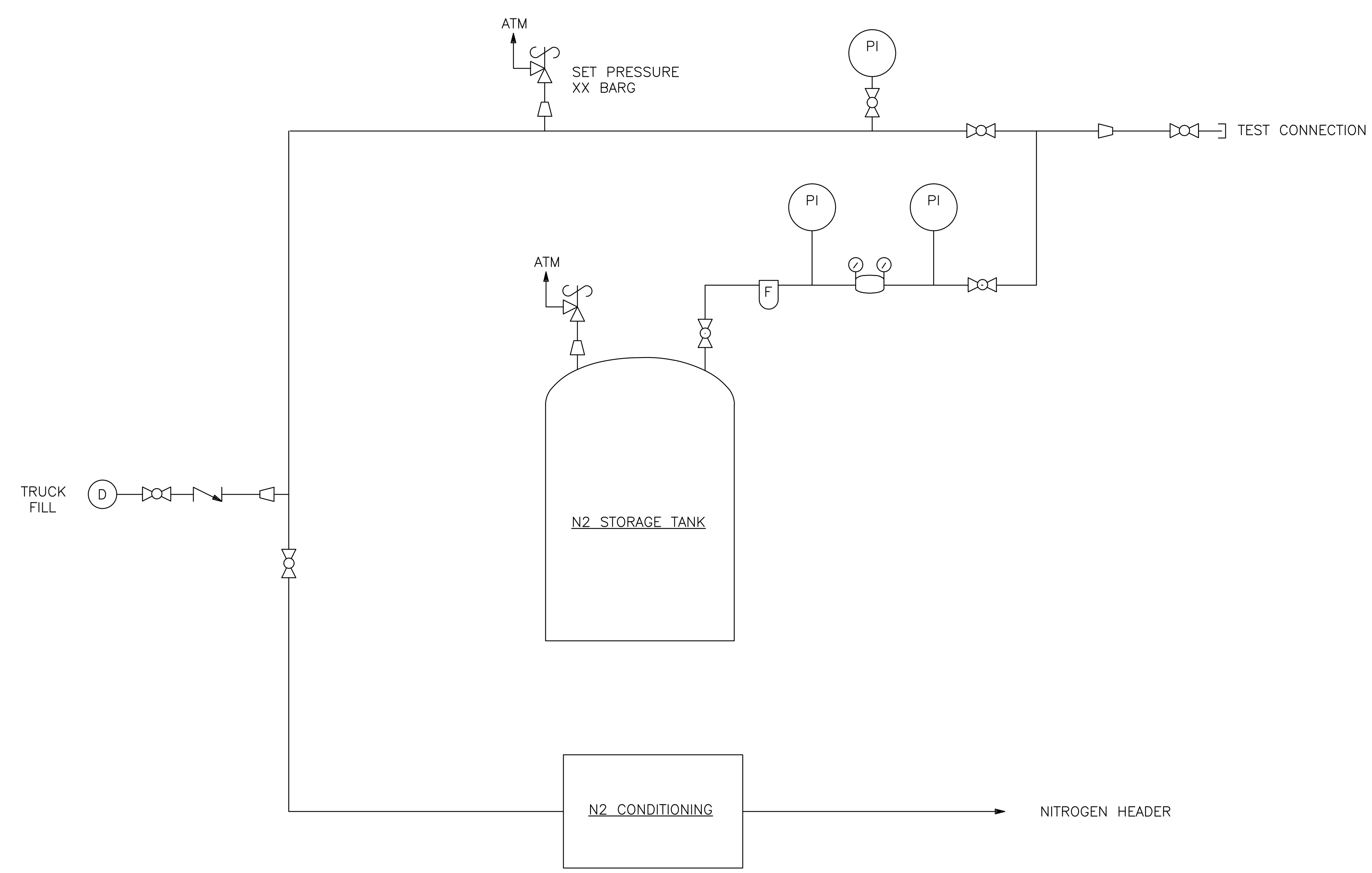

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MOLTEN SALT

PROCESS FLOW DIAGRAM
NITROGEN STORAGE & SUPPLY

PROJECT DRAWING NUMBER REV

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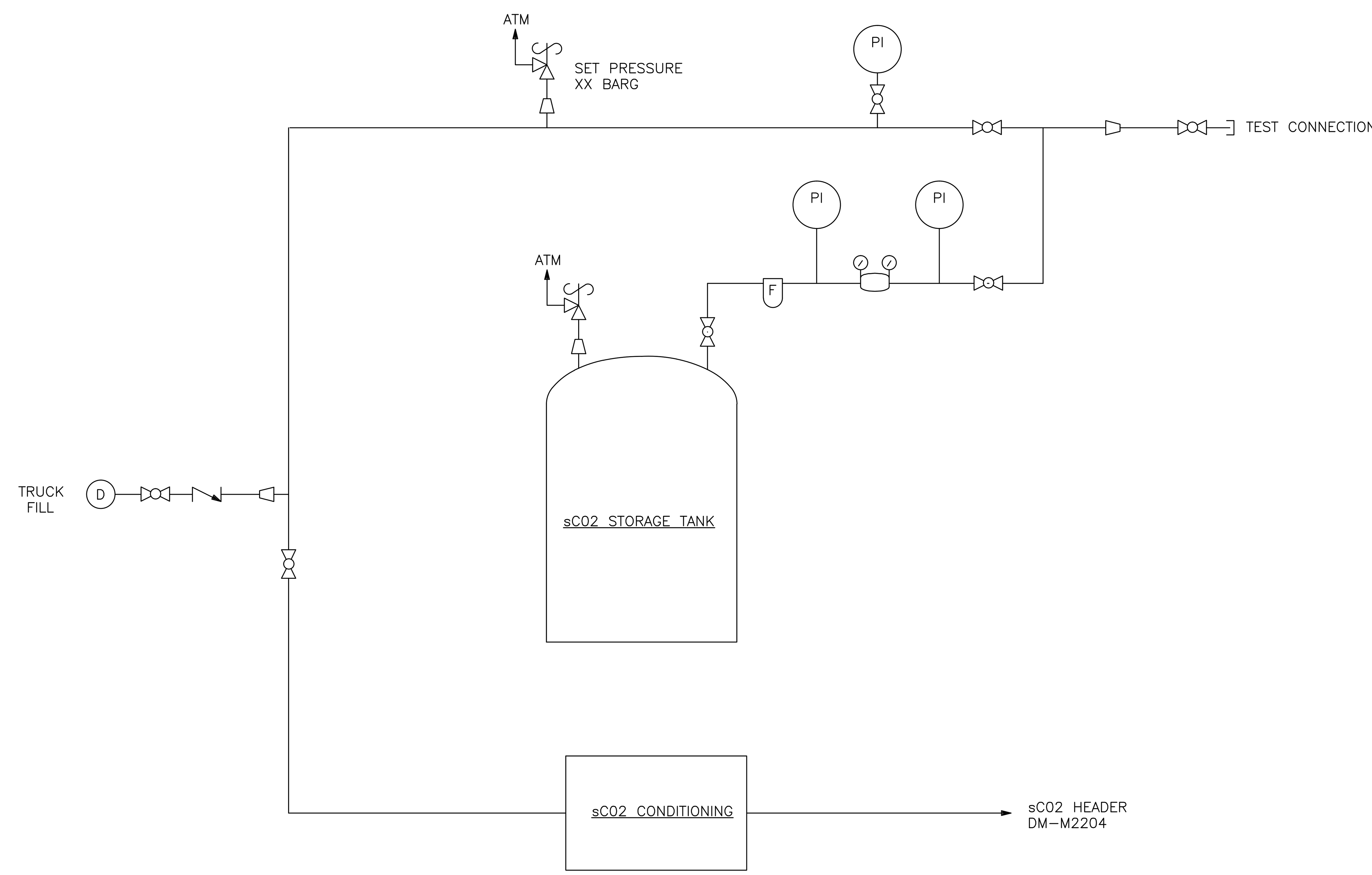

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DOE SUNSHOT
MOLTEN SALT

PROCESS FLOW DIAGRAM
sC02 STORAGE & SUPPLY

PROJECT DRAWING NUMBER REV

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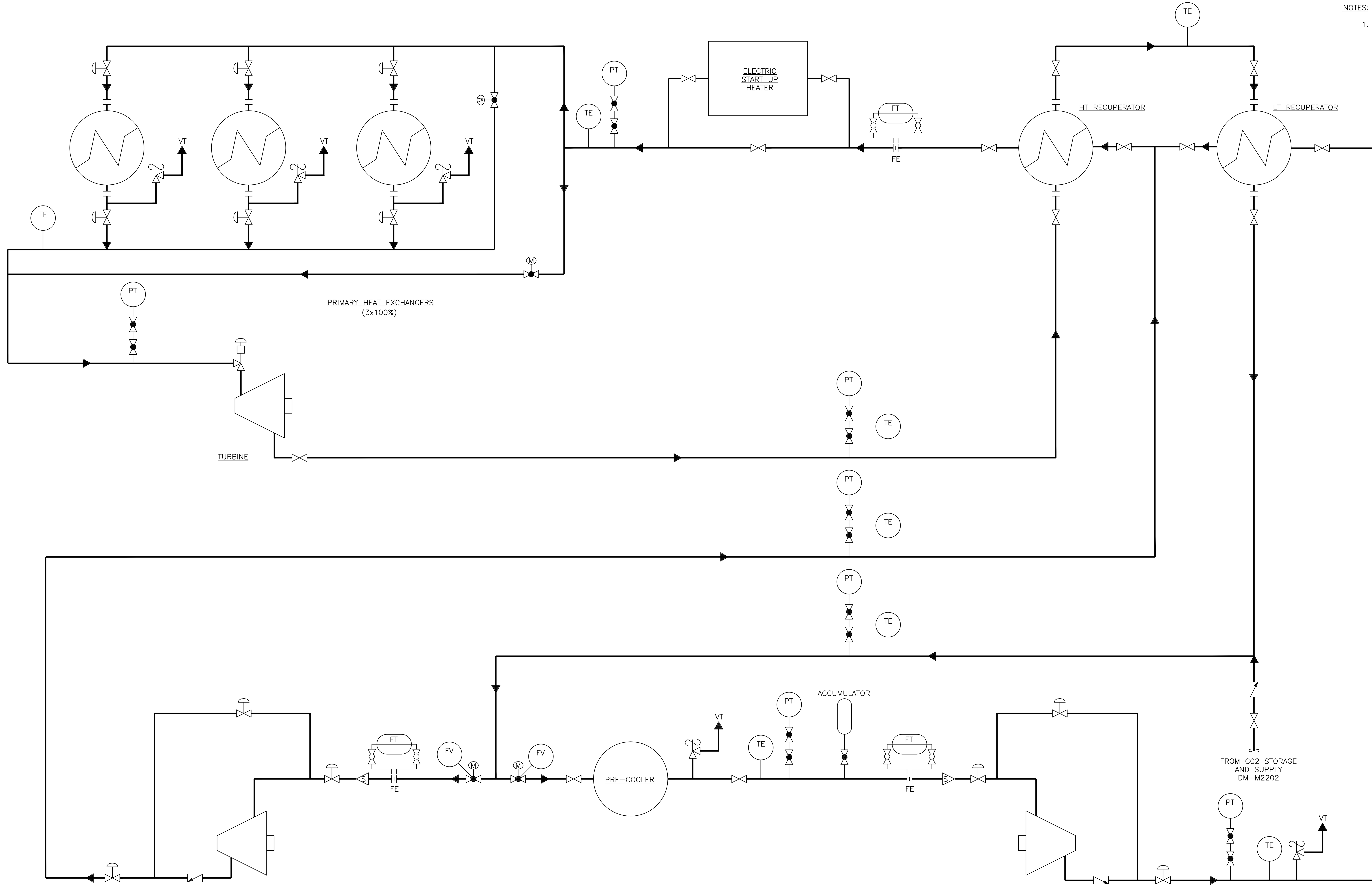

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FV = FLOW CONTROL

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DOE SUNSHOT
MOLTEN SALT

PROCESS FLOW DIAGRAM
sCO2 CYCLE

PROJECT | DRAWING NUMBER | REV
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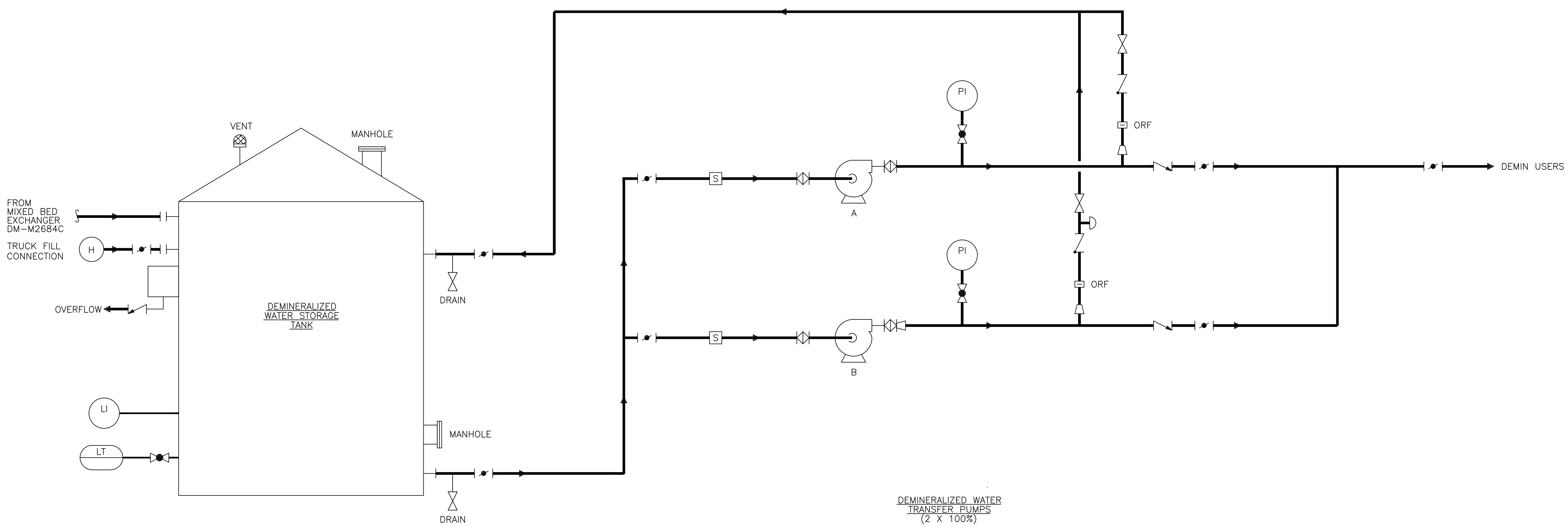

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DOE SUNSHOT
MOLTEN SALT

PROCESS FLOW DIAGRAM
DEMIN WATER STORAGE & SUPPLY

PROJECT | DRAWING NUMBER | REV
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FV = FLOW CONTROL

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CHECKED		DATE	

DOE SUNSHOT
MOLTEN SALT

PROCESS FLOW DIAGRAM
RECEIVER SYSTEM

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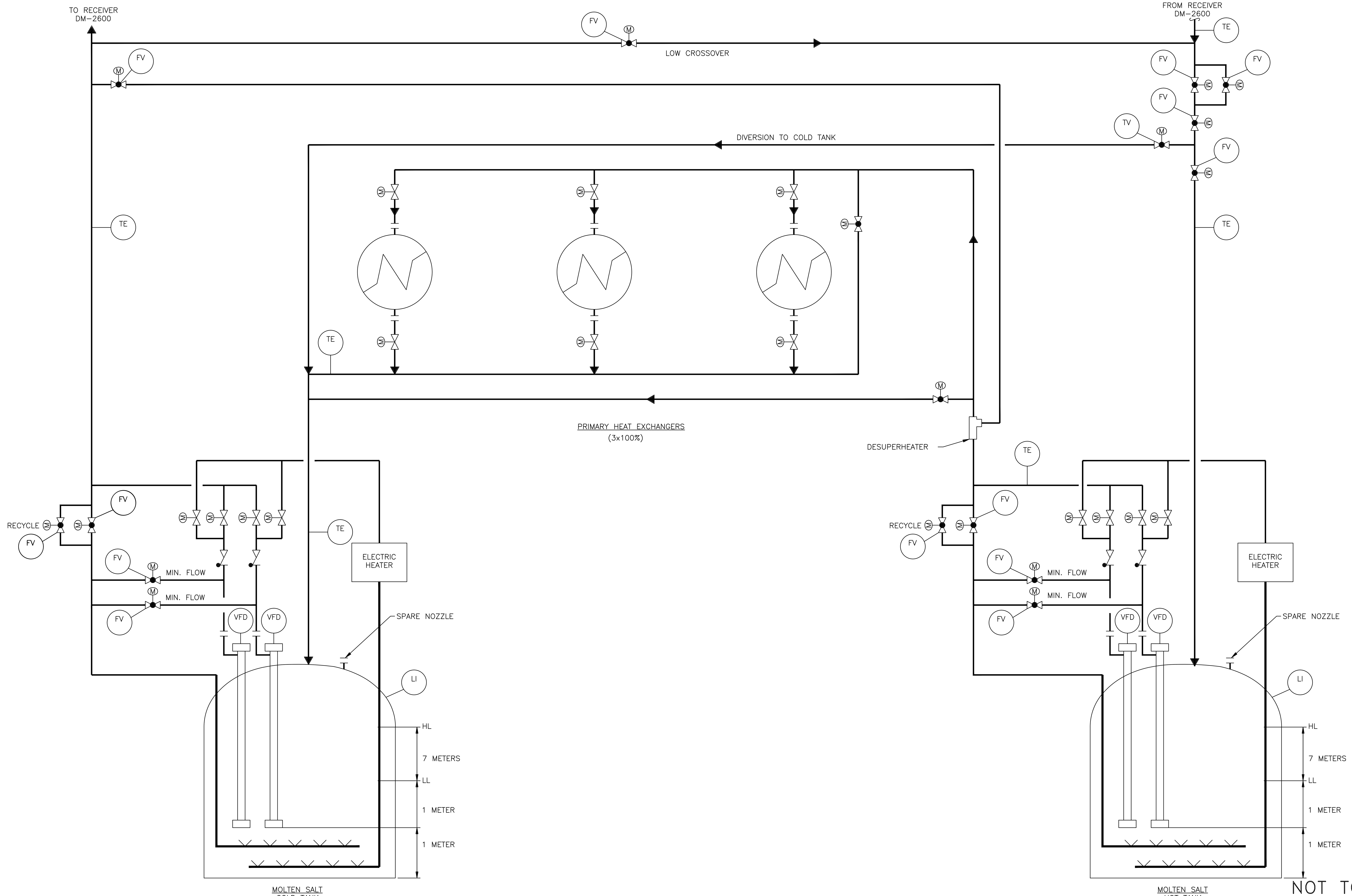

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TV = TEMPERATURE CONTROL

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CHECKED DATE

DOE SUNSHOT
MOLTEN SALT

PROCESS FLOW DIAGRAM
TANKS & PRIMARY HEAT EXCHANGER

PROJECT 042839 DRAWING NUMBER DM-M2601 REV B
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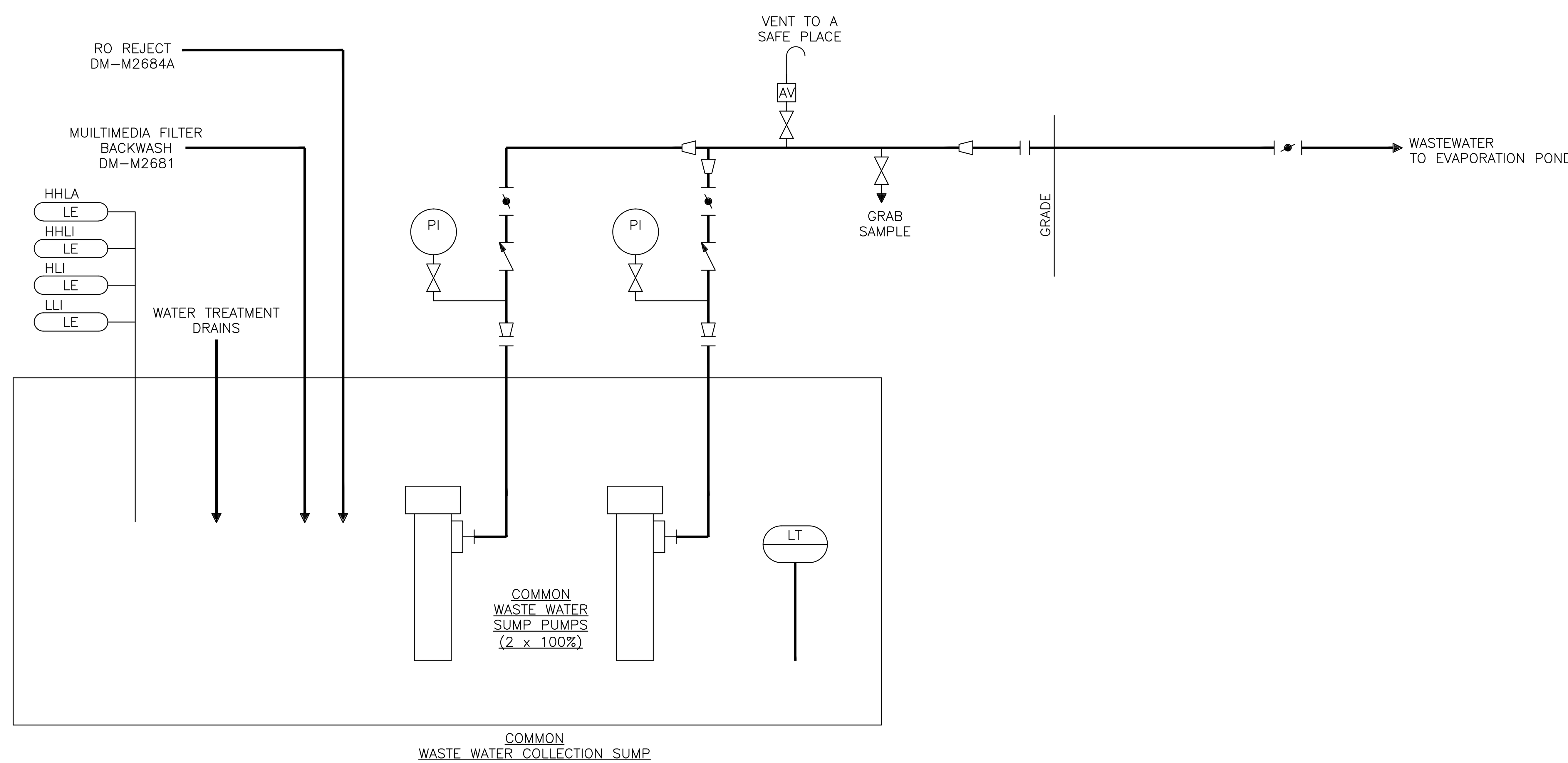

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CHECKED DATE

DOE SUNSHOT
MOLTEN SALT

PROCESS FLOW DIAGRAM
WASTEWATER COLLECTION

PROJECT DRAWING NUMBER REV
042839-DM-M2643 B

CODE
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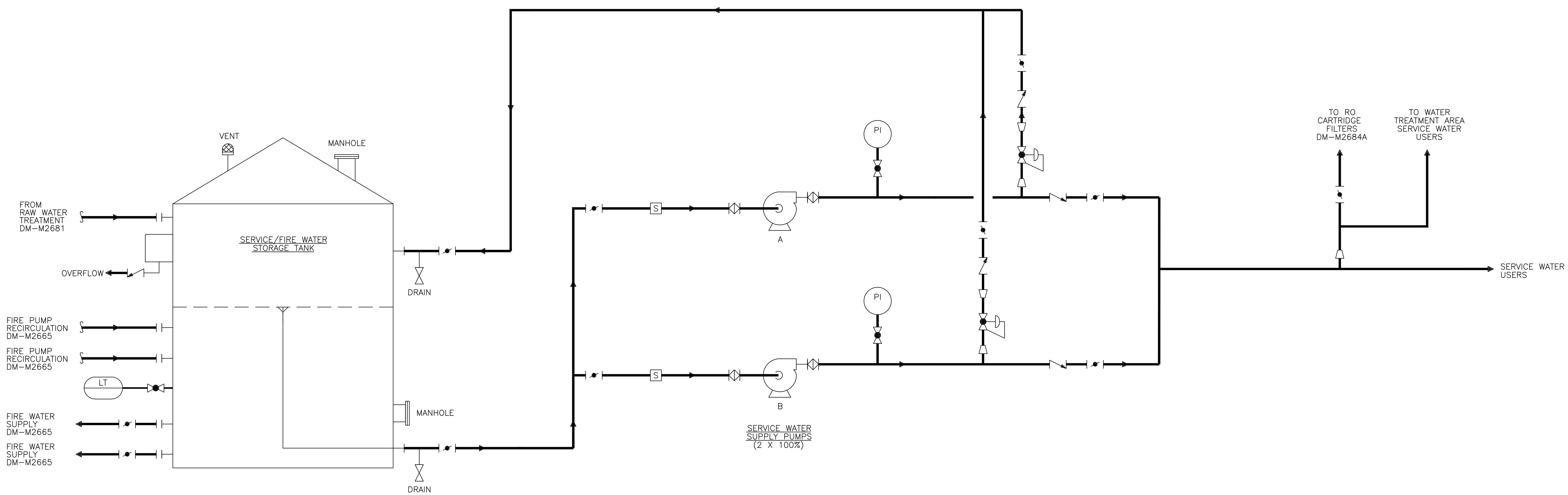

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CHECKED | DATE

DOE SUNSHOT
MOLTEN SALT

PROCESS FLOW DIAGRAM
SERVICE / FIRE WATER

PROJECT 042839 | DRAWING NUMBER DM−M2663 | REV B

CODE

AREA

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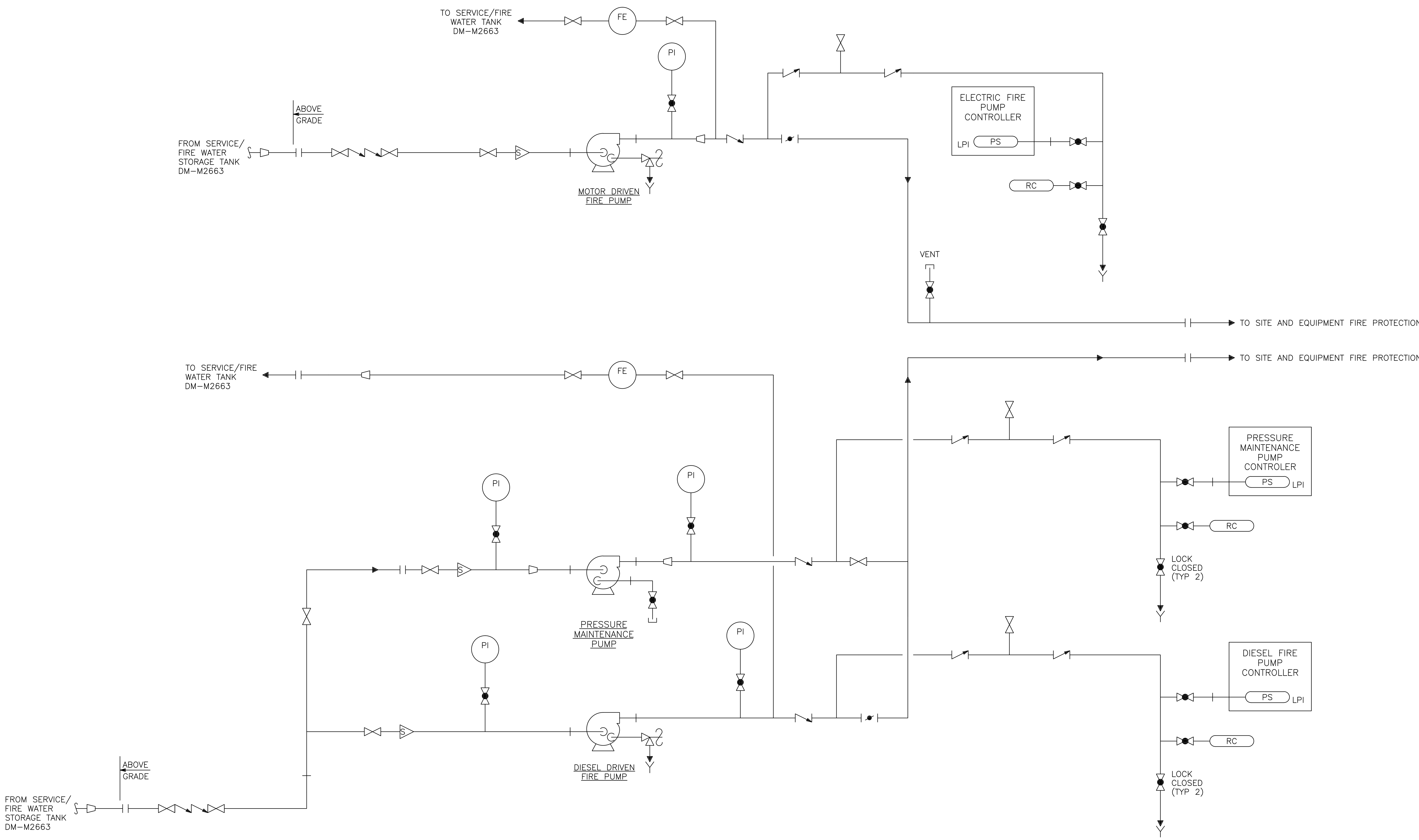

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DATE XX REG NO. XX

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ENGINEER DAA DRAWN PDA

CHECKED DATE

DOE SUNSHOT
MOLTEN SALT

PROCESS FLOW DIAGRAM
FIRE PROTECTION SUPPLY

PROJECT DRAWING NUMBER 042839-DM-M2665 REV B

CODE

AREA

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MOLTEN SALT

PROCESS FLOW DIGRAM
RAW WATER TREATMENT

PROJECT | DRAWING NUMBER | REV
042839-DM-M2681 | B

CODE

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PROCESS FLOW DIAGRAM
DEMIN WATER PRODUCTION

PROJECT DRAWING NUMBER REV

042839-DM-M2684A B

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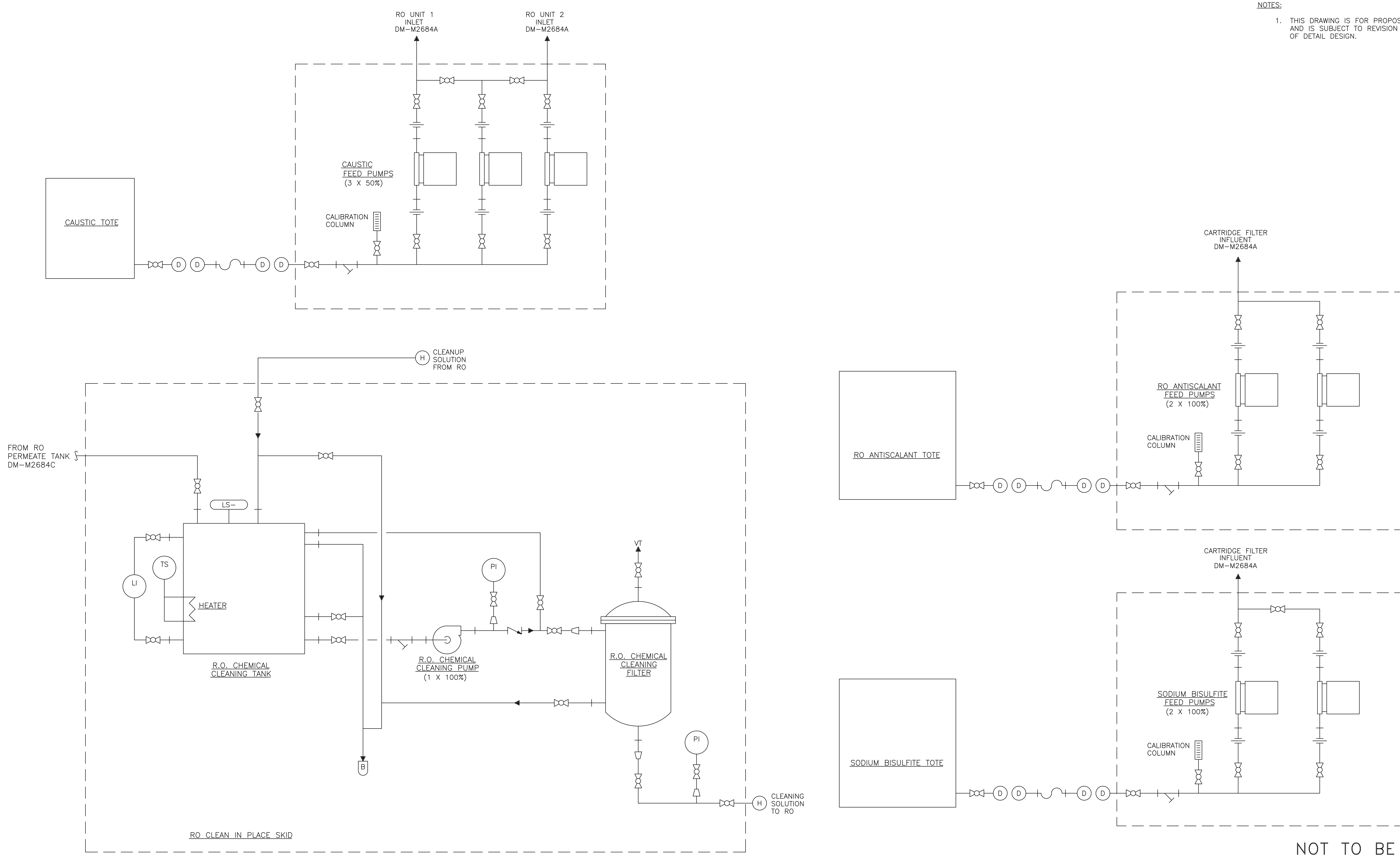

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PROCESS FLOW DIAGRAM
DEMIN WATER PRODUCTION

PROJECT | DRAWING NUMBER | REV
042839-DM-M2684B | B

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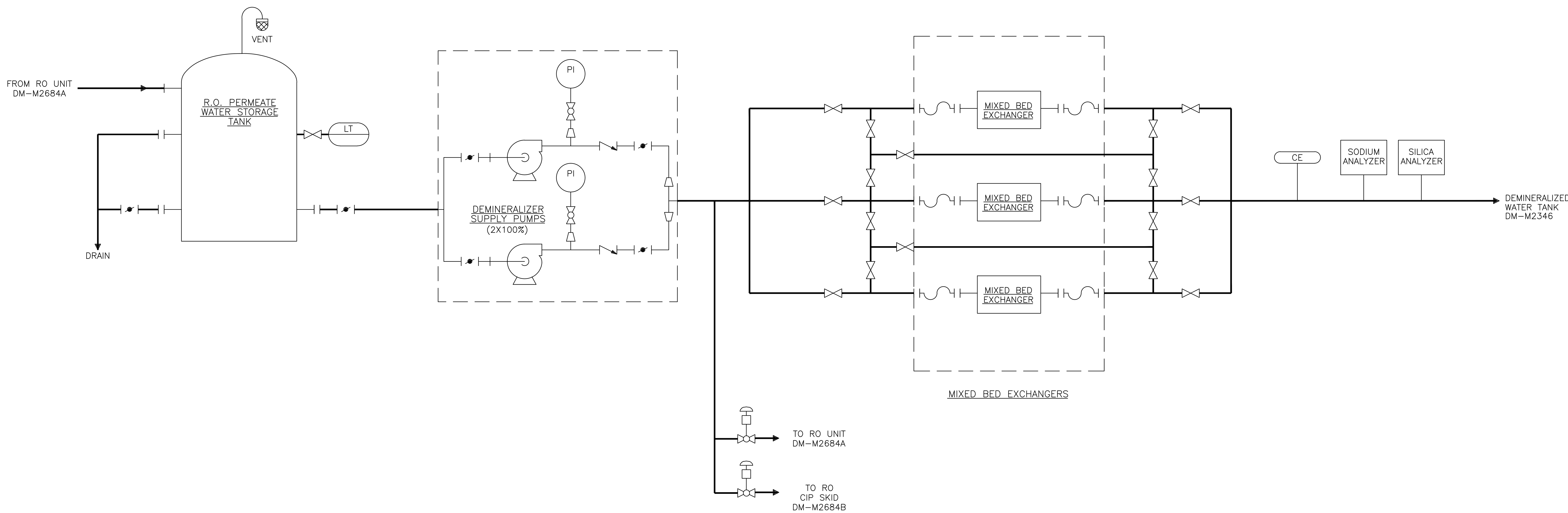

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CHECKED | DATE

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MOLTEN SALT

PROCESS FLOW DIAGRAM
DEMIN WATER PRODUCTION

PROJECT | DRAWING NUMBER | REV
042839-DM-M2684C | B

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Appendix D. Electrical One-line

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CHECKED | DATE

DOE SUNSHOT
MOLTEN SALT

33–4.16 KV
ONE–LINE DIAGRAM

PROJECT / DRAWING NUMBER: 042839–SE–E1000 | REV: B

CODE

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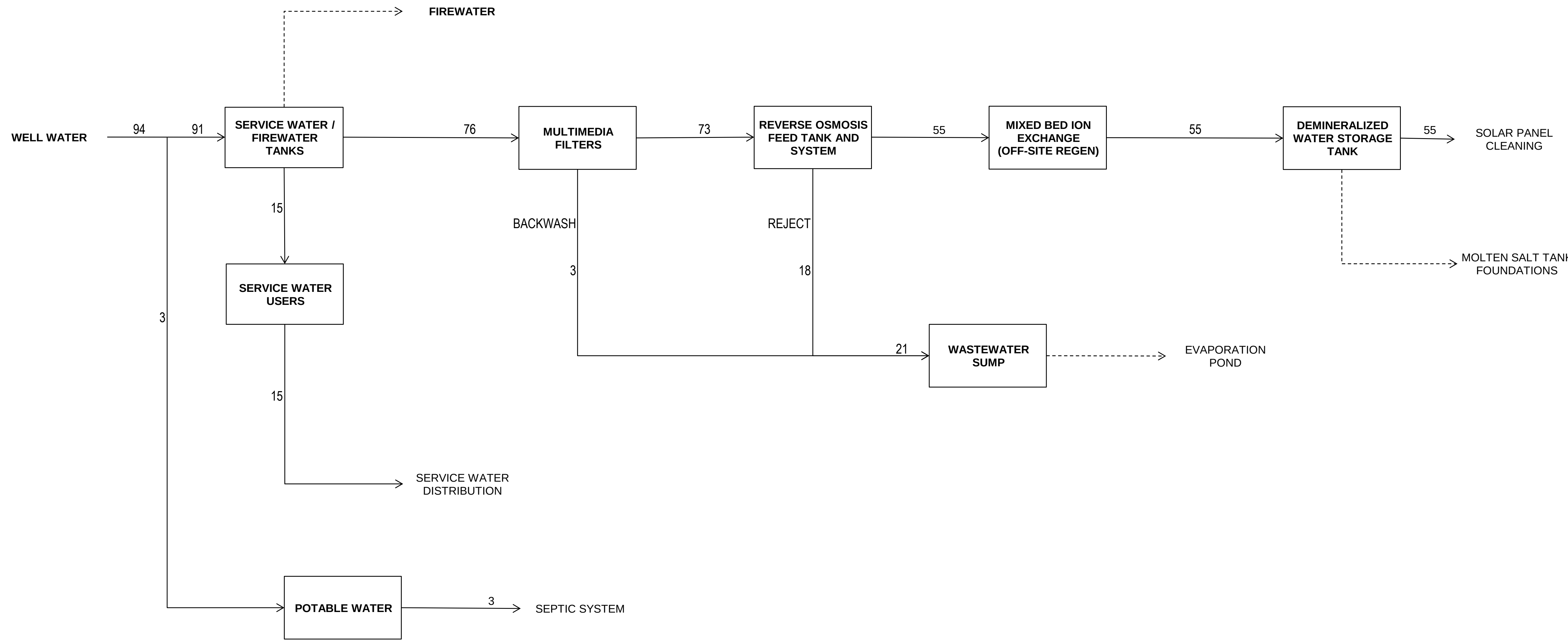
Appendix E. Water Mass Balance Diagram



NOTE:
1. FLOWS ARE IN GALLONS PER MINUTE (GPM).
2. DASHED LINE INDICATES NORMALLY NO FLOW.
3. ALL FLOWS ARE BASED UPON DAILY AVERAGES.

MULTIMEDIA FILTER YIELD	96.0%
REVERSE OSMOSIS YIELD	75%

BLACK & VEATCH

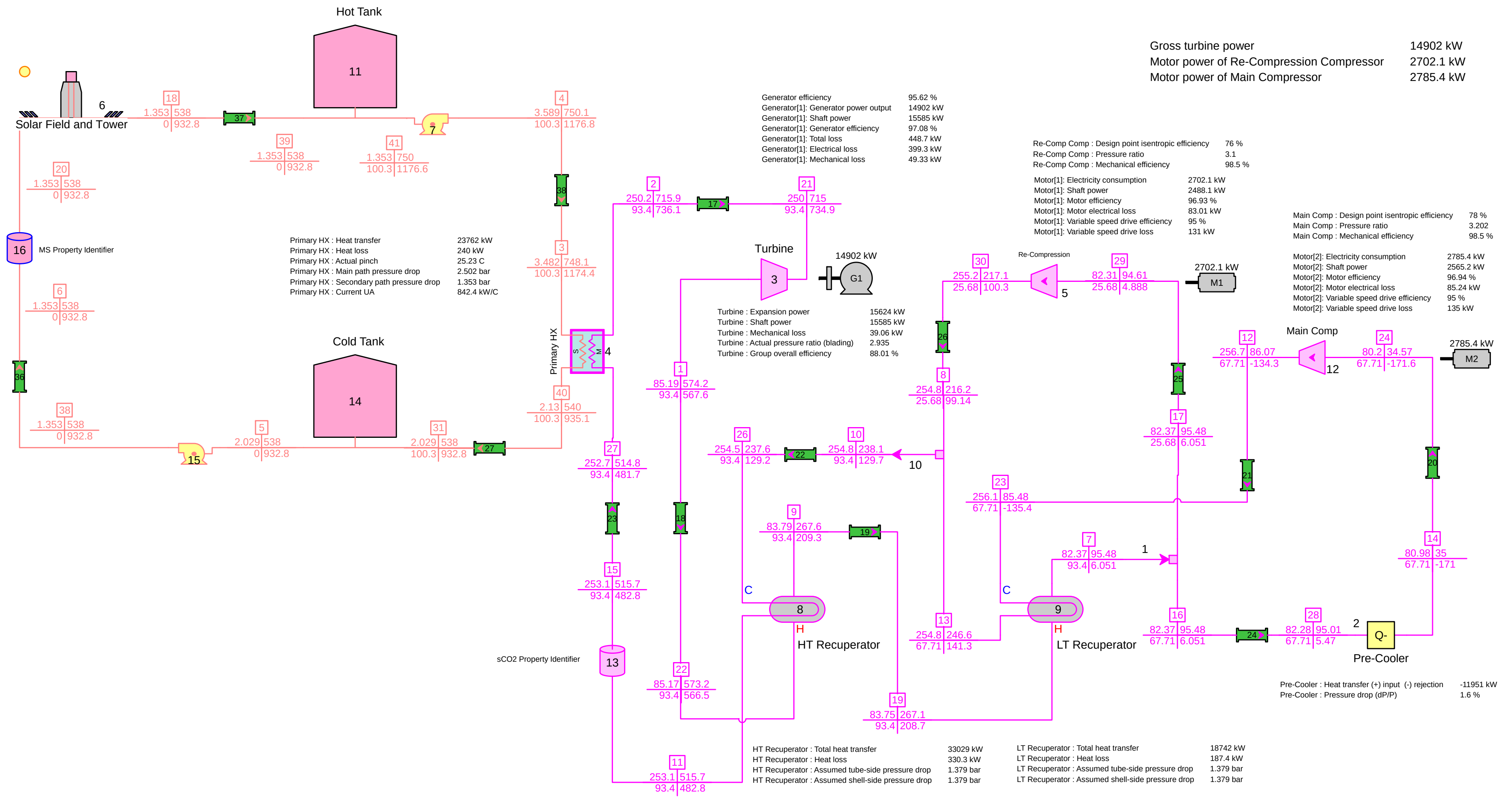
Eng:	AEH	Dwg:	AEH
Check:	DAA	Date:	6/21/2016

DOE
Sunshot
Water Mass Balance
Molten Salt
042839-WMB-0001

Project	Drawing Number	Rev
042839	WMB-0001	A

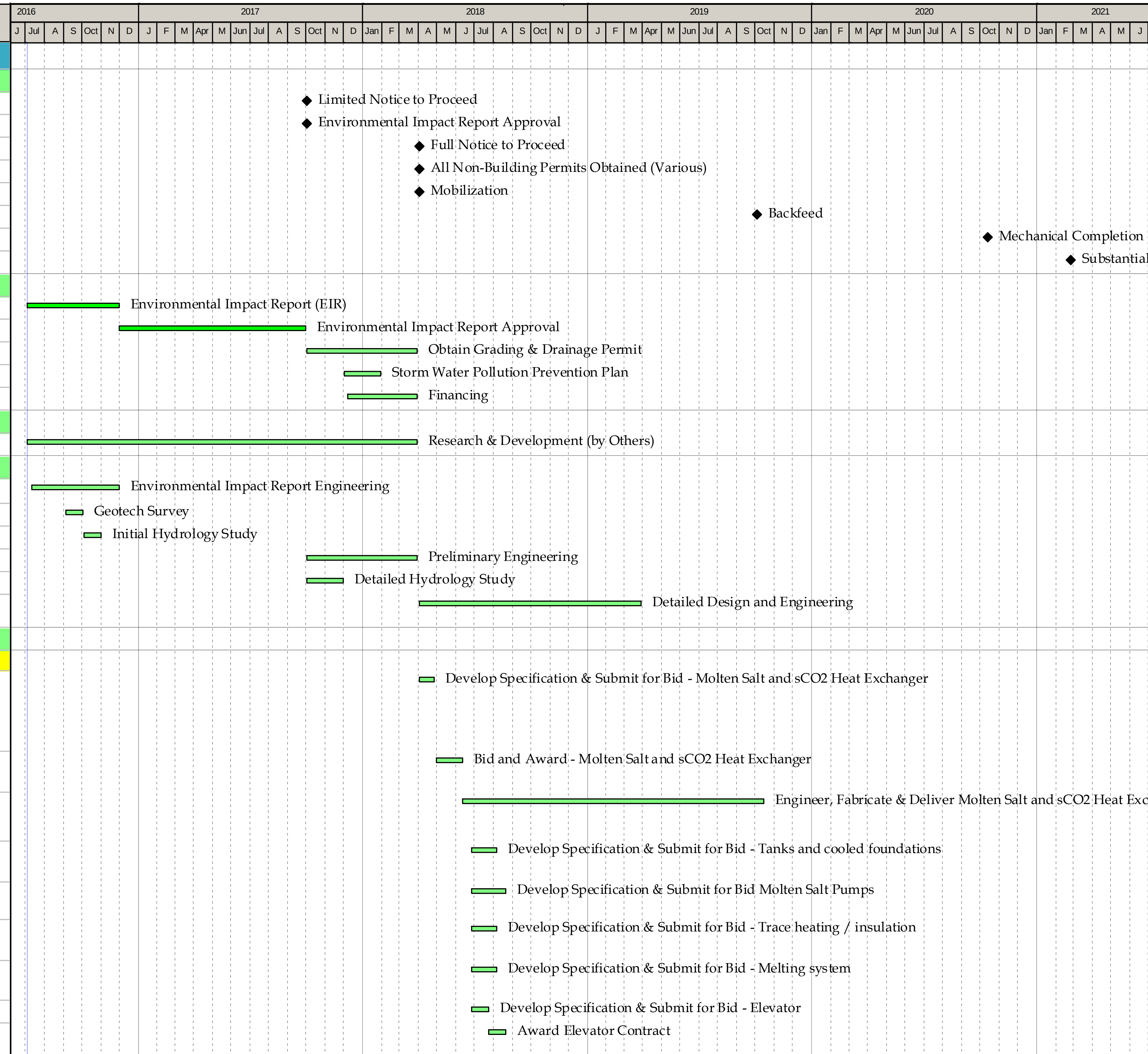
Appendix F. sCO2 Heat Balance Diagram

bar	C
kg/s	kJ/kg



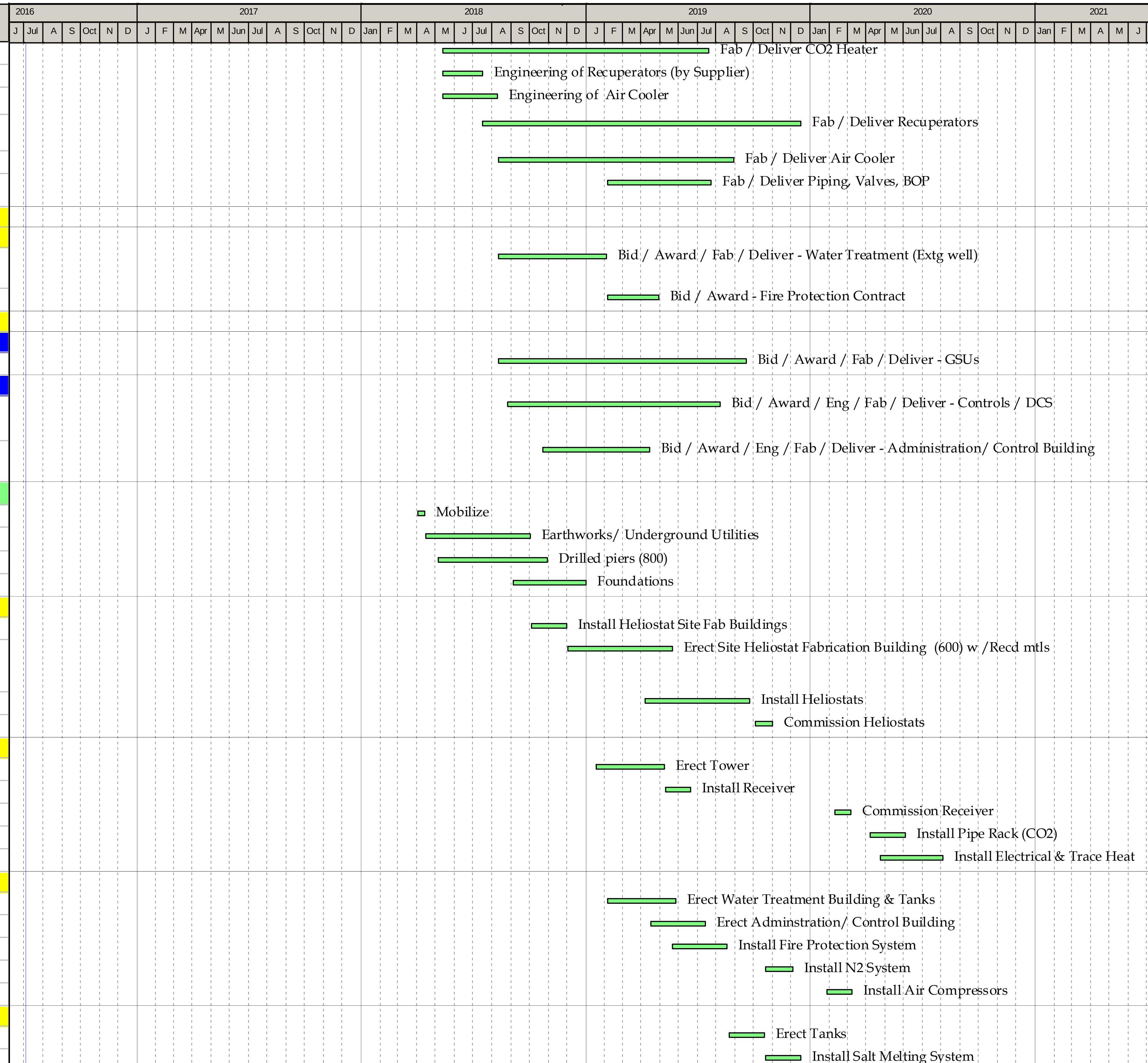
Appendix G. Project Schedule

#	Activity Name	Duration	Start	Finish
1	**Molten Salt Integrated Systems**			
2	**Project Milestones**			
3	Limited Notice to Proceed	0d	02-Oct-17*	
4	Environmental Impact Report Approval	0d	02-Oct-17	
5	Full Notice to Proceed	0d	02-Apr-18	
6	All Non-Building Permits Obtained (Various)	0d	02-Apr-18	
7	Mobilization	0d	02-Apr-18	
8	Backfeed	0d		03-Oct-19
9	Mechanical Completion	0d		12-Oct-20
10	Substantial Completion	0d		25-Feb-21
11	**Permitting and Financing**			
12	Environmental Impact Report (EIR)	104d	05-Jul-16	30-Nov-16
13	Environmental Impact Report Approval	212d	01-Dec-16	29-Sep-17
14	Obtain Grading & Drainage Permit	126d	02-Oct-17	30-Mar-18
15	Storm Water Pollution Prevention Plan	40d	01-Dec-17	29-Jan-18
16	Financing	80d	07-Dec-17	30-Mar-18
17	**Research & Development**			
18	Research & Development (by Others)	442d	05-Jul-16	30-Mar-18
19	**Engineering**			
20	Environmental Impact Report Engineering	100d	11-Jul-16	30-Nov-16
21	Geotech Survey	20d	06-Sep-16	03-Oct-16
22	Initial Hydrology Study	21d	04-Oct-16	01-Nov-16
23	Preliminary Engineering	126d	02-Oct-17	30-Mar-18
24	Detailed Hydrology Study	42d	02-Oct-17	30-Nov-17
25	Detailed Design and Engineering	252d	02-Apr-18	29-Mar-19
26	**Procurement**			
27	**Thermal Energy Storage (TES)**			
28	Develop Specification & Submit for Bid - Molten Salt and sCO2 Heat Exchanger	20d	02-Apr-18	27-Apr-18
29	Bid and Award - Molten Salt and sCO2 Heat Exchanger	30d	30-Apr-18	11-Jun-18
30	Engineer, Fabricate & Deliver Molten Salt and sCO2 Heat Exchanger	340d	12-Jun-18	14-Oct-19
31	Develop Specification & Submit for Bid - Tanks and cooled foundations	30d	26-Jun-18	07-Aug-18
32	Develop Specification & Submit for Bid Molten Salt Pumps	40d	26-Jun-18	21-Aug-18
33	Develop Specification & Submit for Bid - Trace heating / insulation	30d	26-Jun-18	07-Aug-18
34	Develop Specification & Submit for Bid - Melting system	30d	26-Jun-18	07-Aug-18
35	Develop Specification & Submit for Bid - Elevator	20d	26-Jun-18	24-Jul-18
36	Award Elevator Contract	20d	25-Jul-18	21-Aug-18



#	Activity Name	Duration	Start	Finish
37	Award for MS Pumps, Heaters, Piping, Valves, Heat Tracing & Melting System	40d	22-Aug-18	17-Oct-18
38	Fabricate and Deliver - Elevator	100d	22-Aug-18	16-Jan-19
39	TES fabrication & Delivery	214d	18-Oct-18	22-Aug-19
40	**Heliostats**			
41	Develop Specification & Submit for Bid - Heliostats	108d	02-Apr-18	31-Aug-18
42	Award Contract for Heliostats	21d	04-Sep-18	02-Oct-18
43	Fabricate & Deliver Heliostats	128d	03-Oct-18	05-Apr-19
44	**Molten Salt**			
45	Bid / Award / Delivery - Molten Salt	80d	22-Aug-18	14-Dec-18
46	**Tower & Pipe Rack Steel**			
47	Develop Specifications - Tower & Pipe Rack Steel	30d	01-May-18	12-Jun-18
48	Bid / Award - Tower & Pipe Rack Steel	30d	13-Jun-18	25-Jul-18
49	Fabricate & Deliver - Tower & Pipe Rack Steel	120d	26-Jul-18	17-Jan-19
50	**Receiver**			
51	Develop Specification & Submit for Bid - Receiver	30d	01-May-18	12-Jun-18
52	Bid & Award - Receiver	63d	13-Jun-18	11-Sep-18
53	Receiver Engineering	130d	12-Sep-18	19-Mar-19
54	Fabrication / Delivery Receiver	284d	17-Dec-18	31-Jan-20
55	**sCO2**			
56	**Turbine Generator and Compressors**			
57	Develop Specification & Submit for Bid - Turbine Generator, compressors	30d	02-Oct-17	10-Nov-17
58	Bid and Award - Turbine Generator, Compressors	44d	13-Nov-17	17-Jan-18
59	Engineering for Turbine Generator & CO2 Compressors	120d	18-Jan-18	06-Jul-18
60	Fabricate / Deliver Turbine Generator	422d	09-Jul-18	09-Mar-20
61	Fabricate / Deliver CO2 compressors (20 months + eng)	422d	09-Jul-18	09-Mar-20
62	**Heat Exchangers, Air Cooler and CO2 Compressors**			
63	Develop Specification & Submit for Bid - Heat Exchangers, Air Cooler and CO2 Heater	20d	05-Mar-18	30-Mar-18
64	Bid and Award - Heat Exchangers, Air Cooler and CO2 Heater	30d	02-Apr-18	11-May-18

#	Activity Name	Duration	Start	Finish
65	Fab / Deliver CO2 Heater	300d	14-May-18	19-Jul-19
66	Engineering of Recuperators (by Supplier)	44d	14-May-18	16-Jul-18
67	Engineering of Air Cooler	63d	14-May-18	10-Aug-18
68	Fab / Deliver Recuperators	360d	17-Jul-18	17-Dec-19
69	Fab / Deliver Air Cooler	266d	13-Aug-18	29-Aug-19
70	Fab / Deliver Piping, Valves, BOP	120d	05-Feb-19	24-Jul-19
71	**Molten Salt Heat Exchanger**			
72	**Water Treatment & Fire Protection**			
73	Bid / Award / Fab / Deliver - Water Treatment (Extg well)	120d	13-Aug-18	04-Feb-19
74	Bid / Award - Fire Protection Contract	60d	05-Feb-19	29-Apr-19
75	**Electrical Controls**			
76	**GSU**			
77	Bid / Award / Fab / Deliver - GSUs	280d	13-Aug-18	19-Sep-19
78	**DCS**			
79	Bid / Award / Eng / Fab / Deliver - Controls / DCS	240d	27-Aug-18	07-Aug-19
80	Bid / Award / Eng / Fab / Deliver - Administration/ Control Building	120d	23-Oct-18	15-Apr-19
81	**Construction & Commissioning**			
82	Mobilize	10d	02-Apr-18	13-Apr-18
83	Earthworks/ Underground Utilities	120d	16-Apr-18	03-Oct-18
84	Drilled piers (800)	125d	07-May-18	31-Oct-18
85	Foundations	80d	06-Sep-18	02-Jan-19
86	**Heliostats**			
87	Install Heliostat Site Fab Buildings	40d	04-Oct-18	30-Nov-18
88	Erect Site Heliostat Fabrication Building (600) w /Recd mtls	120d	03-Dec-18	22-May-19
89	Install Heliostats	120d	08-Apr-19	25-Sep-19
90	Commission Heliostats	20d	04-Oct-19	31-Oct-19
91	**Tower & Pipe Rack Steel**			
92	Erect Tower	80d	18-Jan-19	09-May-19
93	Install Receiver	30d	10-May-19	20-Jun-19
94	Commission Receiver	20d	10-Feb-20	06-Mar-20
95	Install Pipe Rack (CO2)	40d	08-Apr-20	03-Jun-20
96	Install Electrical & Trace Heat	70d	24-Apr-20	03-Aug-20
97	**Blance of Plant**			
98	Erect Water Treatment Building & Tanks	80d	05-Feb-19	27-May-19
99	Erect Adminstration/ Control Building	63d	16-Apr-19	15-Jul-19
100	Install Fire Protection System	63d	21-May-19	19-Aug-19
101	Install N2 System	30d	21-Oct-19	03-Dec-19
102	Install Air Compressors	30d	28-Jan-20	09-Mar-20
103	**Thermal Energy Storage (TES)**			
104	Erect Tanks	40d	23-Aug-19	18-Oct-19
105	Install Salt Melting System	40d	21-Oct-19	17-Dec-19



#	Activity Name	Duration	Start	Finish
106	Install Balance of Plant	40d	18-Nov-19	17-Jan-20
107	Melting of Salt	10d	20-Jan-20	31-Jan-20
108	Commission TES	5d	03-Feb-20	07-Feb-20
109	**Electrical & Controls**			
110	33kV UG cables to riser pole (trench, spacers, FOC)	40d	25-Jul-19	19-Sep-19
111	MAT, RAT, SUSs, 33kV Switchgear, etc	40d	25-Jul-19	19-Sep-19
112	Set/ Install GSUs	10d	20-Sep-19	03-Oct-19
113	Install DCS	120d	04-Oct-19	26-Mar-20
114	**sCO2**			
115	Install CO2 Heater	40d	22-Jul-19	16-Sep-19
116	Install Molten Salt/ sCO2 Heat Exchanger	60d	15-Oct-19	13-Jan-20
117	Install Air Cooler	105d	08-Jan-20	03-Jun-20
118	Install Recuperators	40d	14-Jan-20	09-Mar-20
119	Install CO2 compressors	40d	10-Mar-20	04-May-20
120	Complete Installation of CO2 Piping, Valves, Insulation, Heat Tracing, BOP Electrical	80d	12-Mar-20	02-Jul-20
121	Install Turbine Generator	40d	08-Apr-20	03-Jun-20
122	Lube Oil and Flush	30d	06-Jul-20	14-Aug-20
123	**Startup & Commissioning**			
124	Air Blows/ N2 Purge	20d	17-Aug-20	14-Sep-20
125	Startup & Commissioning	20d	15-Sep-20	12-Oct-20
126	Performance Testing/ Reliability	30d	13-Oct-20	23-Nov-20
127	Cure Time	63d	24-Nov-20	25-Feb-21