FALLING PARTICLES

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) 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 (FP) facility with thermal energy storage and with a supercritical CO_2 cycle generating approximately 10MWe.

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

Section 2 of the report presents the plant design basis. In summary, the plant design is based on the use of falling particles (FPs) circulated from a cold (540 °C) bin to a solar receiver irradiated by a solar heliostat field, providing hot (750 °C) particles to a hot bin. The falling particles are conveyed to a FP/sCO2 heat exchanger providing heat to a sCO2 turbine generator with motor driven compressors. The site is assumed to be in 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 61,946 m^2 of heliostat mirror area as a north field to the solar receiver, a steel lattice tower with a platform at 65m elevation to support the solar receiver, single hot and cold FP storage bins each with a diameter of approximately 4.85m and 5.42m, respectively, 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 1.8 MW, resulting in a net generation of 7.6MW 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 March 2021.

The capital cost of the facility was developed in Section 5 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. The estimated capital cost of the project is $132,144,000. This cost may be reduced by over $10M by locating the turbine adjacent to the tower; other optimizations may be possible.

The O&M cost of the facility, developed in Section 6, 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 equipment.

There are several major observations:

- Capital costs are extremely high. In particular, the cost of Haynes 230 material for the high pressure/high temperature sCO2 primary heaters and piping to the sCO2 turbine is surprisingly high.
- Suppliers of high temperature equipment, such as falling particle lifting devices, gates 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 sCO2. A program to develop sCO2 corrosion rates should be initiated.

- 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 10MW integrated falling particle/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 falling particles (FPs). In this case, the falling particles are sintered alumina silicate.
3. The falling particles will be conveyed by a lifting device from a cold FP bin to a receiver system at the top of the power tower and will flow to a hot FP bin. The FP in the hot bin will be conveyed by gravity to a supercritical CO2 (sCO2) heat exchanger system to which it will transfer heat, before flowing back to the cold FP bin. The sCO2 heat exchange may be concurrent with receiver heat absorption or non-concurrent, i.e. in night-time hours. All the FP bins and sCO2 heat exchangers are located inside the tower structure.
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 FP/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 FP/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 FP/sCO2 duty as a fixed quantity.

2.2.2 Thermal Storage

The falling particle 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 Falling Particle Product

The falling particle product considered for the design concept basis of this report is CARBO ACCUCAST® ID50-K. This falling particle product is an intermediate-density media used for ceramic casting. The product is engineered in pellet form with high roundness and sphericity that maximizes flowability.

2.2.3.1 Falling Particle Properties

The physical and thermal properties for CARBO ACCUCAST® ID50-K have been treated as confidential.

2.2.3.2 Falling Particle Sourcing

The falling particle (CARBO ACCUCAST® ID50-K) used as the basis of this conceptual study is manufactured by CARBO Ceramics, Inc. The product traditionally is used as a casting media for metal casting production. CARBO Ceramics has three manufacturing facilities within the United States and one in Russia. The most likely manufacturing source for this product would be from CARBO Ceramics plant located in McIntyre, Georgia.

2.2.3.3 Falling Particle Delivery

The falling particle product can be delivered to the solar site either by super sack, truck or rail. The cheapest delivery method is by rail, and then by pneumatic truck trailer. The most expensive delivery method would be by super sack containers delivered by truck.

The solar site is based on a conceptual location in Barstow, California. At this point, the ultimate final location it is not known as to whether or not rail access exists, so pneumatic truck delivery was chosen as the delivery method for the falling particle product.

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 using a north facing solar field is included in Appendix A. An interior loop road provides access to the power block equipment within the innermost ring of heliostats. The area inside the interior loop road is detailed on the Plant Arrangement drawing included in Appendix B. With the north facing solar field, there is space to the south of the solar field to accommodate equipment. 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 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. As shown on the site arrangement drawing, the site will require approximately 155 acres of land.

3.2 FALLING PARTICLE COLLECTOR 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.

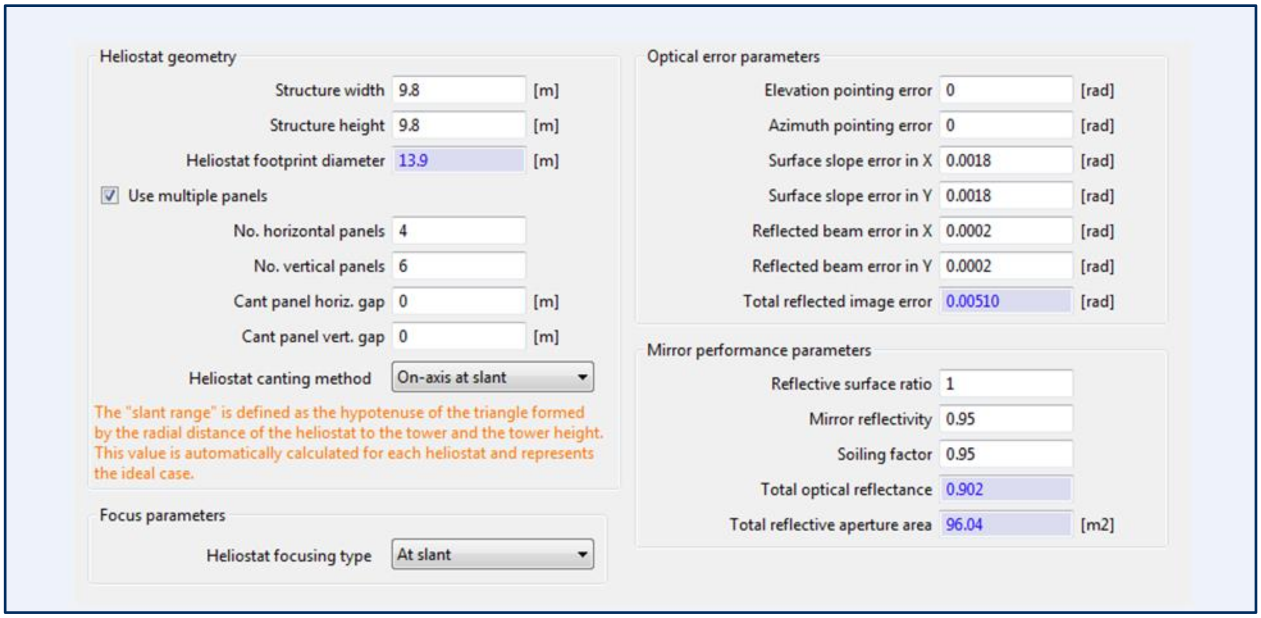


Figure 3-1 Proxy Heliostat Characteristics As Modeled in SolarPILOT and the System Advisor Model

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 falling particle 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 SolarPILOT

In laying out the heliostat field and determining tower height for the 10 MWe molten salt plant, Black & Veatch had used the National Renewable Energy Laboratory (NREL) System Advisor Model (SAM).

Because SAM does not have the algorithms to support modeling the north field used in the falling particle plant, Black & Veatch worked with personnel from NREL to model the north field with SolarPILOT. 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 1980s. 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. SolarPILOT 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.

3.2.4 Solar Multiple and Storage Capacity

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.

For the falling particle system, Black & Veatch assumed the same solar multiple and thermal storage capacity that were determined for the molten salt system. 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 worked with NREL to model the north field configuration for the field, tower, and receiver. The receiver aperture size was scaled from the falling particle test receiver at the NSTTF, resulting in an aperture size of 5.6 m by 5.6 m. The receiver was assumed to have an efficiency of 90 percent. With the 31.2 MWt power from the receiver, the incident power into the aperture was 34.7 MWt. The results of the NREL modeling were as follows:

- Optical tower height: 68.5 m
- Design height for top of tower: 65 m
- Heliostats number: 645
- Heliostat field mirror area: 61,946 m^2

The heliostat layout for the falling particle plant is shown in Figure 3-2. As noted earlier, the site arrangement drawing (042839-DM-G1001) shows the solar field, tower, roads, facilities, and fencing and is provided in Appendix A.

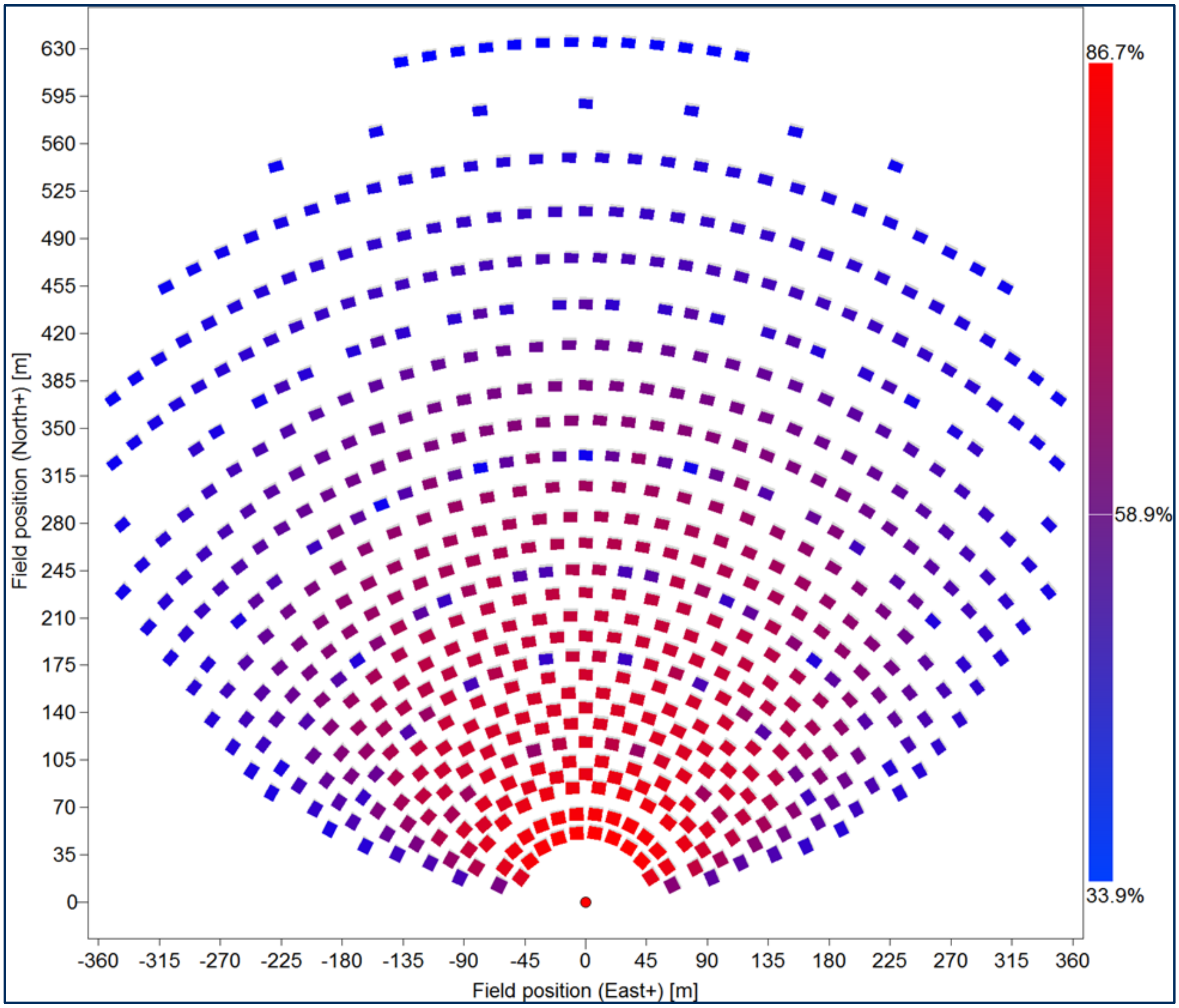


Figure 3-2 Heliostat Layout for 10 MWe Integrated Falling Particle Plant

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-G2001 in Appendix B. The power producing plant sits in the interior loop area (approximately 300 feet diameter) within the heliostat field. Produced power will be fed via direct buried 33 kV 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.
- Falling Particle Makeup area.
- sCO_2 turbine/compressor area.

- sCO2 pre-cooler area.
- Admin/Control building.

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

3.4 CIVIL/STRUCTURAL CONCEPTUAL DESIGN

3.4.1 Concentrated Solar Power Tower

The tower for the Falling Particle Facility will be a steel lattice tower. The base of the tower will be 30 feet x 60 feet, divided into two bays that are each 30 feet x 30 feet One bay was planned for the falling particles and the other bay is planned for the particle hoist. The height of the tower will be 275 feet (83.8 m) extending above the cavity. 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 65m elevation on the north side of the lattice steel tower. Figure 3-3 provides elevation views of the tower as it was modeled.

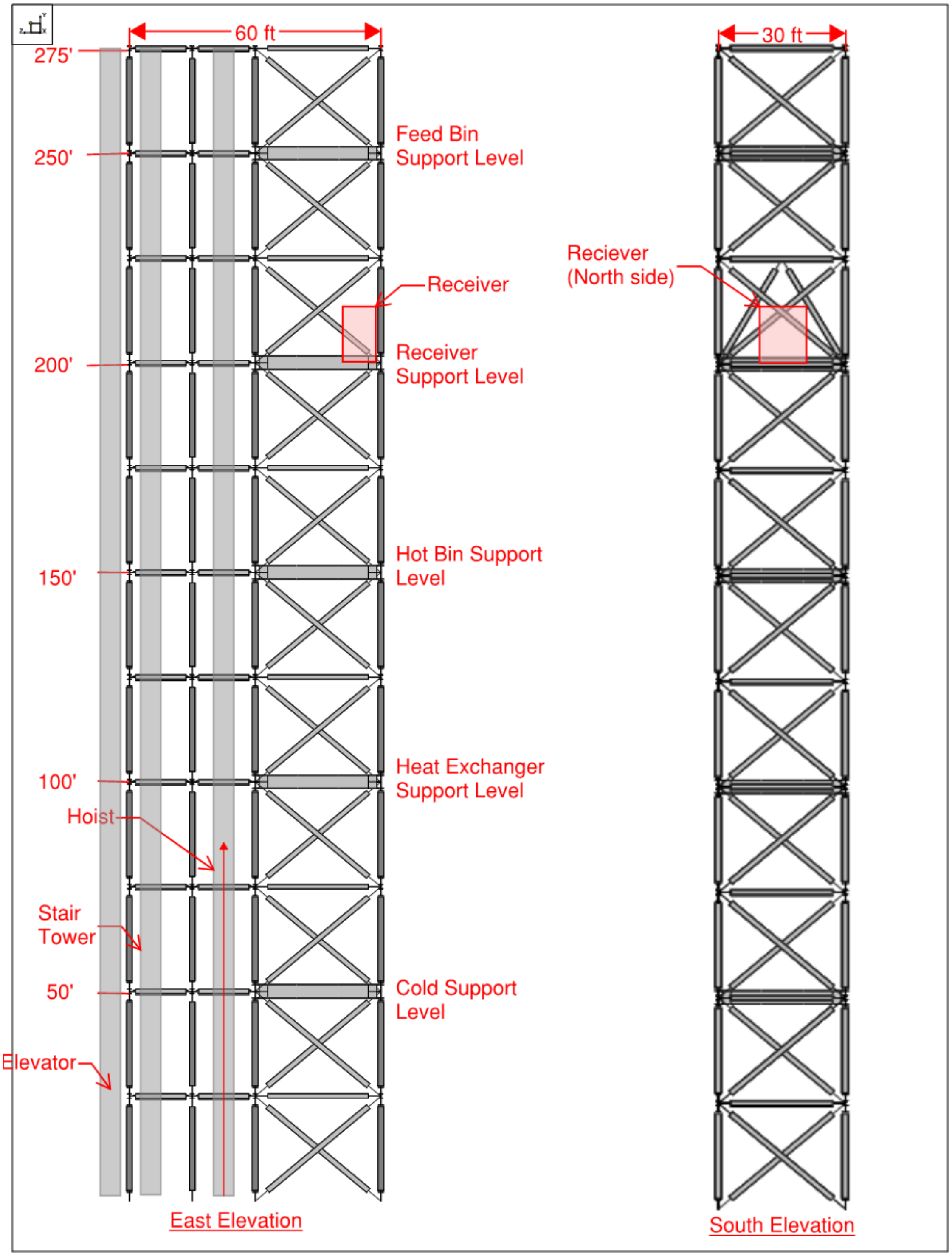


Figure 3-3 Falling Particle Tower Structure

3.4.2 Structural Design

All designs will meet federal, state and municipal building code requirements, including IBC 2012.

Table 3-1 shows the parameters used for the conceptual design of all 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 96 m^2 surface area. Drilled pier foundations with pile caps were sized for the tower based on loads provided from the tower model in RISA. 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 feet wide aggregate surfaced road with the loop roads being reduced to a 20 feet width. Both road widths will allow enough room for vehicles to pass, but the 24 feet 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 six inches of topsoil will be removed to allow for the compaction of the road subgrade and installation of the road base material.

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

There are no secondary containment structures on the falling particle site.

3.4.8 Buildings and Pipe Racks

All buildings on the site except for the tower and piperack are assumed to be pre-engineered metal buildings. These buildings will have a standard slab-on-grade foundation with a thickened edge.

Pipe racks will be constructed out of galvanized hot rolled steel shapes. 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 feet tall galvanized chain link fence with three strand barbed wire above 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 042839-SE-E1001 illustrates the 33 kV and 4.16 kV distribution and backup generation for the Falling Particle Facility.

3.5.2 Power Generation

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 (GSU) transformer and then connected to the primary 33 kV switchgear line-up.

3.5.3 Primary 33 kV Switchgear

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, weathertight, industrial power assembly (IPA) enclosure. The switchgear feeds a 4.16 kV metal-clad switchgear lineup (also housed in the IPA) serving heaters, two large compressors, and heat tracing loads.

3.5.4 Auxiliary Power System

The 33 kV switchgear feeds a 480V secondary unit substation (SUS), which supplies power to pumps, auxiliary loads and the control building.

3.5.5 Outgoing 33 kV Distribution

The 33 kV switchgear will have an underground feeder connected to an overhead distribution line routed on wood poles. The feeder will be sized for exporting approximately 10 MVA of power to the commercial utility system.

3.5.6 Conduit and Cabling

Distribution at 4.16, 13.8 and 33 kV will consist of single-conductor, medium voltage (MV-105), 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.

3.5.7 Motors

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

3.5.8 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.

3.5.9 Lighting Design

All indoor lighting, equipment lighting and area lighting will consist of energy efficient LED fixtures.

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, but may be considered on a case by case basis.

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 FALLING PARTICLE SYSTEMS

The falling particle system is generally described in the Process Flow Diagram 042839-DM-M2022 in the Appendix C.

3.7.1 Feed Bin

3.7.1.1 Falling Particle Feed Bin and Startup Feed Bin System Description

The primary feed bin will be located at the top of the concentrated solar power tower and will collect ceramic media (falling particles) that discharges from the friction hoist skip bucket. The feed bin will be sized to accommodate up to five (5) minutes of FP storage or approximately 37,575 kg. The feed bin configuration will consist of the main cylindrical storage bin with a tapered hopper section immediately below. To ensure bulk mass flow through the bin, the hopper angle will be at least 65 degrees with respect to the horizontal and the overall bin height to diameter ratio will be 3:1. The overall bin height is approximately 7 m and includes 1 m of free board. The cylindrical bin diameter is 2.3 m. Two options for flow control and metering are possible at the hopper exit. The transition duct at the hopper exit can be configured with either one (1) feeder gate or three (3) rotary valves to gently loosen and precisely meter proppant flow into the receiver section. The bulk FP operating temperature within the feed bin can vary from 538 °C to 550 °C. Due to the combination of high operating temperature and abrasive characteristics of the FP, the steel tank wall will be lined with an inner-most layer of abrasion resistant material, followed by a second layer of high alumina, and a third layer of low weight refractory. The composite refractory serves to limit the inner steel tank wall temperature to no more than 300 °C and minimize thermal losses.

In order to minimize thermal shocking of the falling particle to primary heat exchanger, a second bin or 'startup feed bin' will be provided which bypasses the receiver section and allows the introduction of cooler ceramic media downstream of the hot bin gate feeder and into the primary heat exchanger.

A slide gate valve will be located in the inlet chute upstream in the startup feed bin. It will allow cooler ceramic media to also be sent to the startup feed bin. The slide gate valve will also provide isolation during the normal operating conditions.

A startup feed bin gate feeder will be located below the startup feed bin for flow control. Two slide gate valves will be located below the gate feeder which will allow flow to either the primary heat exchanger or back to the cold bin.

When flow is directed to the primary heat exchanger, the cooler FP will be mixed with the hot FP to ensure proper FP temperature entering the primary heat exchanger.

For the purposes of this concept, the startup feed bin size and refractory requirements will match those of the primary feed bin. The startup feed bin size and refractory requirements will have to be revisited once overall plant startup duration requirements have been finalized.

Table 3-2 Feed Bin and Start-up Feed Bin Design Data

DATA-ITEM	FEED BIN
Operating temperature	538 °C
Operating pressure	Atmospheric
Diameter of shell	2.3 m
Overall height	7 m
Product density	2,000 kg/m^3
Storage capacity/duration	37,575 @ 5 min.
Hopper angle	65 degrees
Free board	1 m
A36 shell plate thickness	15.875 mm (5/8")
A36 shell plate corrosion allowance	1.5875 mm (1/16")
Abrasion layer thickness (1st layer)	25.4 mm (1")
High alumina refractory thickness (2nd layer)	101.6 mm (4")
Low weight refractory thickness (3rd layer)	101.6 mm (4")
Note – Refractory thickness designed as thermal barrier for minimizing heat loss and to limit inner tank wall temperature to 300 °C. Refractory thickness will be finalized after detail design and will be depend on an acceptable daily heat loss rate.	

3.7.1.2 Materials of Construction

The main structural shell of the feed bin will be constructed from ASTM type A36 or A572 Grade 50 shapes and plates. The steel plate forming the cylindrical section will not be less than 15.785 mm

(5/8") thick, which includes an allowance for corrosion of 1.5875 mm (1/16"). The steel tank wall will be lined with a composite layer of refractories consisting of the following layers from the inner-most layer up to the inside of the steel tank wall.

- One (1 inch) abrasion liner at the hot face and anchored within a hex mesh.
- Four (4 inch) high alumina refractory.
- Four (4 inch) low weight refractory.
- An ultra-low K factor liner at the steel shell.

In order to anchor the refractory composite layers to the tank wall, a stainless steel hex mesh anchoring system will be utilized.

3.7.1.3 Issues/Concerns

The hopper angle of 65 degrees has proven adequate for bulk solids such as coal; however, a flow model study should be conducted with the ceramic proppant (e.g., CARBO Accucast ID50-K) to confirm the proper slope for the upper section of the hopper. The hopper angle must be adequate to ensure bulk mass flow throughout the bin. Another factor which can affect feed bin sizing is the choice of lift/hoist system. The feed bin size will be smaller for continuous delivery systems as demonstrated by chain bucket elevators. In contrast, skip hoist delivery systems will take longer to fill the feed bin since the conveyance is a batch process. If the skip capacity cannot be increased, then feed bin size will need to increase proportionately to accommodate the longer skip hoist transit times between charging and discharging. In addition, the increase in feed bin height will also increase the solar tower height.

3.7.2 Falling Particle Receiver

3.7.2.1 Falling Particle Receiver System Description

The falling particle receiver is located below the feed bin and above the hot bin. The receiver configuration comprises a square cavity which has a 5.6 m x 5.6 m aperture opening for receiving concentrated sunlight from several ground-based heliostats. The ceramic media from the feed bin enters the top of the receiver and is guided through slots that will evenly distribute the particle flow as a curtain. The concentrated sunlight will irradiate the curtain and cause the media temperature to rise from 538 °C to 750 °C by the time the media exits the receiver section. At these high temperatures, several layers of refractory and insulation will be required to limit the inner steel tank wall temperature to no more than 300 °C and minimize thermal losses.

3.7.2.2 Materials of Construction

The main structural shell of the receiver will be constructed from ASTM type A36 or A572 Grade 50 shapes and plates. The steel plate forming the receiver section will not be less than 15.785 mm (5/8") thick, which includes an allowance for corrosion of 1.5875 mm (1/16").

Due to the high operating temperature, the receiver wall will be lined with a composite layer of refractories consisting of the following layers from the inner-most layer up to the inside of the steel tank wall.

- One (1") abrasion liner at the hot face and anchored within a hex mesh.
- Four (5") high alumina refractory.
- Four (5") low weight refractory.
- An ultra-low K factor liner at the steel wall.

In order to anchor the refractory composite layers to the receiver walls, a stainless steel hex mesh will be utilized.

3.7.2.3 Issues/Concerns

The main concern with the design of the receiver section is mitigation of wind effects on the falling particle curtain. It is important to maintain particle flow rate and radiance within the receiver where wind effects could cause fluctuations in the curtain, which in turn, affects the amount of heat absorption to the particles. Several options are possible and being investigated by Sandia at NSTTF.

3.7.3 Falling Particle Storage Bins

3.7.3.1 Hot & Cold Storage Bin Descriptions

Hot Bin

The hot storage bin will be located between the receiver section above and the falling particle primary heat exchanger below. During normal operation, heated ceramic particles will leave the receiver section and enter the hot bin at 750 °C. Some of the particles admitted to the hot bin will be forwarded to the falling particle/sCO2 primary heat exchanger below, while the remaining particles slowly collect and fill the hot bin. The hot bin will be sized to accommodate up to four (4) hours of FP or 392,170 kg. The hot bin configuration will consist of the main cylindrical storage bin with a tapered hopper section immediately below. The hopper angle will be at least 65 degrees with respect to the horizontal and the overall bin height to diameter ratio will be 3:1. The overall hot bin height is approximately 14.56 m and includes 1 m of free board. The cylindrical hot bin diameter is 4.85 m. The hot bin hopper exit diameter is 0.61 m. Two options for flow control and metering are possible at the hot bin hopper exit. The transition duct at the hopper exit can be configured with either one (1) gate feeder or one (1) rotary valve to gently loosen and precisely meter FP flow into the falling particle to primary heat exchanger. Similar to the feed bin, the hot bin steel tank wall will require a refractory liner; however, the liner thickness will be increased to accommodate the higher operating temperature of 750 °C. The hot bin design data is shown in Table 3-3.

Table 3-3 Hot Bin Design Data

DATA-ITEM	HOT BIN
Operating temperature	750 °C
Operating pressure	Atmospheric
Diameter of shell	4.85 m
Overall height	14.6 m
Product density	2,000 kg/m^3
Storage capacity/duration	392,170 @ 4 hr.
Hopper angle	65 degrees
Free board	1 m
A36 shell plate thickness	15.875 mm (5/8”)
A36 shell plate corrosion allowance	1.5875 mm (1/16”)
Abrasion layer thickness (1st layer)	25.4 mm (1”)
High alumina refractory thickness (2nd layer)	127 mm (5”)
Low weight refractory thickness (3rd layer)	127 mm (5”)
Note – Refractory thickness designed as thermal barrier for minimizing heat loss and to limit inner tank wall temperature to 300 °C. Refractory thickness will be finalized after detail design and will be depend on an acceptable daily heat loss rate.	

Cold Bin

The cold storage bin will be located directly below the falling particle sCO2 primary heat exchanger. The cold bin serves as a collection reservoir for ceramic media which has given up heat to the falling particle to primary heat exchanger. As a result of the heat rejection, the operating temperature of the cold bin is 538 °C. The cold bin will be sized to accommodate up to four (4) hours of FP or 546,710 kg. The cold bin configuration utilizes a main cylindrical storage bin with a tapered hopper section immediately below. The hopper angle will be at least 65 degrees with respect to the horizontal and the overall bin height to diameter ratio will be 3:1. The overall cold bin height is approximately 16.2 m and includes 1 m of free board. The cylindrical cold bin diameter is 5.42 m. The cold bin hopper exit diameter is 0.61 m. The transition duct at the hopper exit will utilize a sliding gate valve for isolation. During normal operation, the slide gate valve is open to admit ceramic media onto a horizontal conveyor. The horizontal conveyor is located immediately below the cold bin chute and will convey product to the hoist charging station. The friction hoist will lift product to the top of the CSP tower where it discharges into the feed bin and repeats the falling particle cycle. The cold/hot bin steel tank wall will be lined with an inner-most layer of abrasion resistant material, followed by a second layer of high alumina, and a third layer of low weight refractory. The composite refractory serves to limit the inner steel tank wall temperature to no more than 300 °C and minimize thermal losses. The cold bin design data is shown in Table 3-4.

Table 3-4 Cold Bin Design Data

DATA-ITEM	COLD BIN
Operating temperature	538 °C
Operating pressure	Atmospheric
Diameter of shell	5.42 m
Overall height	16.2 m
Product density	2,000 kg/m^3
Storage capacity/duration	546,710 kg @ 4 hr.
Hopper angle	65 degrees
Free board	1 m
A36 shell plate thickness	15.875 mm (5/8")
A36 shell plate corrosion allowance	1.5875 mm (1/16")
Abrasion layer thickness (1st layer)	25.4 mm (1")
High alumina refractory thickness (2nd layer)	101.6 mm (4")
Low weight refractory thickness (3rd layer)	101.6 mm (4")
Note – Refractory thickness designed as thermal barrier for minimizing heat loss and to limit inner tank wall temperature to 300 °C. Refractory thickness will be finalized after detail design and will be depend on an acceptable daily heat loss rate.	

3.7.3.2 Materials of Construction

The main structural shell of the cold and hot bins will be constructed from ASTM type A36 or A572 Grade 50 shapes and plates. The steel plate forming the cylindrical section will not be less than 15.785 mm (5/8 inch) thick, which includes an allowance for corrosion of 1.5875 mm (1/16 inch). Since the cold bin operating temperature nearly matches the feed bin temperature, the cold bin composite refractory liner materials and thickness will be the same as for the feed bin.

- One (1 inch) abrasion liner at the hot face and anchored within a hex mesh.
- Four (4 inch) high alumina refractory.
- Four (4 inch) low weight refractory.
- An ultra-low K factor liner at the steel shell.

Due to the higher hot bin operating temperature, the hot bin tank wall will be lined with a composite layer of refractories consisting of the following layers from the inner-most layer up to the inside of the steel tank wall.

- One (1 inch) abrasion liner at the hot face and anchored within a hex mesh
- Four (5 inch) high alumina refractory
- Four (5 inch) low weight refractory
- An ultra-low K factor liner at the steel shell

In order to anchor the refractory composite layers to the cold/hot tank walls, a stainless steel hex mesh will be utilized.

3.7.3.3 Issues/Concerns

As noted previously, the hopper angle of 65 degrees has proven adequate for bulk solids such as coal, but a flow model study will be necessary to confirm if this hopper angle is sufficient to permit mass flow discharge of ceramic media throughout the cold/hot storage bins. A mass flow pattern prevents rat-holing, allows first-in/first-out flow, and minimizes segregation. Of particular concern is the determination of frictional/shear characteristics for the particle flow of CARBO Accucast ID50-K across the abrasion liner material. The flow model results will provide a basis for prediction of liner erosion rates and replacement schedule for the inner abrasion layer.

Another concern is the integrity of the refractory during transient sun-on and sun-off conditions or any other conditions that cause rapid changes in the refractory temperatures. The refractory-lined steel tank may experience wide variation in temperatures after long periods of shut down. The refractory material must be capable of withstanding rapid heating and cooling conditions which cause temperature gradients within the refractory blocks. The large temperature gradients will cause cracking in the material due to unequal thermal stresses. Thermal shock is one of the most important failure modes of refractory installations. Spalling of the refractory material is where there is a loss in fragments from the face of the brick resulting in cracking and rupture, which ultimately exposes the inner portions of the structural tank wall to the high temperature environment within the bin and refractory particles into the falling particle product.

Therefore, in addition to acting as an abrasion layer and thermal barrier, the refractory must have a low rate of thermal expansion to provide adequate thermal shock resistance. The best defense against causing potential thermal shock is to heat up and cool down the refractory as slowly as possible. From an operational point of view, the preference is to heat up and cool down faster. These two considerations will need to be balanced between reducing downtime versus avoiding damage to the lining. Ramp rates should be determined in future research.

3.7.4 Primary Heat Exchanger – Falling Particle/sCO2 System

3.7.4.1 Primary Heat Exchanger Description

The Primary Heat Exchanger will transfer heat from the falling particle system to the sCO2 system. For this conceptual investigation of the falling particle system, design verification was solicited from Solex Thermal. Solex Thermal is currently implementing the falling particle primary heat exchanger design for Sandia's test system and has provided conceptual details for the 10MWe design consisting of an identical vessel shell and tube arrangement. One (1) 100 percent heat exchanger will be installed for the plant system. This may be a single major point of failure.

The Primary Heat Exchanger will supply 100 percent of the design heat load to the Power Generation System with sCO2 at approximately 716 °C. The maximum design heat load and conditions are provided in the table as follows. All heat exchanger designs will be specified with 10 percent excess surface area installed to account for falling particle fouling. The pressure drop across the sCO2 side will be limited to 20 psi maximum.

Table 3-5 Falling Particle Primary Heat Exchanger

CONDITION	VALUE
Overall Heat Transfer	31.2 MWt
Falling Particle Inlet Temperature	750 °C
Falling Particle Outlet Temperature	538 °C
Falling Particle Flow rate	125.3 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

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. Note that lack of redundancy will mean that failure of this heat exchanger will mean loss of the facility.

3.7.4.2 Materials of Construction

The main heat exchanger material is based on a confidential Solex Thermal design.

3.7.4.3 Suppliers Responses

Babcock & Wilcox (B&W) was contacted to provide concept design details. Based on new company initiatives, B&W will no longer be able to support solar projects with a heat exchanger design and has removed this business line from their offerings.

Vacuum Process Engineering (VPE) was additionally contacted and declined to provide design or cost concepts without development funding. VPE may be further solicited for quotation during detailed design.

Solex Thermal was contacted for design information and pricing. A low cost estimate was used as material selection was driving costs too high.

3.7.4.4 Issues/Concerns

It is expected that thermal stress during start-up will be controlled by heating the sCO2 side at a yet to-be-determined ramp rate, and by parallel use of heat tracing and insulation, followed by introduction of cold particles from the start-up (SU) bin with gradual feed from the hot bin in a separate hot bin feeder. The ramp rate will determine the storage capacity of the SU bin, which will hopefully be as small as 5 minutes of storage, not several hours. A cold sCO2 bypass will be used to control turbine inlet temperatures.

Uniform feed through the falling particle system and especially through the FP/sCO2 primary heat exchanger on the falling particle side is especially important. If there exist any voids or obstructions through the heat exchanger, uneven heating and localized hot spots may occur disrupting the operation and control of the heat exchanger and could also result in catastrophic heat exchanger failures.

Materials for the primary heat exchanger need further study.

3.7.5 Falling Particle Lifting Device

3.7.5.1 Falling Particle Lifting Device Description

Since the falling particle receiver uses ceramic solid particles that are directly heated as they fall through a beam of concentrated sunlight, a lifting device will be required to reintroduce solid particles from the bottom of the CSP tower back to top and repeat the solid particle heat addition (e.g., solar irradiation at the receiver) and heat rejection (e.g., at primary heat exchanger) cycle.

This design concept proposes the use of a ground-mounted friction hoist to vertically transport ceramic media from the charging station at the bottom of the CSP tower to the discharging point above the feed bin. The total vertical lift distance is 74 m. The friction hoist capacity rate is 226 m^3/hr (500 tons/hr). The hoist supplier will provide the drive system and all necessary controls. The lifting device design parameters are shown in Table 3-6.

Table 3-6 Falling Particle Lifting Device

HOIST PARAMETER	VALUE	UNITS
Lifting Distance	74	m
Payload	6,000	kg
Hours Per Day	13	
Days per Month	30	
Length of Wind	84	m
Tons per Hour	555.92	tons/hr

The ceramic media will be transported by the hoist in two refractory-lined Kimberly skips. Since the ceramic media operating temperature within the Kimberly skip will be the same as the cold bin operating temperature of 538 °C to 550 °C, the Kimberly skip will be lined with the same composite refractory system used for the cold bin described under Section 3.7.3.2. The refractory liner in the Kimberly skip will limit the temperature exposure of its steel structure to 300 °C. An outside layer of insulation will be added to the skip to minimize heat losses and for human safety reasons.

3.7.5.2 Materials of Construction

Friction hoist components and materials are considered confidential.

3.7.5.3 Issues/Concerns

After contacting with several bulk material vertical lift suppliers, it appears the friction hoist offers many advantages over other lift systems. With the exception of the Kimberly skip, the remaining hoist lifting components will not be exposed to the high ceramic media temperature. The skip can be adequately insulated to minimize thermal losses and the hoist can easily scale with increasing CSP tower height. The overall design of the friction hoist is simple, can minimize heat losses, product leakage, and demonstrates a reasonably low parasitic electric load. Being a batch process, there was concern the cycle time would be excessive and force a size increase to the feed bin. However, this can be compensated for by increasing the payload capacity of the Kimberly skip.

Traditional chain bucket elevators appear to be limited by the combination of product temperature and lifting height which affects the thermal expansion of the chain itself. Some suppliers can work around this limitation by using an inclined lift, which reduces the chain exposure to high temperatures, and by incorporating exotic refractory-type metals for the rollers, pins and sprockets. After survey of several major bucket elevator suppliers, it appears the upper limit on the bulk material product temperature is 230 °C to 260 °C. This also represents the maximum design temperature for their vertical lifting equipment and components.

The "Olds Elevator" is a type of vertical screw conveyor which can also scale with CSP tower height, can handle high temperature materials (149 °C– 704 °C), and accommodate large thermal expansion between the rotating lift tube and the static screw. Given the CSP tower lift height of 74 m, the "Olds Elevator" must be stacked in five (5) sections (16.5 m each) since the overall lift height is far greater than could be handled in a single stage. The limitation is due to drive train requirements (i.e., available torque from VFD motors) to handle large volumes of falling particle media. One advantage to the "Olds Elevator" over the hoist is the elimination of a horizontal screw conveyor below the cold bin. With the "Olds Elevator", the cold bin feeds directly by gravity into the "Olds Elevator" feed hopper via a 45 degree angle chute. Since the "Olds Elevator" must be staged, this requires a dedicated VFD motor to power each stage along with associated controls to monitor flow rate, including level sensors. The "Olds Elevator" becomes more complicated as lift requirements increase and parasitic electric load grows as well. The "Olds Elevator" motor requirement totals 1000 HP (746 kW) for the 5 lifting stages (200 HP each). In comparison, the hoist has a peak load of 589 kW under the same lift height of 74 m.

3.7.6 Falling Particle Control Gates and Valves

Various valves were reviewed. A confidential feeder, not a rotary valve, was ultimately adapted to minimize FP size reduction.

Sliding Gate Valves - A sliding gate valve will be located in the transition duct between the cold bin above and the horizontal screw conveyor below. The purpose of this valve will be to provide isolation of the cold bin ceramic media during times of tank/conveyor servicing and maintenance. During normal operation the gate valve is 100 percent open, and will permit a ceramic media flow rate of 225 cubic meters per hour. The operating temperature of the sliding gate valve is 538 °C. The valve operating pressure above and below the valve is atmospheric.

A sliding gate valve is located in the startup feed bin supply chute and is designed to permit a ceramic media flow rate of 225 cubic meters per hour during startup. The operating temperature of the sliding gate valve is 538 °C . The operating pressure above and below the valve is atmospheric. During normal operation the startup feed bin sliding gate valve is closed. Due to concerns with thermal shocking of the falling particle to primary heat exchanger during startup, the sliding gate will be 100 percent open to permit cooler ceramic media to collect in the startup feed bin. By collecting cooler ceramic media in the startup feed bin, the receiver section is temporarily bypassed and the cooler ceramic media is gradually mixed with the efflux from the hot bin.

Two slide gate valves will be located below the startup feed bin gate feeder which will allow flow to either the primary heat exchanger or back to the cold bin. The operating temperature of the sliding gate valve is 538 °C. The operating pressure above and below the valve is atmospheric.

Feed Bin Rotary Valves (Optional) – A rotary valve can also be used in place of the gate feeder, but is considered as an option since the rotary valve can potentially damage the ceramic media. During normal operation, three (3) rotary valves located in the transition duct at the feed bin hopper exit will be used to gently loosen and precisely meter proppant flow into the receiver section. Three valves were selected to provide an even distribution of particle flow entering the receiver section. For the rotary valves located at the feed bin exit, each valve will operate at 18 RPM and dose up to 75 cubic meters per hour of product. The rotary valve uses a standard chain drive system and 3 HP motor. Each rotary valve has a displacement of 2.4 ft^3/rev at 80 percent pocket fill. The operating temperature of the rotary valve is 538 °C. The operating pressure above and below the rotary valve is atmospheric.

Hot Bin Rotary Valve (Optional) – One (1) large rotary valve is located in the transition duct at the hot bin hopper exit to gently loosen and precisely meter proppant flow of falling particle into primary heat exchanger. This rotary valve will operate at 18 RPM and dose up to 225 cubic meters per hour of product. The rotary valve uses a standard chain drive system and 10 HP motor. The rotary valve has a displacement of 7.76 ft^3/rev at 80 percent pocket fill. The operating temperature of the rotary valve is 750 °C. The operating pressure above and below the rotary valve is atmospheric.

3.7.7 Falling Particle Make-up and Storage Plant

Truck Unloading Area - Ceramic product will be delivered by truck and typically unloaded by using a pneumatic blower mounted on the supplier's truck. The truck mounted blower unit will be usually too small to unload product within a reasonable time of 45 minutes to an hour. In order to reduce the unloading time, a 125-150 HP permanent blower unit will be installed in the unloading area to work in conjunction with the truck blower unit to pneumatically convey product to the falling particle makeup bin.

Falling Particle Makeup Bin - The falling particle makeup bin is located in the falling particle unloading area and will provide long term storage of ceramic media or 22,624 kg (50,000 lb). This is also the typical weight carried by one (1) semi-tractor trailer. The replacement schedule for CARBO Accucast ID50-K is based on 2 percent particle replacement over two (2) years. The daily replacement rate is 170 kg/day (375 lb/day). Therefore, one (1) semi-tractor trailer load would be required to completely fill the falling particle makeup bin after 133 days of operation. The falling particle makeup bin configuration utilizes a main cylindrical storage bin with a tapered hopper section immediately below. The hopper angle will be at least 65 degrees with respect to the horizontal and the overall bin height to diameter ratio will be 3:1. The overall falling particle makeup bin height is approximately 5.88 m and includes 1 m of free board. The cylindrical falling particle makeup bin diameter is 1.96 m. The falling particle makeup bin hopper exit diameter is 0.61 m. Since the falling particle makeup bin stores raw ceramic media and is located outside, the operating temperature will be at ambient conditions.

The main structural shell of the falling particle makeup bin will be constructed from ASTM type A36 or A572 Grade 50 shapes and plates. The steel plate forming the cylindrical section will not be less than 15.785 mm (5/8") thick, which includes an allowance for corrosion of 1.5875 mm (1/16").

Table 3-7 Falling Particle Makeup Bin Design Data

DATA-ITEM	FP MAKEUP BIN
Operating temperature	Ambient
Operating pressure	Vented to Atmosphere
Diameter of shell	1.96 m
Overall height	5.88 m
Product density	2,000 kg/m^3
Storage capacity/duration	22,624 kg @ 133 days
Hopper angle	65 degrees
Free board	1 m
A36 shell plate thickness	15.875 mm (5/8")
A36 shell plate corrosion allowance	1.5875 mm (1/16")

Falling Particle Makeup Feed Screw Conveyor - The falling particle feed screw conveyor will transport stored media in the falling particle makeup bin to the suction point of the lifting device. The screw conveyor feed rate would transport approximately 13 kg/hr product, assuming 13 hour sun-on operation per day, appears to be too low to justify the cost of use in this application. In addition to the screw conveyor cost would be costs for the VFD drive motor, drive components and associated controls. This replacement metric is based on the assumed particle loss rate of 10 percent over two (2) years operation and would need to be confirmed in detail design.

Double Dump Valve - A double dump valve will be installed at the end of the falling particle makeup feed screw conveyor to act as an air lock against the hotter ceramic media located at the suction of the lifting device. Since the ceramic media coming from the Falling Particle Makeup Bin is stored under ambient temperatures, a double dump valve will act as a thermal barrier to minimize heat (i.e., 538 °C media in suction lift device) transferring back into the makeup feed conveyor.

FP Makeup using Super Sacks (Optional) - By using an assumed particle replacement schedule of 2 percent particle loss over a two (2) year period amounts to approximately 170 kg/day (375 lbs/day) loss rate or product replacement rate. This replacement rate is low enough to manually dose the cold bin in lieu of using a complete makeup system comprising the components listed above (e.g., falling particle makeup bin, blower fan, falling particle feed screw conveyor and double dump valve). The bags can be purchased in bulk, depending on desired days of backup storage, and stored in the falling particle bag storage area until required for dosing. Particles can be manually added to the cold bin at the top or inlet near top or side. Particles can be added during down time or during operation by gradual dosing to prevent thermal shock. Super sacks are made of polypropylene and can hold as much as 900 kg of ceramic media. One 900 kg super sack would provide over 5 days of particle replacement. Super sacks are designed to be leak-proof and double zippered to keep the product dry.

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 BOP System Descriptions.

3.8.1 Water Treatment Systems

The Water Treatment Systems will be designed to produce demineralized water that can be used for heliostat cleaning. Potable water, service water, and fire water are also produced for their various purposes.

3.8.1.1 Water Mass Balance

Refer to the Water Mass Balance Diagram 042839-WMB-0002 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 59 gpm.

3.8.1.2 rWater 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 59 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.

3.8.1.3 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.

3.8.2 Compressed Air

The service and instrument 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 Falling Particle areas with risers supplying headers at grade level and at each platform elevation.
- On the pipe rack platform and underneath the pipe rack.
- 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 ¾ inch size.

Large service air supply headers will be 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 pre-filter 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.

3.8.3 Carbon Dioxide System

A carbon dioxide supply system will be furnished to supply carbon dioxide gas to the sCO_2 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.

3.8.4 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 (1) 100 percent horizontal diesel driven main fire water pump.
- One (1) 100 percent electric driven main fire water pump.
- One (1) 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 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.

3.8.5 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 be 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.

3.9 FALLING PARTICLE OPERATION AND CONTROLS

3.9.1 Operating Philosophy

The conceptual design is based on the ability to generate sun-on power for approximately 13 hours per day and sun-off power at a rate of 4 hours utilizing stored hot ceramic media in the hot bin. During the sun-off mode, the stored energy within the ceramic proppant will also be used to generate power.

3.9.2 Operations

3.9.2.1 Start-up with the Hot Bin Empty

In order to minimize thermal shocking of the falling particle to primary heat exchanger, a second startup feed bin will be provided to temporarily bypass the receiver section and therefore introduce cooler ceramic media by blending with the ceramic efflux from the hot bin. A sliding gate valve will be located in the startup feed bin inlet chute to admit and collect cooler ceramic media during startup and also provide isolation during normal operating conditions. In parallel with bypass/blending, the number of heliostats concentrating sunlight on the receiver section will gradually increase. Moreover, the rotary valves or the gate feeder, will provide mass flow control between the hot bin and the falling particle to primary heat exchanger.

Start-up Sequence:

- Startup slide gate valve opens to fill startup feed bin with ambient product while startup feed bin gate feeder is closed.
- Primary feed bin is also filled with ambient product.
- The number of heliostats concentrating sunlight on receiver section is gradually increased.

- The feed bin gate feeder or rotary valve(s) is adjusted to properly dose the receiver section to maintain proper curtain flow.
- Hot bin gradually fills with heated product.
- Superheated CO_2 system and piping is warmed up (e.g., electrical heat tracing) and ready to initiate CO_2 flow through primary heat exchanger at approximately 550 °C simultaneously with initiation of FP flow.
- The hot bin gate feeder is adjusted to properly dose the primary heat exchanger to maintain a full FP moving pack.
- The startup bin gate feeder gradually doses ambient FP through a bypass chute that blends and mixes with the hot FP at the bottom of the hot bin.
- Startup slide gate valve closes and startup bin FP gradually depletes and blending commences.
- All heliostats in the field concentrate sunlight on receiver section.

3.9.2.2 Shutdown

During the power down phase, the falling particle system will utilize the startup feed bin to gradually bypass the receiver section by blending cooler ceramic media with the hot bin efflux material during the heliostat defocus period (e.g. 30 seconds). This process must be gradual in order to minimize thermal shocking to the falling particle to primary heat exchanger. Once the number of heliostats concentrating sunlight on the receiver section decreases to zero, material will be bypassed to the cold SU bin and stored for later use in sCO2 cycle operation. Additional mass flow control is provided by adjusting the falling particle flow rate via the rotary valve or the gate feeder. During long term shutdowns, falling particles may be stored in the cold bin or falling particle makeup bin, with the hot bin inventory dumped (and cooled by sCO2) to the cold bin. If work is required on the cold bin, particles can be stored in the upper feed bins or the hot bin.

Shutdown Sequence:

- The number of heliostats concentrating sunlight on receiver section is gradually decreased.
- Startup slide gate valve opens to fill startup feed bin with 538 °C product while startup feed bin gate feeder is closed.
- Once startup feed bin is full the startup feed bin gate feeder gradually opens to dose 538 °C proppant through a bypass chute that blends and mixes with the 750 °C proppant at the bottom of the hot bin.
- Startup slide gate valve closes and startup bin proppant gradually depletes and blending commences.
- All heliostats in the field are no longer engaged.

4.0 Project Schedule

The Falling Particle 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.

Note that project agreements, e.g., for land, power purchase, grid interconnection and O&M will need to be finalized prior to FNTP.

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 two 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 four months after LNTP. The schedule assumes that the AHJ will approve the grading plans within two 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 sCO_2 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 Full Notice to Proceed (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.

5.0 Capital Cost Estimate

5.1 GENERAL SITE ASSUMPTIONS

5.1.1 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 an average length of 25 feet.
- 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.
- Underground conduits are routed from the engineered documents indicating which power feeders would have underground direct buried conduit routed to the electrical equipment noted on the schedule and as noted on the one-line diagram, Drawing 042839-SE-E1001, Rev. B
- Site and building lighting are accumulated in a line item. The costs noted for lighting in the estimate includes all site and building lighting fixtures, conduit, cable, miscellaneous lighting hardware, labor and trenching.
- Control cables for the facility are accumulated in a one-line item for each site. The costs noted for control cables in the estimate includes all wiring, conduit, terminations and labor for all control cabling from 33kV/4160V Electrical Switchgear, protective relay panel routed and installed.
- All major electrical equipment quantities were accounted for in this estimate from the 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 feet x 20 feet split in two sections, and installed on site. The PDC building will be elevated above grade on steel members. Cable trays will be installed on the underside of PDC building to feed the power, control and instrument cables from site to the PDC 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 how many approximate quantities of heat trace circuits to be installed on site. For accumulating bulk materials an average length was used for these circuits. Approximate average length for cable was 65LF to 75LF and for conduit was 50LF to 60LF was used for each individual HT circuit. Cable terminations were also accounted for from this same list with circuit quantities.

- 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 these 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 feet from the PDC Building to the 400A field power panels.

5.1.2 Civil/Structural Qualifications 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.

5.1.3 Mechanical and Piping Qualifications and Clarifications

- Pipe quantities were provided in BOQs from the design engineers.
- Man-hours for the pipe were based on typical California Union estimates.
- Remaining BOQ pipe was priced based on recent similar pipe pricing.
- 100 percent NDE testing was assumed on the entire Haynes 230 pipe.
- Equipment was estimated based on PFDs and the GAs.
- Equipment man-hours were based on standard rates.

5.1.4 I & C Qualifications and Clarifications

- PFD BOQs were supplied by engineering.
- Hand stations for motor operation from the MCC at local locations.
- Conveyor system has 8 emergency pull cords and 12 plugged chute detectors.
- Scale system includes 4 weigh elements, 1 weigh indicator and 1 weigh transmitter all supplied by the vendor.
- For process tubing, 40 linear feet is used for single users.
- Indicating devices are assumed mounted remote from process pipe.

5.1.5 CMCI Qualifications and Clarification

- Role: CMCI included as management only.
- Base: 50-hr work week.
- Mobilization Date: 4/2/2018, or as per the schedule subject to change.
- Site Security including security staff, guard houses, fence modifications, etc. has been included.
- Environmental, Health and Safety Management has been included.

5.2 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 the cost estimate.
- 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.

5.3 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	$524,000	$225,000	$380,000	$0	$1,129,000
Foundations & Concrete	$858,000	$693,000	$1,394,000	$0	$2,945,000
Buildings	$0	$0	$1,829,000	$0	$1,829,000
Steel	$700,000	$1,968,000	$0	$0	$2,668,000
Mechanical					
Process & Mechanical Equipment	$889,000	$19,787,000	$8,664,000	$0	$29,340,000
Piping & Piping Specials	$770,000	$3,669,000	$150,000	$0	$4,596,000
Electrical & Control					
Electrical Equipment	$226,000	$5,439,000	$0	$0	$5,664,000
Electrical Bulks	$1,681,000	$954,000	$3,000	$0	$2,638,000
Instrument Equipment	$167,000	$437,000	$0	$0	$605,000
Instrument Bulks	$208,000	$113,000	$0	$18,000	$339,000

DESCRIPTION	LABOR TOTAL	MATERIAL TOTAL	SUB CONTRACT	CONSTRUCTION EQUIPMENT	TOTAL
Insulation	$24,000	$693,000	$0	$0	$717,000
Solar					
Heliostats	$0	$0	$10,221,000	$0	$10,221,000
sCO2 Piping and Piping Special	$1,341,000	$27,912,000	$0	$0	$29,252,000
sCO2 Mechanical Equipment	$658,000	$16,739,000	$0	$0	$17,397,000
Construction Management	$2,278,000	$930,000	$0	$0	$3,208,000
Construction Indirects	$0	$42,000	$0	$276,000	$318,000
Head Office & Engineering Services	$3,528,000	$0	$0	$0	$3,528,000
CM Labor Burden	$912,000	$0	$0	$0	$912,000
US Payroll Burden	$2,472,000	$0	$0	$0	$2,472,000
Procurement Payroll Burden	$353,000	$0	$0	$0	$353,000
Subcontractor Markup	$12,013,000	$0	$0	$0	$12,013,000
				Total	**$132,144,000**

6.0 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 estimated as a percentage of capital cost for each asset. The applied percent of capital was as such;
  - Convention Assets is 2 percent/yr
  - First-of-Kind Assets is 4 percent/yr
- Material Damage, breakdown, and Business Interruption insurance costs based on equipment purchase and installation costs.
- Labor rates based on expected Daggett, CA labor rates.

6.1 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 operator, 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 and 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 (may not be needed depending on water treatment system deployed). 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 6-1 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	6	$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

RESPONSIBILITY	PER SHIFT	SHIFTS	TOTAL	ANNUAL BASE WAGES	TOTAL LOADED ANNUAL EXPENSE
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**

6.2 O&M COST ESTIMATE

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 6-2 Annual Fixed O&M Estimate

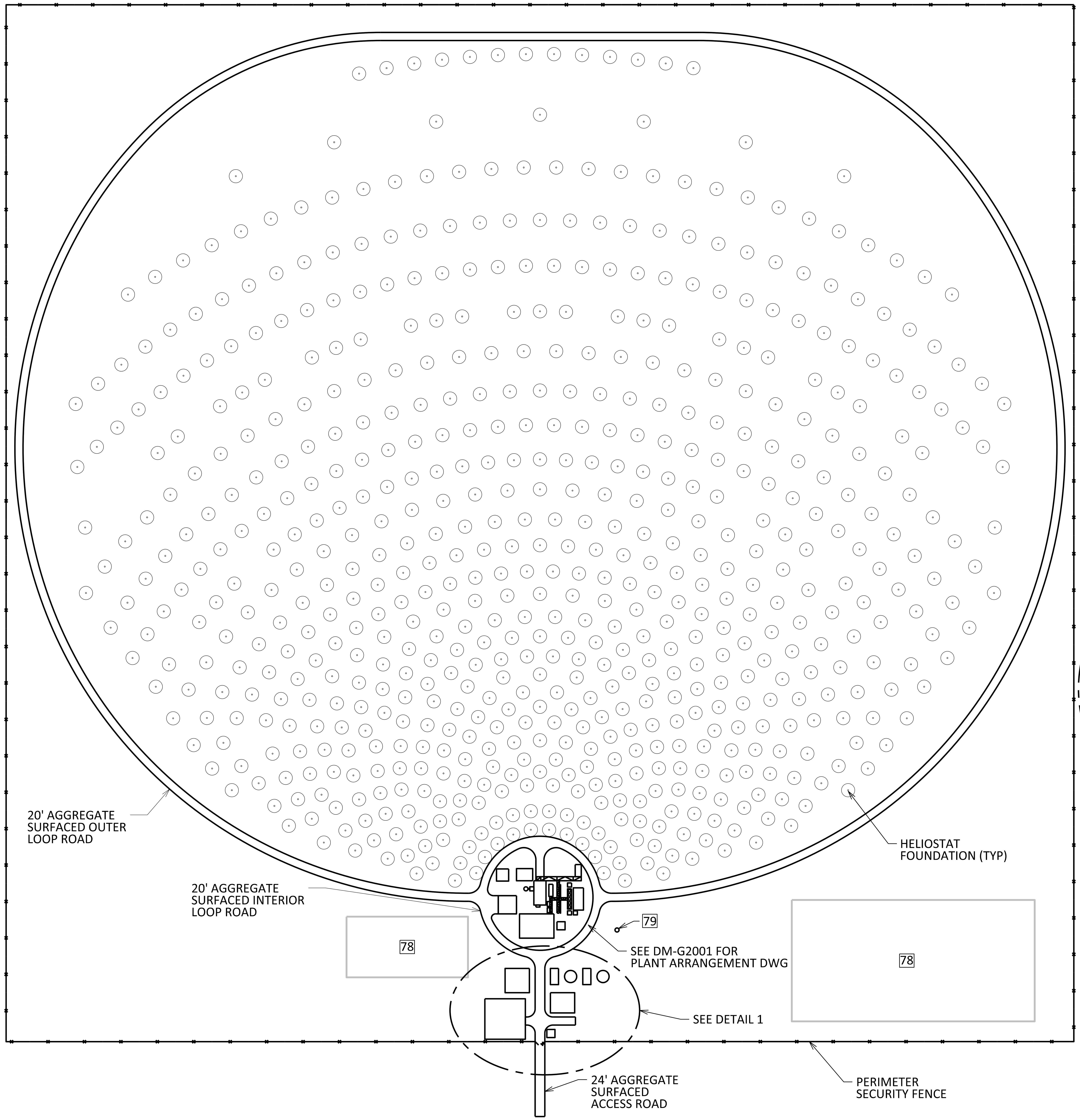
O&M COSTS	USD/1000
Site Labor	$3,170
Site Specific Training	$40
General Site Purchases	$250
Insurance	$760
Total	**$4,220**

Table 6-3 Annual Variable O&M Estimate

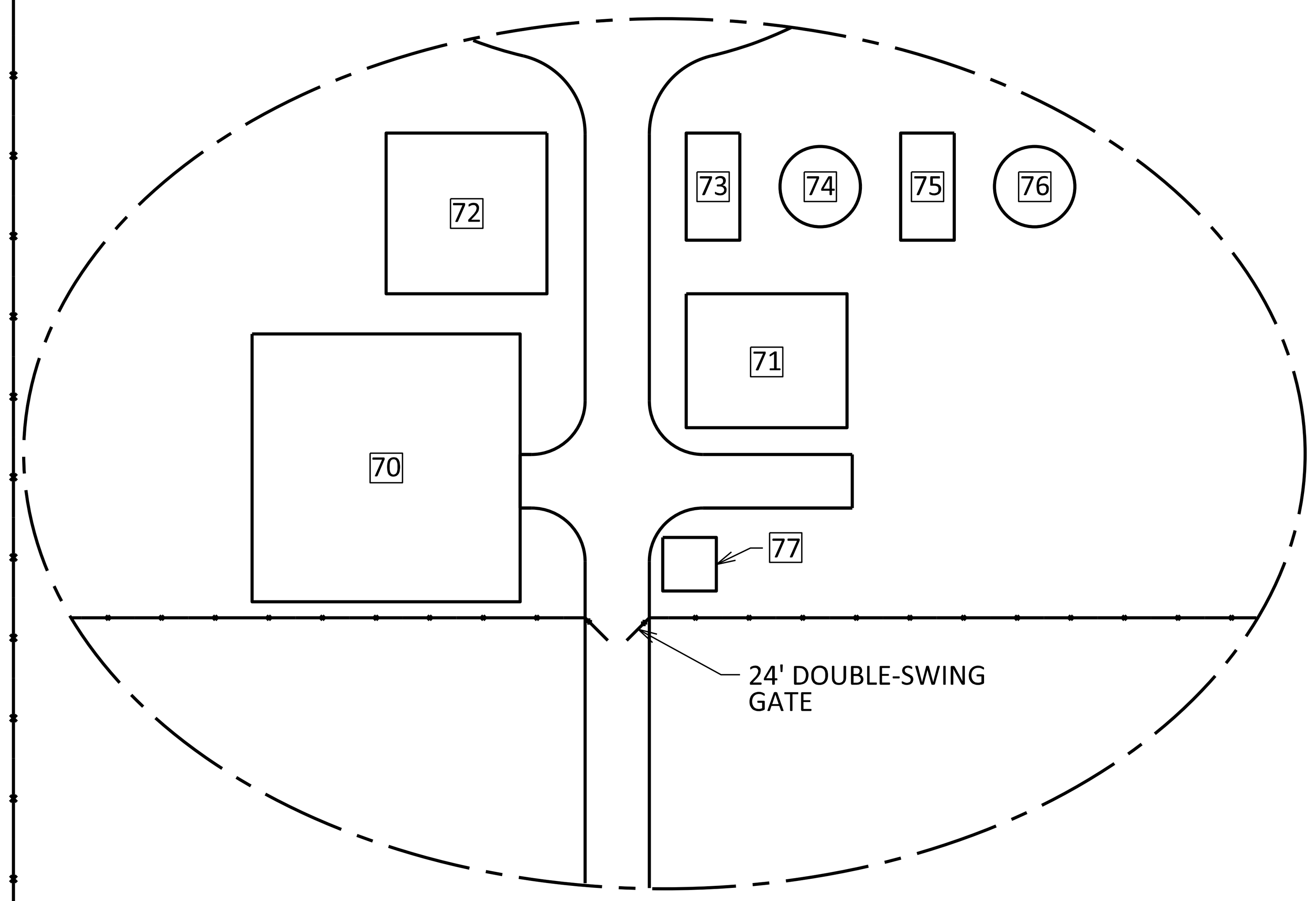
ANNUAL VARIABLE O&M COSTS	USD/1000
Maintenance	$2,050
Total	$2,050

Appendix A. Site Arrangement

ID	FALLING PARTICLE
70	HELIOSTAT ASSEMBLY BUILDING
71	WATER TREATMENT BUILDING
72	HELIOSTAT ASSEMBLY AREA
73	DEMIN PUMP SKID AND SUNSHADE
74	DEMIN TANK
75	SERVICE/FIRE WATER PUMP SKID AND SUNSHADE
76	SERVICE/FIRE WATER TANK
77	SECURITY GATE HOUSE
78	EVAPORATION POND
79	TERMINAL 33kV RISER POLE
80	STORM WATER DETENTION AREA



FALLING PARTICLE SITE ARRANGEMENT
SCALE: 1"=150'



DETAIL 1
SCALE: 1"=50'

150' 75' 0 150' 300'
1"=150'

N

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C	24/JUN/16	ISSUED FOR CLIENT REVIEW	MJP	MJP		JRB	
B	13/JUN/16	ISSUED FOR CLIENT REVIEW	MJP	MJP		JRB	
A	27/MAY/16	ISSUED FOR IN HOUSE REVIEW	MJP	MJP		JRB	

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SIGNED
DATE REG NO.

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DESIGNER MJP | DRAWN MJP
CHECKED JRB | DATE

DOE SUNSHOT
FALLING PARTICLE SITE ARRANGEMENT

PROJECT DRAWING NUMBER 042839-DM-G1001 REV C
CODE
AREA

MicroStation v8.11.9.578 1 = 1
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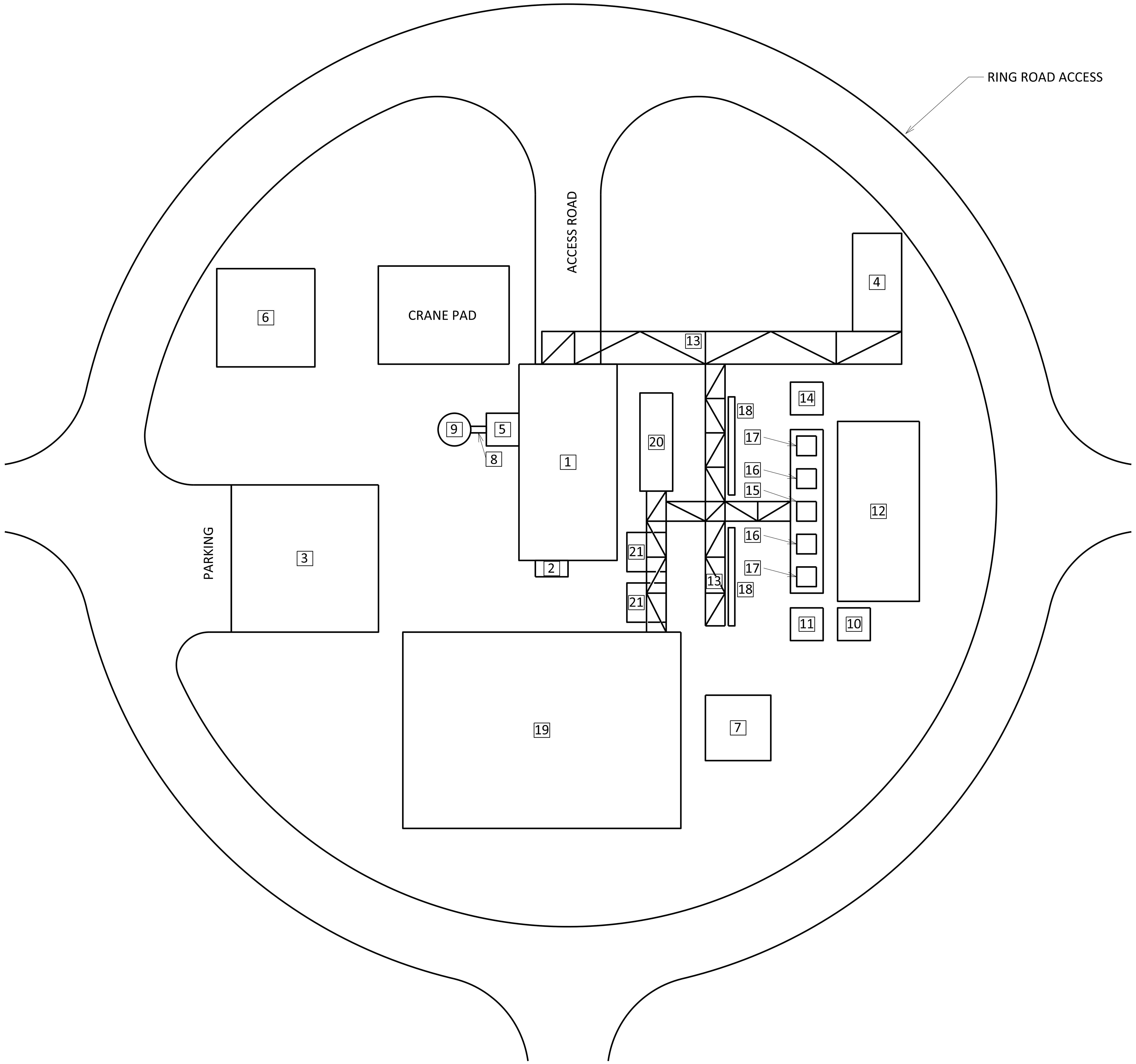
Appendix B. Plant Arrangement



FALLING PARTICLE PLANT ARRANGEMENT
SCALE: 1"=20'

EQUIPMENT IDENTIFICATION LIST

ID	(FP-FALLING PARTICLE)
1	CONCENTRATED SOLAR POWER TOWER
2	ELEVATOR
3	ADMINISTRATION/CONTROL BUILDING
4	COMPRESSED AIR EQUIPMENT
5	FP LIFTING DEVICE
6	FP BAG STORAGE AREA
7	CO2 STORAGE
8	FP MAKEUP FEED SCREW
9	FP MAKEUP BIN
10	GENERATOR STEP UP TRANSFORMER 1
11	AUXILIARY TRANSFORMER
12	POWER DISTRIBUTION
13	PIPE RACK
14	GENERATOR STEP UP TRANSFORMER 2
15	SCO2 TURBINE
16	SCO2 GEAR
17	SCO2 GENERATOR
18	SCO2 RECOUPERATORS
19	SCO2 PRECOOLER
20	SCO2 COMPRESSORS
21	SCO2 COMPRESSOR VFD

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B	13/JUN/16	ISSUED FOR CLIENT REVIEW	PDA	DAA		SMA	
A	27/MAY/16	ISSUED FOR IN HOUSE REVIEW	PDA	SMA		SMA	

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DATE REG NO.

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DESIGNER SMA | DRAWN PDA
CHECKED | DATE

DOE SUNSHOT

FALLING PARTICLE
PLANT ARRANGEMENT

PROJECT | DRAWING NUMBER 042839-DM-G2001 | REV C

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AREA

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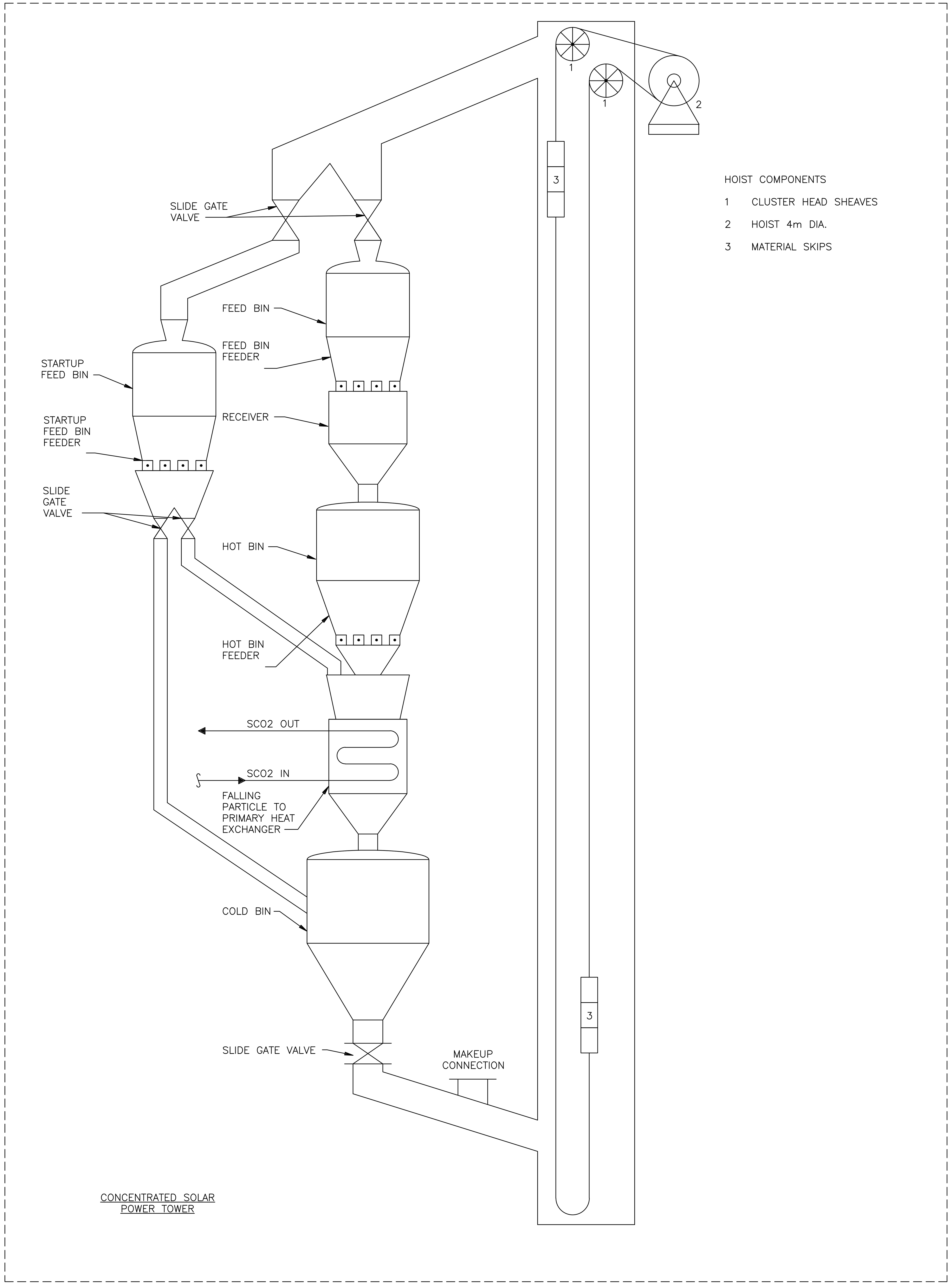
Appendix C. Process Flow Diagrams

NOTES:

1. THIS DRAWING IS FOR PROPOSAL USE ONLY AND IS SUBJECT TO REVISION AS A RESULT OF DETAIL DESIGN.



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DATE XX REG NO. XX

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ENGINEER DAA | DRAWN PDA
CHECKED | DATE

DOE SUNSHOT
FALLING PARTICLE

PROCESS FLOW DIAGRAM
BINS & PRIMARY HEAT EXCHANGER

PROJECT / DRAWING NUMBER: 042839–DM–M2022

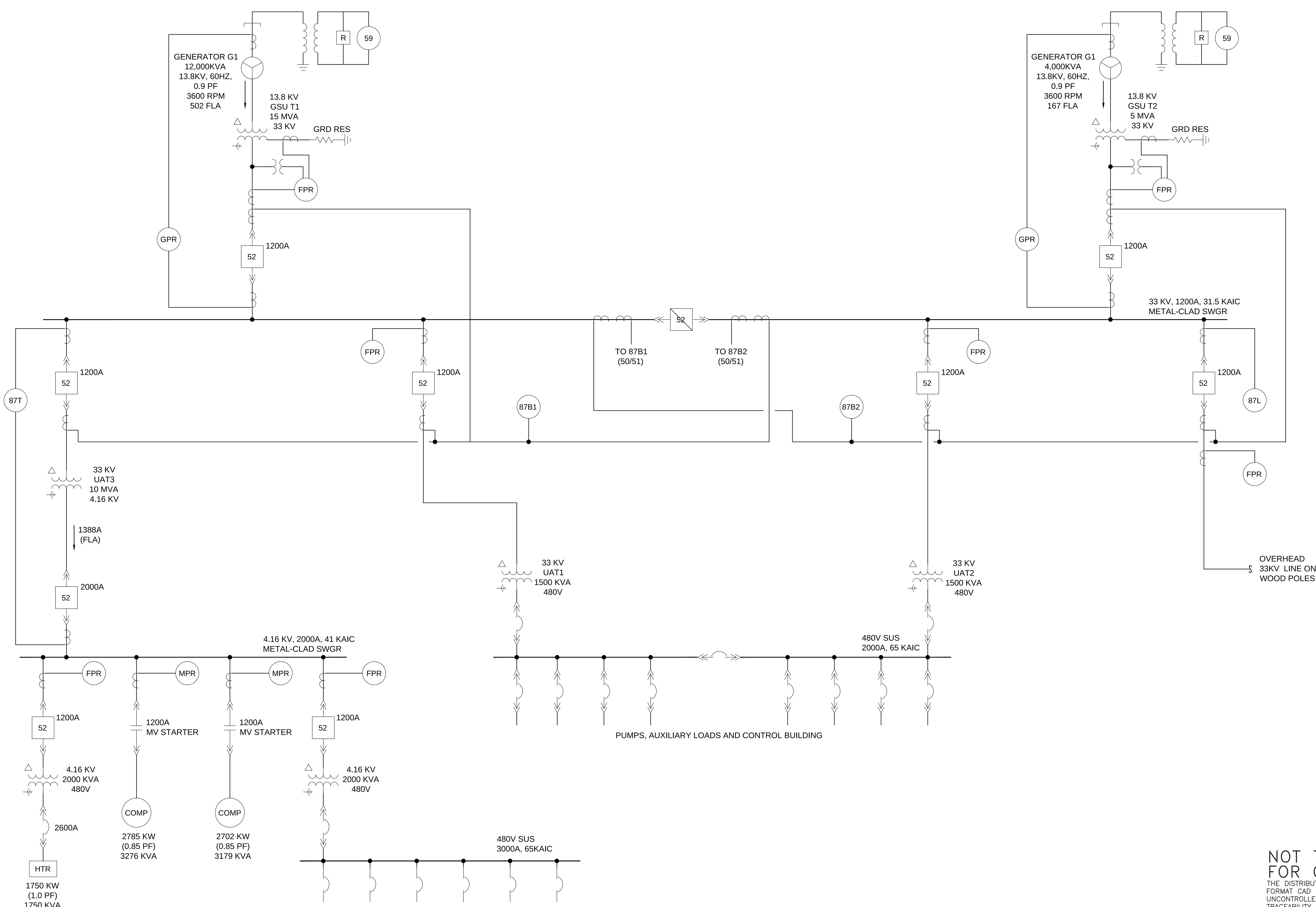
REV: A

CODE

AREA

ARM00099 A1ASL015 06/30/16 D1 1=1 06:54:24 ACAD 18.2s (LMS Tech)

Appendix D. Electrical One-line



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A	27/MAY/16	ISSUED FOR IN HOUSE REVIEW	SEL	PAS		–	–

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DATE XX REG NO. XX

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ENGINEER PAS | DRAWN SEL
CHECKED | DATE

DOE SUNSHOT
FALLING PARTICLE

33–4.16 KV
ONE–LINE DIAGRAM

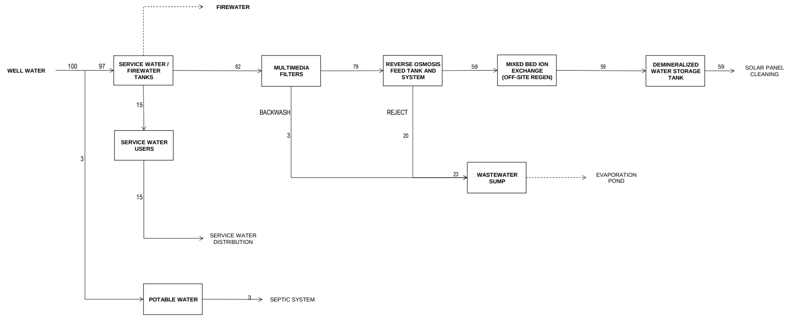
PROJECT | DRAWING NUMBER | REV
042839–SE–E1001 | | B

CODE

AREA

ARM00099 A1ASL015 05/26/16 09:44:23 D1 1=1 ACAD 18.2s (LMS Tech)

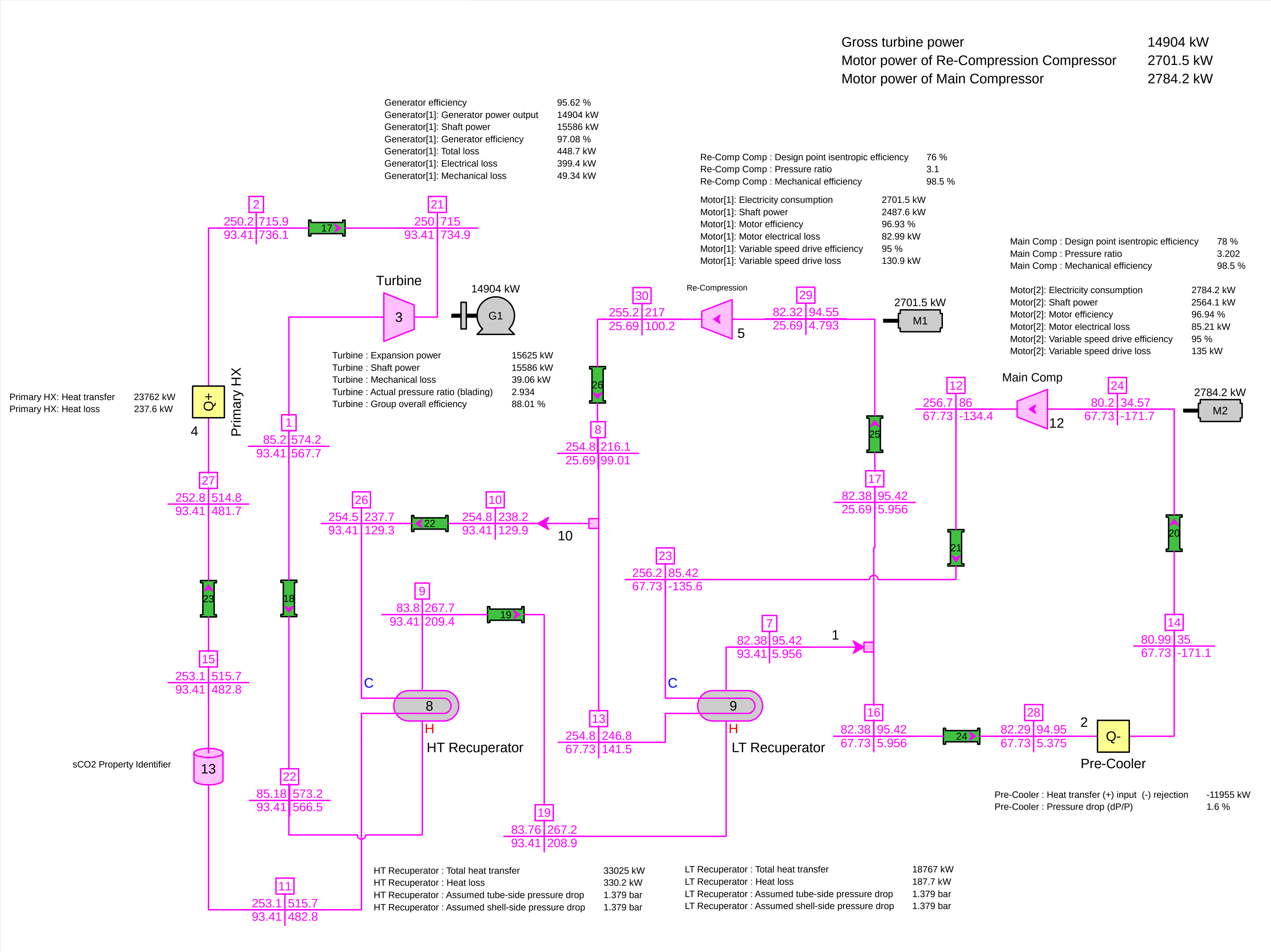
Appendix E. Water Mass Balance Diagram



NOTE:			MULTIMEDIA FILTER YIELD	96.0%	BLACK & VEATCH	**DOE**	**Project**	**Drawing Number**	**Rev**
1. FLOWS ARE IN GALLONS PER MINUTE (GPM).			REVERSE OSMOSIS YIELD	75%		**Sunshot**	**042839**	**WMB-0002**	**A**
2. DASHED LINE INDICATES NORMALLY NO FLOW.						Water Mass Balance			
3. ALL FLOWS ARE BASED UPON DAILY AVERAGES.					Eng: AEH Dwg: AEH	Falling Particle			
					Check: DAA Date: 6/21/2016	042839-WMB-0002			

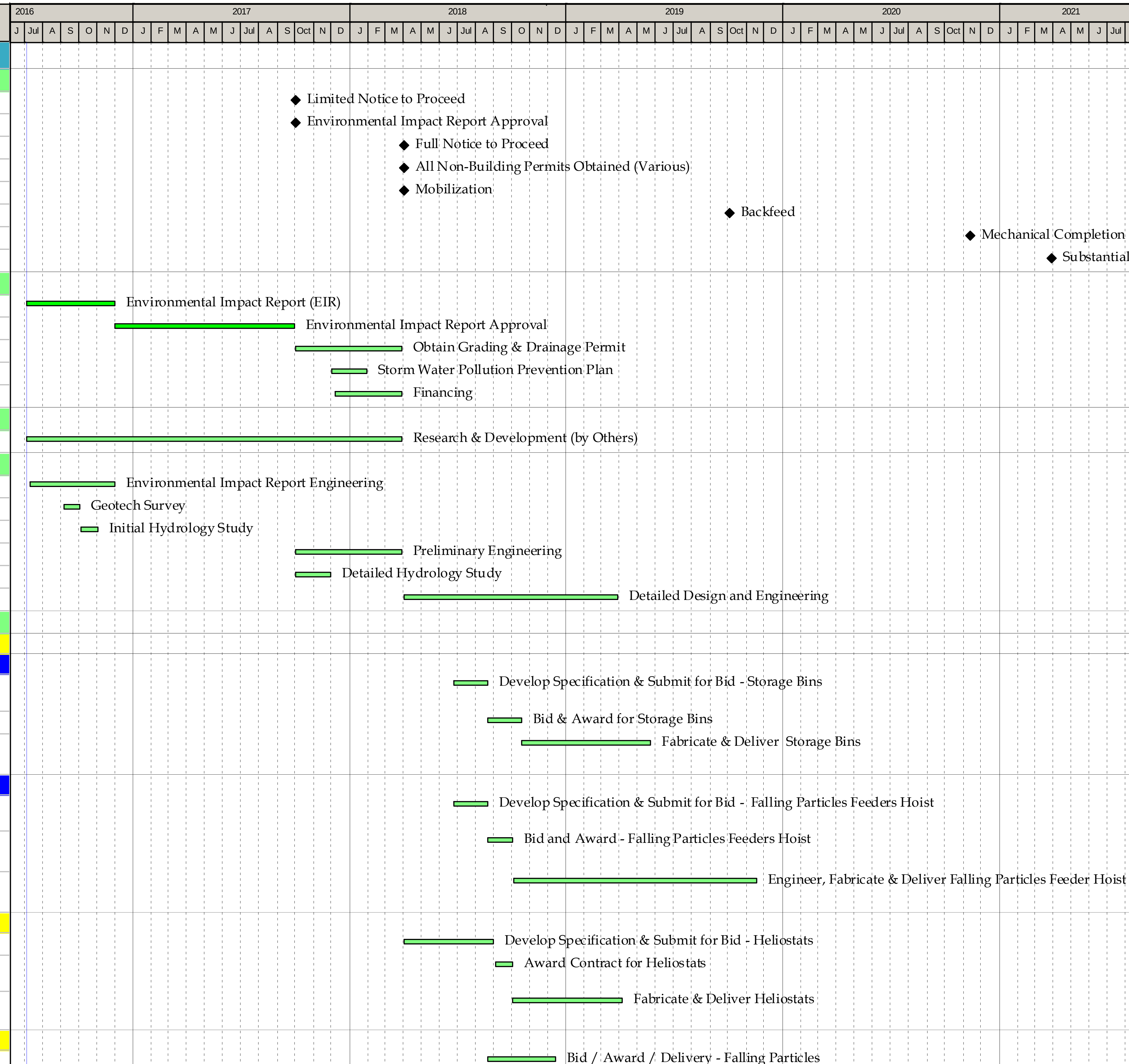
Appendix F. sCO2 Heat Balance Diagram

bar | C
kg/s | kJ/kg



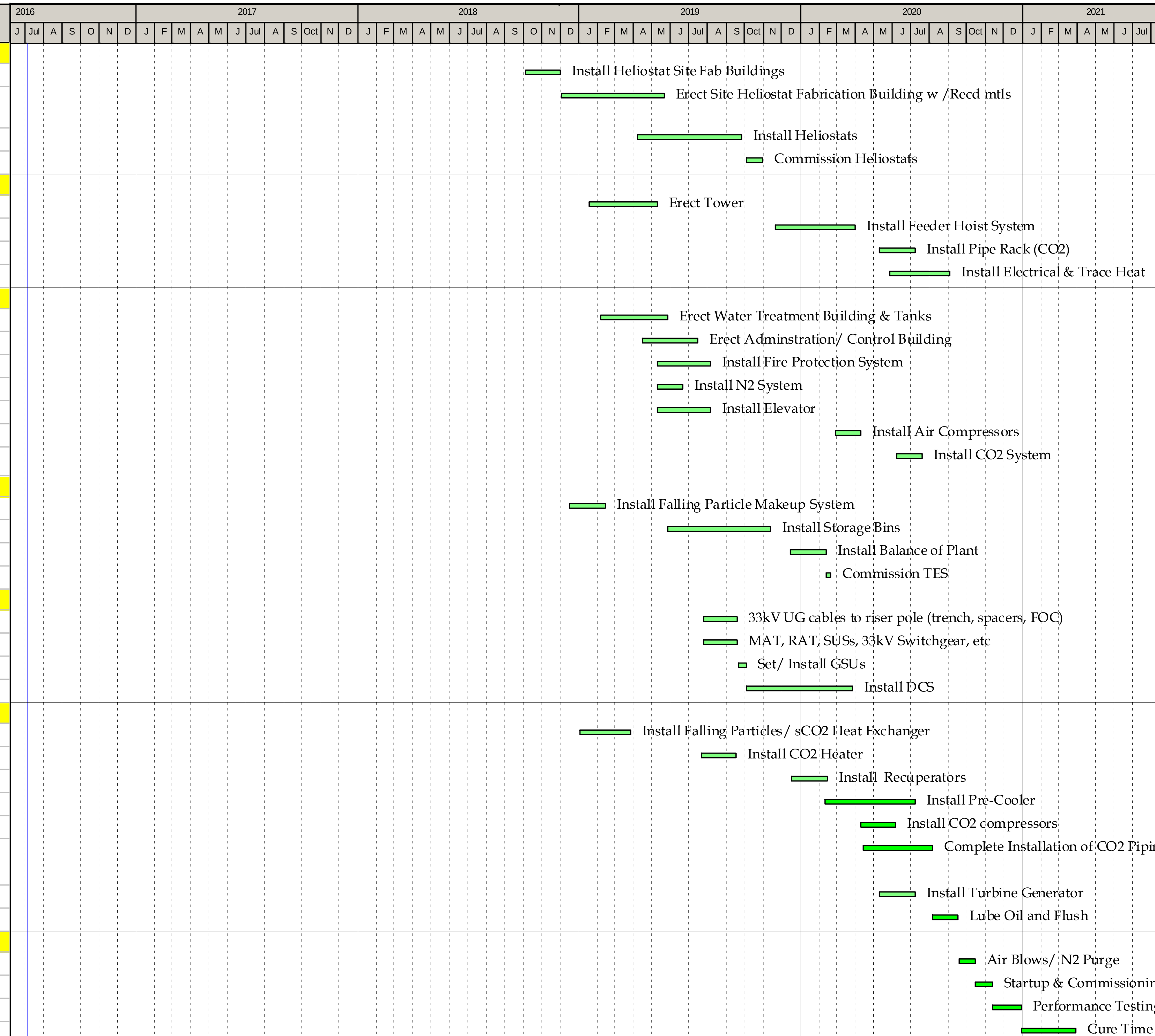
Appendix G. Project Schedule

#	Activity Name	Duration	Start	Finish
1	**Falling Particle 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-Nov-20
10	Substantial Completion	0d		30-Mar-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	**Storage Bins & Feeders**			
29	Develop Specification & Submit for Bid - Storage Bins	40d	26-Jun-18	21-Aug-18
30	Bid & Award for Storage Bins	40d	22-Aug-18	17-Oct-18
31	Fabricate & Deliver Storage Bins	152d	18-Oct-18	24-May-19
32	**Feeder Hoist System**			
33	Develop Specification & Submit for Bid - Falling Particles Feeders Hoist	40d	26-Jun-18	21-Aug-18
34	Bid and Award - Falling Particles Feeders Hoist	30d	22-Aug-18	03-Oct-18
35	Engineer, Fabricate & Deliver Falling Particles Feeder Hoist	286d	04-Oct-18	19-Nov-19
36	**Heliostats**			
37	Develop Specification & Submit for Bid - Heliostats	108d	02-Apr-18	31-Aug-18
38	Award Contract for Heliostats	21d	04-Sep-18	02-Oct-18
39	Fabricate & Deliver Heliostats	128d	03-Oct-18	05-Apr-19
40	**Falling Particles**			
41	Bid / Award / Delivery - Falling Particles	80d	22-Aug-18	14-Dec-18



#	Activity Name	Duration	Start	Finish
42	**Tower & Pipe Rack Steel**			
43	Develop Specifications - Tower & Pipe Rack Steel	30d	01-May-18	12-Jun-18
44	Bid / Award - Tower & Pipe Rack Steel	30d	13-Jun-18	25-Jul-18
45	Develop Specification & Submit for Bid - Elevator	20d	26-Jun-18	24-Jul-18
46	Award Elevator Contract	20d	25-Jul-18	21-Aug-18
47	Fabricate & Deliver - Tower & Pipe Rack Steel	120d	26-Jul-18	17-Jan-19
48	Fabricate and Deliver - Elevator	100d	22-Aug-18	16-Jan-19
49	**sCO2**			
50	**Turbine Generator and Compressors**			
51	Develop Specification & Submit for Bid - Turbine Generator, compressors	30d	02-Oct-17	10-Nov-17
52	Bid and Award - TG, Compressors	44d	13-Nov-17	17-Jan-18
53	Engineering for Turbine Generator & CO2 Compressors	120d	18-Jan-18	06-Jul-18
54	Fabricate / Deliver TG	445d	09-Jul-18	09-Apr-20
55	Fabricate / Deliver CO2 compressors	445d	09-Jul-18	09-Apr-20
56	**Pre-Cooler and CO2 Compressors**			
57	Develop Specification & Submit for Bid - Pre-Cooler and CO2 Heater	20d	05-Mar-18	30-Mar-18
58	Bid and Award - Pre-Cooler and CO2 Heater	30d	02-Apr-18	11-May-18
59	Engineering of Recuperators (by Supplier)	44d	14-May-18	16-Jul-18
60	Fab / Deliver CO2 Heater	300d	14-May-18	19-Jul-19
61	Engineering of Pre-Cooler	63d	14-May-18	10-Aug-18
62	Fab / Deliver Recuperators	360d	17-Jul-18	17-Dec-19
63	Fab / Deliver Pre-Cooler	266d	13-Aug-18	29-Aug-19
64	Spec/ Bid/ Award CO2 System	60d	18-Oct-18	16-Jan-19
65	**Water Treatment & Fire Protection/ BOP**			
66	Bid / Award / Fab / Deliver - Water Treatment (Extg well)	120d	13-Aug-18	04-Feb-19
67	Spec/ Bid/ Award N2 System	60d	18-Oct-18	16-Jan-19
68	Fab / Deliver Piping, Valves, BOP	120d	05-Feb-19	24-Jul-19
69	Bid / Award - Fire Protection Contract	60d	05-Feb-19	29-Apr-19
70	**Electrical Controls**			
71	**GSU**			
72	Bid / Award / Fab / Deliver - GSUs	280d	13-Aug-18	19-Sep-19
73	**DCS**			
74	Bid / Award / Eng / Fab / Deliver - Controls / DCS	240d	27-Aug-18	07-Aug-19
75	Bid / Award / Eng / Fab / Deliver - Administration/ Control Building	120d	23-Oct-18	15-Apr-19
76	**Construction & Commissioning**			
77	Mobilize	10d	02-Apr-18	13-Apr-18
78	Earthworks/ Underground Utilities	120d	16-Apr-18	03-Oct-18
79	Drilled piers	125d	07-May-18	31-Oct-18
80	Place Foundations	80d	06-Sep-18	02-Jan-19

#	Activity Name	Duration	Start	Finish
81	**Heliostats**			
82	Install Heliostat Site Fab Buildings	40d	04-Oct-18	30-Nov-18
83	Erect Site Heliostat Fabrication Building w /Recd mtls	120d	03-Dec-18	22-May-19
84	Install Heliostats	120d	08-Apr-19	25-Sep-19
85	Commission Heliostats	20d	04-Oct-19	31-Oct-19
86	**Tower & Pipe Rack Steel**			
87	Erect Tower	80d	18-Jan-19	09-May-19
88	Install Feeder Hoist System	90d	20-Nov-19	31-Mar-20
89	Install Pipe Rack (CO2)	40d	11-May-20	07-Jul-20
90	Install Electrical & Trace Heat	70d	28-May-20	03-Sep-20
91	**Blance of Plant**			
92	Erect Water Treatment Building & Tanks	80d	05-Feb-19	27-May-19
93	Erect Adminstration/ Control Building	63d	16-Apr-19	15-Jul-19
94	Install Fire Protection System	60d	10-May-19	05-Aug-19
95	Install N2 System	30d	10-May-19	20-Jun-19
96	Install Elevator	60d	10-May-19	05-Aug-19
97	Install Air Compressors	30d	28-Feb-20	09-Apr-20
98	Install CO2 System	30d	08-Jun-20	20-Jul-20
99	**Thermal Energy Storage (TES)**			
100	Install Falling Particle Makeup System	40d	17-Dec-18	13-Feb-19
101	Install Storage Bins	120d	27-May-19	13-Nov-19
102	Install Balance of Plant	40d	16-Dec-19	12-Feb-20
103	Commission TES	5d	13-Feb-20	19-Feb-20
104	**Electrical & Controls**			
105	33kV UG cables to riser pole (trench, spacers, FOC)	40d	25-Jul-19	19-Sep-19
106	MAT, RAT, SUSs, 33kV Switchgear, etc	40d	25-Jul-19	19-Sep-19
107	Set/ Install GSUs	10d	20-Sep-19	03-Oct-19
108	Install DCS	120d	04-Oct-19	26-Mar-20
109	**sCO2**			
110	Install Falling Particles/ sCO2 Heat Exchanger	60d	03-Jan-19	27-Mar-19
111	Install CO2 Heater	40d	22-Jul-19	16-Sep-19
112	Install Recuperators	40d	18-Dec-19	14-Feb-20
113	Install Pre-Cooler	105d	10-Feb-20	07-Jul-20
114	Install CO2 compressors	40d	10-Apr-20	05-Jun-20
115	Complete Installation of CO2 Piping, Valves, Insulation, Heat Tracing, BOP Electrical	80d	14-Apr-20	05-Aug-20
116	Install Turbine Generator	40d	11-May-20	07-Jul-20
117	Lube Oil and Flush	30d	06-Aug-20	17-Sep-20
118	**Startup & Commissioning**			
119	Air Blows/ N2 Purge	20d	18-Sep-20	15-Oct-20
120	Startup & Commissioning	20d	16-Oct-20	12-Nov-20
121	Performance Testing/ Reliability	30d	13-Nov-20	30-Dec-20
122	Cure Time	63d	31-Dec-20	30-Mar-21



Falling Particle Integrated Systems

Run Date: 21-Jun-16 Rev.1