2010

MODEL THERMAL OUTPUT OF SOLAR FIELD

Pacific Light & Power's

LOCATION:

- Latitude: 21º 57' 58.24" N
- Longitude: 159º 41' 29.63" W.

937000-PLP1-GEN-01-GEN-007

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1. SCOPE

The aim of this document is to establish the proposal for a Solar Thermal Field design and CSP engineering support in initial development of a 10 MW Kauai facility.

The initial project scope of work entails:

- Solar Field Layout utilizing the Albiasa Trough (AT-150) on the selected site.
- Optimal Solar Field design and associated generation with allocation for power block & Optimal amount of TES.

Thermal energy generation estimate, “8760” table, for MWht coming from Albiasa solar field with de maximum hours of TES that can be practically implemented at the site for a typical meteorological year on 3Tier weather data.

2. LOCATION

The location of the project is on the island of Kauai, State of Hawaii, with the coordinates:

- Latitude: 21º 57’ 58.24” N
- Longitude: 159º41’29.63” W.

Figure 1: Location of the Kauai project, courtesy Google Earth

3. ASSOCIATED DOCUMENTS

The following documents are an integral part of this specification:

- New Typical Meteorological Year of Kauai realiced by Albiasa Solar based on data provided by 3TIER "KAUAI.tm2".
- Results 31 Loops & 2 TES for Kauai rev P1 (New DNI 2027).xlsx

4. SOLAR FIELD LAYOUT

The solar field layout for the Kauai Project is composed of a solar field with a potential maximum of 31 loops with a row spacing of 15.5 meters with a thermal energy storage system of the 2 hours. The size of the solar field of the project was optimized for revenue (production) as advised by the project promoter Pacific Light & Power. Typically this optimization results in higher amounts of dumped energy from the solar field. The loops are those that appropriately balanced the field. It is assumed that each loop consists of four 150 meter length Albiasa Trough (AT-150) collector assemblies each with an effective collector area of 817.5 m^2.

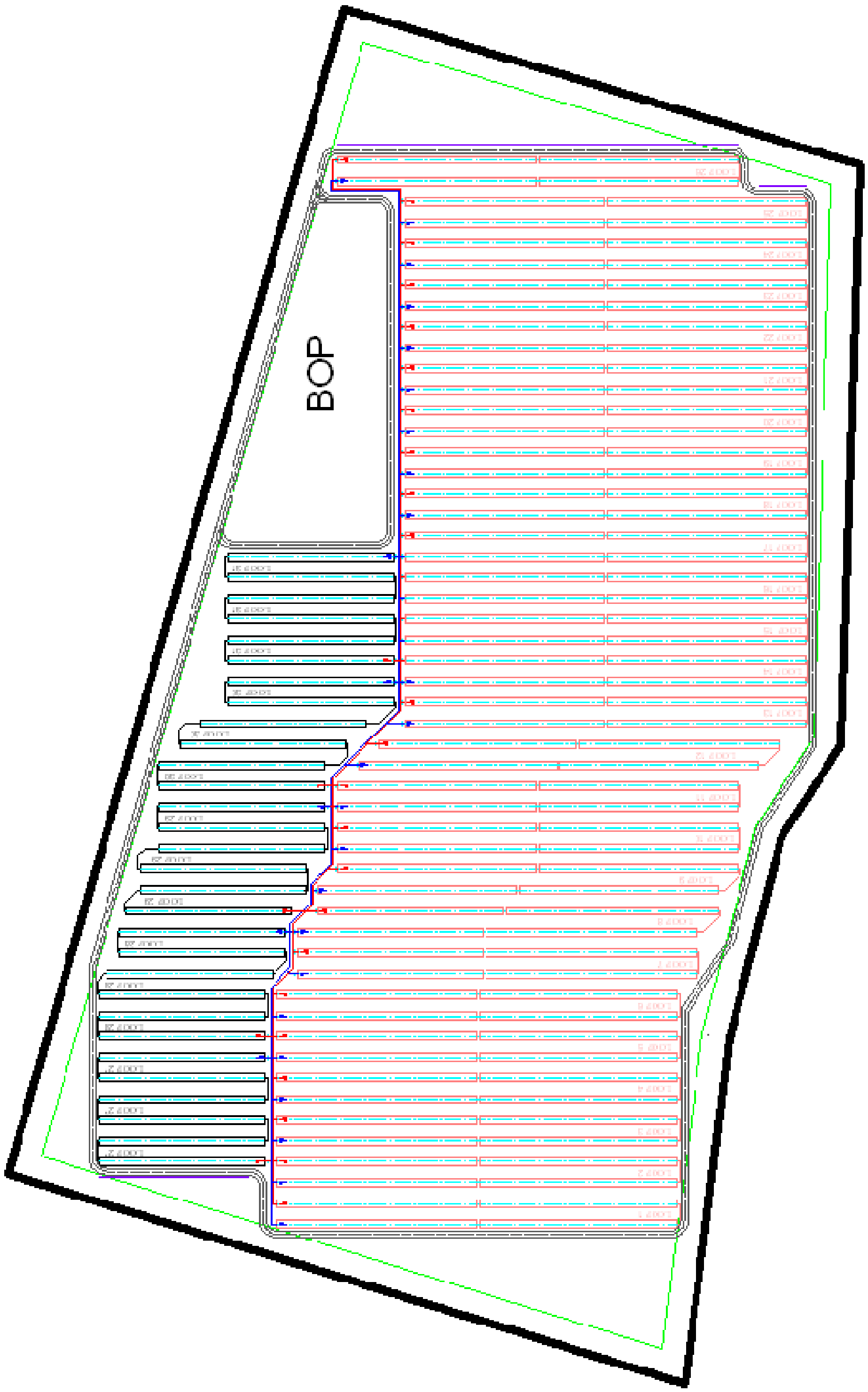


Figure 2: Kauai Solar Field Layout

5. PLANT CONFIGURATION

A solar thermal plant can be broken down into five interlinked principal subsystems:

- The Solar Field
- The Heat Transfer Fluid (HTF) system
- The Power Block
- The Thermal Energy Storage (TES) system.
- The Cooling Water system

5.1. SOLAR FIELD

The elemental unit of the solar field is a parabolic trough solar collector module, which for this project it is assumed to be the Albiasa Trough. Each module is approximately 12 meters long and consists of the following components:

- Supporting Foundations
- Supporting pylons
- Space frame/ribs and torque tube
- Parabolic mirrors mounted on the frame
- Coupling joints
- Heat collector element (HCE) located axially along the mirror focal point

Figure 3: Prototype Albiasa Trough, located in the Plataforma Solar of Almeria (PSA)

The Albiasa Trough collector is composed of 12 modules that are rigidly connected in series to form a solar collector array (SCA). Each module comprises 28 parabolic mirror panels, 7 along the horizontal axis between pylons and 4 in a vertical cross-section. Each mirror is supported on the structure at four points on its backside. This permits the glass to bend within the range of its flexibility without effect on the focal point.

Each SCA is driven by a hydraulic drive system to allow it to track the movement of the sun throughout the day.

As part of the Albiasa Trough design, there are four SCA’s per loop. The exact number of loops and their arrangement are determined by site specific design factors and optimized according to the available solar radiation, gas usage limits, amount of thermal energy storage as well as taking into account financial considerations.

Table 1: : Albiasa Trough with Flabeg[1] Mirrors	
Focal Length	1.71 m
Absorber Radius	3.5 cm
Aperture Width	5.76 m
Aperture Area	817.5 m^2
Collector Length	148.5 m
Number of Modules per Drive	12
Number of glass Facets	336
Number of Absorber Tubes	36
Mirror Reflectivity	93% [2]
[1] Subject to further verification form supplier	
[2] Subject to purchase agreement with the vendor	

Field loops are connected in parallel to common inlet and outlet headers to form a solar field. The loops are oriented in a north-south direction, thereby allowing the SCA's to track the sun as it traverses the sky from east to west. The distance between adjacent rows of SCA's is 15.5 meters.

A critical component of the collector is the UVAC 2008 receiver from Solel. The UVAC incorporates glass to metal seals and metal bellows in order to achieve the vacuum tight enclosure. The vacuum enclosure serves primarily to reduce heat losses at the high operating temperatures. The cermet selective coating has an absorptivity higher than or equal to 0.96 for direct beam solar radiation and a design emissivity of lower that 0.1 at 400 °C. The outer glass enclosure has an anti-reflective coating on both surfaces with transmisivity higher than or equal to 96.5%.

Table 2: UVAC 2008 Design[1]	
Length of Stainless Steel Tube	4060 +/- 1mm
Outer Diameter of Stainless Steel Tube	70 +/- 0.3 mm
Equivalent Aperture Length	≥ 95.7 %
Glass Tube Outer Diameter	115 mm +/- 3mm
Weight	~23 kg
Coating	Sputtered, Selective
Absorptive Factor	≥ 0.96
Emissivity Factor	< 0.10 at 400° C
Operating Temperature	Up to 400° C
Transmisivity of Coated Glass Envelope	≥ 96.5% coated along glass aperture
Abrasion Resistance	Pen Test − 50 strokes
Vacuum	To ensure minimum heat loss due to convection and conduction < 10^{-3} mbar
Residual Gas Pressure	< 10^{-4} mbar
[1] Subject to further verification form supplier	
[2] Subject to purchase agreement with the vendor	

The overall optical efficiency is based on the parameters of the Albiasa Trough and the UVAC receiver. An overall cleanliness factor has been incorporated as well which accounts for the mirror cleanliness and the amount of dust on the receiver envelope. The cleanliness factor assumes the proper operation and maintenance strategy for regular cleaning of the solar field. A proper strategy is based on an economic optimization of plant performance and the necessary operation and maintenance costs.

5.2. HEAT TRANSFER FLUID SYSTEM

The Heat Transfer Fluid (HTF) System is designed to transfer the thermal energy collected in the solar field to the power block in order to generate steam for driving the steam turbine.

The HTF is pumped through the solar field by several main HTF pumps. The flow rate is primarily controlled by the solar field outlet temperature, which during normal operation is held at 391° C. In the event of low insolation, the flow rate is reduced to maintain the solar field outlet temperature. Conversely, during periods of insolation higher than the design point, once HTF flow is at its maximum, the SCA's may be defocused to ensure that the field outlet temperature does not exceed 391ºC.

At the outlet of the solar field, the HTF flows to the heat exchanger train, where the HTF flow is divided. The heat exchanger train consists of four separate heat exchangers; super-heater, steam-generator and pre-heater arranged in series, and a re-heater arranged in parallel to the first three. The HTF leaves the heat exchangers at 290ºC and from there flows to the expansion vessel.

From the expansion vessel, the HTF returns to the HTF pump intake and is recirculated through the solar field.

In periods of minimal or no insolation, a small auxiliary HTF pump is available to maintain low levels of HTF flow through the system. This pump is typically used in conjunction with the HTF heater.

The gas-fired HTF heater is used for several purposes:

- To maintain HTF temperature above its solidification temperature (about 13 ºC) during spells of cold weather (antifreeze protection).
- To provide a "boost" to HTF heating during morning startup.
- To supplement solar thermal output during periods of low solar insolation.

The ullage system is intended to condense and collect HTF vapor and noncondensable degradation gases forced from the expansion vessel during field warm-up, and vented from high points in the HTF system. The system also delivers nitrogen gas to maintain a positive pressure in the HTF system during field shutdown.

5.3. POWER BLOCK (STEAM CYCLE)

For large scale systems the solar thermal industry has selected the condensing steam Rankine cycle as its preferred design. Temperatures above 500 ºF are typical. The Nevada Solar One project, for example, operates at steam temperature near 700 ºF. The steam plant design contains several factors that diminish its cost effectiveness and/or environmental stewardship:

- Steam Condenser: Steam power plants are usually water cooled with a wet cooling tower. Cooling by air is very expensive due to the very high specific volume of steam.
- Steam Turbine: Condensing steam turbines in the 10 MW class are large in diameter expensive, and require years of manufacturing lead time. The latter has the effect of adding cost to the project by not being able to produce power earlier.
- Off-Dessign. As the sun rises the plant heats up, the steam turbine inlet valve remains closed until the steam reaches full temperature and pressure. Standard steam plant practice is to wait for the steam to reach near design superheated conditions before opening the inlet valve to being operation. The solar insolation that reaches the collectors during non-peak periods is not converted to power resulting in loss of generated energy and plant revenues.
- Steam Plant Operating Cost: A fully condensing high temperature steam plant is expensive to operate because of the need to keep the water very clear, free of oxygen (air), and to maintain a deep vacuum at the exit of the turbine.

The Organic Rankine Cycle (ORC) is much better suited to air cooling, does not operate in vaccum, uses smaller turbines requiring shorter lead times and is less expensive to operate. The ORC also overcomes the off-design problem by being able to operate at part load vapor conditions- The RPI STIC system combines the best features of steam and ORC.

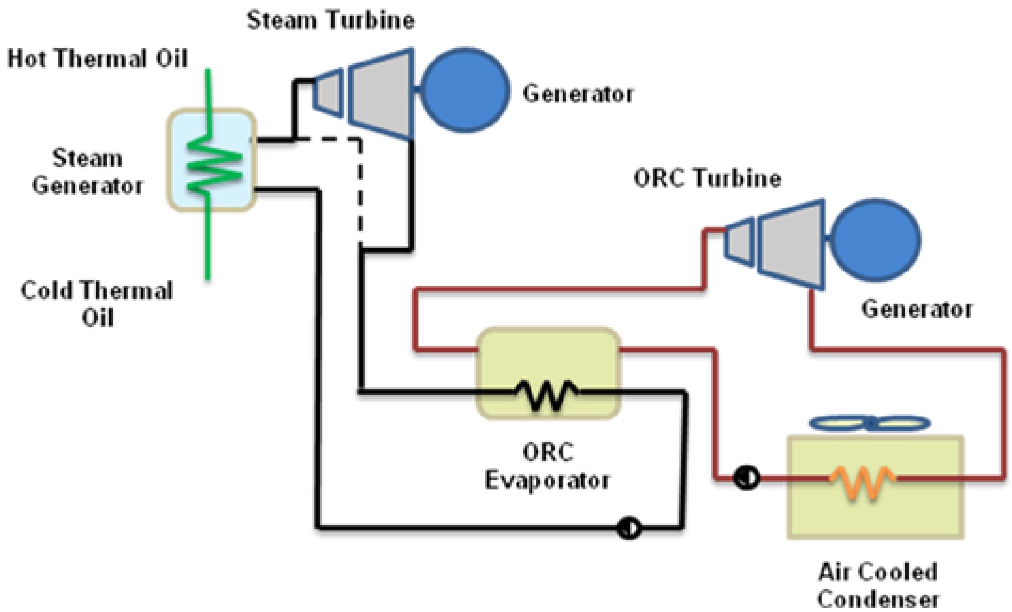


Figure 4: ORC Schematic

The system is comprised of a steam boiler, back pressure steam turbine, followed by an ORC including with air cooled condenser. The result is a power system having the following benefits:

- High peak cycle temperature and high thermal efficiency,
- Ability to generate power during morning and evening warm-up and shut down periods,
- Smaller more compact and lower cost air cooled condenser, and
- Shorter delivery lead times for back pressure turbine (no condensing stages).

5.4. PRINCIPAL OPERATING MODES

5.4.1. GENERAL

The proper mode of operation will depend on a number of parameters:

- The existing state of the plant when the mode is commenced:
  - Whether all plant systems are available for operation.
  - Whether the systems of the plant are in hot, warm or cold states.
- The projected operating conditions:
  - Whether the insolation will be sufficient to sustain 100% STG load.

  - Whether TES charging will be employed, and if so, whether the TES will reach its maximum capacity or the maximum charging rate that will necessitate dumping at some later stage.
  - What the subsequent operational mode will be (for example, moving from solar to TES discharge, or discharge to solar, or hybrid).
  - Whether the plant will enter an idle state for an extended period.
- Any operational imperatives from the local electrical authority.

The selection of the appropriate operational mode is therefore a decision that will need to be made on a daily basis (often several times a day), subject to a variety of parameters, and within certain considerations which will be discussed in this document.

5.4.2. SOLAR MODE

Plant efficiency is maximized when operating at 100% solar mode. Therefore, it is always preferable to run the STG at 100% and store any excess energy in the TES, rather than the opposite.

On days of good insolation, typically the STG will be operated at 100% and the TES will be charged at whatever rate is permitted using any residual thermal energy from the solar field.

However, towards the end of a day, the level of insolation will begin to drop, and there will no longer be sufficient energy absorbed by the solar field to run both the STG and charge the TES. In most cases, the plant will then begin to operate in TES/Solar hybrid mode (discussed below), whereby the TES system discharge is commenced in parallel with normal solar mode.

In certain instances, it may be required to delay TES discharge. In such cases, towards the end of a day the plant will remain in solar mode with ever reducing STG load.

However, at a certain point (TBD during basic engineering phase), the STG efficiency will drop to a level where, even after considering the added TES in/out parasitics and reduced thermal efficiency, it will becomes more advantageous to stop the STG and direct all remaining thermal energy from the solar field to the TES for later discharge at a higher efficiency than running the STG at partial load (- this assumes that the TES is not already fully charged).

5.4.3. TES CHARGING MODE

The TES system and HTF system are designed to facilitate charging of the TES within a period of 3 hours. However, on days when an extended period of high insolation is expected, it may be feasible to reduce the charging rate. Charging the TES system over a longer period involves reducing the HTF rates. This, in turn, reduces the pressure losses in these systems and consequently the specific parasitic energy consumption (parasitic energy consumed per MWh of energy stored).

It is calculated that thermal losses from the TES system will be between 0.5 and 1.5 MW, subject to ambient conditions, which represents a loss of between 0.06 and 0.2% of heat stored per hour. These losses can be mitigated to some degree through over-charging the system. A one degree increase in HTF temperature in the storage tanks represents an additional 1% of thermal energy- or approximately 8 hours of thermal losses from the TES system.

The marginal benefit of these operations will have to be fully assessed at a more advanced phase of the engineering effort once all performance characteristics of the plant systems are known.

5.4.4. TES DISCHARGING MODE

TES discharge should be done as soon as possible after charging to minimize thermal losses and degradation in the thermal energy available for discharge.

TES discharge should always be done at full discharge rate to ensure maximum efficiency.

5.4.5. *HYBRID OPERATION – SOLAR/TES MODE*

Typically towards the end of a day, the level of insolation will begin to drop, and there will no longer be sufficient energy absorbed by the solar field to run both the STG and charge the TES. In most cases, the plant will then begin to operate in TES/Solar Hybrid Mode.

The plant control system shall be designed to enable a smooth transition from 100% Solar Mode to 100% TES Discharge Mode. The transitional state is Solar/TES Hybrid

Mode. However, it should be noted that this mode will occur not only at the end of a day, but possibly during periods of intermittent sunshine, when the TES system alternate between TES Charging Mode and TES Discharging Mode to supplement fluctuating solar field output.

In general, it can be stated that the aim of any operational period shall be to maintain output at 100% for as long as possible. If the TES system is charged, it should be used in parallel with the solar field to maintain output at maximal conditions. The HTF temperature at the steam generation heat exchangers will be a flow-weighted sum of the HTF temperature from the solar field and the TES system.

TES system discharge shall be used preferentially to the auxiliary heaters for hybrid operation.

5.4.6. *STARTUP*

Start-up operations aim to have the Turbo generator in operation as soon as feasible.
The plant design provides the necessary features for best achieving this goal. Due to the early stage of the issue of the present document in the preliminary design, discussion on the operation strategies for the start up operation is delayed until a later stage of the preliminary Engineering effort.

5.4.7. *SHUTDOWN*

[To be discussed later]

5.4.8. *ENERGY “DUMPING”*

In certain instances, the solar field may be able to collect more energy than can be absorbed and utilized by the installed plant systems. If unattended the solar field could “run away”, with outlet temperatures rising above the maximum design temperature and causing damage to the HTF, the HCE’s and other plant equipment. This necessitates an action referred to as “dumping”.

Circumstances requiring “dumping”:

- During periods of very high solar radiation. The STG is generating at maximum allowable capacity and TES system is absorbing energy at its maximum design rate.
- During periods of high and extended solar radiation. The STG is generating at maximum allowable capacity and the TES system has reached maximum storage capacity (the hot HTF tank is full).
- STG has tripped, or the plant has been directed to go offline.

To achieve affective dumpling, several actions may be taken, which involve defocusing either partially or fully sections of the solar field. (If no operator action is taken, the SCA local controllers will defocus any collector whose HTF temperature reaches alarm levels).

Alternatively, or in conjunction with the above actions, system temperature set points can be adjusted to direct more thermal energy to the TES (if not fully charged) or to the STG, as described earlier.

5.4.9. *MAINTENANCE*

The regular maintenance of the plant shall be scheduled to coincide, where possible, with planned idle periods –nighttime and periods of low insolation. Major plant inspections and maintenance procedures shall be scheduled for an 8-10 day annual shutdown, normally during December or January (periods of low insolation). Major plant overhauls, which it is anticipated may be required every 5-7 years and last from 4 – 6 weeks, shall also be scheduled (as required) during December of January.

During major shutdowns, Supplier representatives and maintenance personnel will be brought to the site to inspect major equipment and manage/perform any non-routine maintenance procedures.

Equipment shall be classified according to their influence on plant production in case of failure, and preventative maintenance shall be scheduled accordingly. Classification will include Critical Equipment (e.g. the STG, Main HTF pumps,) Special Technology Equipment (e.g. the Solar Field SCA’s) and regular ‘off the shelf’ equipment (e.g. dosing pumps).

Critical and Special Technology equipment may require manufacturer participation (via a binding contract) in the maintenance operations, while maintenance for other categories will be performed independently in accordance with manufacturer recommendations.

Mirror cleaning shall be scheduled during evening and night hours when the solar collectors are offline. The frequency of mirror cleaning shall be regulated according to the specific weather conditions (such as dust storm, rainy periods, etc.) Optimal methods and specifications for the equipment for mirror cleaning shall be developed in the next engineering phases.

6. BASIS OF DESIGN CONDITIONS

6.1. POWER BLOCK

- 10 MW Net Ram Power ORC.
- Max efficiency of turbine of 30.04 % at 10 MW.
- Power Block availability of 97% (apart from 9 days annual average shut-down for maintenance).

6.2. SOLAR FIELD

- Solar field size of 101,370 m^2 and equivalent to 31 loops.
- Distance between rows in the solar field is 15.5 meters.
- The solar field is based on Albiasa Trough (AT-150) SCA’s with Solel UVAC 2008 receivers
- Mirror reflectivity is 93% minimum.
- The yearly Direct Solar Irradiation (DNI) available at the project location is 2,027.01 kWh/m^2. It’s attached the file “KAUAI.tm2” used as the basis for the project design.

7. BASE CASE DESIGN CONDITION PERFORMANCE RESULTS

The performance analysis will be carried out at the design condition as well as at off design conditions. The first condition shown below is at the design condition with all of the assumptions stated above including the design solar beam radiation of 2,027.01 kWh/m^2 as defined in paragraph 6.2 above.

Table 3: Design Condition Performance Results

Available Solar Radiation (kWh/m^2)	2,027.01
Heat Transfer Fluid (HTF)	Therminol VP-1
Number of Loops (uds)	31
Rowspacing (meters)	15.5
Hours TES	2
Solar Field Area (m^2)	101,370
Power Block Gross Efficiency (%)	30.04
Net Electricity Power (kW)	10,000
Parasitic Electricity ORC (%)	12.5
Gross Electricity Power (kW)	11,250
Nominal Thermal Power in Heat Exchanger (kW)	37,006.58
Temperature Inlet HTF (ºC)	290
Temperature Outlet (ºC)	391
Minimum Part Load Operation[1] (%)	10
Annual Thermal Energy absorbed in the Solar Field (MWht)	102,530
Annual Thermal Energy Dumped (MWht)	2,794
Annual Thermal Energy Discharge of TES (MWht)	10,512
Annual Thermal Energy in Heat Exchanger	102,600

[1] Of Nominal Thermal Power

Table 4: Design Condition Yearly Thermal Energy Absorbed in the Solar Field (MWht)	
January	5,657.30
February	7,449.70
March	8,419.90
April	9,893.10
May	11,364.00
June	11,522.00
July	10,849.00
August	10,619.00
September	9,308.70
October	6,345.20
November	6,064.40
December	5,032.80

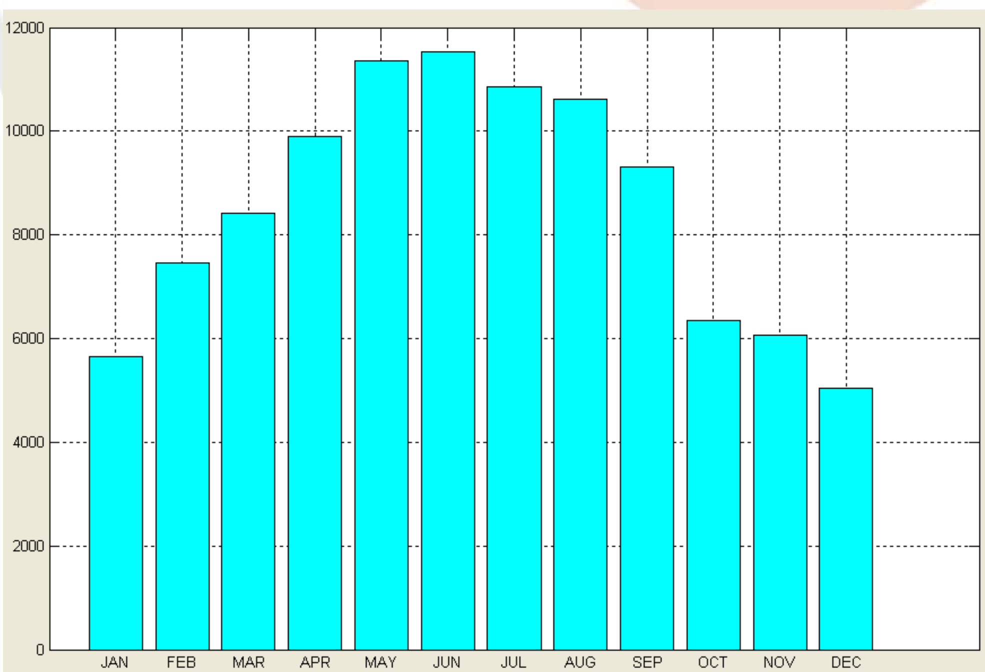


Figure 5: Yearly Thermal Energy Absorbed in the Solar Field (MWht)

Table 5: Design Condition Yearly Thermal Dumped Production (MWht)	
January	8.25
February	21.51
March	31.50
April	430.07
May	896.48
June	508.61
July	360.23
August	347.85
September	137.15
October	11.21
November	18.70
December	22.46

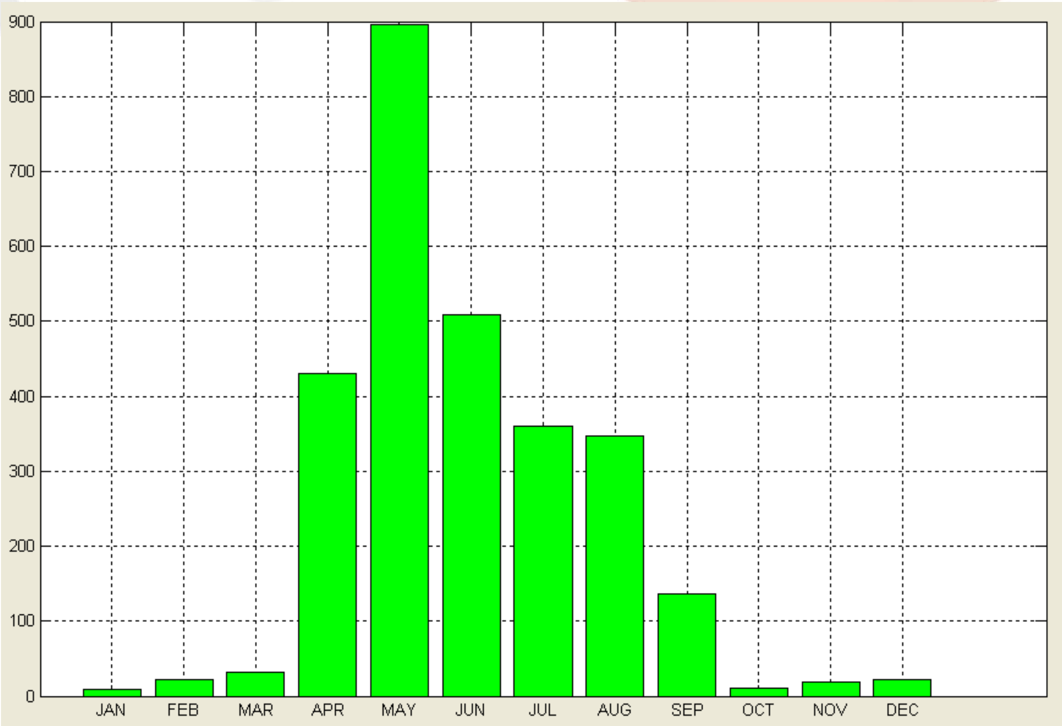


Figure 6: Yearly Thermal Dumped Production (MWht)

Table 6: Design Condition Yearly Thermal Energy Discharge of TES (MWht)	
January	33.60
February	466.49
March	798.18
April	1,402.60
May	1,851.50
June	1,736.30
July	1,452.30
August	1,447.70
September	1,036.80
October	191.63
November	53.39
December	41.85

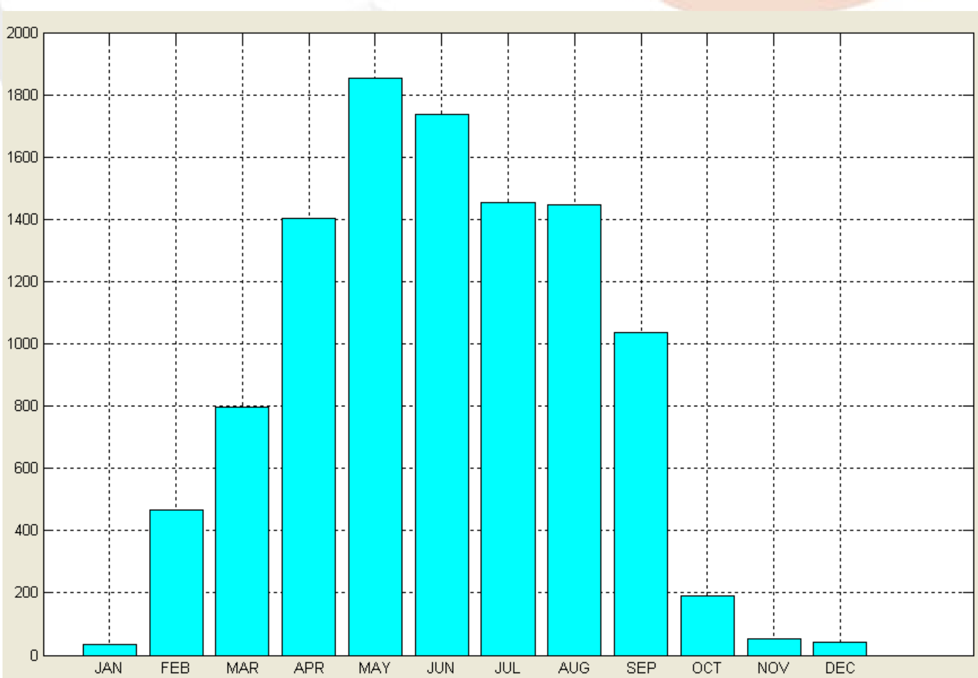


Figure 7: Thermal Energy Discharge of TES (MWht)

Table 7: *Design Condition Yearly Thermal Energy in Heat Exchanger (MWht)*	
January	5,657.30
February	7,449.70
March	8,419.90
April	9,903.50
May	11,389.00
June	11,535.00
July	10,859.00
August	10,629.00
September	9,312.30
October	6,341.80
November	6,067.70
December	5,032.80

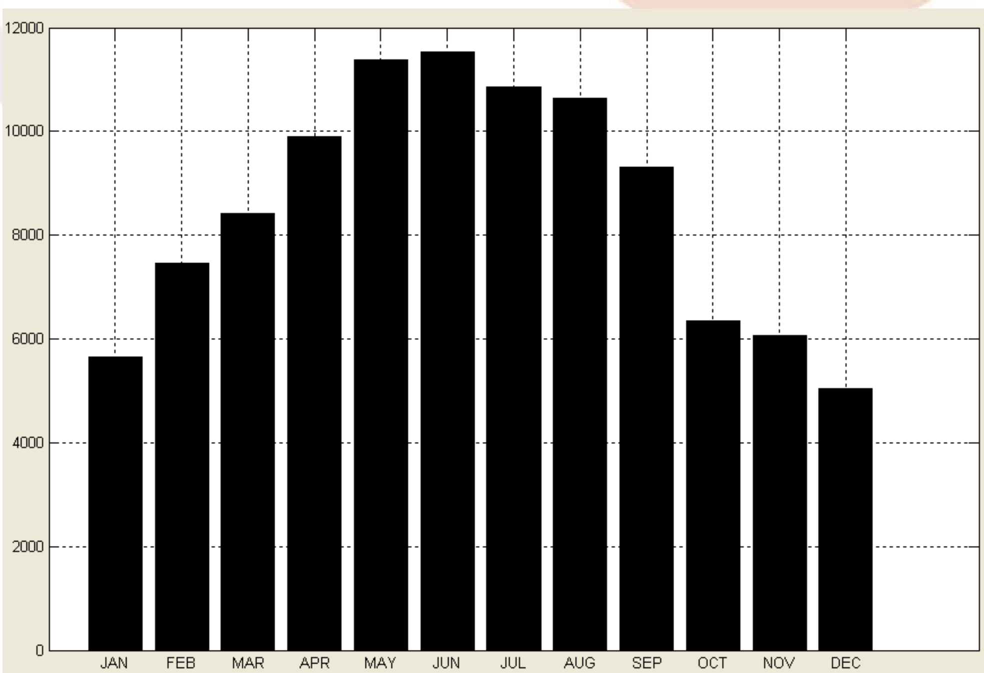
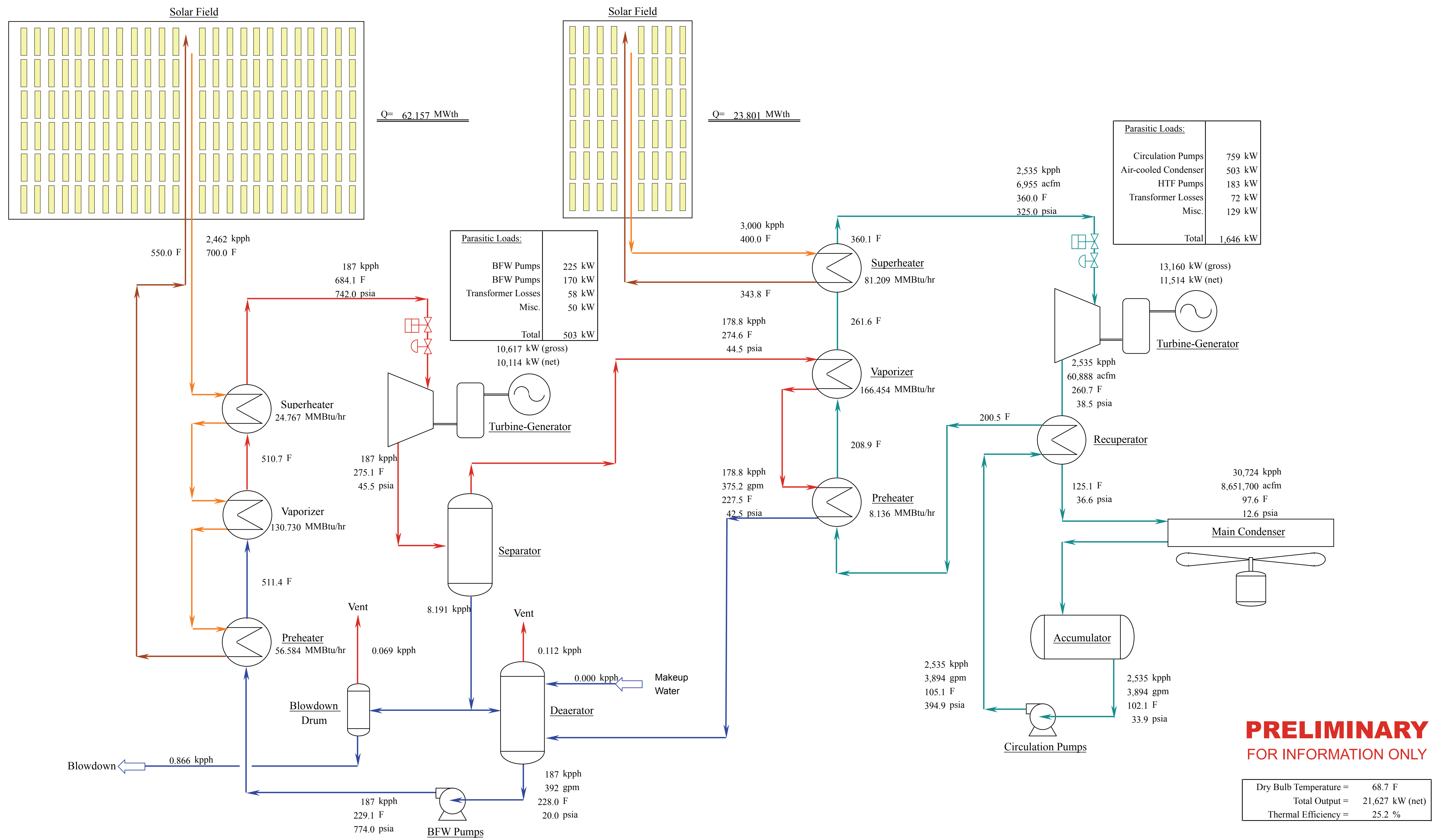


Figure 8: Design Condition Yearly Thermal Energy in Heat Exchanger (MWht)

Renewable
Energy Systems

Update Data

Description	Unit	ORC	SteamCycle
Heat Source Flow Rate	GPM	700,000	700,000
Heat Source Tin	F	391	391
Heat Source Tout	F	290	290
Elevation	Ft	0	0
Dry Bulb	F	55	55
Wet Bulb	F	45	45
Refrigerant		R245fa	Water
Flow	lb/h	700,074	62,839
Pin	psia	634.0	953.0
Tin	F	489.8	682.7
Pout	psia	39.1	3.0
Efficiency (estimated)	%	79.00%	80.00%
Generator output	kW	5,046	5,845
Refrig pump power	kW	(402)	(75)
Fan power	kW	(232)	(215)
Transformer loss	kW	(13)	(6)
Misc loss	kW	(50)	(50)
Net output	kW	4,329	5,499



REV.		DESCRIPTION		
A		ISSUED FOR REVIEW	JRB	3-17-09

Ram Power, Inc.

Nevada
Solar/ORC Power Project

PROCESSES UNLIMITED International, Inc.

Nevada

PFD - Case X

SHEET
1 of 1

DRAWING NUMBER
3763-000-PF-001