An Educational Primer Series

# Concentrating Point Focus Solar Thermal Power Generation

*Achieving Concentrating Point Focus (CPF) Solar Thermal Collection Efficiencies and Temperatures Beyond Performance Barriers of Existing CSP Technology*

## 1. About Technology

**What is it?** The Concentrating Point Focus (CPF) technology OG-5 system introduced has the ability to demonstrate solar-thermal energy to conventional power block equipment at temperatures needed to produce steam well beyond the current performance barriers of existing Concentrating Solar Power (CSP) technology systems. Future development goals for elevated steam temperature and pressure Rankine turbines are expected. CPF technology is the catalyst for subsequent system integration, engineering scale-up, and near-term commercial production of the next generation solar thermal systems; capable of achieving cost parity with existing electrical generation technology by the end of the decade. OG-5 Solar Collector and Energy Storage Unit

**Why is it Important**? Solar energy absorbing surface areas having the same radiation losses back to nature are very inefficient. A CPF cavity-trap converter has larger heat transfer area and flow cross section without affecting the radiation losses from the absorber surface. In the OG-5 system, the thermal energy collected at each dish focal plane cavity entrance is transferred to the heat transfer fluid (ambient air) and heated to a maximum of 2,000$^0$F before entering the thermal energy storage unit at collection efficiencies and temperatures well beyond current CSP technology systems. Comparison of Cavity Converter and Surface Absorber Receiver

**What is Water and Land Usage?** Power plants use a tremendous amount of raw water supplied from local water resources to provide for the needs of the plant. In order to determine the overall effectiveness in thermoelectric power plants, both water and energy need to be considered. The raw water usage can be the determining factor for plant siting and permitting, as it may have a significant impact on local water availability and environmental restrictions. The Concentrating Point Focus (CPF) technology used in OG-5 systems is the most efficient technique to maximize steam Rankine operating temperatures and minimize energy losses, water, and land usage. A comparison of theoretical limits of various technologies shows the OG-5 technology produces the most energy per acre of land with least amount of total raw water usage. Comparison of Water & Land Usage

## 2. Background/Evolution of the Proposed Design

The principal inventors of the design/engineering team have been actively engaged in the development of concentrating point-focus (CPF) solar thermal technology since the oil embargo of 1973. A Parabolic Dish Test Site (PDTS) was established at the Jet Propulsion Laboratory (JPL) California Institute of Technology's Edwards Test Station in the California Mojave Desert to carry out Department of Energy (DOE) sponsored work in testing solar point focusing concentrator systems and related hardware. JPL's Parabolic Dish Test Site by T.I. Hagen

Current team members were instrumental in design and fabrication of the first commercial point-focusing dish system tested at the Parabolic Dish Test Site (PDTS) in 1979 for commercial evaluation. OMNIUM-G Concentrator Test Results by J.D. Patzold A complete OMNIUM-G System (Model OG-7500) was cost analyzed for production quantities ranging from 25 to 100,000 units per year. JPL's Costing the OMNIUM-G System by H.R. Fortgang.

These solar units were manufactured and delivered to customers in private industry, universities, government agencies, and individual consumers. The pioneering prior work in the design, validation, and manufacture of single and dual collector point-focus solar thermal electric generating systems, together with their subsequent design refinements serves as the sound scientific foundation upon which the current proposed solar thermal technology is built. Concept of the HTC-25 Tracking Concentrator by S.H. Zelinger

Despite the still pervasive belief that high concentration ratio point focusing technology is too expensive to be considered commercially viable for use in CSP systems, members of the design team originally developed an economical means of producing very high concentration point focusing concentrators more than thirty years ago. A technical summary published by JPL (JPL 400-98) in January 1981, consolidates descriptions of all known parabolic dish concentrator designs currently in production pr under development. Parabolic Dish Concentrator Designs and Concepts by Brian Beveridge

Drawing upon their collective expertise in radar systems, infrared optics, electronics and analysis, the current team members have long been able to produce very high concentration ratio point focusing solar collectors (necessary for high accuracy two-axis solar tracking CPF systems) sustainable in inclement weather and severe wind loading conditions without loss of form and only minimal loss of reflectivity over a 30 year lifespan

In order to achieve a steady and controlled delivery of thermal energy suitable for power generation, the earliest system designs used molten aluminum to achieve roughly an hour of thermal ballast to buffer against the temporary loss of the sun's radiation. The melting temperature of aluminum alloy, 1100$^{o}$F (593$^{o}$C), thereby determined the operating temperature of the team's earliest CPF processes designed and developed in the 1970's despite the early generation collector's capacity for substantially higher temperatures.

In-house development of a wide-range of manufacturing techniques during the early years of development and production assured a strong proprietary knowledge base. During this period, both the team member's business and their customers were funded or primarily motivated by government sponsored solar initiatives. Upon cessation of these subsidies and the subsequent pull-back in the emerging solar industry in the early 1980's, the team member's, however, learned first-hand that long-term commercial viability cannot be premised on continuing government subsidies or support.

During the intervening period, the principals came to realize that commercially viable CPF systems required the collection of solar energy on a scale much larger than was possible with single or dual-collector systems. In 1985, the task of designing a system of practical size (long life/minimum cost) and having practical levels of efficiency began. The designers again selected CPF solar thermal process as the only viable means of producing high enthalpy steam capable of driving modern high-efficiency turbines from solar thermal energy without supplemental fossil-fuel augmentation. After multiple refinements, and a series of progressively advanced generations of design concepts iterations, the design team has arrived at its fifth generation conceptual design – an optimally sized energy-on-demand CPF solar electrical generating system capable of achieving cost parity with existing base load electrical generators – referred to as OG-5. OG-5 Pathway of Development

**3. Solar Thermal Process**

OG-5 is an advanced energy generation system that collects solar energy, stores it as thermal energy and then, it generates grid-quality electricity from the stored thermal energy when needed. The stored thermal energy is delivered on-demand to a steam generator (boiler) and turbine generator, to generate high quality steam and electricity to the local grid. The OG-5 Process Diagram shows the Solar-Thermal Steam-Electric Power Plant Elements. These elements make it attractive for a wide-range of small or large-scale solar-fueled deployment options by supplying electricity and/or high temperature steam on-demand.

The system utilizes a high efficiency Steam Turbine Generator set. The solar energy storage provides all the energy needed to generate the required steam at 1,050$^{o}$F and pressures up to 2,500 psia for maximum efficiency turbine. Storage is accomplished by heating air transfer fluid up to 2,000$^{o}$ F during sunlight hours then transferring this energy into inert materials at that temperature. No fossil fuel augmentation is required to operate at these elevated temperatures and pressures.

The chosen collector field sizes of arrays are matched to the turbine-generator size. Additional arrays will permit the turbine-generator to run even more hours per year. This scalability of the system also permits a graceful buildup upon initial installation. The power block will begin generation when the first four arrays have been installed. As additional arrays are installed, the night-time run-time hours increase proportionally. A comparison of available OG-5 system configurations show a typical matching turbine-generator nameplate, available land use, and collector field size; see: OG-5 Configuration Comparison

**4. The Solar Dish Array**

The OG-5 system has been carefully designed to minimize costs. Sixteen standard modules of CPF parabolic dish concentrators are mounted on a common carriage frame that allows all dishes to track the sun simultaneously. The array is driven in azimuth and elevation each with a common drive so that all dishes point to the sun's position.

Each array consists of 1076 $m^2$ of collecting surface accurately pointed at all times to collect the sun's energy at its normal incident rate. Solar Dish Array Using a unique system of individual mobile energy storage transport vaults, energy is stored at each array. During sunset to sunrise hours, the vaults may be removed and transported to a central steam generating station. This contemporary design has the advantage of producing higher pressure central steam generation, permitting the use of higher efficiency turbine-generators while eliminating conventional steam line connection losses in large solar fields having distributed boiler configurations. Since each energy transport vault is an inert solid, there is no danger of toxic spills without consumption or depletion of the storage material. Storage material is inert, self-contained and doesn't require replacement during the expected life of the system.

The thermal energy collected at each dish focal point is transferred to the air Heat Transfer Fluid (HTF). The HTF is heated to a maximum of 2,000$^{o}$ F and the thermal energy is transported by HTF in such a way as to aggregate the sensible heat (no phase change) energy from all of the dishes for entering the thermal vault (placed on board the array carriage platform to minimize thermal loss).

**5. The Solar Collector Field**
The amount of energy collected in a day's time is directly proportional to the area of the collectors and the intensity of the direct sunlight. The specified amount of energy to be delivered in a year's period of time ultimately determines the size of the solar collector field. Multiple arrays are conveniently grouped together, thus permitting graceful scaling and build-up of power plant sizes to generate outputs of electricity, within limitation of excellent sun and land availability.

Scalability of a collector field is the practical solution to the logistic puzzle of how and when components arrive at a field, skill required to erect the field, skill to operate and maintain the field, the life of the field, and ultimately its cost. After over 35 years of continual trade-off studies, the final configuration maximizes all the parameters, and has resulted in a configuration considered optimal for survivability in 45 meters per second (106.7 mph) Cyclone Region A4 environments. Solar Collector Field

**6. The Point – Focus Concentrator**
The OG-5 point focus dish concentrator intercepts and concentrates solar energy using CPF parabolic dishes (each an individual parabola of revolution) to focus the radiated energy to a point. Each CPF concentrator is a parabolic dish having reflecting segments with a combined collector area of 8.4 $m^2$. As a result of the ultra-high reflectivity and accuracy of the collector, the diameter of the resulting focal point is minimized- which allows the concentrator to produce thermal energy at temperatures in excess of 2,500$^oF$ (1371$^oC$).

The CPF parabolic dish concentrator is therefore the most crucial and most costly component of the system. Thirty-year service life and high specular reflectivity of collector reflecting surface over the entire solar spectrum is obtained using front-surface aluminum with a protective coating. This component is designed to withstand harsh environments, wind loads, and wind buffeting (85 mph maximum non-gusting operational wind speed & 120 mph max survival wind speed) while accurately and reliably directing its collected solar energy rays into the small entry aperture of the focal plane converter (less than 2.0 mrad optical error in both calm and windy conditions).

The receiver function of the OG-5 dish concentrator consists of a cavity converter responsible for capturing the sun's focused rays and converting this solar energy to heat ambient air with minimum thermal loss. Ambient air injected into the focal plane components is servo regulated to maintain a set temperature of hot air leaving the dish concentrator. High thermal efficiency is achieved by conversion of concentrated solar radiation to heated air inside an insulated cavity with small entrance opening. The converter components are projected to operate at temperatures that produce 1093ºC hot air (the HTF) and produce projected annual average thermal efficiency greater than 90%. Point Focus Concentrator

**7. Unique Features**
In addition to having less environmental impact (minimized land utilization and no pollution) in large part due to having the highest end-to-end efficiency among competing technologies, the system operates at very high temperatures for the purpose of storing its energy for subsequent delivery when and how needed. Since the system operates at such high temperatures, it is easily able to power conventional off-the-shelf steam turbine generating systems at their peak efficiency levels without requiring the use of any augmentation (fossil fuel or otherwise). Furthermore, there is an ability to store energy in the form of heat efficiently using an inert, nonvolatile substance (requiring minimum maintenance over the 30-year life cycle) for delivery at the generator's nameplate power capacity.

Another unique feature of our technology, besides temperature and storage, allows for gradual build-out ("ramp-up") of the solar collector field to full delivery capacity of any chosen turbine generator set nameplate capacity. Naturally, it will take some time to populate the solar field able to produce the target amount of annual energy. A single array can charge five storage vaults in five days with sufficient energy to drive the turbine at full nameplate capacity while finishing the installation. This cannot be done with trough or other CSP technologies because their steam generator is centralized.

The unique feature of having energy storage provides enormous flexibility when sizing a system for a specific purpose. The system can be sized (configured) to deliver energy continuously 24-hours per day, seven days per week year-round, or can be sized to deliver a specific amount of energy on demand or can be sized to deliver all of its stored energy only during the most profitable time period (on-peak). Unique Features

Energy on Demand: The OG-5 solar-thermal steam generation process consists of three steps — collection, storage, and delivery. Solar energy is collected and point-focused to raise the temperature of ambient air that is used as the heat transfer fluid, to approximately 2000$^{o}$F. The energy is stored in an inert material at that temperature. When energy is needed (on-demand, dispatched or continuous), steam is created from the stored heat energy to drive conventional high efficiency steam Rankine cycle turbine generators. Energy delivery is decoupled and independent of the collection and storage steps. Because collection is decoupled from delivery, the concept of Annual Capacity Factor for a solar process no longer depends on the hours the sun is shining (~30% of the year) but how the energy is delivered from storage. For instance, the Annual Capacity Factor could be unity if storage was sufficient to drive a turbine generator 100% of the time at its nameplate rating.

National Grid Compatible: A key limitation in the dispatching of electricity from generating power plants to substations near population centers is that, without electrical energy storage, electric generation supply must closely match the user demand. If supply and demand, are not in balance, the generation plants and transmission equipment can shut down causing major regional blackouts. Ability of the OG-5 system to store and deliver energy on-demand ensures that supply and demand are always in balance, thus generation plants and transmission equipment do not face 'shut-down'. Our on-demand conditioned power is compatible with the National power grids.

In contrast, PV solar cells, windmills, and Stirling engine-base systems are all sporadic power generators and incompatible with local independent grids. In fact, the OG-5 system is able to balance the sporadic effects of these technologies for connection to the local grids.

Independent Local Grid Compatible: Independent local electric grids need continuous power, but the local population must adapt their activities to sporadic power derived from most renewable energy sources. However, the OG-5 system provides continuous power delivery that is compatible with independent local grids. Added advantage is these smaller units are built for grid extension to the National grid.

### 8. Site Characteristics

One key competitive advantage of parabolic dish concentrators in renewable energy systems is their close resemblance to most of the power plants created by the utility industry. The OG-5 system utilizes many of the same technologies and equipment used by conventional central power plants, but substituting the concentrated power of the sun for the combustion process. This advanced design aspect is easily integrated into today's central power plants – even replacing the fossil fuel combustion process.

Construction of a OG-5 solar thermal electrical generating plant follows standard processes and procedures for conventional utility power plants, except the fossil fuel combustion process is eliminated. Other than fossil fuel elimination, the most significant difference between OG-5 and conventional plants is the associated collector field, sized to capture the sunlight falling on the earth's surface in any specific location. It is scientifically recognized that CPF technology (parabolic dish concentrators) is the most efficient technique to maximize Rankine Cycle equipment operating temperatures, minimize land size and energy collection losses. Site Characteristics

**9. Deployment Options**

OG-5's unique ability to operate pollution-free anywhere the sun shines, makes it attractive for a wide range of small or large-scale solar driven deployments by supplying electricity and/or high enthalpy steam on-demand without the use of any fossil fuels. In addition, it stores its thermal energy during sunshine hours and may deliver that energy when needed to ballast PV stand-alone power during sunset to sunrise.

A single OG-5 array contributes the thermal energy needed by a modern conventional steam-Rankine turbine-generator power block to generate about 500,000 kWh-e each year.

OG-5 arrays may be deployed in three ways:

1. In groups of four arrays powering a dedicated steam boiler. This grouping is called a Quad, and its output is steam on-demand to a large centralized turbine-generator condenser power block or a dual-function water desalination/grid power generation suite. Quad Distributed Boiler Layout Quad configured power plants are limited to a maximum of approximately 50 quads (approximately 100 million kWh-e per year).

2 Individually in a large field of arrays where each array contains removable thermal energy storage vaults that are transported to and from a centralized new or pre-existing boiler/turbine/generator power block. Array Transportable Vault

   The transportable vault configured power plant is limited to about 400 arrays (approximately 200 million kWh-e per year)

3. In groups of four (Quad) additive to existing Coal Plant Steam Augmentation to offset existing coal burning carbon emissions. Quad Steam Generator

   A typical solar thermal Project Timeline is shown here. Project TimeLine

**10. Manufacturing Option**

A factory in the region near the local site location is needed to produce the components that will be assembled and put in place at the site location of the power plant. To satisfy this condition, the overall manufacturing concept is to employ a local workforce, teach the required skills, and employ those skills in the distributed workshops located within the factory. This multiple shop approach emphasizes making piece parts and supplier agreements to drop-ship to site location. Parts and components are then distributed to meet assembly schedules as required.

The Company will design a manufacturing facility in a US location able to be replicated in areas where power plants will be implemented. Our vision is that personnel from participating countries come to the United States for formal training and learn the mass production operations. At that time, replica factories may be initiated at other locations around the world and training cycle continues. Each factory is expected to reach a maximum capacity to produce 250,000 square meters collecting surfaces per year, employing 650 people with annual wages of USD$50 million, to fulfill the requirements of one 50MW power plant annually or smaller combinations of smaller units, i.e. five 10 MW plants. Factory Job Opportunity