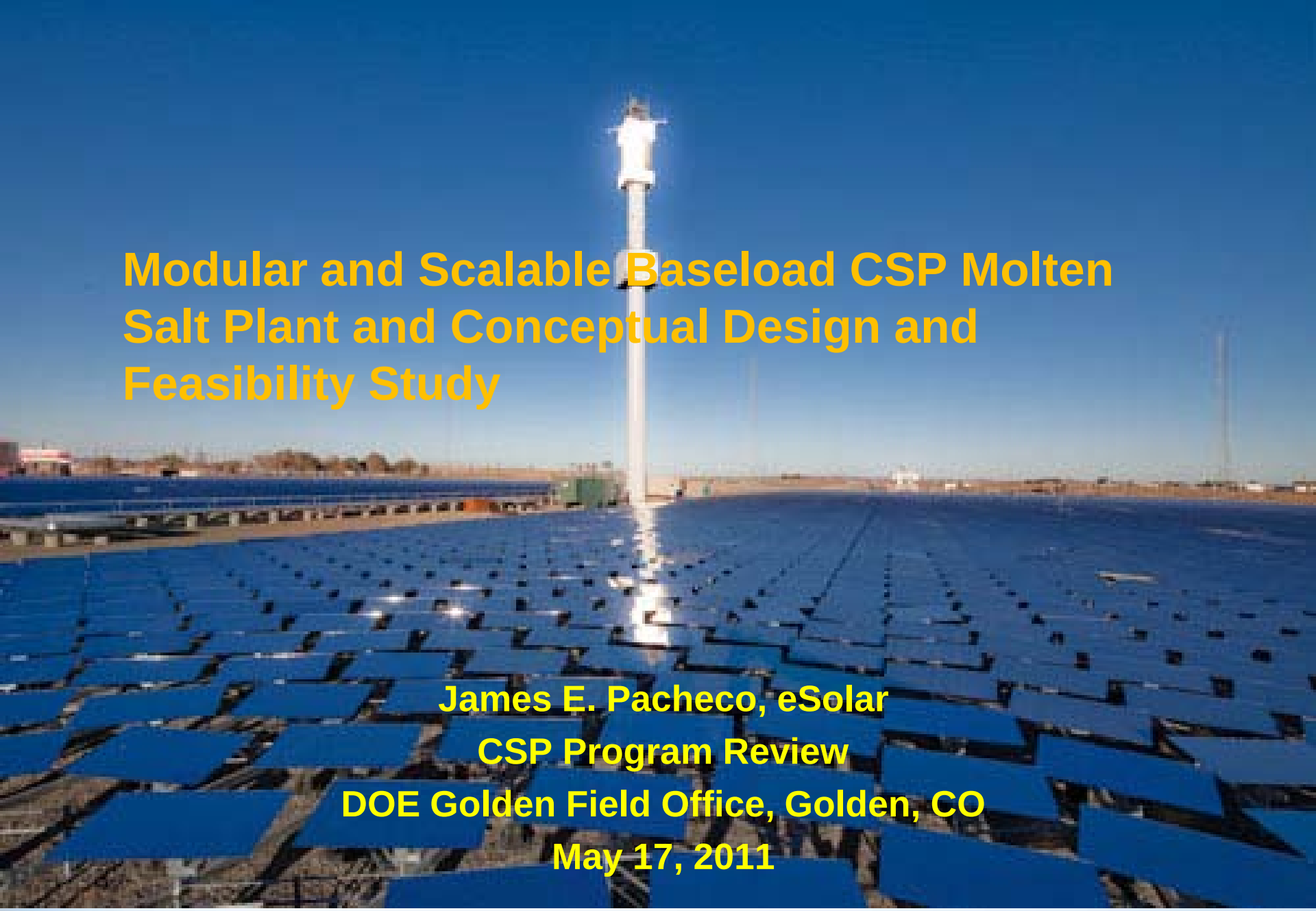


Modular and Scalable Baseload CSP Molten Salt Plant and Conceptual Design and Feasibility Study

James E. Pacheco, eSolar

CSP Program Review

DOE Golden Field Office, Golden, CO

May 17, 2011

Strategic Partnership

- eSolar and B&W have teamed together to develop molten salt power technology

Outline

- High-Level Objectives
- Approach
- Key Results and Accomplishments
- Summary to Date
- Future Work Planned

High Level Objectives and Description

Objectives

- **DOE requirements**
  - 100 MWe plant size
  - 75% Capacity Factor
    - Can be coupled with hybrid technology (<15%)
    - Can be another renewable energy source or fossil
  - Levelized Cost of Energy competitive with fossil-fire generators
    - $0.08-0.09/kWh by 2020 in 2009$.

Project Description

- **Phase I: Feasibility study and conceptual design**
  - Define system requirements,
  - Develop conceptual design and optimize
  - Conduct initial performance analysis and capital costs estimate
  - Conduct target R&D
  - **Date started September 2010.**
  - **Completed March 31, 2011**
- **Phase II: Engineering design**
  - Preliminary design of commercial plant
  - Preliminary design of prototype module
  - **Currently underway**
- **Phase III: Demonstration**
  - Build, a full-scale molten salt receiver, heliostat field, a scaled SGS, and scaled TSS.
  - Conduct test and evaluations

Approach

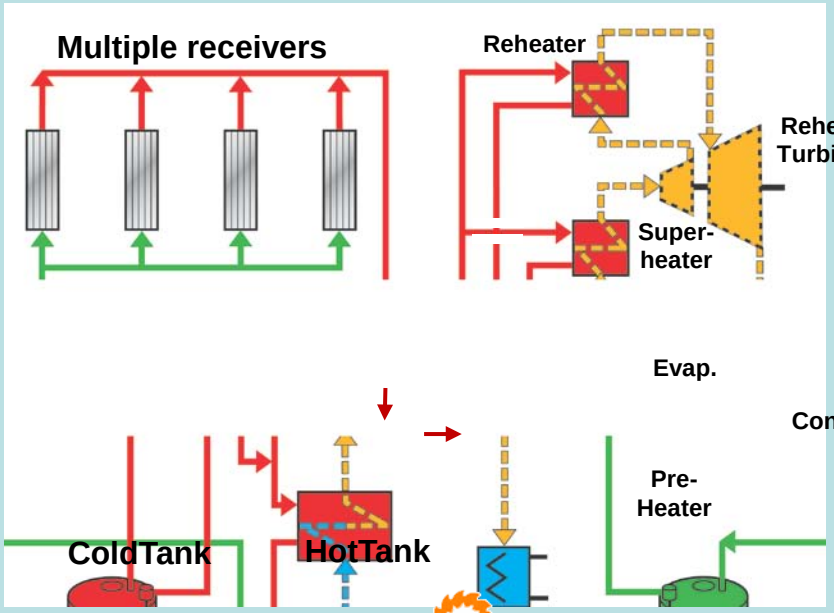
- **Modularity**
  - Modular, factory-built heliostats, receivers, towers, steam generator heat exchangers
  - Shipped to site
  - Rapidly assembled and commissioned
  - Results in higher quality fabrication (factory vs field) and rapid deployment
- **Scalability**
  - Modular blocks of heliostat fields and receivers allow plants to be designed to meet the customer's requirements for output and capacity factor
  - Plant systems (particularly Solar Collector System and Solar Receiver System modules) do not require costly and risky redesign for each plant size.

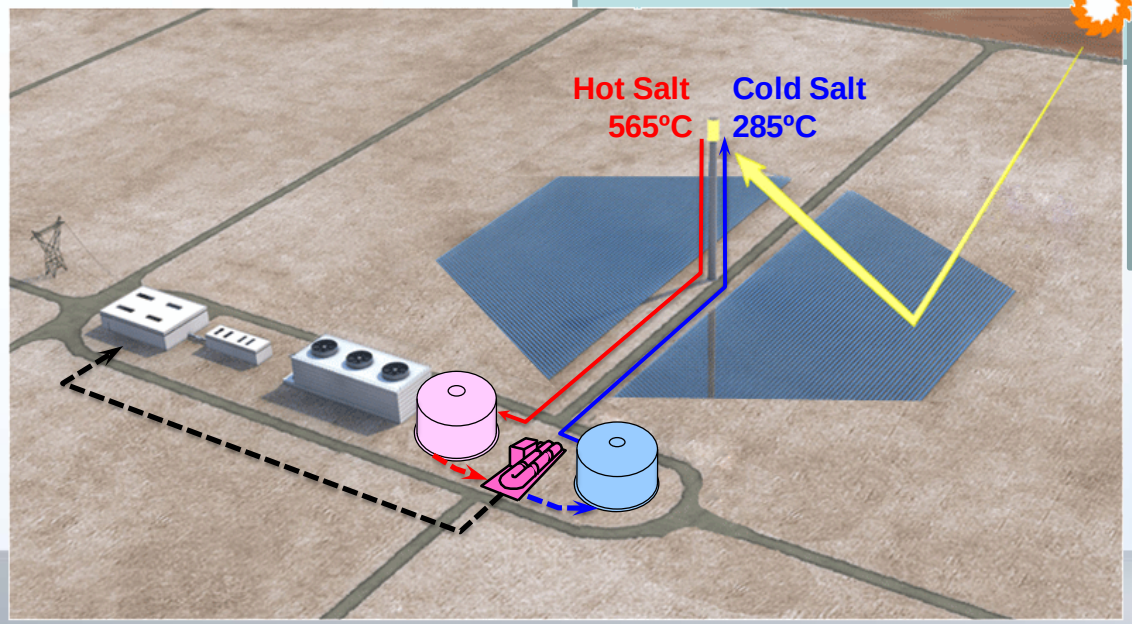
B&W

eSolar

Plant Concept

- **Multiple modules in parallel**
  - Heat molten salt in parallel receiver system.
- **Thermal storage and steam generator systems**
  - Centralized thermal storage system
  - Salt pumped from the hot tank produces superheated steam and reheat steam in steam generator that powers a conventional Rankine cycle turbine generator.

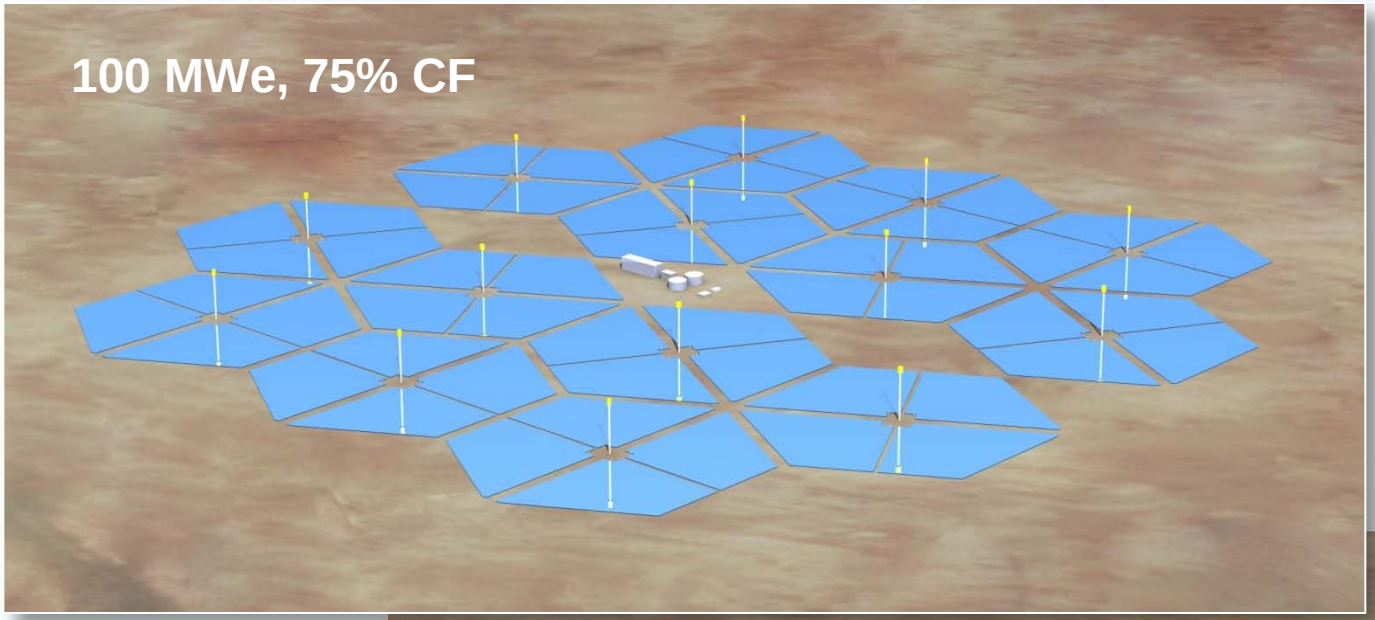


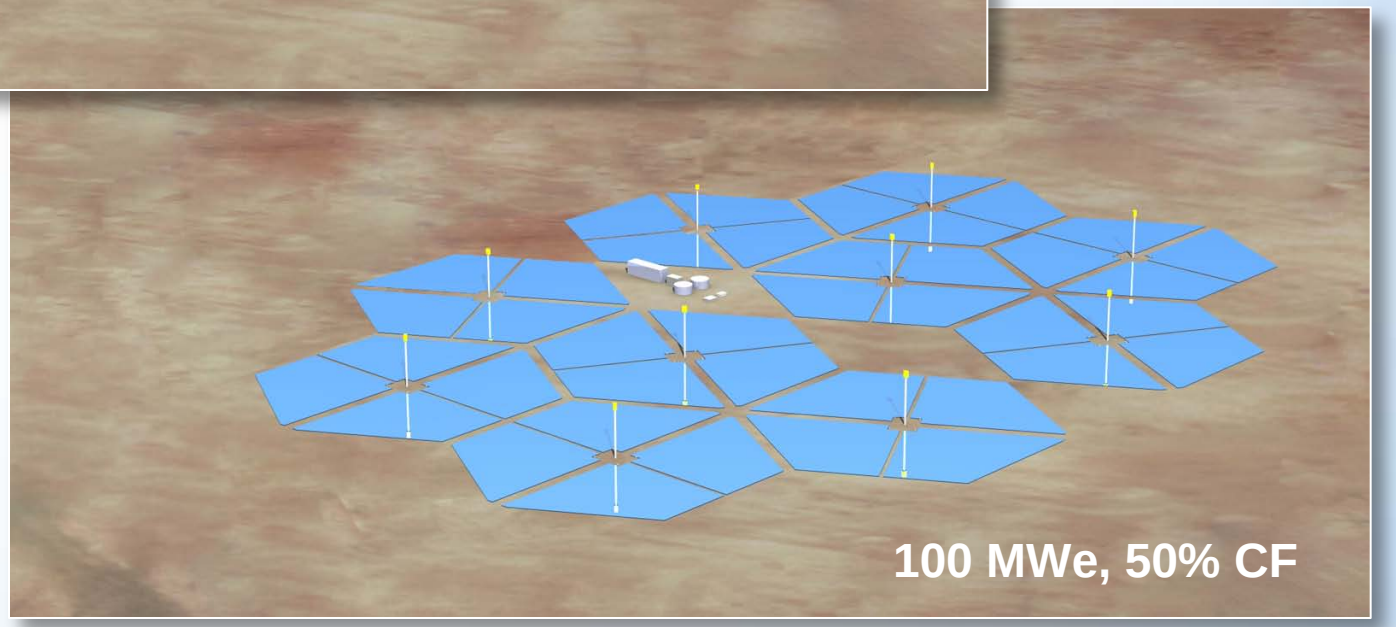


Legend

- "Cold" molten salt
- "Hot" molten salt
- Water
- Steam

General Arrangement – 75% & 50% CF Configurations



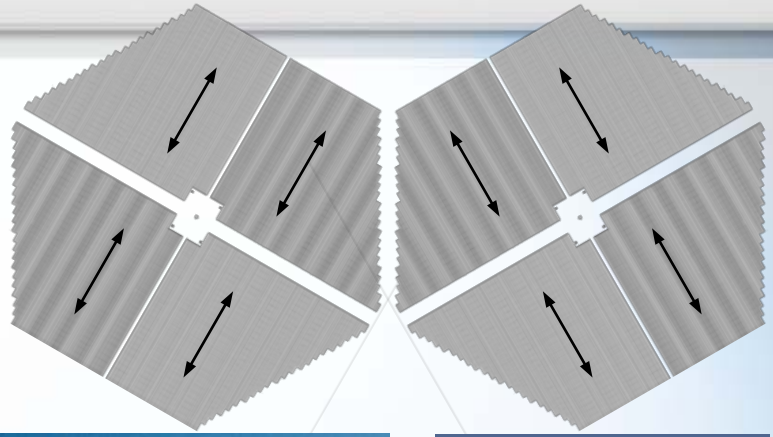


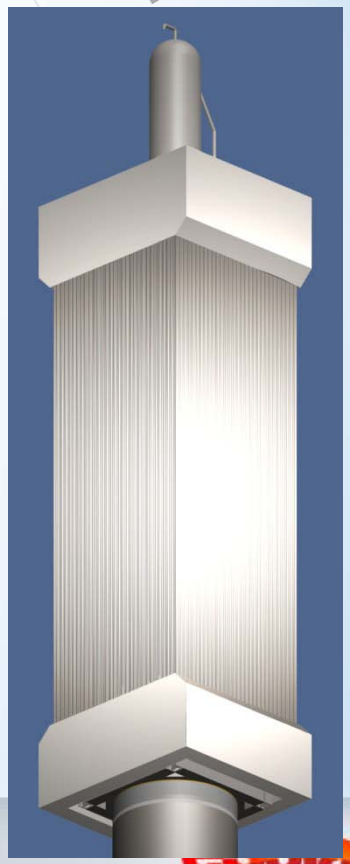
100 MWe Baseload Molten Salt Plant

- **Conceptual Plant Design**
  - Thorough definition of system requirements and multiple trade studies
  - 14 modules, each consisting of 105,000 m^2 hex-packed heliostat fields and 50 MW_t external box-shaped, molten salt receiver on monopole tower
  - 23 MW_t natural gas-fired molten salt heater
  - 3500 MWh two-tank thermal storage system
  - 275 MW_t steam generator system
  - 100 MWe net reheat steam turbine generator with air-cooled condenser
  - Distributed plant control system with remote I/O at nodes
  - Conventional balance of plant

Solar Collector System and Receiver System

- **Hexagonal heliostat fields.**
  - Fields rotated depending on tower location and plant configuration
- **External, salt-in-tube receivers mounted on monopole towers**
  - Rated for 50 MW-thermal.
  - 100 m optical height
- **Piping system to distribute salt to and from the centralized storage system**
- **Tank-mounted vertical turbine cold salt pumps**





Thermal Storage System and Auxiliary Fuel System

Thermal Storage System

- **Arrangement**
  - Two Tank System (atmospheric)
  - Similar to Solar Two and Andasol
  - Thermal Capacity: 3500 MWh_{th}
  - Hours of Rated SGS Capacity: 13

System consists of:

- **Nitrate Salt**
  - 60% $NaNO_3$/40% KNO_3 by weight
  - Limits specified for impurities
  - Total salt mass: 36,500 metric tons
- **Cold Storage Tank**
  - Operates at 288C
  - 39m dia x 16m high, A516 carbon steel
- **Hot Storage Tank**
  - Operates at 565C
  - 39m dia x 17m high, 321 or 347H SS
- **Tanks:** API 650 design, externally insulated

Auxiliary Fuel System

- Natural gas-fired molten salt heater with recuperator to achieve 75% capacity factor
- Utilizes existing SGS and TSS hardware

Steam Generation System (SGS)

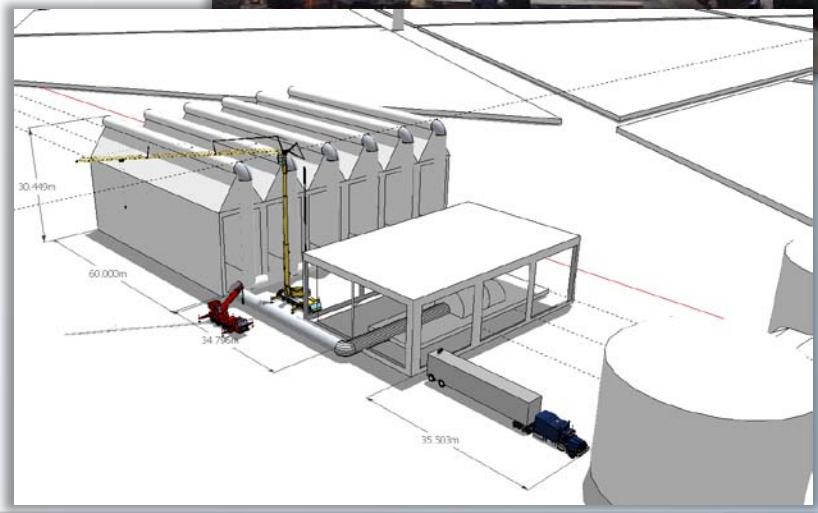
- **Key Features**
  - Tube-and-shell heat exchangers
  - Molten salt on the shell side
    - Eliminates risks associated with tube ruptures due to salt freezing in tubes
  - Water/steam on the tube side
  - Steam drum or vertical separator
  - Fully drainable and ventable

- **Operational Specification**

	Temperature ºC	Pressure bar
Water In	234	140
Superheater Out	540	132
Reheater Out	538	28
Salt In	560	12
Salt Out	288	2.3

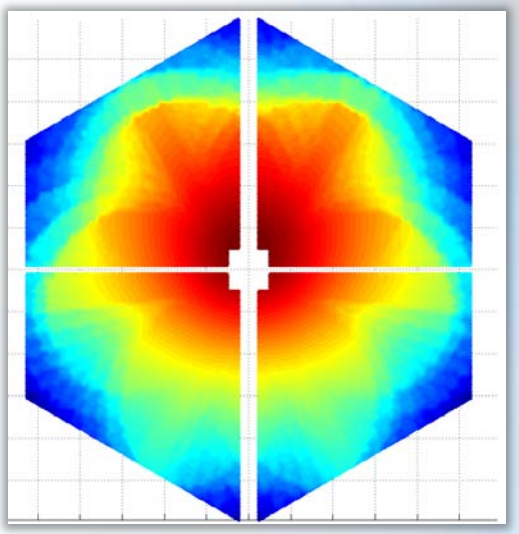
Power Generation System (PGS)

- **Reheat Rankine cycle steam turbine generator**
  - 132 bar, 540°C superheat
  - 28 bar, 538°C reheat
- **This system includes the following subsystems:**
  - Transmission interconnection
  - Steam turbine generator (STG)
  - Extraction steam
  - Condensate
  - Main steam
  - Feedwater
  - Air Cooling
  - Auxiliary boiler (if included)
  - Operations and maintenance (O&M)



Plant Performance Summary

Attribute	ACC	Wet Cooling
Solar Capacity Factor/Annual Energy	72% / 630 GWh	75.3% / 660 GWh
Natural Gas MS Heater Contribution	3% / 27 GWh	0%
Total	75% / 657 GWh	75.3% / 660 GWh



Results to Date

- A conceptual design of a modular, molten salt power plant has been completed that can meet the DOE requirements by 2020.
- Performance analysis shows 75% capacity factor is achievable with hybridization for a system using an air cooled condenser, or by solar only with wet cooling.
- Pathway to achieve LCOE target is through aggressive reduction in solar collector and receiver systems costs. Plans are underway to realize these cost reductions through internal eSolar resources on the SCS and B&W resources on molten salt systems.
- Project has completed Phase I conceptual design.

Future Work Planned

- **Currently in Phase II - Engineering Design**
  - Advance the preliminary design of the plant focusing on risk reduction and cost uncertainties
  - Develop design of module
  - Continue R&D on receiver material characterization and instrumentation
  - Refine annual plant model
  - Survey potential sites for demo
- **Phase III will demonstrate a single module**
  - Permitting on selected site
  - Detailed design of module
  - Construction, startup, and commissioning
  - Test and evaluations

Jim Pacheco
jim@esolar.com