# Hybrid Geothermal-Solar

Project Officer: Tim Reinhardt

Total Project Funding: $285K

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**Presenter: Dan Wendt (INL)**

Low Temperature

# Relevance/Impact of Research



**Objective:** Evaluate the feasibility of integrating concentrated solar power (CSP) into operation of air-cooled binary plant

- Challenges: Hydrothermal resource productivity
  - Production may not match plant design conditions
  - Lost revenue from reduced power sales
  - Penalties for not meeting contractual levels of output in power purchase agreement (PPA)
  - Cost and risk associated with drilling makeup wells - may not be sufficient resource capacity to makeup production shortfall
- Innovation: CSP hybrid plant
  - Increase power generation during hotter periods of day (high demand)
  - Restore geothermal fluid temperature to design value
- Benefits
  - Potential to lower risk associated with developing well field
  - Alternative to makeup well drilling
  - Expand geothermal development

# Scientific/Technical Approach



**Determine impact of resource productivity on binary power plant output**

- Integrate methods to predict plant performance and project economics as functions of resource productivity
  - Predict hourly plant output over project life
  - Estimate project costs
- Quantify effects of deficient resource productivity
  - Use discounted cash flow analysis to establish generation cost at ‘design’
  - Evaluate impact of resource productivity decline scenarios on power generation and net present value (NPV)
  - Assess effects of performance penalties and time of day pricing

**Establish the potential of CSP to mitigate effects of lack of resource productivity**

- Integrate concentrated solar power (CSP) supplemental heat and determine associated costs
  - CSP benefits relative to drilling makeup wells
  - Performance penalties and/or time of day pricing
  - Effect of reducing costs/risk associated with well field development on LCOE
- Optimize CSP array sizing and installation date
  - Identify resource/pricing scenarios where CSP provides benefit
  - Estimate the CSP costs needed to lower LCOE using hybrid plant technology

## Accomplishments

- Simulated effect of resource productivity on binary plant output
  - Aspen Plus simulations of air-cooled plant
  - 20 $MW_{net}$ design for 350ºF and 280ºF resource temperatures
  - Fix plant equipment sizes and establish sensitivity of power output to production fluid and ambient temperatures
- Evaluated hybrid binary plant configurations
  - Preheating geothermal fluid produces more power than post-heating (did not examine heating working fluid directly)
  - Higher temperature resources require less CSP heat input to restore power production to the same level after equivalent levels of temperature degradation
- Developed geothermal-solar evaluation model to assess potential scenarios and benefits

# Geothermal-Solar Evaluation Model

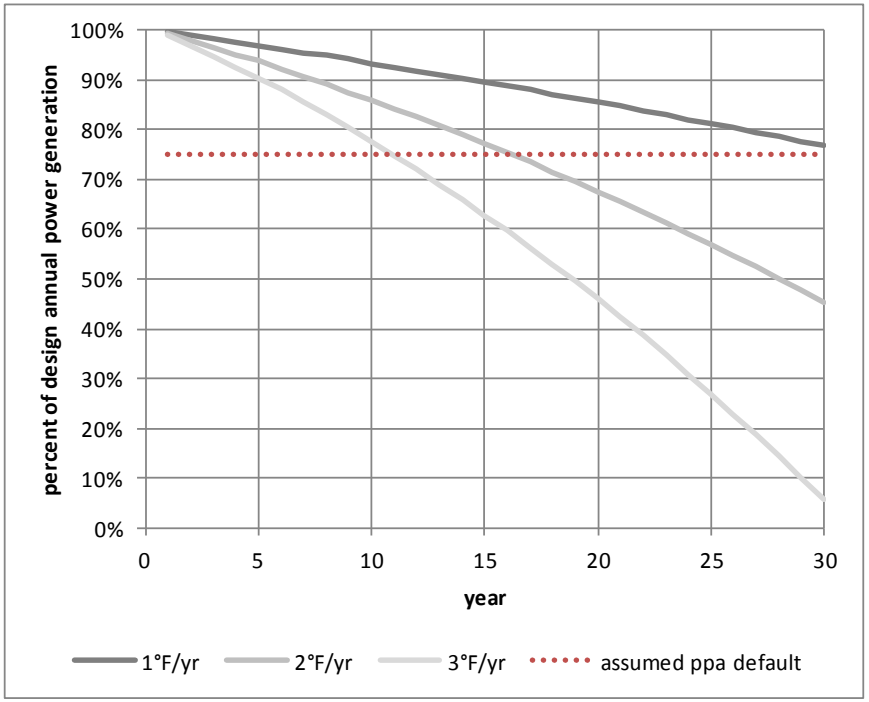
*Model Input*

- Aspen Plus plant simulation results – model performs data regression to predict binary plant performance as function of ambient and resource conditions
- Well field costs from GETEM
- CSP performance, CSP cost, and ambient temperature data imported from NREL System Advisory Model (SAM)
- Resource performance and financial assumptions (user defined)

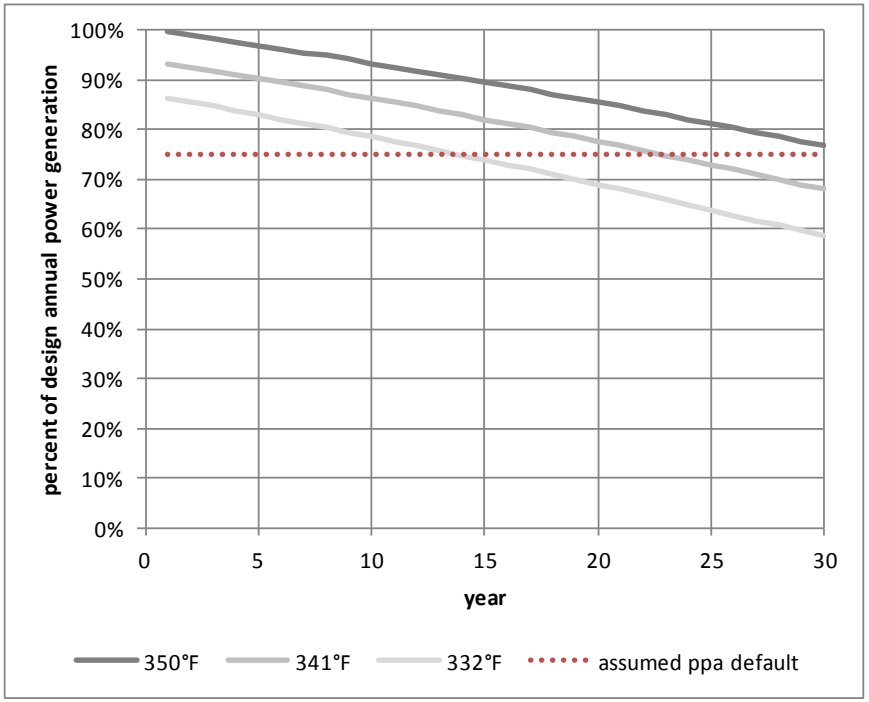
*Model Output*

- Calculation of hourly power generation for entire project life
  - Design vs. actual
  - Function of resource temperature & flow and CSP sizing & performance
- Discounted cash flow analysis
  - Establish selling price for power at design scenario
  - Determine net present value (NPV)

## Effect of resource temperature decline on 20 MW plant in NV (350ºF design)



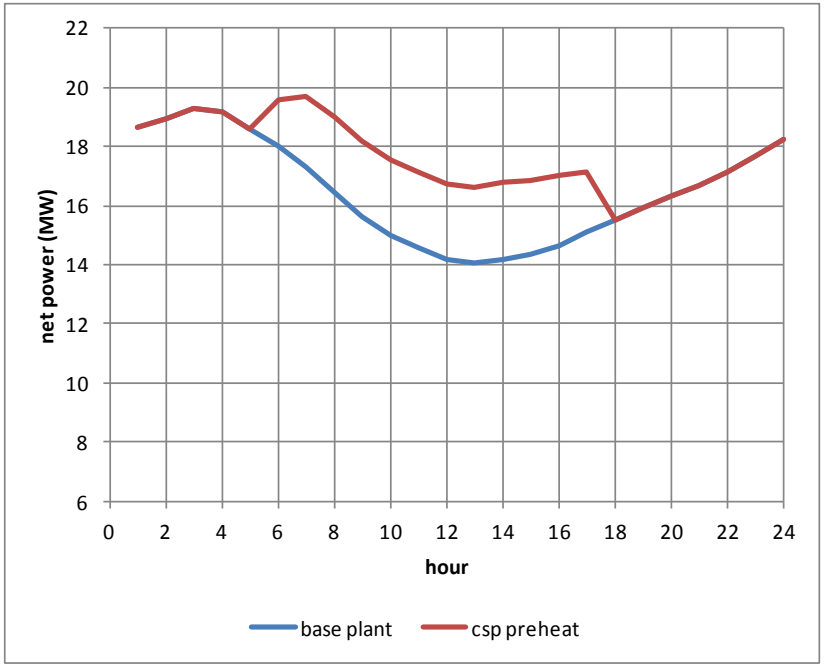

Fluid temperature decline of 1, 2, and 3ºF/year with 350ºF (design) initial production temperature



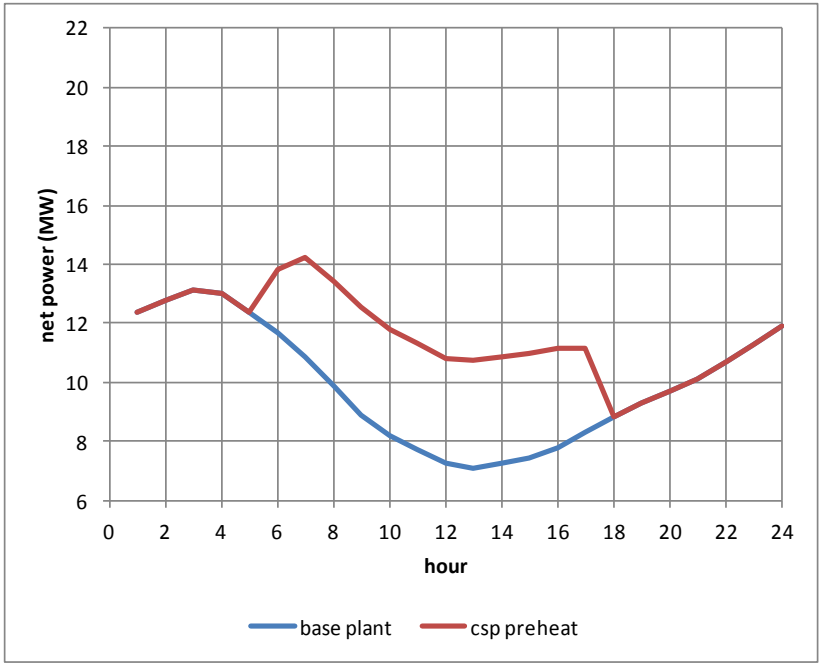

Fluid temperature decline of 1ºF/year with initial production temperatures of 350ºF (design), 341ºF, and 332ºF

## Case Study

- 350ºF design resource temperature, 2ºF/year decline; northern NV location
- CSP array sized to recover 50% of difference between mid-June min and max daily power generation at design condition (283,500 ft$^2$ array; ~$10M)



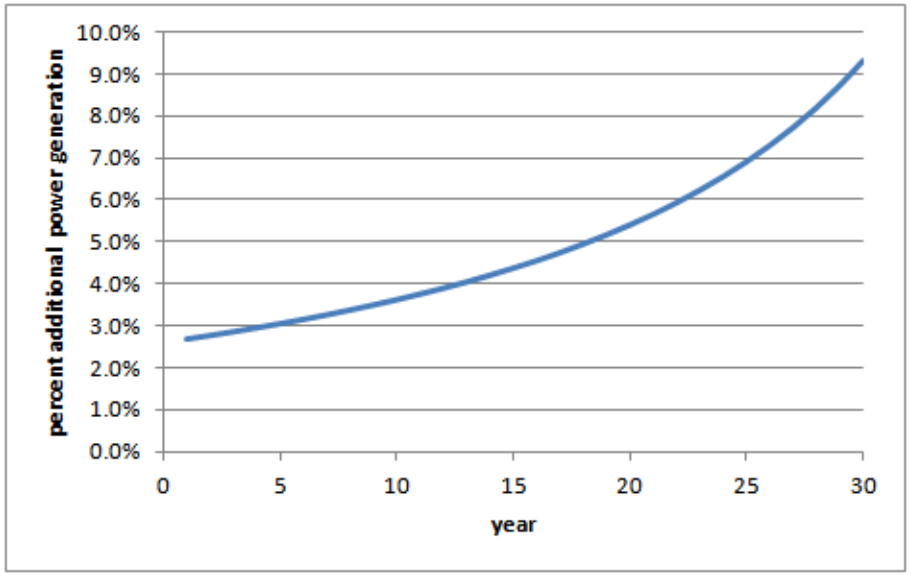

**Power generation with design resource conditions**

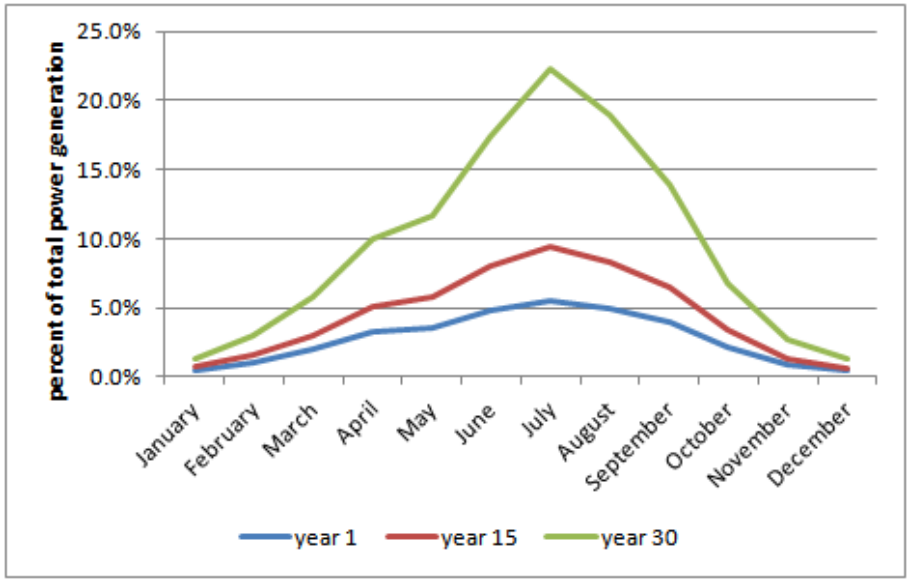



**Power generation in year 20 with 2ºF/year decline from design temperature**

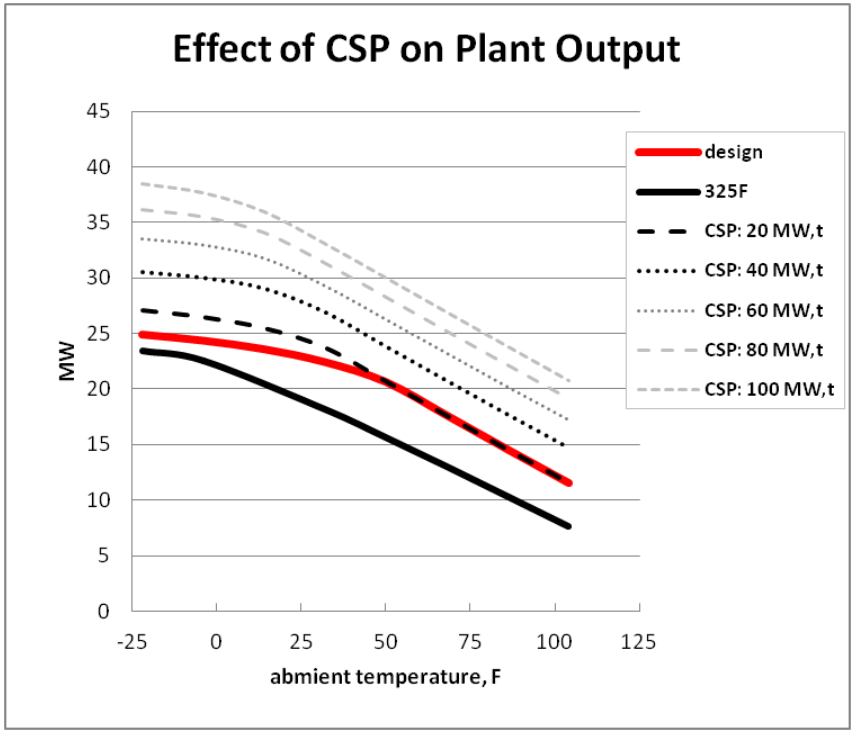
## Case Study (continued)

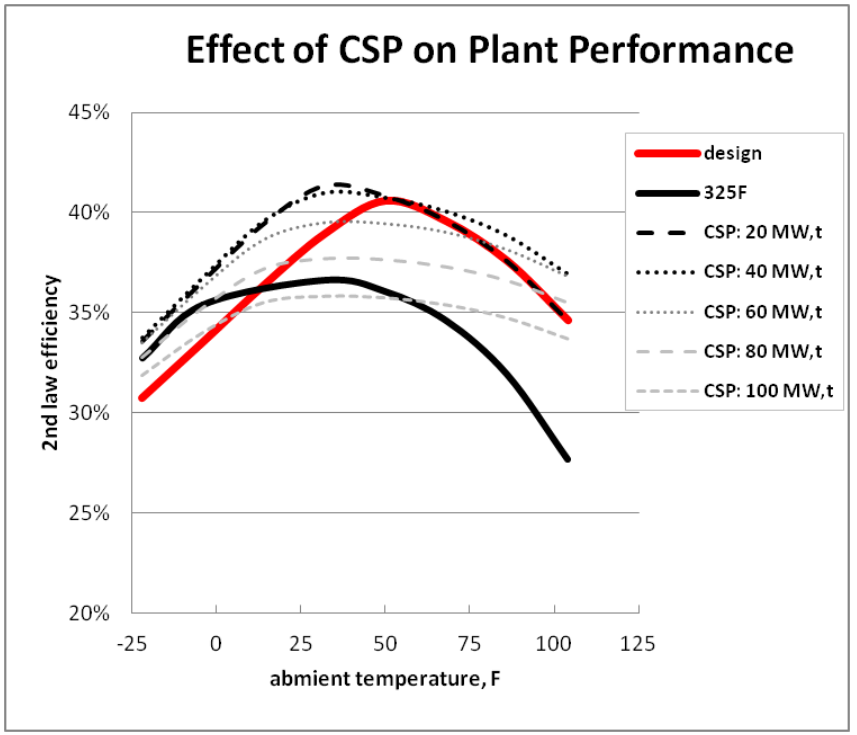
- Percent of power generation attributed to CSP increases with time (constant array size)
- Percentage of total power generation from CSP is maximum in summer (and in middle of day)



# Accomplishments, Results and Progress




**The effect on plant output and performance when of adding varying levels of heat to a 20 MW plant whose produced fluid temperature has declined from 350$^0$F (design) to 325$^0$F**

## Geothermal-Solar Evaluation Model Analyses Planned

- Effect of different scenarios for resource productivity and CSP input on both power generation and NPV
- Determine date and size of CSP array installation to maximize NPV
- Effect of level vs. peak pricing
- Effect of reducing financing costs during development of well field: less risk because CSP can offset lack of initial resource productivity
- Cost and performance of CSP vs. drilling makeup wells

## Preliminary Results

- CSP can bring plant output and conversion efficiency to design levels and above
- CSP impact on plant output increases as production fluid temperature decreases from design value
- Economic benefit
  - CSP can improve NPV when PPA penalties might be imposed
  - Time of day pricing scenarios can produce more favorable hybrid plant economics
  - Reduced CSP capital costs will improve potential for positive NPV
  - CSP could lower generation costs if it reduces risk & financing costs during confirmation and development of resource

# Accomplishments, Results and Progress

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

| Original Planned Milestone/ Technical Accomplishment | Actual Milestone/Technical Accomplishment | Date Completed |
|---|---|---|
| Develop evaluation model to assess different resource and pricing scenarios – April 2013 | | |
| Show that CSP augmentation produces a plant conversion efficiency $\geq$ design – May 2013 | Can show that CSP can restore plant efficiency to design; have not shown economic feasibility of doing so | Feb 2013 |
| Identify plant configuration and scenario that lowers LCOE – January 2014 | | |
| Final report that identifies resources conditions that justify use of CSP – August 2014 | | |

# Future Directions



FY2013

- Complete development of regressions that allow both lower resource temperature and flow to be evaluated simultaneously – April 2013
- Perform thorough evaluation of expanded range of resource conditions and levels of CSP inputs – August 2013
- Assess potential impact of CSP in reducing risk during well field confirmation and development – September 2013

FY2014

- Assess potential for CSP capital cost reductions
- Complete economic assessment of viability of using CSP
- Prepare final report

# Mandatory Summary Slide



- CSP can restore/improve hybrid plant output and performance
- Benefit from utilizing additional solar heat
  - Increases as geothermal fluid temperature decreases
  - Begins to diminish once heated geothermal fluid temperature exceeds the plant design value
- The hybrid plant can improve project NPV when used to avoid penalties associated with low power output caused by decreased resource productivity

# Project Management



- Monthly internal INL review of cost and schedule – explanation required for variances
- Project on or slightly ahead of schedule
- Utilization of tools developed by others to assess impact of CSP on binary plant (binary plant simulations, SAM, GETEM)
- Plan to present results at GRC

Timeline:

| Planned Start Date | Planned End Date | Actual Start Date | Actual /Est. End Date |
|---|---|---|---|
| 10/1/2012 | 9/30/2014 | 10/1/2012 | 9/30/2012 |

Budget:

| Federal Share | Cost Share | Planned Expenses to Date | Actual Expenses to Date | Value of Work Completed to Date | Funding needed to Complete Work |
|---|---|---|---|---|---|
| $285,000 | $0 | $73,000 | $70,000 | $70,000 | $215,000 |