Geothermal Risk Reduction via Geothermal/Solar Hybrid Power Plants

Project Officer: Joshua Mengers

Total Project Funding: $1200K

May 12, 2015

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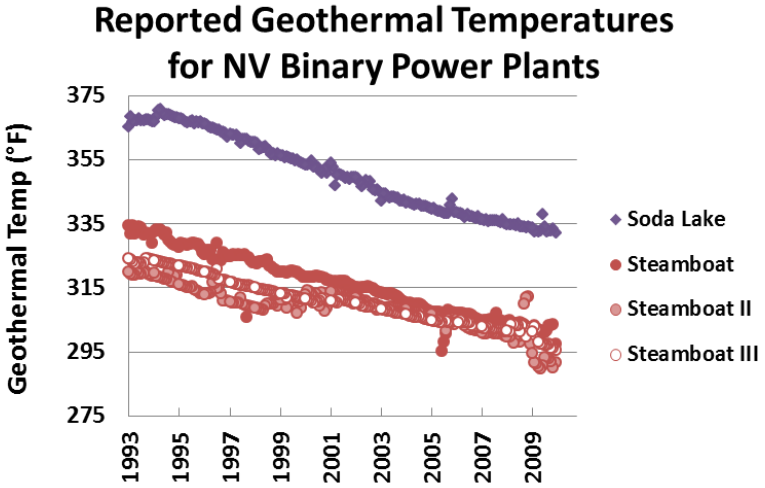
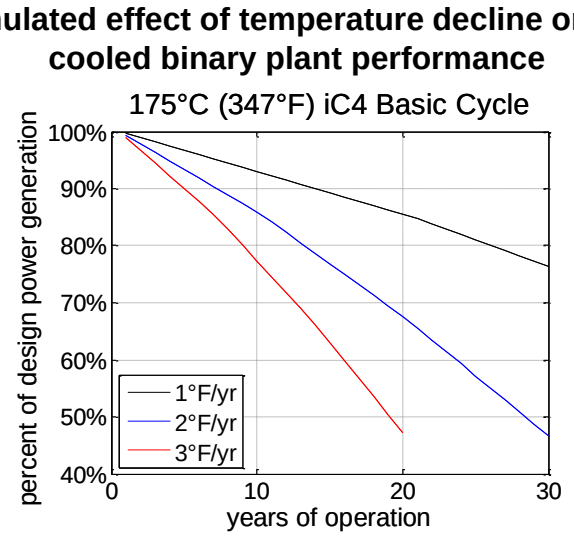
Low Temperature

Relevance/Impact of Research

Motivation: Not uncommon for geothermal power plants to experience declines in resource productivity (temperature and/or flow rate)

- Caused by number of reasons including reservoir cooling, production fluid loss, and injection strategy (well location)
- As resource productivity decreases from the power plant design point the detrimental effect on the plant performance is compounded by decreasing plant efficiency
  - Lost revenue from reduced power sales
  - Penalties for not meeting contractual levels of output in PPA
- Cost and risk associated with drilling makeup wells





Relevance/Impact of Research

Objective: Examine the viability of using a solar-thermal source to augment the energy input to a geothermal power plant

- Examine ways to mitigate risk associated with the uncertainty in [future] geothermal production capacity by using solar-thermal heat to offset any lack of geothermal resource productivity
  - Lower risk alternative to drilling new production wells
  - Restore geothermal fluid temperature to design value
  - Lower risk option versus drilling new production wells
- Explore synergistic integration of geothermal and solar-thermal heat sources
  - Increase power generation during hotter periods of day (high demand)
  - Reduce LCOE [either through reducing project development financing costs or by increasing output (per unit cost) of power plants]
  - Take advantage of recent advances in solar thermal collector technology

Scientific/Technical Approach

Technical Approach:

- Evaluate geothermal/solar-thermal hybrid plant performance relative to stand-alone power plants over representative time periods and operating scenarios
  - Performance or economics have to be superior to stand-alone plants for the concept to have merit in a greenfield application
  - A retrofit hybrid plant is examined to overcome other technical limitations (such as degradation in the geothermal resource and inability to drill additional wells)
- Hybrid plant performance simulated using SAM solar array and Aspen Plus power plant models validated with data from operating hybrid plant

Key Issues:

- Capital cost of solar hardware remains an impediment to greater deployment – quantify conditions where addition of solar heat results in positive NPV
- High temperature but transient nature of solar heat poses challenges for integration with geothermal heat source - define hybrid plant designs with performance and/or economics superior to two separate, stand-alone plants

Scientific/Technical Approach

Project Execution

- Joint AOP project
  - NREL provides expertise on solar collector selection and models the performance of solar hardware
  - INL simulates the performance of geothermal power plants including designs that integrate solar energy inputs from NREL's solar performance models
- Industrial collaboration
  - Enel Green Power, NREL, and INL signed CRADA on August 1, 2014
  - Goals of optimizing performance at EGP Stillwater Hybrid Plant
  - Exploring next-generation hybrid plant design concepts
  - CRADA opportunity necessitated changes to the original task plan

FY14 Accomplishments

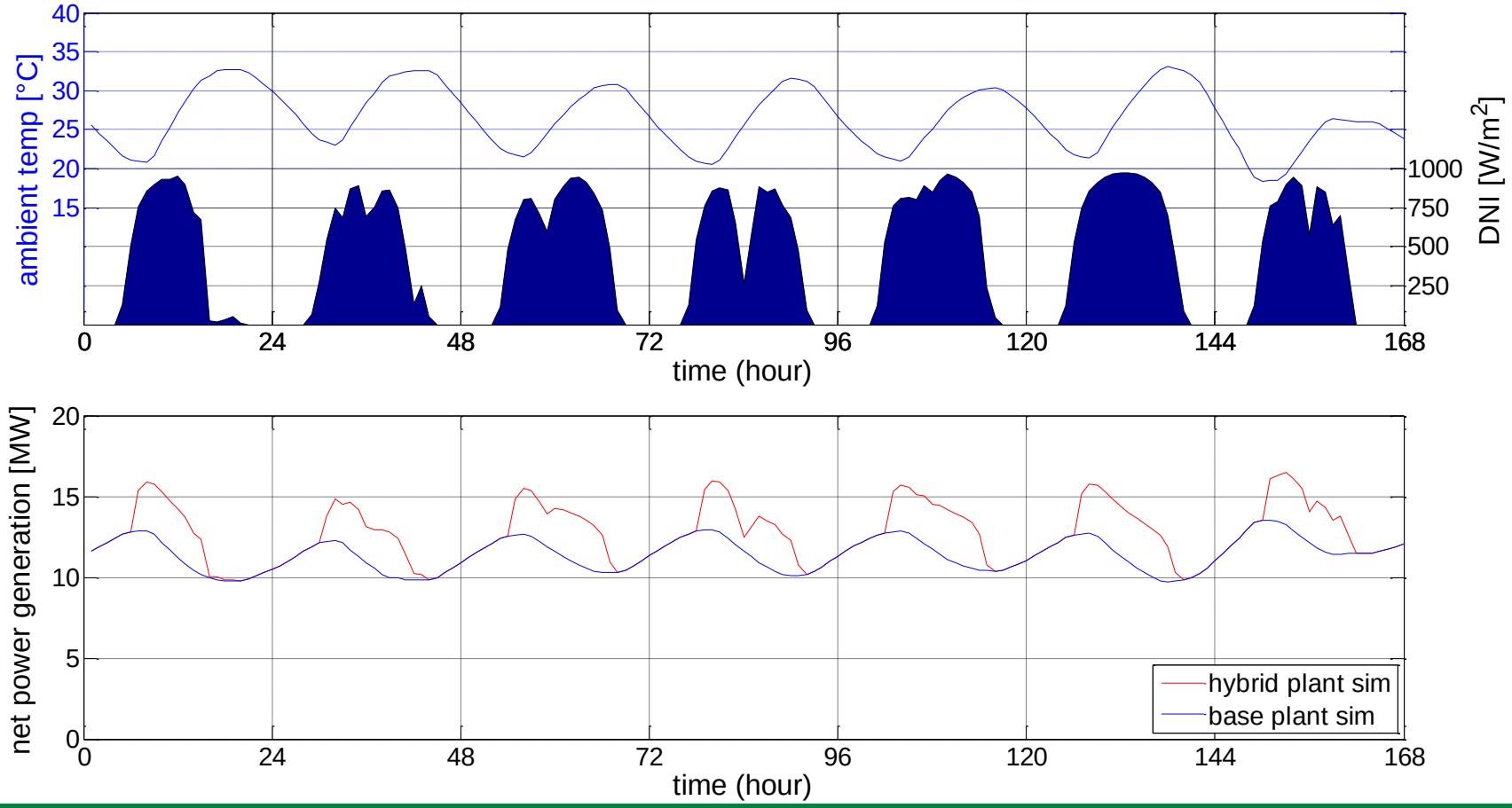
Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Technical evaluation of current CSP concentrator designs to identify the economic optimum for hybrid geo-solar power plants (NREL)		12/20/2013
Identify retrofit hybrid plant configuration and scenario capable of reducing LCOE by target of 5% (INL)		1/31/2014
Identify greenfield hybrid plant configuration and scenario capable of reducing LCOE by target of 5% (INL)		6/30/2014
Final report that identifies economic feasibility for different resource conditions that justifies the use of hybrid geo-solar technology	Sign and begin Enel / INL / NREL CRADA. Identified necessary data requirements for Stillwater plant simulation.	8/11/2014
	Present geo-solar hybrid analysis at the Geothermal Resources Council 2014 Annual Meeting. Submit presentation slides and papers covering the NREL (feedwater heating) and INL (binary cycle) analyses.	9/30/2014

FY15 Accomplishments to date

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Simulation results of the Stillwater power plant before and after solar-thermal integration transmitted electronically in tabular or graphical form. (INL/NREL)		12/23/2014
As-built optical efficiency of solar field at Stillwater hybrid plant with recommendations for field adjustments. (NREL)		12/31/2014
Parabolic trough solar-thermal output model decoupled from SAM power block assumptions; performance comparison with Stillwater solar field data. (NREL)		3/31/2015

Sample Base and Hybrid Plant Simulation Results - Reno, TMY week 26 (SAM data)

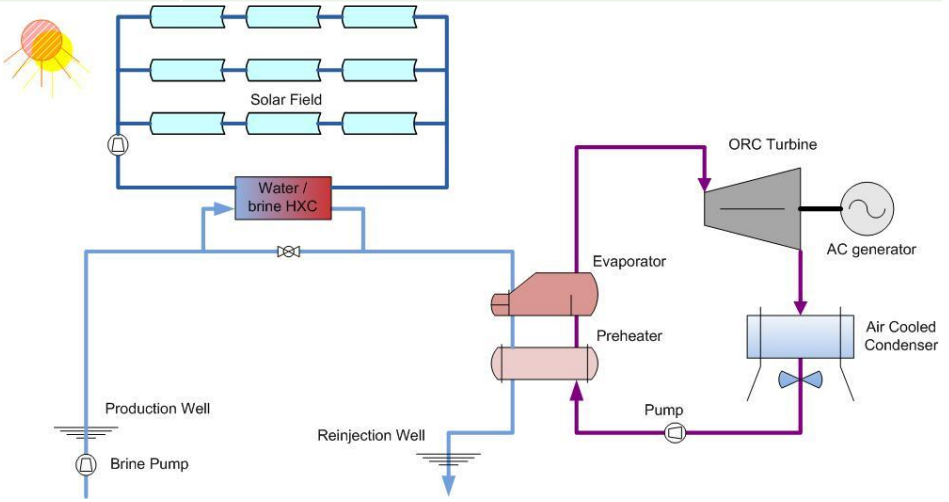
- **Design: Recuperated iC4 geothermal plant, 175°C production fluid**
- **Actual: 15°C T decrease; 20% flow decrease; ~28K m² SCA aperture retrofit**



Retrofit Design:

Solar preheating of geothermal production fluid

Benefits	Limitations
Hybrid plant performance less sensitive to high-ambient temperature or geothermal resource degradation	Low-cost solar field ($300/m^2 installed) and imposition of PPA penalties required for viable economics
Decrease PPA penalties for low power delivery	
Wholesale electricity price reduction up to 6% depending on assumed plant configuration	
Flexible solar array installation schedule	

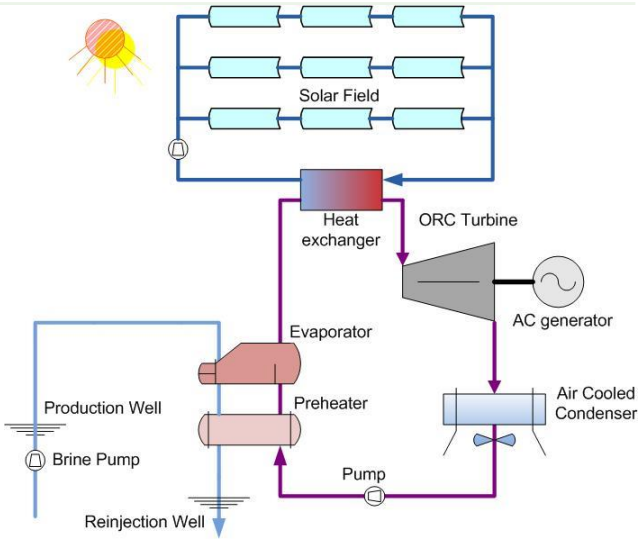


Reference: D. Wendt, G. Mines, T. Williams, C. Turchi, G. Zhu and S. Jenne, “Draft report to DOE confirming potential for up to 5% reduction in LCOE from hybrid configuration,” Milestone Report Submitted to DOE Geothermal Technologies Office January 2014.

Greenfield Design:

Solar heating of ORC working fluid

Benefits	Limitations
Hybrid plant performance less sensitive to high-ambient temperature or geothermal resource degradation	Low-cost solar field ($360/m^2 installed) and imposition of PPA penalties required for viable economics
Decrease PPA penalties for low power delivery	
Wholesale electricity price reduction up to 5% depending on assumed plant configuration and design conditions	Additional working fluid pumping capacity and heat exchanger result in higher initial plant capital cost
LCOE reduction greatest with time-of-delivery pricing using SAM default TOD rates	
Flexible solar array installation schedule	

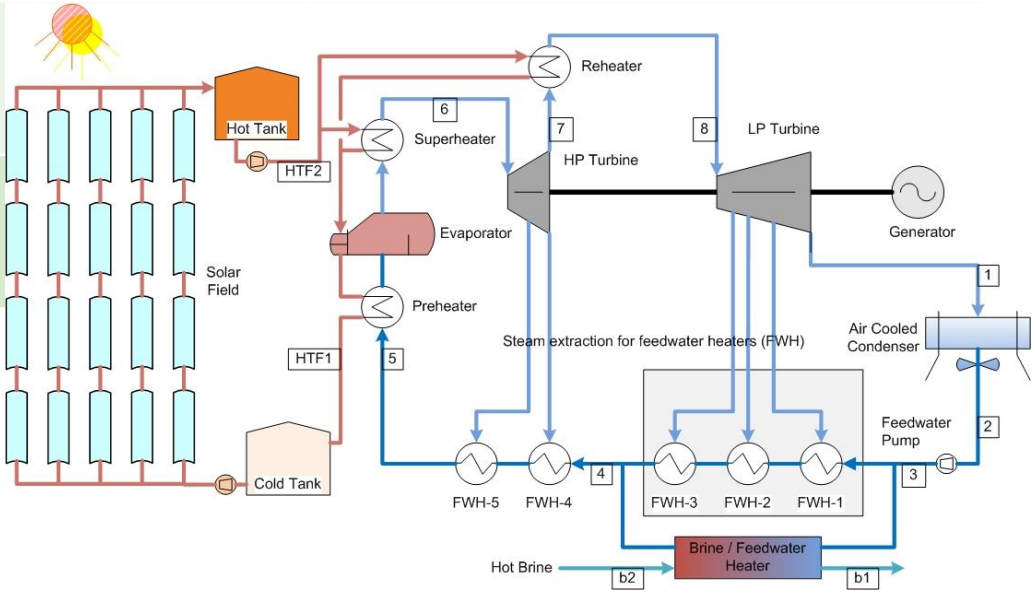


Reference: D. Wendt and G. Mines, “Greenfield hybrid plant configuration and scenario capable of reducing LCOE by a target value of 5%,” Milestone Report Submitted to DOE Geothermal Technologies Office June 2014.

Greenfield Design:

Geothermal feedwater heating for steam-Rankine solar plant

Benefits	Limitations
2x higher thermal-to-electric conversion efficiency of geothermal energy	Solar availability limits run time of the hybrid plant. Annual generation of hybrid was 2% lower than equivalent stand-alone plants
8.5% greater power output vs. equivalent stand-alone plants	
1.3% lower installed cost than 2 stand-alone plants	
Hybrid plant performance less sensitive to high-ambient temperature or geothermal resource degradation	
Bid price benefit of 2% to 6% depending on assumed plant availabilities and using typical California time-of-delivery rates	

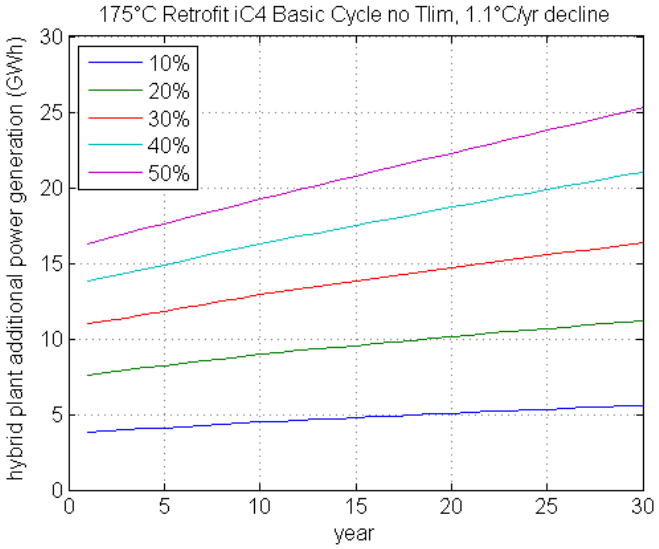


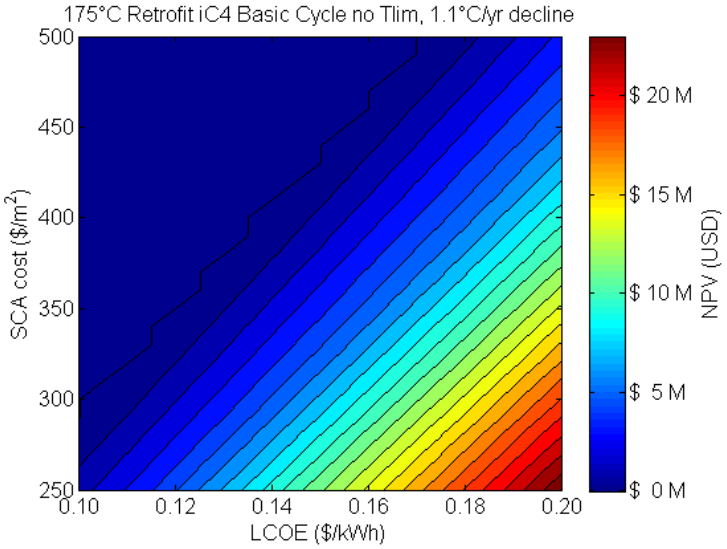
Reference: Turchi, et al. in GRC Transactions, 2014

Accomplishments, Results and Progress

Solar retrofit of air-cooled geothermal binary power plants NPV analysis (base plant economics not considered)

- Production fluid temperature declines at rate that decreases annual power generation by 50% following 30 years of base plant operation
- NPV calculation (r = 7.0%) includes CapEx, depreciation, revenues
- Analysis does not include project-specific items including taxes, insurance, O&M, royalties, contingencies, Renewable Energy Credits, PPA penalty offset





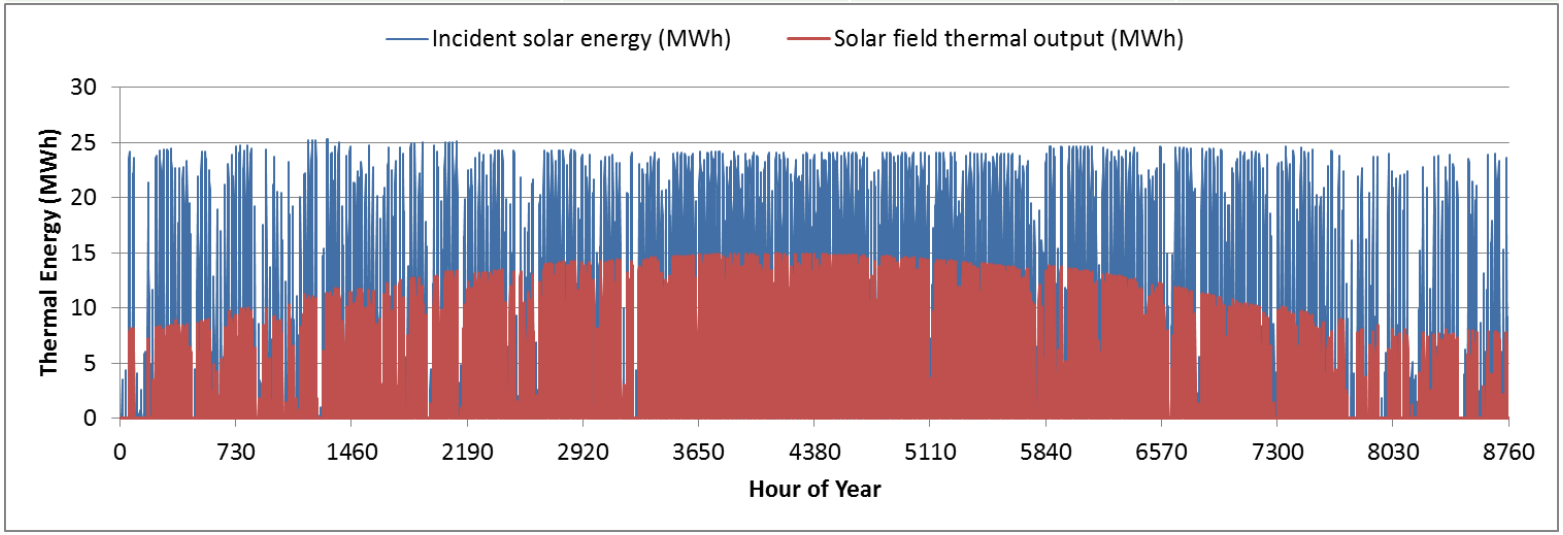
Reference: Wendt and Mines in GRC Transactions, 2014

Accomplishments, Results and Progress

Stillwater Hybrid Plant Solar Field Characterization

- Optical characterization of solar array (mirror reflectance, mirror slope error, and receiver position error)
- Compare predicted solar field performance and measured solar field performance
- Recommended adjustments as appropriate to improve solar field performance

Parameter	Vendor Literature	Measured (average)	Estimate after recommended changes
Reflectance	0.93	0.904	0.904
Overall geometric accuracy	0.940	0.883	0.998
Calculated Annual Performance (values provided to INL for inclusion in the system model)			
Annual delivered thermal energy, MWh (24,778 m^2 solar field)	32,840	29,590 (-10%)	TBD



Reference: G. Zhu, et al., "Comprehensive and Accurate Optical Characterization of a Large-Scale Parabolic Trough Collector Field," in preparation for ASME Power & Energy 2015.

Stillwater Hybrid Plant Simulation

- Equipment specifications
- Control strategy
- Historical operating data

Model Validation Results

- Base plant simulation results and operating data compared for 12 separate week-long periods (168 hrs) during calendar year 2013
  - $R^2 \geq 0.95$ for all 12 of the 168 hr intervals analyzed
  - Cumulative power within $\pm 2\%$ for all 12 of the 168 hr intervals analyzed
- Hybrid plant operating data recently made available – model validation efforts underway

Future Directions

- Utilize the validated Stillwater hybrid plant model to explore and quantify the potential benefits of different operating strategies and integration schemes at the Stillwater plant as well as alternative sites
- Modeling and analysis of the hybrid flash cycle, feedwater-heating hybrid, and Kalina KCS-34 cycle and summarizing the performance of each of these cycles for selected geothermal resource performance scenarios.

Milestone or Go/No-Go	Status & Expected Completion Date
Model validation reported as statistical R^2 analysis of model fit to Stillwater plant data for subsystems (e.g., solar collectors, ORC power block) and full plant (INL/NREL)	Rescheduled to 4/30/2015 to accommodate availability of hybrid plant operating data
Predicted electricity cost as a function of site conditions and project costs (solar resource, geothermal resource, geothermal and solar system costs, power cycle efficiency) at four U.S. sites. Define conditions necessary for economic deployment. (INL/NREL)	6/30/2015
Completion of report that identifies LCOE reductions from geothermal-only baseline configurations and identifies one or more scenarios that lead to LCOE benefits in excess of 5%. Report will include relevant geo/solar hybrid power cycles, plant configurations, performance, and economic feasibility; identifies current technology limitations and future research recommendations. (INL/NREL)	9/30/2015

Mandatory Summary Slide

- Technical evaluation has confirmed the performance benefits associated with geo-solar hybrid plants
- Economic analyses indicate that hybrid geo-solar plants can result in positive NPV and/or reductions in LCOE in assorted scenarios
- EGP Stillwater solar field optical characterization resulted in recommendations that could improve performance; complementary analyses currently being performed for complete retrofit hybrid plant
- Continuing investigation of synergistic integration of geothermal and solar-thermal heat sources as part of overall technology evaluation