Dixie Valley Binary Plant

Beowawe Binary plant

Low Temperature Project Analysis

Project Officer: Tim Reinhardt

Total Project Funding: $650K

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Principal Investigators

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Tom Williams, NREL

Systems Analysis and Low Temp

Project Objectives

- Conduct technical evaluations of DOE funded low-temperature geothermal projects to:
  - Understand the actual performance of the project compared to predicted performance
  - Improve simulation models to allow assessment of technologies in future projects and in other environmental conditions
  - Evaluate the technical and economic performance of projects to inform future DOE RD&D directions and support commercial deployment by the industry

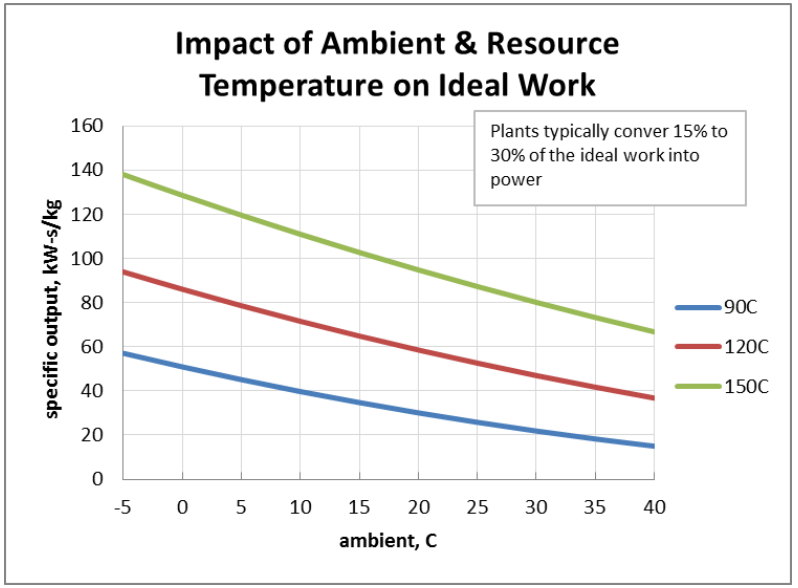
Scientific/Technical Approach

- Aggregate performance and cost data provided by each project and evaluate discrepancies between predicted and actual experience
- Interview plant operators to fill data gaps and enhance understanding of operations and field experiences
- Develop models of plant operation and compare to expectations
- Calculate pro-forma economic evaluation
- Document “Lessons Learned”

Scientific/Technical Approach

Challenges for predicting low temperature project performance:

- Power output sensitive to changes in resource and ambient conditions
- High flows needed: ~1,000 gpm required to produce 1 MW from 120ºC resource)
- Unexpected deviations in plant performance or geothermal conditions can have significant impact on power generation/sales
- Smaller plant size means unexpected costs are more difficult to recover with sales revenues



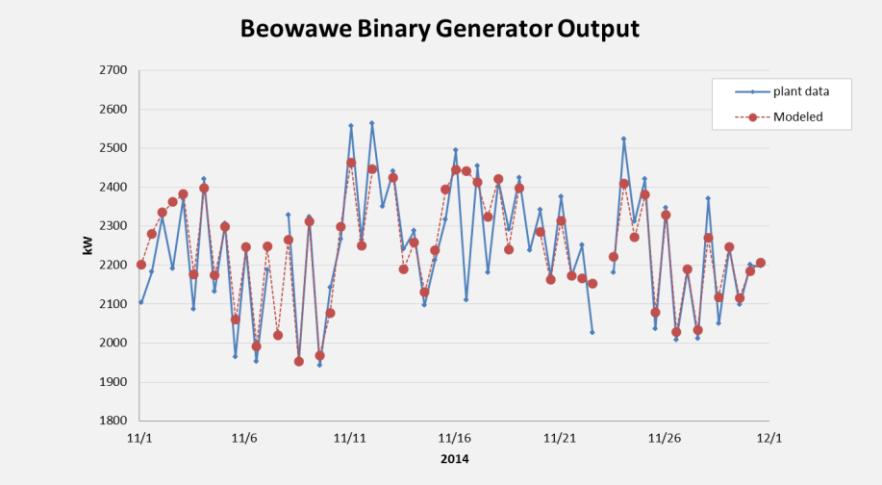
Accomplishments, Results and Progress

Case studies performed/in progress

- Beowawe: water-cooled binary bottoming cycle
  - Project Completed
  - 2 years of operational data for plant output and O&M
- Dixie Valley: air-cooled binary bottoming cycle
  - Project Completed
  - 2 years of operational data for plant output and O&M
- Electratherm: air-cooled binary unit using fluid from mining operation
  - Project Completed
  - Intermittent supply of hot fluid to unit did not allow extensive operation
  - Minimal power output data and no O&M cost data.
  - Decided not to continue with evaluation of this project
- Data/Information Gaps
  - Both Beowawe and Dixie Valley curtailed or shutdown operations when ambient temperatures were higher
  - Capital costs not itemized
  - Revenue streams
  - Discrepancies in reported configuration of plant

Unexpected operation: summer daytime shutdowns at Beowawe and Dixie Valley

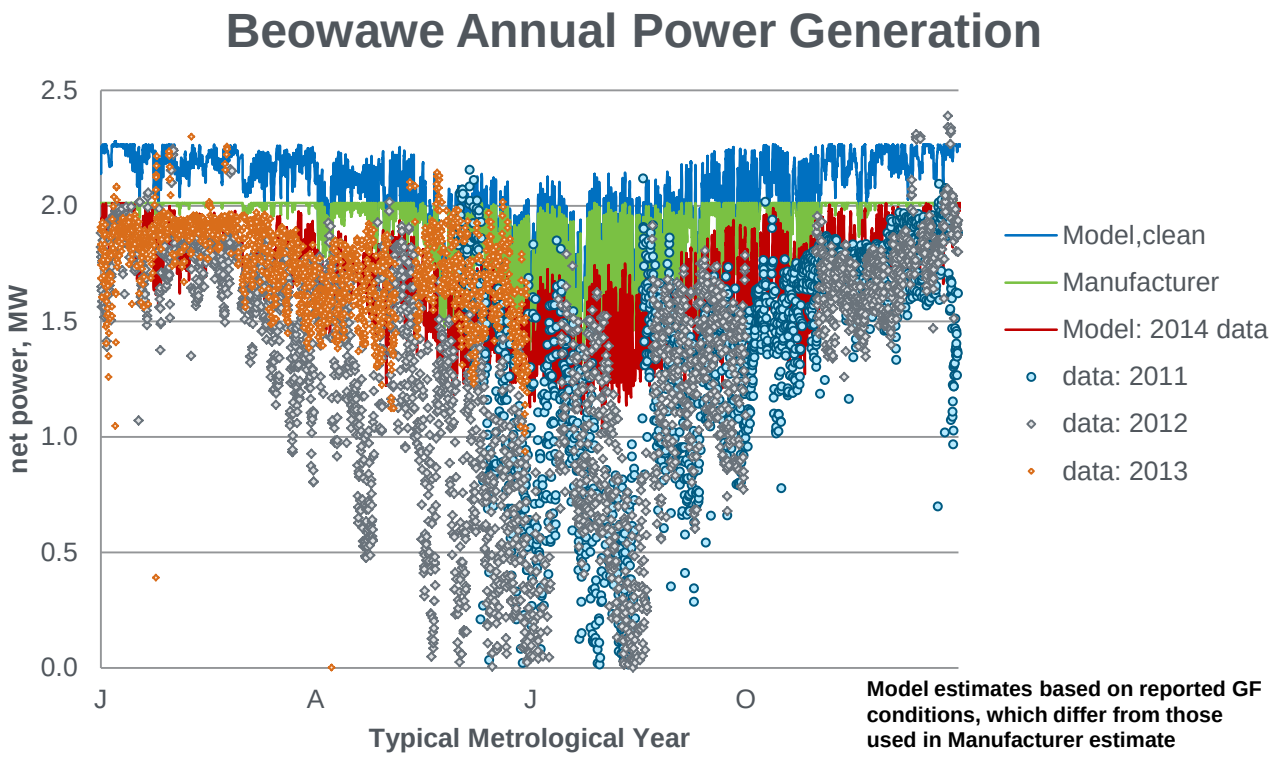
- To answer whether these should have been expected, developed plant performance model to predict output
- Beowawe model refined using ~~provided~~ detailed data files provided for November 2014, similar data not provided by Dixie Valley
- Beowawe indicated operation curtailed due to high condenser pressures.
  - Modeling suggests due to cooling water fouling in condenser – consistent with operator reported heat exchanger cleaning
  - Improved cooling water treatment protocol is being used – minimal curtailment during summer of 2014
- Dixie Valley operation curtailed due to low power output – likely due to geothermal fouling



Operational factors incorporated into performance models

- Fouling in geothermal heat exchangers and water-cooled condenser (Beowawe)
- A minimum temperature constraint placed on cooling water at Beowawe to prevent freeze damage.
- Changes to brine flow conditions to binary units at both plants (raised temperature and lowered flow rate.

Accomplishments, Results and Progress



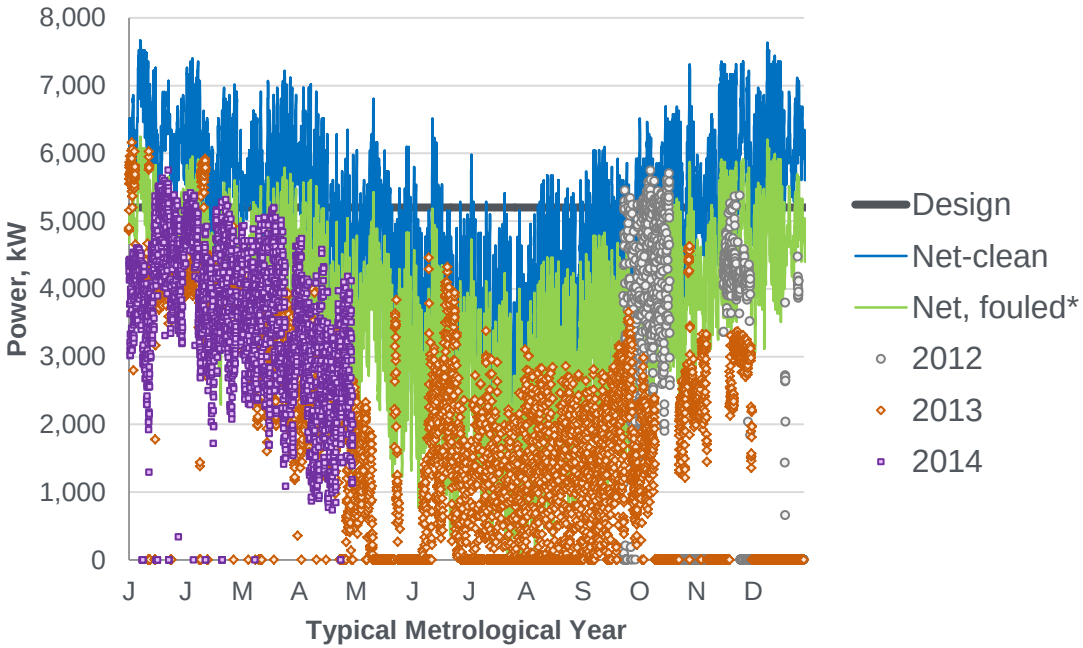
- The equipment manufacturer's estimate is based on original design brine conditions, with clean exchangers. The changes the operator made to the operating brine conditions are outside of the corrections to flow and temperature provided by the manufacturer

Accomplishments, Results and Progress

Dixie Valley Air Cooled Bottoming Unit

- Output curtailed due to fouling of the geothermal heat exchangers
- Detailed information on plant equipment expected in final report was not included
- Process operating data not provided – will re-visit with operator
- Operator has changed brine conditions – less flow, higher temperature

Dixie Valley Annual Power Generation

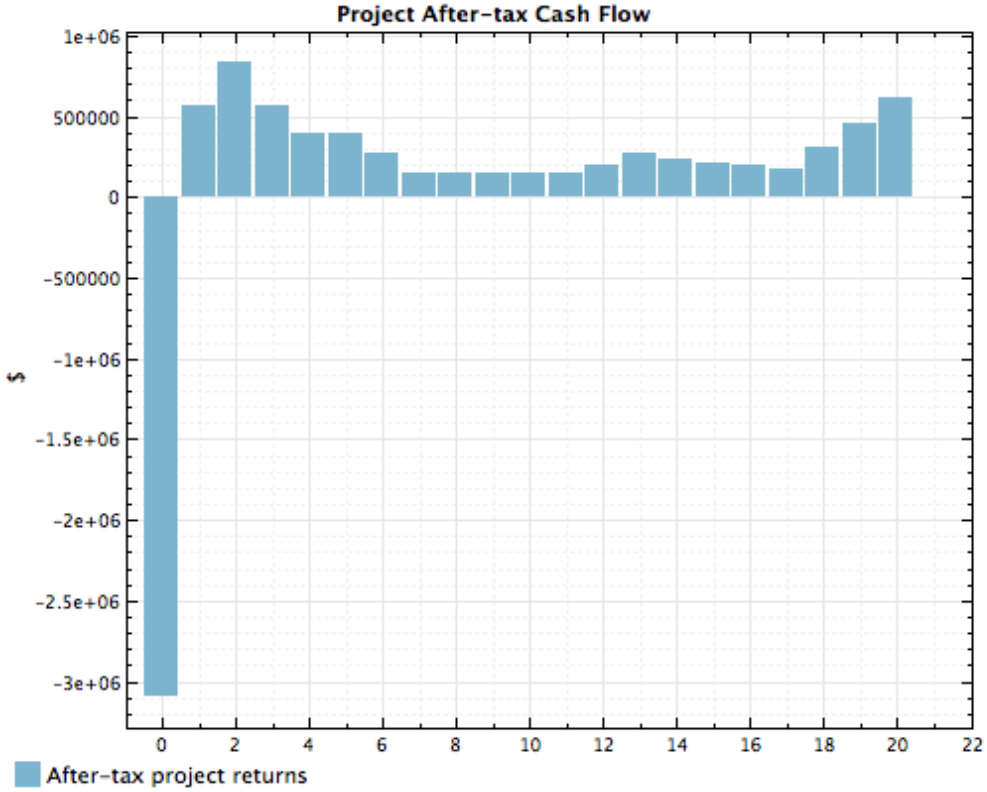


*** R,fouling = 0.010 °F-ft²-hr/btu**

Accomplishments, Results and Progress

Economic Evaluation for Beowawe

- Used NREL's SAM Model
- Power Purchase Agreement of $0.055/kWh results in Internal Rate of Return = 10.7%



Metric	Value
Power Purchase Agreement (PPA)	$0.055/kWh
PPA Escalation	1% annual
Inflation	2.5% annual
Project Life	20 years
Financing	50% debt
Debt Cost	8%
Production Tax Credit	None
Investment Tax Credit	10%

Lessons Learned:

- Operational data collection insufficient for detailed modeling
- Cost reporting should be standardized and provide more detail
- Impact of seasonal temperature variations higher than expected when project was developed
- Non-ideal conditions, such as heat exchanger fouling, were not always factored in to project expectations
- Engineered working fluids are expensive. Losses should be minimized, including recovering fluid vented when relieving excess pressure.
- The two projects that have successfully completed the 3 project phases have been at existing facilities with both an existing PPA, as wells as production and injection capabilities.
- Final reports would be enhanced with attention to economic feasibility of a follow-on project and capturing lessons learned relevant to commercial deployment

Accomplishments, Results and Progress

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Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Obtain information for performance modeling	Completed	Q1 FY15
Evaluate projects with at least one year of operation	Planned for Q2 FY15. Beowawe evaluation is largely complete	Ongoing
Prepare paper for GRC	Planned for Q3 FY15	On track
Provide DOE with summary economic and performance analysis	Planned for Q4 2015	On track

Future Directions

- Complete simulation model for Dixie Valley
- Complete additional sensitivity analyses for economic evaluation
- Evaluate prospects and barriers for commercial adoption
- Document recommendations for data collection that can be used in future DOE projects
- In FY16 apply approach and methodology developed to remaining low temperature projects

Summary

- Operational data collection and reporting is insufficient for detailed modeling and should be improved
- Cost reporting should be standardized and provide more detail
- Impact of seasonal temperature variations higher than expected when project was developed
- Non-ideal conditions, such as heat exchanger fouling, were not always factored in to project expectations