CEC Staff Workshop: Identifying Research Priorities on Flexibility and Other Operational Needs for Existing Geothermal Power Plants

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Comments by Michael R. Erbes, Ph.D., Enginomix, LLC, Menlo Park, California

During my 30+years of research and development work, primarily focused on the development and application of software for the design, analysis and optimization of power plants, I've noted key technical areas relating to geothermal energy that would benefit greatly from R&D support from the CEC. I recommend that these R&D priorities be addressed in the upcoming CEC solicitation in support of geothermal energy development in California. These R&D priorities can be grouped into three areas:

1) Property methods
2) Enhanced steady-state and transient systems and equipment modeling capabilities
3) Geothermal Operator Training Simulator (OTS)

<u>Property Methods:</u>

During my past geothermal modeling work (for Coso, the Geysers, CalEnergy and others) we've sometimes had to limit what we could accomplish due to a lack of appropriate and available property methods for geothermal technologies. Property methods are the foundation of energy system modeling software, and property methods are readily available for a wide variety of thermodynamic fluids used to model conventional energy technologies. We've developed and worked with such software and property packages in the past (such as the GateCycle software, based on my Ph.D. work at Stanford, which has been used to model geothermal steam cycles at the Geysers, in spite some of its property method shortcomings), and we've typically tried to use industry standard methods for property calculations as much as possible (such as the ASME and IAPWS formulations for pure H2O, and the NIST REFPROP properties for ORC, sCO2 and Kalina technologies). Currently, the development of robust, commercial-grade thermodynamic modeling software to design and analyze geothermal systems in California is hampered by a lack of standardized, readily available property formulations for geothermal technologies, particularly in regards to brine fluids (which need to account for TDS content, non-condensable gases and flash properties), mixtures of H2O and NCG (which are more critical in geothermal systems than in more conventional power technologies), and solids properties. I recommend that CEC include topics in their solicitation for the development of standardized, readily-available property methods for geothermal system modeling to address these shortcomings.

<u>Enhanced steady-state and transient systems and equipment modeling capabilities:</u>

Another area of R&D needed to help support the development of geothermal resources in California is the extension of existing energy system modeling software to incorporate better support for some of the unique characteristics of geothermal power generation technologies, both for flash geothermal technologies and advanced heat-recovery technologies. Ideally, these modeling enhancements could be used for both steady-state and transient analyses. Steady-state modeling is used for design and off-design performance modeling of power plants, while transient modeling is required to design and analyze the time-dependent response of energy systems, for applications such as control system design and tuning, studies of alternate operating and control strategies (including startup and shutdown, load following, flexible operation etc.) and integration with storage technologies. Open-equation modeling frameworks represent the current state-of-the-art for system simulation of chemical and energy systems (including commercial modeling platforms such as Aspen Custom Modeler, gPROMS and IPSEpro) as well as open-equation modeling technologies such as Modelica, and the use of the open-equation technology makes it easier to keep separate the proprietary and non-proprietary technologies during the development process (so that the results of the modeling improvements can be more readily shared). These open-equation software systems generally use simultaneous solution convergence techniques, which are well suited for both steady-state and transient analyses (as opposed to the more traditional sequential-modular solution techniques used by software such as GateCycle, which are not well suited for transient modeling applications). As noted above, robust and accurate property methods are the foundation needed for energy system modeling software, and with an improved property foundation open-equation modeling frameworks could be easily extended to better support geothermal system modeling. Another important advantage of open-equation modeling technologies such as IPSEpro, gPROMS and Modelica is that modeling extensions can be added with considerably less effort than is needed with more traditional modeling software, since in those packages engineering calculations are by nature inseparable from the proprietary software code. As such, open-equation software systems require considerably less effort to extend to fully support modeling of geothermal systems. Some of the modeling extensions needed to support the modeling of geothermal power technologies in California include:

- Support for design and off-design modeling of two-phase flow in piping networks
- Integrated design/off-design calculations for pressure/flow relationships including geothermal wells, piping networks and steam power cycles
- Improved models for key flash geothermal equipment including flash tanks, steam separators, crystallizers, and separator-boilers
- Incorporation of design and off-design modeling of advanced heat recovery technologies, such as ORC, sCO_2 and Kalina cycles, both for stand-alone geothermal power generation and hybrid cycles (bottoming cycles integrated into flash geothermal plants).

<u>Geothermal Operator Training Simulator (OTS):</u>

The third R&D area related to geothermal energy that would benefit greatly from CEC support is the development of a generic Operator Training Simulator (OTS) framework for geothermal power, which could be developed and used collaboratively by industry and academia. Thermodynamic modeling of energy systems requires a multi-tiered development effort, with property methods as the base and detailed systems and equipment modeling, both steady-state and transient, as the next layer. On top of these, with additional transient development and integration of OTS software technologies, one can build an operator training simulator (OTS) which could then be used for operating training, education and research, as well as engineering and control studies. There is a significant need in California for such an OTS modeling framework for geothermal technologies, particularly given the current interest in exploring new operating strategies for geothermal technologies including flexible power generation. With an appropriate structuring of the solicitation (I recommend CEC consider not requiring cost sharing), a generic OTS system could be developed in collaboration with California universities to support engineering education and R&D programs related to geothermal energy. A geothermal OTS system could also help train a new generation of plant operators and engineers and help lay the foundation for the maintenance and expansion of geothermal power generation in California. This geothermal OTS collaboration effort could be structured similarly to an ongoing DOE-NETL research and development project for IGCC technologies (IGCC = Integrated Gasification Combined Cycle). As a part of this ongoing project, DOE supported the development of a fully featured, generic OTS modeling system for IGCC power plants. Something similar should be done for geothermal technologies in California, and the resulting OTS framework could be shared with industrial and academic organizations for collaborative research, engineering, education and operator training purposes to help support and grow the development of geothermal power technologies in California.