A New Look at the Thermal Regime around Roosevelt Hot Springs, Utah

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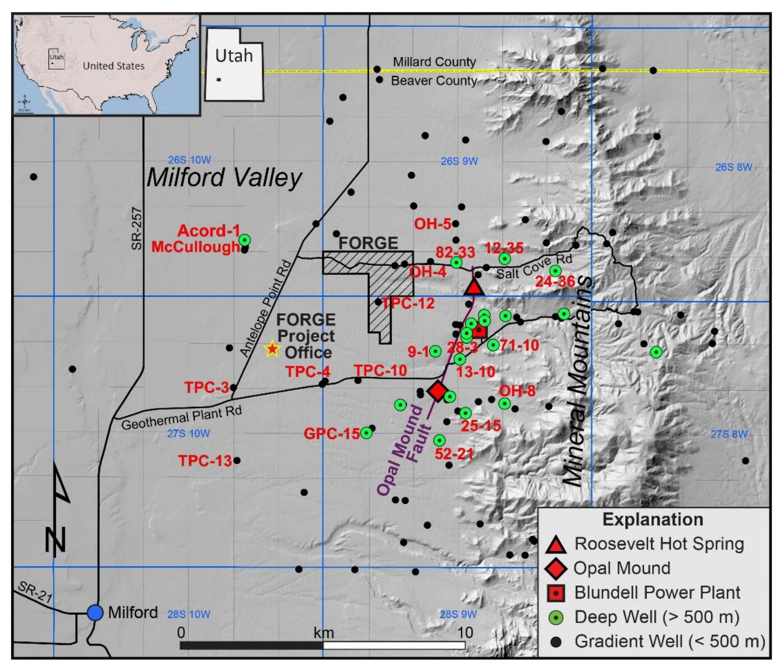
ABSTRACT

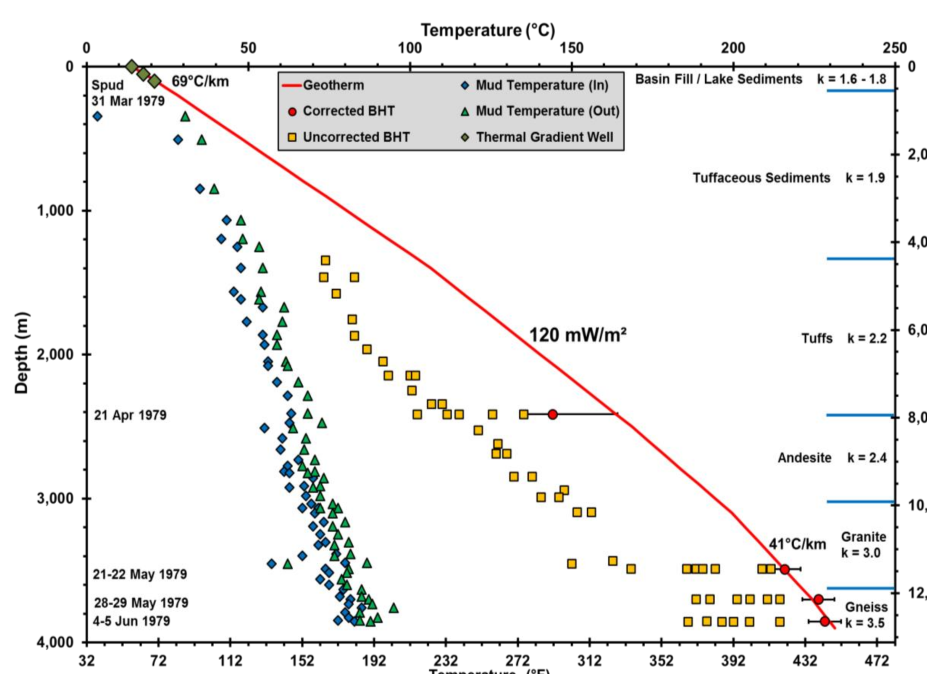
Recent re-evaluation of thermal data from over 100 wells drilled mostly during the 1970s and 1980s in the area of Roosevelt Hot Springs (RHS) has refined earlier interpretations of the thermal regime. These data have been combined with pre-existing gravity and magnetotelluric data to construct a 3-D model of the area as part of the site characterization phase of U.S. Department of Energy's Frontier Observatory for Research in Geothermal Energy (FORGE) initiative. The project goal is to create an enhanced geothermal system (EGS) reservoir in crystalline rock where temperatures of 175 to 225˚C are present at depths between 1.5 and 4 km to test development concepts and technology. The 3-D model is amply supported by well data, both in terms of suitable temperatures and depth to crystalline basement (Precambrian gneiss and Tertiary plutons), and shows that FORGE temperature and lithologic requirements can be met over an area of at least 100 km². The total volume of crystalline basement rock with temperatures over 175˚C above 4 km depth is more than 100 km³. Temperatures greater than 175˚C within plutonic basement rock are expected at depths ranging from about 1.8 to 3.0 km, depending on the specific location, over most of the area best suited for deep FORGE drilling based on land ownership, existing roads, and topographic features. Nearly all of the FORGE area achieves 175˚C by 4 km depth. While RHS is an active hydrothermal system, heat transport farther to the west, on the opposite side of the Opal Mound fault, is primarily conductive. The thermal regime, based on deep temperatures and reservoir rocks, suggests the site is ideal for FORGE development.

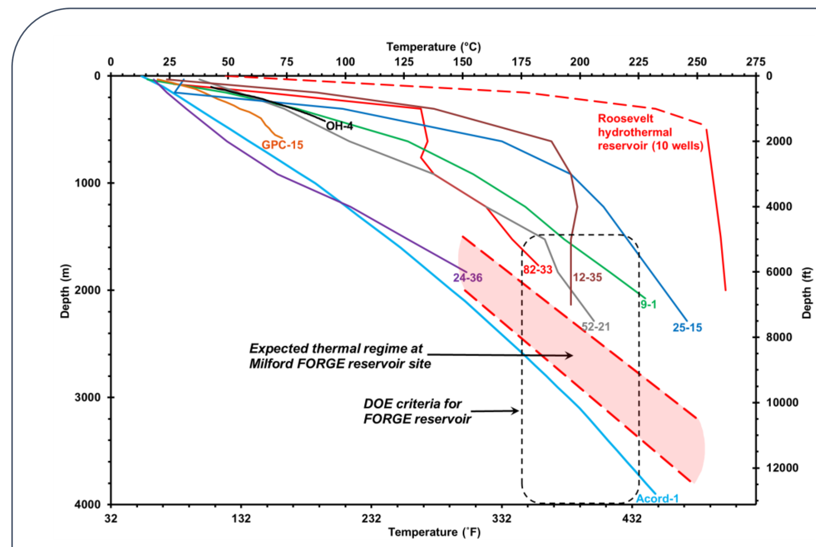


Locations of the FORGE drill site (hatched area), FORGE office site, Acord-1 well, and other wells. Only wells shown in other figures are annotated.

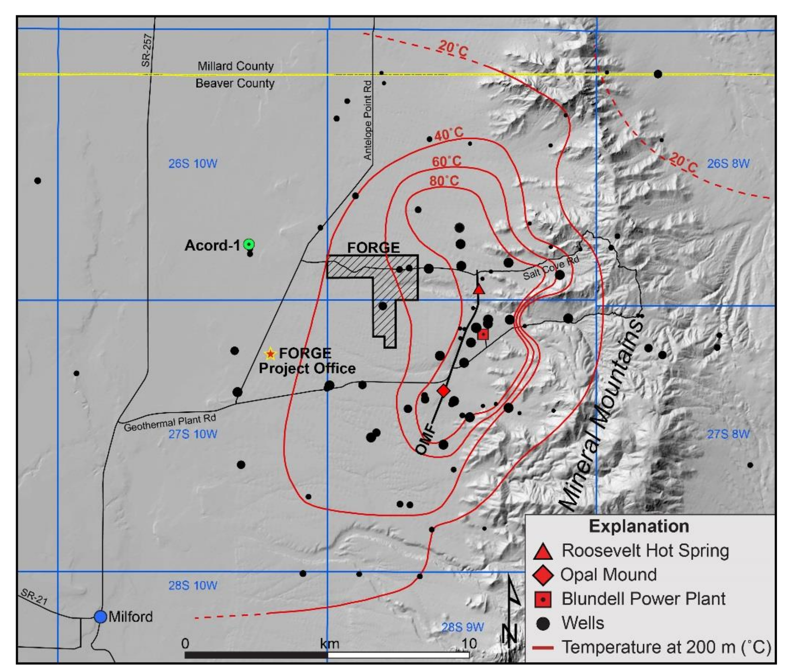
View to the east showing the SunEdison photovoltaic array in the foreground, a FirstWind turbine array on the right, and PacifiCorp's Blundell geothermal power plant near the base of the Mineral Mountains in the far distance. The red star is the center of the FORGE drill site.

Temperature data from Acord-1. The bottom hole temperatures (BHTs) are consistent with a conductive profile, and the best-fit geotherm has a heat flow of 120±20 mW/m² (uncertainty due to thermal conductivity [k] assumptions; geotherm fits both the observed shallow thermal gradient from the McCullough well near the Acord-1 and the corrected BHTs). The temperature gradient in the granite is 41°C/km. The thermal conductivity variation with increasing depth is used to calculate geotherms for other thermal gradient wells in northern Milford Valley.

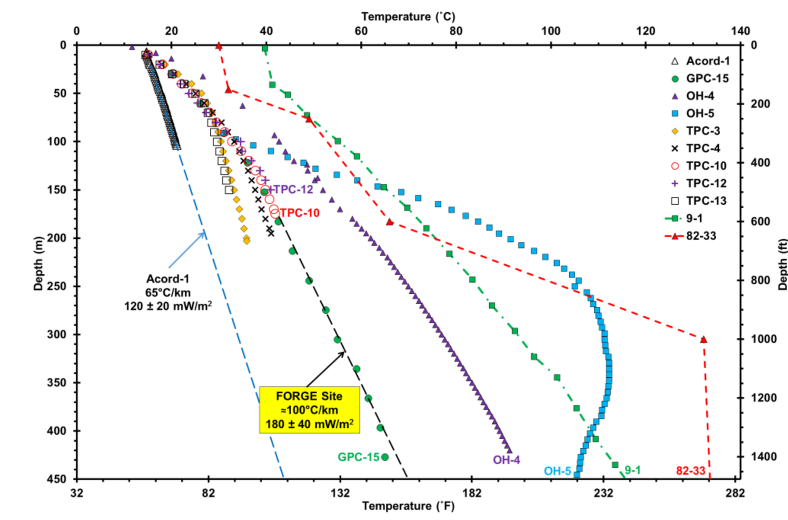




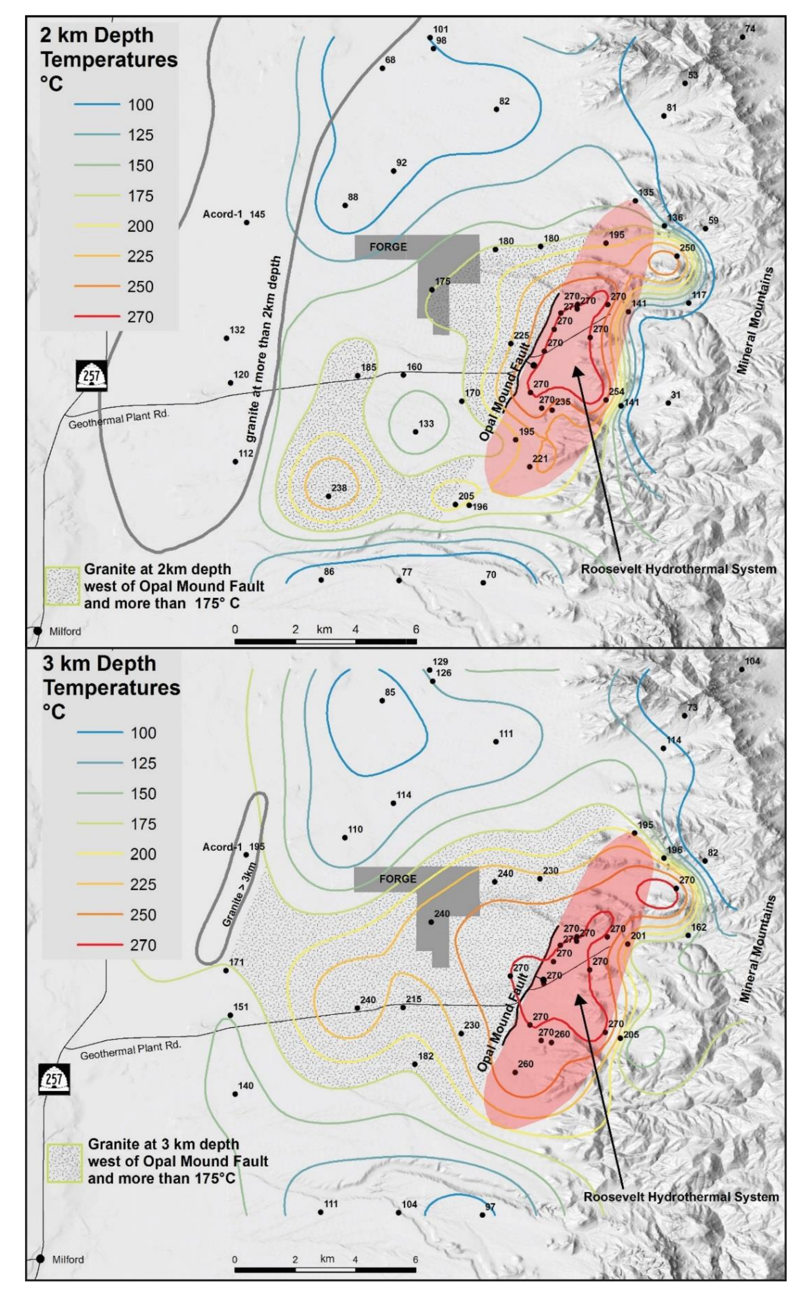
Likely thermal regime at the Milford FORGE deep drill site based on profiles in surrounding deep and thermal-gradients wells. The expected thermal regime beneath the site lies centrally within the bounding constraints specified by DOE. The two red dashed lines bound the likely uncertainties. The nearest wells to the site are 9-1 and 82-33, and are mostly in granite; the only wells mostly in basin fill are Acord-1, GPC-15 and OH-4. Productive wells tapping the Roosevelt hydrothermal system lie east of the Opal Mound fault and have near-surface temperature profiles that follow boiling-point-for-depth conditions. The hydrothermal well profiles represent pre-development conditions; subsequent fluid production has lowered some of these profiles by more than 300 m (Allis and Larsen, 2012).



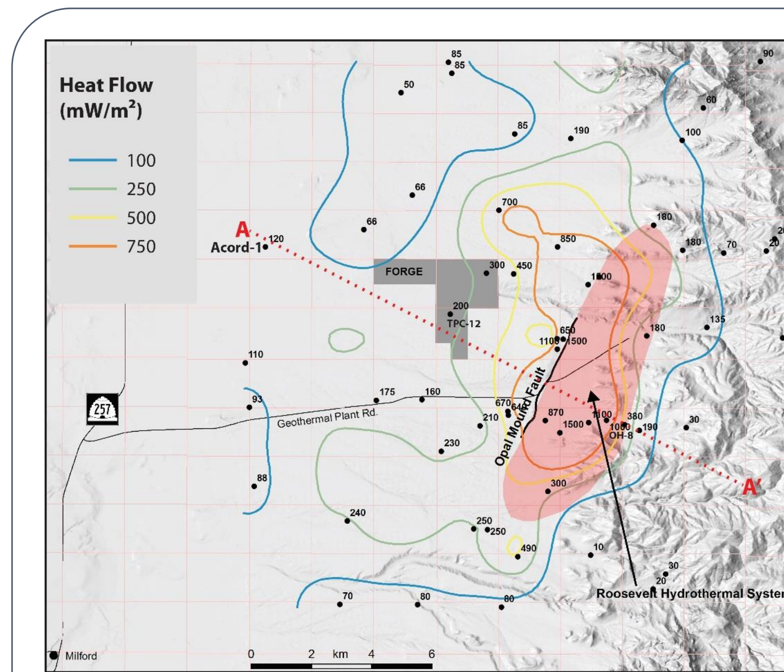
Temperature contours at 200 m depth in northern Milford Valley. The size of the well symbols reflect the degree of certainty of the temperature data, which constrain the geometry and position of the isotherms. The largest circles represent wells deeper than 200 m, where the temperature was directly measured. The smallest circles represents wells at least 50 m deep, where the temperature had to be extrapolated to depth. On the east side, the contours represent the temperature at 200 m beneath the 1830 m above sea level datum, which is the approximate elevation of the alluvial fan near the Mineral Mountains. This approach allows the contours to be smoothed across the ridges and valleys, but requires that higher-elevation wells be extrapolated to greater depths (up to 405 m from the actual ground surface). Farther to the west, the contours represent the temperature 200 m beneath the ground surface, which is about 1325 m asl near the center of the valley.



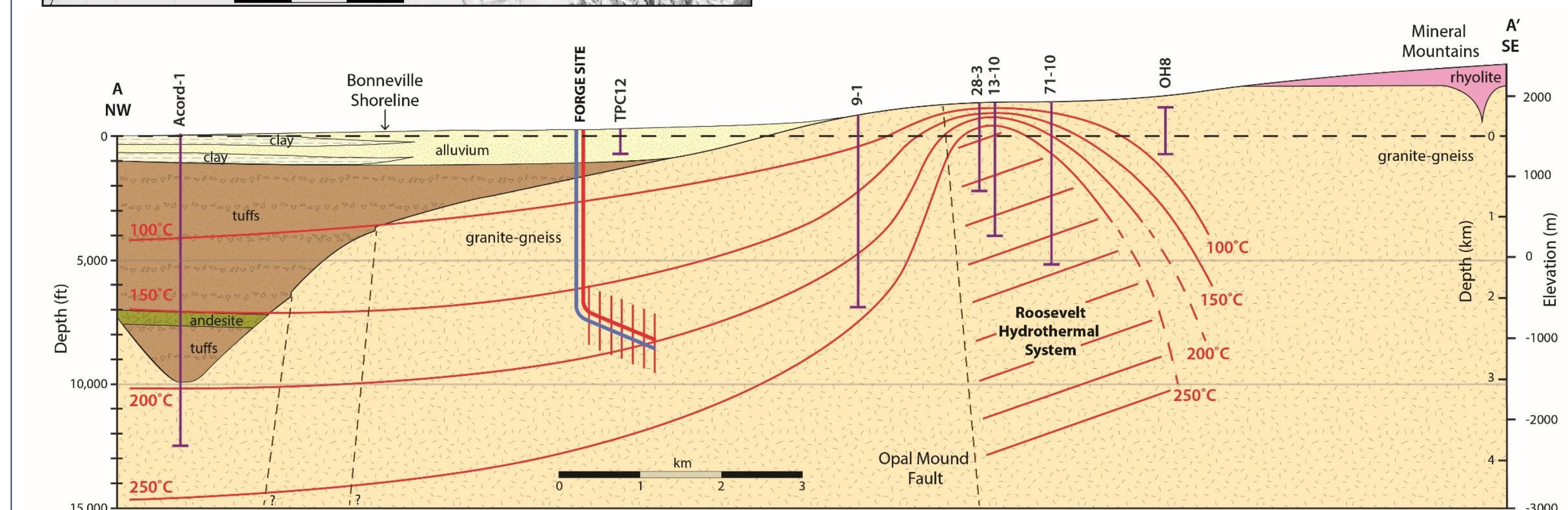
Temperatures in selected geothermal gradient wells and the upper portion of three deep wells west of the Opal Mound fault zone. Thermal gradients are 50–65˚C/km in the central valley and increase eastward towards the Opal Mound fault zone. TPC-12 is within the FORGE site and indicates a deeper gradient of close to 100°C/km. OH-4 indicates even higher temperatures and is located 600 m east of the eastern boundary of the FORGE deep drilling site. The profiles for 82-33 and 9-1 are from Faulder (1994).



Temperature at 2 and 3 km depths derived from observations in deep wells and geotherms fitted to thermal gradient wells. Temperature contours typically have a geostatistical mean uncertainty of ±13˚C. The stipple pattern highlights where granite at that depth is hotter than the minimum FORGE temperature constraint of 175˚C. On the 3 km map, granite hotter than 175˚C extends significantly west and north of Acord-1, but has not been shown because of inadequate well control. The red shading shows the extent of the Roosevelt Hydrothermal System based on pressure measurements in deep wells.

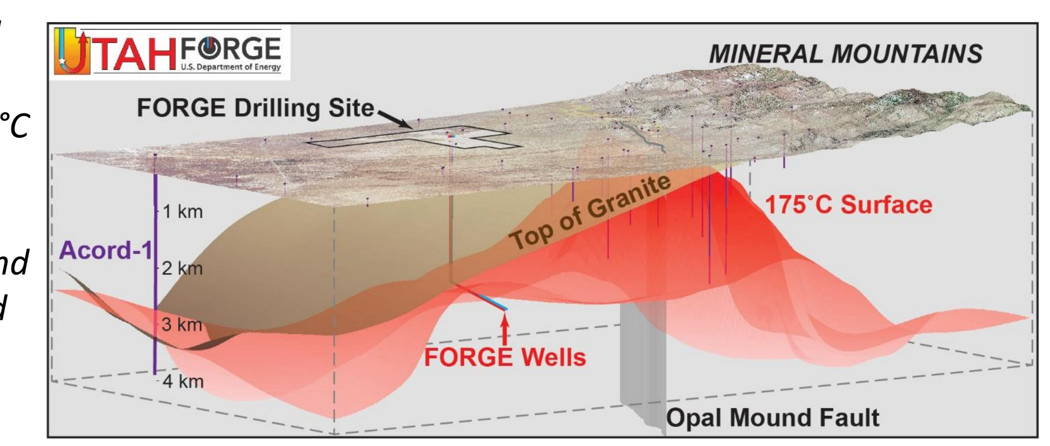


Contours of conductive heat flow derived from wells around the Roosevelt Hot Springs hydrothermal system. Most values are from the temperature gradients in wells less than 200 m deep. Very high heat flows over the hydrothermal system (pink shaded area) reflect high temperature gradients overlying upflowing hot water, which at shallow depth is constrained by boiling-point-for-depth conditions. West of the hydrothermal system, delineated by the Opal Mound fault, the thermal regime is conductive at depth and follows a pattern of decreasing heat flow towards the west. A-A' defines the ends of the geologic cross section shown below.



Geologic cross section A-A' from the figure above, showing the stratigraphy, structure, and the FORGE deep well site. The zero datum for the depth axes is at 1524 m asl. Precambrian gneiss and Tertiary plutonic rocks are undifferentiated. The RHS hydrothermal system lies east of the Opal Mound fault. Isotherms are interpreted from well measurements, and the contact between granite-gneiss and overlying basin fill is interpreted from gravity measurements (Allis et al., 2016; Hardwick et al., 2016). The trajectories of the FORGE deep wells deviate towards the southeast from the western side of the deep-well site. The lower part of the basin fill in Acord-1 has been interpreted to contain about 1 km of andesite (Hintze and Davis, 2003), however, subsequent logging and X-ray Diffraction analyses of the cuttings suggests the andesite is much thinner and interlayered with volcaniclastics and tuffs (Janae Wallace, Utah Geological Survey, personal communication, 2016; Jones and Moore, 2016).

*Modified snapshot from the 3-D model showing topography, the brown upper surface of the granite, and the red 175°C surface. Existing wells are purple. View is to the northeast with no vertical exaggeration. Along with other data and information, the model can viewed and manipulated (rotated in any plane, features turned on or off, etc.) at **http:www.forgeutah.com/site/.***



CONCLUSIONS

- The thermal regime around RHS has been extensively studied since the 1970s and this work merges many diverse datasets to create the most comprehensive geothermal picture of the RHS area.
- In addition to the RHS hydrothermal system, a conductive thermal anomaly that may be caused by residual partial melt at depths greater than 5 km, covers over 100 km² in northern Milford Valley.
- The conductive zone consists of crystalline basement and basin fill extending far to the west of RHS.
- The volume of basement rock at depths less than 4 km with temperatures ≥175˚C is over 100 km³.
- This work expands our understanding of the thermal regime in and around RHS and shows that, along with other factors such as existing infrastructure, the area is ideal for development as the FORGE site.

ACKNOWLEDGMENTS

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For additional information, see the FORGE website at **http://energy.gov/eere/forge/forge-home.**

A complete list of references is included in the accompanying paper.