# Appendix H

## Mirror Reflectivity (SunLab Input)

# H. MIRROR REFLECTIVITY (SUNLAB INPUT)

The terms “mirror reflectivity” and “reflectivity” are used throughout this report, unless specified otherwise, to refer to the solar-weighted specular reflectivity—the fraction of the incident solar energy reflected in a specular (rather than diffuse) fashion. The solar-weighting of reflectivity is achieved by measuring the spectral reflectivity across a wide range of solar-thermal wavelengths (typically 0.3µ to 2.5µ), then weighting by the ASTM-accepted wavelength-dependant energy content of sunlight after it passes through the earth’s atmosphere (ASTM G159-98 air mass 1.5 solar spectral irradiance is the standard). The specular nature of a mirror’s reflectivity is quantified by measuring the intensity of reflected light only in a limited collection region along the ideal angle of reflection. Both laboratory and field portable instruments have been developed that measure the specular reflectivity at adjustable acceptance apertures ranging from 1 to 100 milli-stearadian (2π stearadian equals the complete hemisphere of possible reflection). A tower receiver subtends about 5 milli-stearadian from the furthest heliostat at a very large plant. The accuracy of both the spectral reflectivity and specular reflectivity are assured when the measurements are referenced to directly traceable NIST standard reference materials, the fundamental geometric optics of the instrumentation is determined, and the mirror scattering characteristics are known. The Optical Materials Branch at the National Renewable Energy Laboratory and the Primary Standards Laboratory at Sandia National Laboratories provide support in characterizing the reflectivity of mirror materials.

Microscopic surface irregularities, called specularity errors, in a mirror’s substrate or superstrate material slightly reduce a mirror’s measured specular reflectivity because they cause non-specular (scattered) reflections that fall outside the acceptance aperture of the measurement instrument. Specularity errors can be measured on small mirror samples and generally have a much smaller impact on plant performance than “slope” and “curvature” errors, which are errors in the shape of the mirror surface over larger (macroscopic) areas of the surface that must be measured on full-size samples. Slope and curvature errors are included and reported in the optical performance (efficiency) metric of CSP plants, not in the mirror reflectivity.

The reflectivity of an ideal (front-surface) silvered mirror is approximately 97%. Since silver degrades quickly in the outdoor environment, more durable back-surface glass mirrors have typically been used at CSP plants. Glass superstrates result in transmission losses (increased absorption) through the glass medium, with losses increasing as a function of both iron content in the glass and thickness. The reflectivity of typical, 4-mm thick, low-iron, float glass mirrors, such as the SEGS trough plants in California, is approximately 94%. The manufacturing technology for mass-produced commercial glass, which employs formulations with higher iron content, is extensive and mature. Mirrors constructed from this type of glass exhibit lower reflectivity, ≤90%, due to increased absorption and thickness. Large amounts of low-iron glass are manufactured for use in flat-plate collectors used for water heating, but the manufacturing volume is much less than conventional glass. Because of the current, low-volume manufacturing capability for low-iron glass products, small order quantities of low-iron glass mirrors are expensive. As larger or more numerous CSP plants are built, the cost of low-iron mirrors should approach the price-point of the mass-produced conventional glass.

An approach to increasing reflectivity using conventional glass formulations is to use thin glass mirrors, produced in large quantities for commercial applications such as compact cosmetic mirrors, to reduce the transmission losses. Thin glass mirrors are typically no less expensive per square meter of reflector than thick glass mirrors because the raw material cost savings are offset by increased handling costs and breakage. The baseline trough and tower designs use thicker glass as a structural element. The conversion to thin glass in these designs would require additional structural support. Additional mirror module support elements could be justified in stable markets where high volume, low-cost production approaches would become practical, e.g., metal forming of automotive body panels.

Flexible ultra-thin mirror constructions consisting of silvered micro-thin glass superstrates, all-dielectric (non-metallic) multilayer constructions, and silvered polymer or sheet metal substrates are being investigated and could enable innovative concentrator designs that offer the possibility of lower costs than current designs. Reflectivity values >94% have been demonstrated, but a cost-effective mirror product durable enough for use in a CSP plant, which requires both long-term outdoor exposure and frequent cleaning, must still be developed and proven.