Concentrating Sunlight to Make Clean Fuels Using Shape-Adjusting Heliostats

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Background – previous mirrors to concentrate sunlight

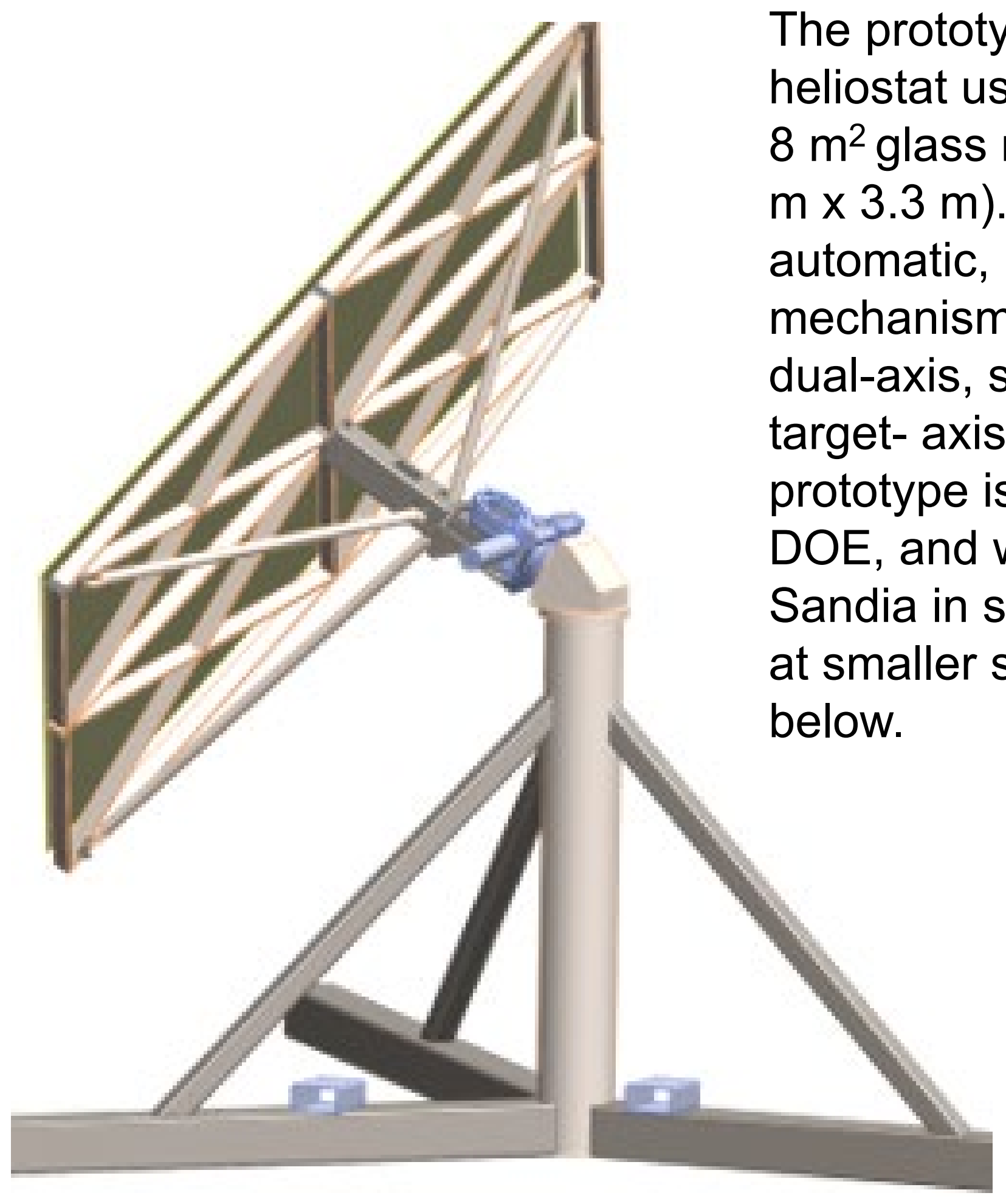
Solar energy has been stored by focusing it to melt and heat salt and using the stored heat to make electricity at night. The most recent and advanced facility to do this is the Noor Energy 100MW power tower, shown below, located only 40 miles from Dubai. It has a 2 km diameter field of 70,000 heliostats, flat mirrors that are turned individually through the day to direct sunlight onto a 250 m–high tower-mounted receiver, as shown.

A new approach now being explored is to use concentrated sunlight to power chemical reactions to make fuels such as H_2 from water or CO from CO_2. A cost of $2/kg is targeted for solar thermal H_2 (NREL). But these reactions need very high temperature, 1500 °C, much higher than the 565 °C of the Noor Energy tower. This requires the sunlight to be more strongly concentrated using concave instead of flat mirrors.

The University of Arizona manufactures the world's largest telescope mirrors and has built on this experience to make concave mirrors for sunlight concentration as shown above, each one 10 m^2 in area and producing a solar focus intense enough to melt a 15 mm diameter hole in 6 mm thick steel (inset) in 10 seconds, at 1,400 °C. The U Az also made the smaller mirrors displayed by SolarSpace LLC.

Twisting the mirrors to get the highest power and concentration

To make fuel (e.g. hydrogen) at commercial scale, a similarly intense but larger focus is needed to reach the reaction temperature. This can be achieved by superposing the light from many curved heliostats, with each mirror curved to focus sunlight on a distant receiver. The highest possible concentration is obtained when each heliostat forms an image of the solar disc, which requires changing its shape during the day with the sun's angle of incidence. We have developed heliostats to do this at low cost, using a mechanism to automatically twist a float-glass mirror to the optimum shape as the heliostat is turned to follow the solar motion.

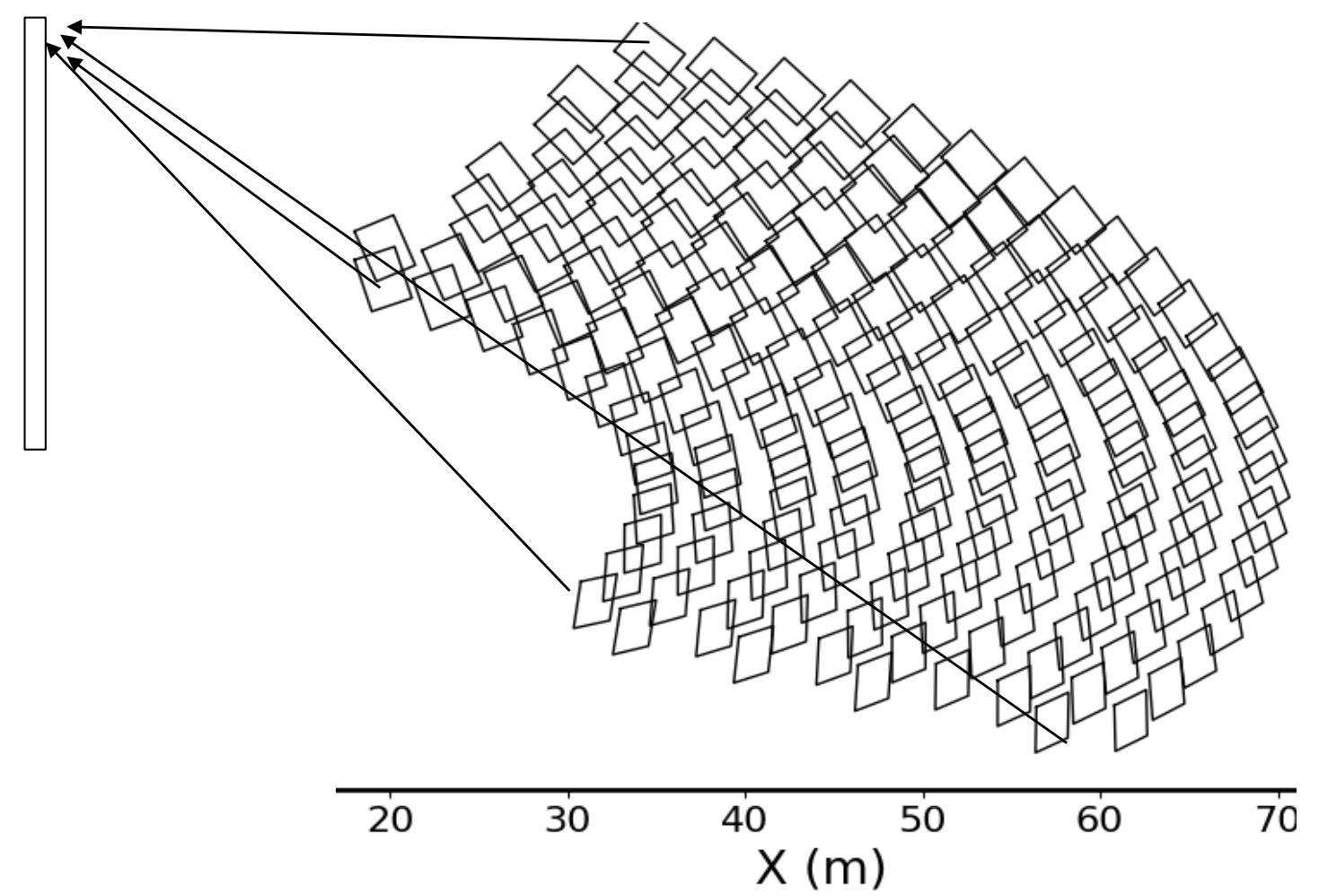


The prototype twisting heliostat uses an initially flat, 8 m^2 glass mirror reflector (2.4 m x 3.3 m). The twisting is automatic, made by a cam mechanism operated by the dual-axis, sun-tracking, target- axis mount. This prototype is funded by the DOE, and will be tested at Sandia in spring 2024. A test at smaller scale is shown below.

Solar disc image formed late in the day (angle of incidence 60°) by a single 1.6 m^2 twisting mirror heliostat at 40 m distance. Similar quality solar images are achieved throughout the day.

Heliostats in smaller fields for high temperature reactors

To obtain a highly concentrated focus, the solar disc images from all the twisting heliostats are superposed at the chemical reactor entrance. The chemical reactions to make fuel take place in an otherwise evacuated chamber, with a window to let in the concentrated sunlight. The window size is limited by the need to resist atmospheric pressure - we take an upper limit of 1 m diameter. Then the heliostats can be no more than about 110 m distant to keep the solar disc image within this diameter. We are now planning to build a test field with ~ 200 twisting heliostats to power experimental 1,500 °C reactors to make hydrogen and other fuels. This 2 MW_{th} test field will have only 1/1000 the reflector area of the Noor Energy field, and its tower will be 1/10 the height. Fields of this size, once mass produced, will have a cost per unit of focused sunlight power on par with that of Noor Energy. The first test field is to be built at the UAz Tech Park Solar Zone.



Test field with twisting heliostats

CONCLUSIONS

The research described here demonstrates how the fundamental limits to optical concentration may be reached for commercial scale reactors. The high intensity needed to obtain the required very high (1500 °C) reaction temperatures is realized at 2 MW scale in meter-sized reactors. These units may be mass produced for production of fuel from water or CO_2 at commercial scale.

REFERENCES

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Figure 5. Dish (point focus) reflector made from 4 self supporting glass segments, molded and silvered at the University of Arizona Mirror Lab