Sunflower Heliostat

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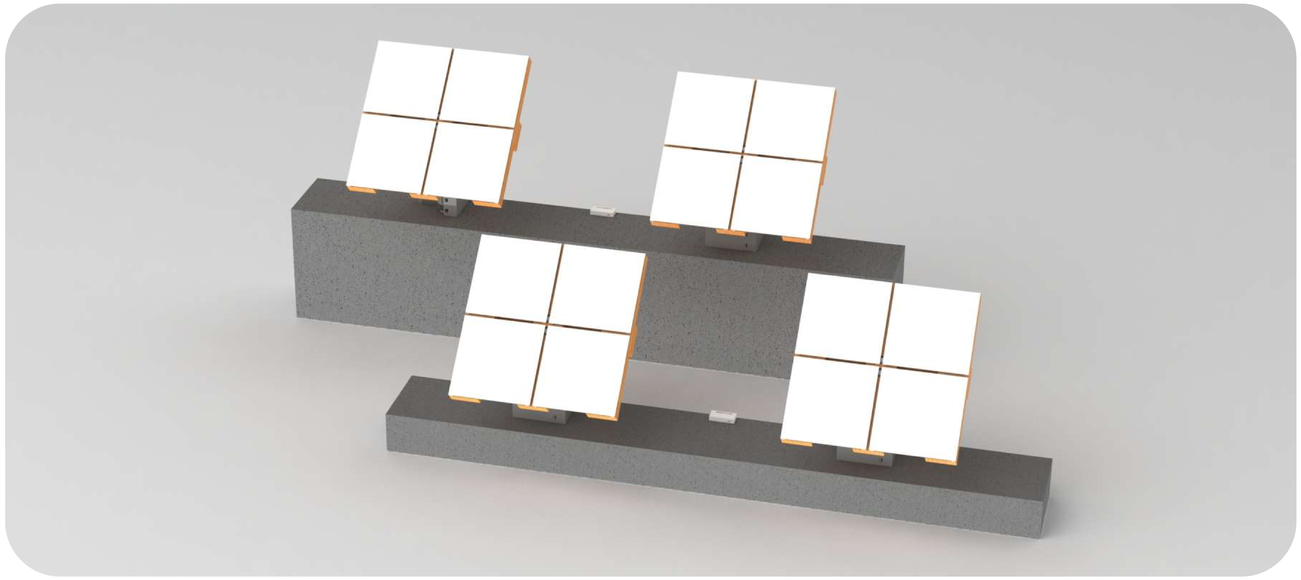
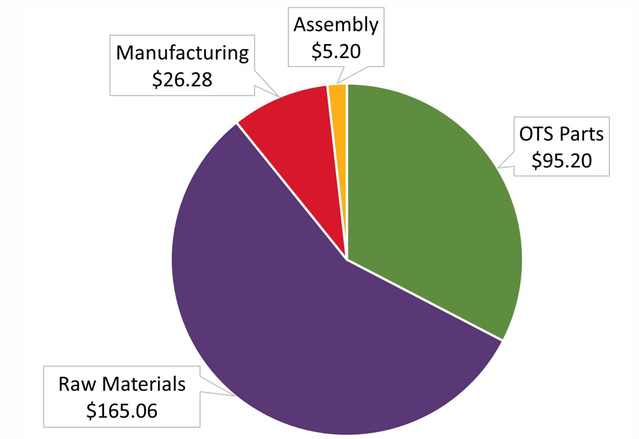
EML4501
Group 2, Fall 2021



Abstract

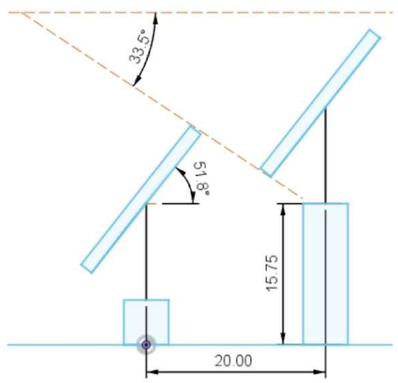
We are Electric Sunflower Technologies. Our Hedgehog Concept is to design a small-scale heliostat with a minimal part to heliostat ratio, which will increase simplicity, decrease cost, and maintain functionality. The design we chose is comprised of four small heliostat modules, each with a 0.25m² collection area. The structure consists of two concrete blocks of different heights, with each step housing two heliostats. With our "step and stagger" design, we eliminate shading and allow for tight spacing between modules. The motion subsystem consists of two mechanisms, each controlling a separate degree of freedom. In one axis, a worm and helical gear system driven by a small gearmotor rotates the heliostat 360° while ensuring minimal loading on the motor. For the other, the reflective surface is rotated using a lightweight motor and high reduction gear train, increasing control and range of motion. With these two mechanisms, this design is able to track the sun effectively throughout the day, on any day of the year. The frame for the reflective surface consists of pressure-treated wooden beams, which can last for more than 20 years while being more cost-effective than metal alternatives. The reflective surface itself is composed of four small, annealed glass mirrors that help reduce dispersion losses and required maintenance. We believe the combination of smaller heliostats with unconventional materials makes our design the most simple and effective.

Cost Breakdown



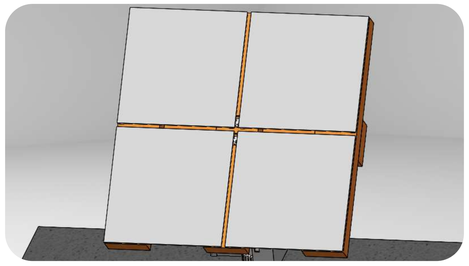
Note: The cost is expected to decrease as more accurate quotes can be obtained from raw material and OTS part suppliers.

Shading Visualization



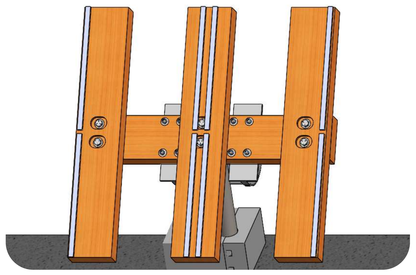
Stepped layout alleviates shading concerns while keeping a compact footprint.

Reflective Surface



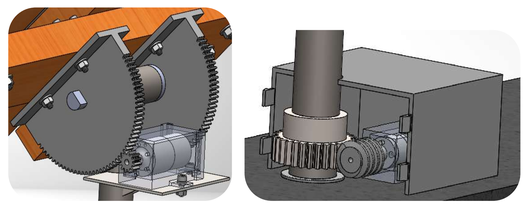
- 3mm thick, 0.0625 m² area, silverized, annealed glass mirrors
- Four mirrors per heliostat
- 1000 modules needed to produce 1 MW
- Capable of reflecting 95% of the sun's thermal power

Reflective Backing



- Pressure-treated 2x4 cedar beams
- Rigid backing allows for stable reflection
- Thick adhesive layer connects backing and reflective surface
- Manages differences in expansion from thermoductivity and shrinking/swelling

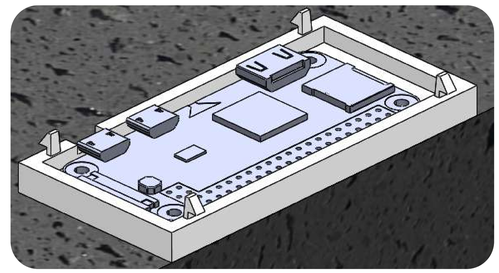
Motion



(1) (2)

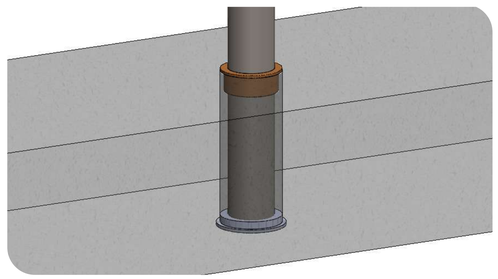
- High torque 8:1 gear train (1)
- Worm and helical gear system (2)
- 360° and 170° of rotation in primary and secondary axes, respectively
- High mechanical advantage ⟶ low cost
- Can operate in 40 mph winds

Electronics



- Uses Raspberry Pi Nano 0W
- Controls two heliostats at a time
- Protective plastic casings with rubber seals for all electronics

Structure



- "Step and Stagger" for zero shading, close module spacing
- Concrete = high durability and cheap
- Bronze bushings and plastic furniture sliders for low friction support

Product Functionality

Each heliostat tracks the sun via movement in two axes. The worm gear train at the base of the assembly allows for 360° rotation about the center support pole, while the second gear train at the top controls the tilt angle of the mirrors. The motors are controlled by Raspberry Pi Zero W modules that wirelessly receive position commands from a central processing unit. The accuracy of the motors is ensured by the encoders that send position information back to the controller.

(9) Sun tracking automated/motor controlled

(9) Scale of 0-3 of features

(12) Reflecting surface should be washable

(12) $Water_{pass}$ = 0

(12) Waterproof seals safe to 10,000 psi

(5) Must be able to track sun

(5) Heliostat must pivot on 2 axes

(5/7) Range of motion for 1st axis: +/- 67.5°

(5/7) Range of motion for 2nd axis: +/- 39.25°

(8) Low cost

(8) < $100/$m^2$ at final installation

(8.1) Desired target price = US DOE price

(8.1) < $ 60/m^2 desired (full scale)

(13) Factor of safety = 2

(13) FoS >= 2

(14) Lifetime of 20

(14) Cycles >= 7300

(4) Optical losses from tracking <40%

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(15) Operate in LV, Nevada

(15a) $F_{max} = \frac{1}{2}\rho v_{max}^2 A$

(15b) $T_{working}$ >= 117°F

(3) Module composed of 4-16 heliostats

(3) Number of mirrors between 4-16

(6) Individual h-stats can't shade others

(6) $X_{shading} = L_{heliostat} * (\cos\Theta + (\sin\Theta\tan\Phi + 23.5 + \alpha))$

(10) Module are relative reflecting surface is small

(10) $A_{module} / A_{heliostat} < 2$

(11) Parts should be cheap

(11) $Cost_{custom} <= Cost_{OTS}$

(1) Design capitalizes on small heliostat innovations

(1) Scale of 0-5 of problems

(2) Small scale

(2) Collection Area <= 1 m^2

(7) Redirect sunlight to tower

(7) 0 m <= $h_{receiver}$ <= 100 m

(16) 1 MW input power

(16) Q_{total} >= 1 MW

(17) Concentration > 1000 suns

(17) SCR > 1000

(18) Limited dispersion losses <= 100 m

(18) $Loss_{dispersion} = 0$

Electronics

(8) Raspberry Pi Zero W

(9) Bluetooth, I/O capabilities, motor encoder

(11) Injection molded plastic

(12) Minimized water entry in case

Motion

(4) Accurate and reliable motors

(5) Worm gear system/torque gear

(7) 80° tilt of heliostat in 360° circle

(8) Two actuators per heliostat

(8.1) Cheap motors/plastic gears

(13) Material/motor selection/gear ratio

(14) Structural dimensions

(15a) Safety mode and geared down motor

Reflective Backing

(1) Cheap structural materials

(13) Frame dimensions

(14) Pressure treated 2x4 beams

(15b) Wood and epoxy adhesive

Structural

(2) Total module area

(3) 4 heliostats per module

(6) Platform steps

(10) Platform steps and field layout

(15b) Low thermal expansion concrete

Reflective Surface

(1) Lightweight mirrors

(2) Collection area = 1m^2

(4) Plastic bushings

(7) Mirror size

(16) Mirror size/module quantity

(17) Mirror size/module quantity

(18) 0.25m^2 mirrors