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Sandia National Laboratories

# CPS 38491 NSTTF Operations and Maintenance Project Final Report (FY22-24)

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## ABSTRACT

This report details operations and maintenance (O&M) activities performed across Fiscal Years 2022 through 2024 in support of the continued capabilities of the National Solar Thermal Testing Facility (NSTTF) at Sandia National Laboratories. The NSTTF O&M project is funded by the U.S. Department of Energy Solar Energy Technologies Office (SETO) to support research activities and testing on behalf of external customers at the facility under award number CPS 38491. During the project period, the NSTTF made progress in the areas of site metrics, site maintenance and utilization tracking, and customer engagement. The O&M project also supported special initiatives including procurement of a heat exchanger for particle concentrating solar thermal processes and a scoping and cost study for refurbishment and repair of component in the NSTTF heliostat field.

## PROJECT DETAILS

| | | |
|---|---|---|
| **a.** *Federal Agency* | Department of Energy | |
| **b.** *Award Number* | CPS 38491 | |
| **c.** *Project Title* | DOE's National Solar Thermal Test Facility Operations and Maintenance | |
| **d.** *Recipient Organization* | Sandia National Laboratories | |
| **e.** *Project Period*[1] | *Start:* 10/01/2021 | *End:* 09/30/2024 |
| ***f.*** *Budget Period*[2] | *Start:* 10/01/2022 | *End:* 09/30/2023 |
| ***g.*** *Reporting Period* | *Start:* 10/01/2022 | *End:* 09/30/2023 |
| ***h.*** *Report Term or Frequency* | Annually | |
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Signature

20 November 2024
Date

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[1] *If you have received No Cost Time Extensions (NCTE), please add a note below the table indicating the length of each one and which budget periods were affected.*

## ACKNOWLEDGEMENTS

Special thanks to the following individuals who contributed to maintenance, tracking, and reporting activities at the NSTTF: Ken Armijo, Lam Bahn, Roger Buck, Matt Chavez, Robert Crandell, Anthony Evans, Kevin Good, Margaret Gordon, Roberta Gonzales, Madeline Hwang, Rob Keene, Miguel Leyba, Micaela Padilla, Eugenio Perez IV, Daniel Ray, Tim Riley, Estevan Rodriguez, Ezekiel Salama, Kathryn Small, Jeremy Sment, Jim Stone, and Benson Tso.

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# EXECUTIVE SUMMARY

## 1.1. Major Goals and Objectives

This three-year project seeks to operate and maintain the National Solar Thermal Test Facility (NSTTF) to support the research, development, testing, and implementation of Concentrating Solar Thermal (CST) technologies and to support DOE SETO goals for the advancement of CST. The NSTTF offers services to advance the goals of the global CST industry and support the development of technology to reach higher efficiencies, reliabilities, and temperatures while lowering costs and risk to increase the penetration of renewable energy in the market.

This project ensures the operation and maintenance activities of the existing critical capabilities and infrastructure at the NSTTF for assuring success of CST. The primary goal of the project is to provide a safe and fully operational facility with testing capabilities to support DOE goals, providing services to DOE awardees while also building an external CST customer base.

## 1.2. Technical Achievements

During the three-year budget period of the project, Sandia made progress in the implementation of a computerized management maintenance system (CMMS) and implemented practices to enable the NSTTF to move toward a more anticipatory, less reactive stance for asset management, site maintenance, and testing activities. We implemented new systems to improve the tracking and analysis of testing and weather at the NSTTF. We also updated our outreach materials and methods to solicit feedback more effectively from customers and partners and better communicate unique NSTTF capabilities to the industrial and research communities.

## 1.3. Project Schedule Summary

- Task 1 – NSTTF Site Metrics Definition and Criticality Ranking
  - The criticality methodology and database were updated from 2019.
  - Re-inventory and classification were almost fully completed.
- Task 2 – NSTTF Site Maintenance and Utilization
  - Maximo heliostat field integration was completed, and work orders were issued.
  - Key performance indicators were implemented in Maximo.
  - Significant capability upgrades were made at the heliostat field, furnace, and simulator.
  - A test day prediction study was performed to improve site utilization.
  - A new customer experience survey was drafted and implemented.
  - A survey of the R&D community about the NSTTF was performed after SolarPACES 2022.
- Task 3 – Customer Engagement Concentrating Solar Thermal (CST) Collaboration Hub
  - An update to the NSTTF website was undertaken and is partially complete.
  - Customer outreach was performed through the CSP seminar series, site visits, and events.
  - The share of solar-related testing campaigns was increased to surpass the target of 60%.
- Task 4 – Procurement of Heat Exchanger
  - A heat exchanger was procured, and a long-term maintenance/usage plan was created.
- Task 5 – Heliostat Refurbishment/Repair
  - A heliostat refurbishment cost study was conducted, and a technical work plan was generated.

## 1.4. Project Budget Summary

The total project budget was $3,670,000, of which $3,000,000 was baseline funding and $670,00 supported additional tasks under the umbrella of the NSTTF O&M Project ($520,000 for Task 4 and $150,000 for Task 5). To date, >99% of the total project budget is spent or committed, with remaining funding supporting recurring maintenance, emergency maintenance, and end of year reporting. The project budget supported critical equipment needs including replacement of an 80' boom lift which reached the end of its operational lifetime, replacement of the damaged uninterruptible power supply for the heliostat field, and addition of capabilities including systems and technoeconomics modeling software to be used on a wide variety of NSTTF projects. FY24 and total project categorial spending and total approved budgets are summarized below.

**Table 1. FY24 spending summary.**

| Category: | Q1 | Q2 | Q3 | Q4 | Total | Approved Budget |
|---|---|---|---|---|---|---|
| Personnel | $ 76,525.27 | $ 137,321.55 | $ 146,565.59 | $ 14,060.58 | $ 374,472.99 | |
| Supplies | $ 40,167.41 | $ 9,736.57 | $ 8,685.01 | $ 7,050.42 | $ 65,639.41 | |
| Travel | $ - | $ 1,249.72 | $ 1,788.79 | $ - | $ 3,038.51 | |
| Equipment | $ - | $ - | $ - | $ - | $ - | |
| Contractual | $ (833.29) | $ 46,136.87 | $ 35,699.26 | $ 17,369.76 | $ 98,372.60 | |
| Other/Chargebacks | $ 100.00 | $ 21,606.00 | $ (1,244.82) | $ 1,672.49 | $ 22,133.67 | |
| Indirect Charges | $ 91,180.74 | $ 162,608.25 | $ 154,628.38 | $ 17,631.34 | $ 426,048.71 | |
| **Totals** | $ 207,140.13 | $ 378,658.96 | $ 346,122.21 | $ 57,784.59 | $ 989,705.89 | $ 1,000,000 |

**Table 2. Project period spending summary.**

| Category: | FY21 | FY22 | FY23 | Total | Approved Budget |
|---|---|---|---|---|---|
| Personnel | $ 356,334.80 | $ 333,122.99 | $ 374,472.99 | $ 1,063,930.78 | |
| Supplies | $ 38,836.01 | $ 89,887.43 | $ 65,639.41 | $ 194,362.85 | |
| Travel | $ - | $ - | $ 3,038.51 | $ 3,038.51 | |
| Equipment | $ 64,800.00 | $ 389,740.19 | $ - | $ 454,540.19 | |
| Contractual | $ 12,549.38 | $ 249,708.25 | $ 98,372.60 | $ 360,630.23 | |
| Other/Chargebacks | $ 7,474.66 | $ 5,726.08 | $ 22,133.67 | $ 35,334.41 | |
| Indirect Charges | $ 445,597.49 | $ 491,259.55 | $ 426,048.71 | $ 1,362,905.75 | |
| Total Charges | $ 925,592.34 | $ 1,559,444.49 | $ 989,705.89 | $ 3,474,742.72 | |
| | | | Un-invoiced Commitments | $ 168,000.00 | |
| | | | **Totals** | $ 3,642,742.72 | $ 3,670,000 |

## 1.5. Key Personnel Changes

At the beginning of FY23, Mark Spier and Francisco Alvarez departed the NSTTF for other assignments at Sandia. Evan Bush assumed the role of interim PI for the remainder of the three-year budget period. New hires among the technologist team and technologist interns also joined the NSTTF during the budget period, including Eugenio Perez IV (Mechanical Technologist), Anthony Evans (Electromechanical Technologist), Matt Chavez (Mechanical Technologist), Jim Stone (Mechanical Technologist), Madeline Hwang (Intern Year Round, R&D Undergrad), and Estevan Rodriguez (Intern Year Round, Technical Undergrad). Miguel Leyba (R&D Systems Engineer) also joined the O&M team to lead the site criticality database update. Kathryn Small (R&D Mechanical Engineer) participated in weather and test conditions analysis to improve communications with customers needing high-flux testing. Ezekiel Salama (Visiting Undergraduate Intern, DOE MSIIP) assisted in related activities. During FY24, the NSTTF was divided into two SNL organizations: 08923 Concentrating Solar Technologies and a new organization, 08925 Solar Thermal Testing and Demonstration managed by Rob Keene, who assumed leadership of the core capabilities proposal for the upcoming FY25-27 NSTTF O&M project.

## ACRONYMS AND TERMS

Click here, then press delete to remove guidance.

**Required**

On an odd-numbered page. Spell out on first use in document and only include acronyms if used more than once. Only capitalize proper nouns.

| Acronym/Term | Definition |
|---|---|
| CMMS | Computerized maintenance management system |
| CSP | Concentrating solar thermal/technologies |
| CST | Concentrating solar power |
| DNI | Direct normal irradiance |
| ETF | Electric-heating Test Facility |
| G3P3 | Generation Three Particle Pilot Plant |
| KPI | Key performance indicator |
| MTBF | Mean time between failures |
| MTTR | Mean time to repair |
| MSIIP | Minority Serving Institutions Internship Program |
| NOAA | National Oceanic and Atmospheric Administration |
| NSTTF | National Solar Thermal Test Facility |
| PI | Principal investigator |
| PM | Preventative maintenance |
| PMC | Preventative maintenance compliance |

## 2. PROJECT RESULTS AND DISCUSSION

### 2.1. Task 1 – NSTTF Site Metrics Definition and Criticality Ranking

#### *2.1.1. Planned vs. Actual Activities*

A site criticality ranking database was developed in 2019 to determine the priority for maintenance and repair of equipment at the NSTTF. The ranking characterizes the need for asset maintenance and impact of asset failure for equipment and facilities across the site. The database ranks assets considering customer/project impact, maintenance history (preventive and corrective/reactive), types and volume of failures, and spare parts lead time. A new inventory ranking and assessment was performed in FY23 to update this database. In the new ranking, for each tracked asset, criticality was defined as:

$$C = I \times P \tag{1}$$

where the impact of failure *I* and the probability of failure *P* are subjective rankings between 1 and 3, the product of which represents a semi-subjective/objective criticality ranking between 1 and 9, where *C* = 9 indicates the most critical assets and *C* = 1 indicates the least. Additional information included for all database assets were location and inventory of spare parts, manufacturer and serial numbers, and asset photos.

The database update was undertaken with the goal of completion according to the schedule shown in Figure 1. To date, the criticality assessment has been updated for 90% of locations on-site. All locations have been surveyed for virtually all equipment onsite, with the documentation of building capabilities outstanding.

These tasks, in combination with internal meetings among the NSTTF O&M PI and managers, also fulfilled Subtask 2.5: Annual "Infrastructure and Equipment Management Plan/Capital Equipment Needs" program continuation.

| Location | Mar | | | | | Apr | | | | May | | | | | June | | | | | | July | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ETF Test Cell 3 | | | ✓ | ✓ | ✓ | | | | | | | | | | | | | | | | | | | | |
| ETF Test Cell 1, 2 | | | | | | ✓ | ✓ | | | | | | | | | | | | | | | | | | |
| Solar Furnace | | | | | | | | ✓ | ✓ | | | | | | | | | | | | | | | | |
| Tower East Donut | | | | | | | | | | ✓ | ✓ | | | | | | | | | | | | | | |
| Tower West Donut | | | | | | | | | | | | ✓ | ✓ | | | | | | | | | | | | |
| Tower Basement and Roof | | | | | | | | | | | | | | ✓ | ✓ | | | | | | | | | | |
| Module | | | | | | | | | | | | | | | | ✓ | | | | | | | | | |
| Tower 180' Level | | | | | | | | | | | | | | | | | ✓ | | | | | | | | |
| Tower 200', 220' Level | | | | | | | | | | | | | | | | | | ✓ | | | | | | | |
| Tower 240' - 260' Level | | | | | | | | | | | | | | | | | | | ✓ | | | | | | |
| Tower 270', 280' Level | | | | | | | | | | | | | | | | | | | | ✓ | | | | | |
| Assembly Building | | | | | | | | | | | | | | | | | | | | | ✓ | ✓ | | | |

**Figure 1. Site criticality assessment update schedule.**

#### *2.1.2. Explanation of Variance*

Funding limitations in late FY24 led to a pause in the update of the database, with plans for completion early in the FY25-27 funding cycle, including meeting with technologists and PIs to define or update criticality ranking scores, documentation of building capabilities (electrical, gas/water supply, etc.) and the creation of facility fact sheets.

## 2.2. Task 2 – NSTTF Site Maintenance and Utilization

Task 2 is divided into five subtasks listed below:

- Maintenance Schedule Transfer to Computerized Maintenance Management System (CMMS)
- Site Maintenance and Repair Metrics Tracking
- NSTTF Site Utilization, Revenue and Customer List Tracking and Use Metrics
- NSTTF Customer Feedback
- Annual "Infrastructure and Equipment Management Plan/Capital Equipment Needs" Program Continuation

### *2.2.1. Maintenance Schedule Transfer to Computerized Maintenance Management System (CMMS)*

#### 2.2.1.1. Planned vs. Actual Activities

Implementation of the NSTTF CMMS was performed in Maximo with the assistance of two undergraduate technologist interns. The heliostat field was selected for the initial Maximo integration due to its frequency of use at the NSTTF and the advanced age of the heliostats. In total, 218 heliostats were entered as assets into Maximo and PM schedules and work orders were defined for each unit. A PM for the heliostats encompassed the yoke, torque tube, mirror facets/facet mounts, and azimuth and elevation drives and was defined to include:

- Weld and bolt inspections
- Roller lubrication
- Oil leak inspection and replacement
- Broken or missing hardware inspections
- Cleaning/debris removal

To access the oil port for the elevation drive on some units, it was necessary to plasma cut a half circle cutout as shown in Figure 2. This procedure was added to the work orders.

**Figure 2. Elevation drive oil port access modifications to a heliostat shown before (left) and after (right) plasma cutting.**

It was determined that the oil change procedure was a potential bottleneck in the PM process due to delays caused by low temperatures, oil supply chain, and plasma cutting time. During winter months, all PMs were paused as increased oil viscosity prevented easy pumping of the oil from the system, and as the oil supplier reported order delays. It was decided in the spring of FY23 that the work orders for the oil changes and general PM would be separated to allow them to proceed separately and in parallel from the rest of the PM procedure, and the PMs therefore resumed. The oil supply chain delays have since been resolved and the time commitment of each task has lessened as key personnel gain experience.

Procedures for PMs, oil changes, and entry and completion of work orders were produced and shared on internal NSTTF channels to be used as future training documents for new technologists and interns. Historical heliostat work orders and associated notes, previously stored in a Microsoft Access database, were manually imported to Maximo for information retention and to provide baseline data for CMMS metrics implementation. Other modifications were made to the software, including the ability to mark heliostats down as a group, as failures often impact more than a single heliostat and individual marking down would be time prohibitive for 218 units.

The team incorporated lessons learned to revise PM procedures as they completed heliostat PMs throughout FY23 and FY24. In FY24, it was determined that different levels of likelihood and impact for modes of heliostat failure made it more efficient for PMs to be further split into categories (rather than only three work orders each for plasma cutting, oil changes, and remaining tasks). Therefore, four categories of PM were defined, with differing renewal intervals defined based upon experience.

- Biennial electrical: range of motion exercise; electronics and connectors inspection
- Annual electrical: heliostat controls electronics box inspection
- Biennial mechanical: Torque bolts and lubrication inspection
- Annual mechanical: Azimuth/elevation drive oil levels check, structural, welds, fasteners, cables inspection; general cleanup

The specification of multiple PM types should enable PMs to be completed at a sufficient interval while conserving project funds. Performing all activities on the same, more frequent interval was found to be both unnecessary and prohibitively time and budget intensive. Oil changes were decided to be performed only on an as-needed basis based on the results of the biennial mechanical inspection, as many unit drives were found to still have sufficient oil levels without presence of contaminants or metal shavings even after multiple decades of operation.

Heliostat cleaning is currently an exercise separate from PM at the NSTTF and is performed situationally when the highest flux levels are required for testing. Analysis of cleaning for testing on behalf of NASA in FY24 allowed an estimate of cleaning costs: when a two-person intern team performed cleaning, each unit could be cleaned in approximately 10-15 minutes, resulting in an approximate cost of $50/hr or $10-12.5 per heliostat. This exercise allowed achievement of peak flux levels of 229 W/cm$^2$ for a customer in FY24 Q4.

#### 2.2.1.2. Explanation of Variance

By the end of FY24, 83% of the field had undergone critical electrical inspections (all but rows 6 and 7). Due to limitations of funding, the remainder of the electrical inspections as well as plasma cutting and oil changes were paused. Funding for the FY25-27 core capabilities proposal has been allocated to better ensure uninterrupted PM activity starting in FY25.

### *2.2.2. Site Maintenance and Repair Metrics Tracking*

#### 2.2.2.1. Planned vs. Actual Activities

The NSTTF Maximo implementation was modified to provide snapshot and detailed historical tracking of multiple site maintenance and repair metrics. Mean time between failures (MTBF) and mean time to repair (MTTR) metrics were implemented as key performance indicators (KPIs) with a graphical dashboard shown in Figure 3, along with a preventative maintenance compliance (PMC) metric defined as the percentage of work orders completed within the target date, currently four weeks from issue. The current PMC is shown as 0%, as all work orders were generated before the winter pause in FY23 and therefore not completed within the target time. In winter-spring, failure of the uninterruptible power supply for the heliostat field led to a several week downtime of the entire field, which caused the MTTR metric to fall outside of the target range of < 168 h. Previously, the MTTR was significantly lower than the target, so we do not expect this to be a persistent issue. Similarly, the event pushed the MTBF outside of the target range of 730 h, although still within the green level of performance. These results indicate that day-of failure of the heliostat field preventing testing is a rare occurrence despite some troubleshooting that often takes place during testing, but that failures, when they can occur, can cause extended downtimes due to the uniqueness of high-consequence, high-cost components.


**Figure 3. Key performance indicators, from left to right, for preventative maintenance compliance percentage, mean time between failures (in days), and mean time to repair (in hours), shown as target metric (white dial) and current performance (dark arrow).**

### *2.2.3. NSTTF Site Utilization, Revenue, and Customer List Tracking and Use Metrics*

#### 2.2.3.1. Planned vs. Actual Activities

The strategy for logging and communication of customer, activity, and asset data was considered during FY22-24 with an eye toward improving NSTTF and customer readiness and efficiency. This exercise led to the creation of an information flow diagram, shown in Figure 4, summarizing when and how various data systems communicate with one another. This exercise guided improvements to various systems on-site, most specifically activity tracking. During the three-year period, the NSTTF increased the automation and consistency of data collection for local weather, testing logs, and customer information to improve our test tracking and analytics.

**Activity Tracking**

Among the changes were standardization of site test logs at the solar tower, solar furnace, electric-heating test facility, and molten salt test facility (apartment complex). Test operators log setup and test activity on an hourly basis. This data is then automatically referenced by the NSTTF team calendar, which acts as a dashboard summarizing daily testing activity across the site. Logged tests are referenced against a database of active projects at the NSTTF to track test activity by customer type and subject area (solar or non-solar), and to track and create test billing requests. Test activity is referenced against local weather data in an automated manner to estimate NSTTF efficiency in making use of good weather conditions for testing, or as a percentage of days in a month for off-sun facilities. The system improvements led to complete coverage of utilization data for the first time, and for significant decrease in utilization tracking costs through the automated systems.

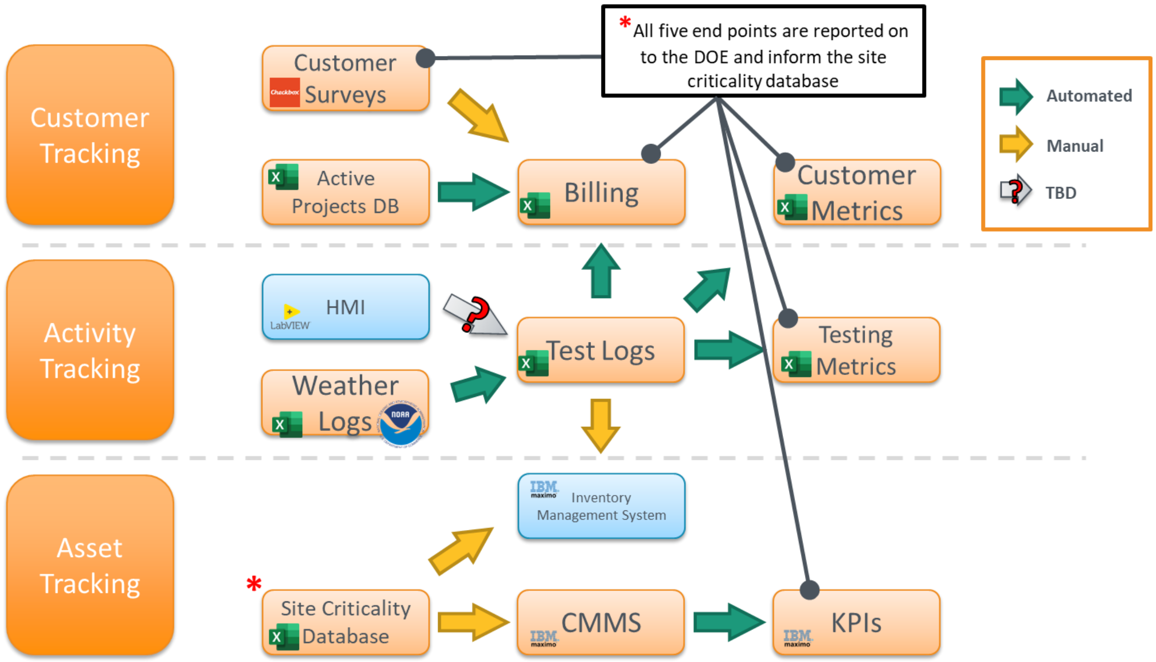


**Figure 4. Site tracking information flow. Blue boxes are future capabilities or those which don't currently communicate with other systems.**

### Site Utilization

Site utilization for FY24 through mid-September is summarized monthly in Figure 5 and quarterly in Table 3Table 3. On-sun capability utilization percent is tracked relative to the number of good-weather test days in a reporting period. Due to the construction of the Generation 3 Particle Pilot Plant (G3P3), which began during the reporting period, weekday (Mon-Thurs) testing at the NSTTF solar tower was curtailed. Starting in February FY23, the utilization percentage for the solar tower was based on the number of weekend (Fri-Sun) good weather test days. The solar furnace was unaffected by construction and continued to be evaluated relative to weekday weather.

*FY24 Summary:* In general, testing at the solar tower was limited due to the constraints of construction and the challenge of transitioning to a weekend testing schedule for customers and personnel. The solar furnace and solar simulator experienced heavy demand for capabilities throughout the year. ETF utilization was reduced due to delays in the fabrication of a heat exchanger to be used by multiple customers. The solar simulator also was taken down for several weeks throughout the year for repairs and upgrades. The high-temperature furnace room began to be utilized as a multi-capability space and therefore saw an increase in utilization over the summer. The apartment complex became busier later in the year due to molten salt/metals projects becoming active. Optics lab capability utilization grew and remained high as optics capabilities began to be deployed throughout the site, both within the optics lab and, increasingly, in the field.


**Figure 5. Monthly site utilization metrics for on-sun (top) and off-sun capabilities (bottom). On-sun utilization is compared relative to the number of good weather days, which for the solar furnace is during the workweek (M-F) and for the solar tower is the weekend (F-Su) due to G3P3 construction restricting tower activity from M-Th. Off sun utilization percentages are relative to a 30-day month, except for the optics lab for which the percentage is an estimate of the usage of lap capabilities, which often takes place outside of the optics lab space.**

**Table 3. Quarterly site utilization metrics. Good weekend weather day began in February of Q2, and the incomplete data for Q1 and Q2 are therefore indicated with an asterisk.**

<table>
<tr><th></th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>FY24</th></tr>
<tr><td>Good Weather Weekdays</td><td>36</td><td>26</td><td>39</td><td>54</td><td>155</td></tr>
<tr><td>Good Weather Weekend Days</td><td>21</td><td>13</td><td>18</td><td>22</td><td>74</td></tr>
<tr><td>Tower Total Test Days</td><td>2</td><td>0</td><td>8</td><td>13</td><td>23</td></tr>
<tr><td>Tower + Heliostats Percentage Test Days Used</td><td>6%</td><td>0%</td><td>21%</td><td>24%</td><td>15%</td></tr>
<tr><td>Total Use Days Furnace (Test + Setup + Calibration)</td><td>22</td><td>21</td><td>21</td><td>44</td><td>108</td></tr>
<tr><td>Furnace Percentage Use</td><td>61%</td><td>81%</td><td>54%</td><td>81%</td><td>70%</td></tr>
<tr><td colspan="6">Percentages for Furnace and Tower/Heliostats calculated with "good weather" weekdays and weekends (F-Su), respectively.</td></tr>
<tr><td>Simulator Use Days</td><td>10</td><td>1</td><td>9</td><td>0</td><td>20</td></tr>
<tr><td>Simulator Percentage Use</td><td>11%</td><td>1%</td><td>10%</td><td>0%</td><td>6%</td></tr>
<tr><td>Apartment Complex Use Days</td><td>6</td><td>0</td><td>49</td><td>44</td><td>99</td></tr>
<tr><td>Apartment Complex Percentage Use</td><td>7%</td><td>0%</td><td>54%</td><td>49%</td><td>28%</td></tr>
<tr><td>HX Stand Use Days</td><td>10</td><td>16</td><td>7</td><td>4</td><td>37</td></tr>
<tr><td>HX Stand Percentage Use</td><td>11%</td><td>18%</td><td>8%</td><td>4%</td><td>10%</td></tr>
<tr><td>HT Furnace Room Use Days</td><td>0</td><td>19</td><td>25</td><td>3</td><td>47</td></tr>
<tr><td>HT Furnace Room Percentage Use</td><td>0%</td><td>21%</td><td>28%</td><td>3%</td><td>13%</td></tr>
<tr><td>Optics Lab Percentage Use</td><td>57%</td><td>63%</td><td>95%</td><td>95%</td><td>82%</td></tr>
<tr><td>Module Use Days</td><td>0</td><td>8</td><td>0</td><td>0</td><td>8</td></tr>
<tr><td>Module Percentage Use</td><td>0%</td><td>9%</td><td>0%</td><td>0%</td><td>2%</td></tr>
<tr><td colspan="4">Percentages for Simulator, ETF, Apartment Complex, Module based on number of days in the month. Good weather is winds below 15mph and cloud cover below 30%. In some instances testing can occur outside these parameters.</td><td colspan="2" rowspan="2">Facility Average<br><br>28%</td></tr>
<tr><td colspan="4">Molten Salt Test Loop, Rotating Platform, Dish Area currently not used and may require work to bring up to working condition. Fabrication Area (Low and High Bay) heavily used and assumed to be at 100%.</td></tr>
</table>

On average, the NSTTF achieved a utilization percentage of 28% across the site. While utilization across all facilities are not necessarily directly comparable due to different levels of demand, complications of testing, or facilities being down for repair or upgrade, these number serve as a useful benchmark for future years, and for evaluating if and how site information flow improvements increase the efficiency and predictability of testing.

*Note: a bug was found in the utilization spreadsheet which inflated the number of testable weekdays in prior FY24 quarterly presentations. When corrected, annual utilization across the site increased by 2%, and furnace utilization increased by 18%.*

It was determined that, on 35 occasions, representing 33% of all test days, testing occurred despite some indicator of weather being outside the defined limit. In all of these instances, the disagreement was due to cloudcover recordings being greater than 30% and testing still occurring. There was little difference between furnace and tower testing in terms of the frequency of disagreements. It should be noted that the opposite scenario—testing not occuring due to weather despite meeting the definition of a good weather day, could not be tracked due to cancelled test days not being systematically recorded with the reason for cancelled testing. These results provide motivation for some of the weather analyses detailed in the following section, and may suggest need for an update to the reported conditions defining a good weather day at the NSTTF.

**Weather Tracking**

A study of predictability of good weather test days was performed by comparing historical forecasts and weather logs for the nearby Albuquerque Airport, as well as daily surveys conducted with the cooperation of test operators. Data was analyzed to understand annual percent "good weather", forecast reliability, and test operator accuracy and variation in accurately making day-of decisions on whether to test. The data collected for this analysis are summarized in Table 4.

**Table 4. Test day classification study data summary.**

| Type of Data | Description | Source | Data Resolution |
|---|---|---|---|
| Test day classification | Yes/no/partial test day classification based upon participants' current methodologies | Test operators and directors at the NSTTF | 9 participants, 1 response per day each (maximum) |
| Historical local weather data | Cloud-cover, wind speed, DNI, precipitation | NOAA | Collected at 6 hr interval |
| Site local weather data | Weather station data from locations at NSTTF | NSTTF | Variable |
| Hourly weather prediction | Cloud-cover, wind speed, DNI, precipitation | NOAA | Collected at 6 hr interval |

A simple analysis of historical weekday weather over a five-year period, shown in Figure 6m revealed that Fall test conditions were most often optimal, while Summer conditions were least often. Despite higher temperatures in the summer and higher direct normal irradiance on clear days, the Summer monsoon season limits testable days. While Spring testing is impacted by seasonal winds, seasonal conditions still were comparable to the Winter and more often optimal compared to the Summer. In FY24, 188 or 87% of total bad weather events were high cloudcover, while 25 or 12% of events were high wind. Note that events were classified such that multiple bad weather events could occur on the same day.

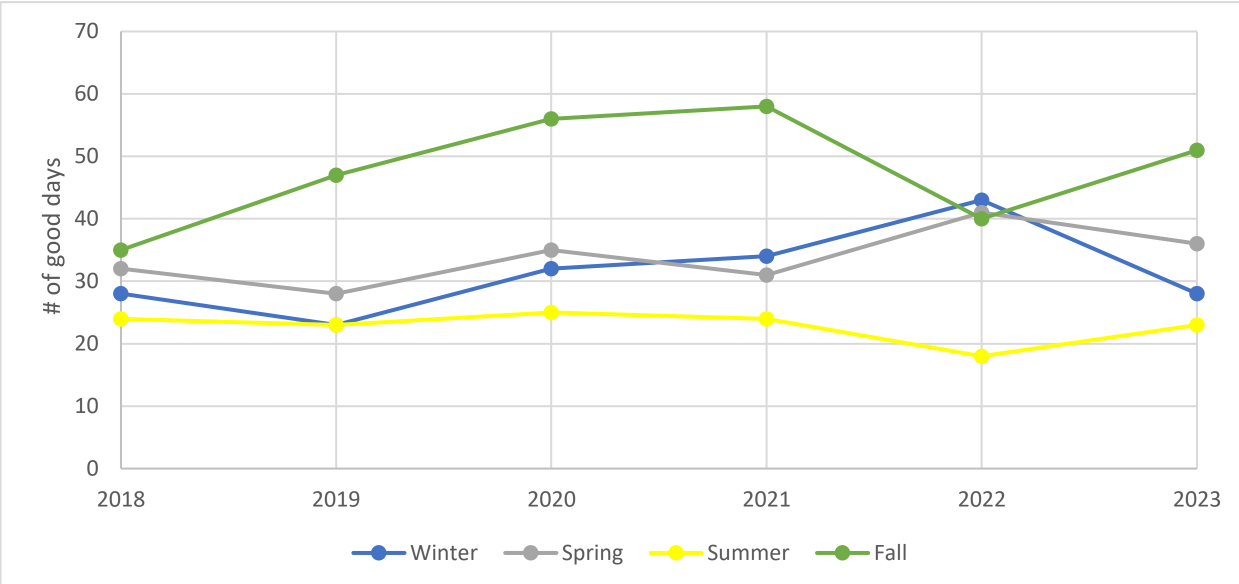


**Figure 6. Comparison of "good weather" weekdays, defined as average wind speeds below 15 mph and cloudcover below 30%, per season at the NSTTF.**

The same criteria used to classify good weather days was compared against surveys of test operators and engineers at the solar furnace and solar tower. Surveys were conducted daily via an emailed web poll, and respondents indicated whether they would test, wouldn't test, or if the day would be a partial test day. Participants were directed to use their typical methodology for classifying test days and not to alter or coordinate their methods. The data therefore are a product of the unique participant methodology, the uncertainty of weather prediction within a short (1-3 hour) time interval, and the suitability of the stated < 30% cloudcover, < 15mph wind testing standard at the NSTTF. The results, summarized in Table 5, therefore should not be considered a measure of "accuracy" of the respondent, but instead as the level of agreement between the respondents' abilities to predict short term test suitability and the reported NSTTF standards for good weather.

The bottom of the table compares the averaged matching frequency among all respondents per facility, as well as the matching frequency for "experts", or operators who actively used the facility during the year. Participants most familiar with the solar furnace testing agreed slightly more often with the NSTTF standards than non-"experts", with a matching frequency of 64% compared to 61%, while there was no such expertise divergence at the solar tower. It is possible this result is influenced by reduced testing activity at the solar tower due to G3P3 construction.

**Table 5. Summary of solar furnace and tower testing staff (operators and test engineers) degree of agreement with historical weather data classifications of good and bad days; responses are submitted the morning of testing.**

| **Respondent Info** | | **Solar Furnace** | | | **Solar Tower** | | |
|---|---|---|---|---|---|---|---|
| *Respondent* | Facility Test Type | *Matching Response* | *Conflicting Response* | *% Matching* | *Matching Response* | *Conflicting Response* | *% Matching* |
| Test Operator 1 | ST | 62 | 44 | 58.5 | 65 | 41 | 61.3 |
| Test Operator 2 | SF | 15 | 7 | 68.2 | 15 | 7 | 68.2 |
| Test Operator 3 | ST/SF | 90 | 46 | 66.2 | 92 | 44 | 67.6 |
| Test Operator 4 | ST | 9 | 12 | 42.9 | 9 | 12 | 42.9 |
| Test Operator 5 | SF | 107 | 79 | 57.5 | 66 | 34 | 66.0 |
| Test Engineer 1 | N/A | 54 | 36 | 60.0 | 55 | 35 | 61.1 |
| Test Engineer 2 | N/A | 93 | 61 | 60.8 | 89 | 65 | 57.8 |
| Test Operator 6 | ST | 31 | 14 | 68.9 | 31 | 14 | 68.9 |
| Test Operator 7 | SF | 100 | 56 | 64.1 | 98 | 58 | 62.8 |

| | **Solar Furnace** | **Solar Tower** |
|---|---|---|
| **Average % Matching** | 60.8 | 61.8 |
| **Standard Deviation** | 11.4 | 11.8 |
| **"Expert"-only Average** | 64.0 | 60.2 |

**Customer Tracking**

A new customer exit survey was generated with the goal of improving customer response rate via improved accessibility and reduced time-to-complete. The ten-question survey was implemented in the commercial tool Checkbox and sent to the customer post-testing via email. Customers respond according to their level of agreement (0-10) with specific statements, shown below, and can provide custom written feedback at the end of the survey. Across FY23 and FY24, excluding reminder emails, a total of fourteen customer unique survey requests were sent. Only one response (shown below as green numeric values next to each question) was received, indicating a significantly lower response rate than the 30% mark typically defined as a “good” rate for email surveys and the target “excellent” rate of 50%. While the new exit survey was significantly more accessible (online link) and simple to complete (one single field for custom feedback) than the old form, which was sent as a Microsoft Word attachment with multiple requested fields to complete, clearly a more thorough strategy is needed for boosting response rates. Changes going forward may include involving NSTTF PI/test engineers in the survey process, as they have existing relationships with the test customer, and defining automatic reminder intervals.

1. Scheduling and planning my test campaign was reasonably straightforward. 9
2. The availability of resources at the NSTTF did not delay my desired testing timeline. 9
3. I received sufficient technical support from the NSTTF in planning and running my test. 9
4. Interfacing with the provided data acquisition and control systems was easy. 9
5. The availability of information on NSTTF capabilities to customers is sufficient. 10
6. I was able to get access to the site to set up and perform my test in a timely manner. 8
7. NSTTF capabilities were appropriate and sufficient for my test campaign. 9
8. My testing data was provided in a clear and convenient format. 10
9. The costs of testing and support were reasonable. 7
10. The costs of testing and support did not significantly limit the scale and type of testing I performed. 8

**Asset Maintenance and Upgrades during FY22-24**

- **Solar Furnace Test Stand**

  A palletized system for sample installation was built at the Solar Furnace, which significantly speeds up and standardizes sample installation and makes it more frequently possible to run multiple campaigns in parallel. The sample stand uses a breadboard-style platform to which supports for reactors and staging of test articles may be affixed. Multiple stands enable the preparation of one test campaign in parallel with completion of another. The stands also are reconfigurable and capable of supporting small test articles without removing larger systems such as reactor chambers, which means intermittent tests can be conducted without complete teardown of longer-term test campaigns.

- **Heliostat Communications**

  In support of future activities such as the heliostat refurbishment and the DOE Heliostat Consortium (HelioCon), a fiber optic and ethernet communications upgrade of the heliostat field was conducted to upgrade from the data-over-power protocols previously in use. Data is transferred partway to each heliostat row via fiber optic cables, with the remainder of the transfer completed via individual ethernet connections to each unit. The upgrade significantly improved data transfer rates in the field, increasing sleep-to-wake from 30-60 s to 5-10 s per unit and mitigating communications losses due to interference, to which the prior communications were prone. The installation of communication lines was completed in FY23, while some cable management tasks and preventative maintenance/rebuild of drive motors took place in FY24.

- **Solar Simulator**

  Hardware and software upgrades were performed on the solar simulator to improve functionality and repair or improve reliability of the system. The LabView data acquisition and control software was updated to be consistent with existing frameworks at the NSTTF for greater ease of adaptation in the future. A door (Figure 7, left) and maglock were installed on the west side of the enclosure (previously a partial-wall accessed by a rail-mounted robotic arm) to increase the ease of sample installation, particularly for large test articles, and improve system safety. The maglock was integrated into the control software to engage during lamp operation to prevent access by users. A water chiller was installed at the facility to provide cooling for flux mapping targets and reactor/receiver apertures. The room compressor (Figure 7, right) was upgraded by Sandia facilities to provide more reliable pressure supply for pneumatic components. Finally, a rotating table and improved sample shutter for shielding were built and integrated with the control software to allow reliable multi-sample and multi-exposure control of samples according to time- or target temperature-programmed heating schedules.


**Figure 7. (Left) automatic locking door on solar simulator; (right) compressor**

#### 2.2.3.2. Explanation of Variance

Based upon conversations with DOE during quarterly reviews in FY23, there was consensus that the assessment metric for Subtask 2.1 (“All NSTTF-maintained assets on site added to program”) may not be practical goal for the implementation of CMMS due to the wide variation in what type of preventative maintenance is required for a R&D facility, and due to the relatively small number of assets at the site vs. commercial/industrial settings in which Maximo is typically used. Therefore, it was verbally agreed that the NSTTF will evaluate each remaining asset to determine which will benefit from the time investment of full Maximo integration and which will not.

There were no unexpected delays of the project goals for Subtask 2.2. In upcoming years, implementation of a site inventory management system and anlaysis of the manner in which control software communicates with other systems on-site will enable more sophisticated asset tracking and help increase accuracy in test time reporting.

Analysis of testable days prediction will continue in the next project period. This work is supported by Ezekiel Salama, a mathematics undergraduate visiting student working with the NSTTF via the DOE MSIIP program. Ezekiel will continue his analysis of historical weather data and develop models to refine NSTTF policies for testable days, with a goal of reducing uncertainty in test planing.

### *2.2.4. Annual "Infrastructure and Equipment Management Plan/Capital Equipment Needs" Program Continuation*

#### 2.2.4.1. Planned vs. Actual Activities

The NSTTF performs an annual review to anticipate future capital equipment needs, which is informed by the site asset criticality database which is updated throughout the year. Capital equipment are defined as DOE-owned resources expected to bring future value to Sandia over the course of their lifetime. Capital equipment must be valued at $500,000 or more and have a useful lifetime equal to or greater than two years. For defining the value threshold, a piece of capital equipment may either be a discrete purchase which retains its original characteristics, or multiple purchases which are combined after purchase to become a permanent system, distinct in purpose from the purposes of the individual parts. The NSTTF O&M PI and managers identified the following potential capital equipment needs in the upcoming year or project period:

- Lucker lift replacement: The Lucker Lift is a high-cost, high consequence capability at the NSTTF. The Lucker lift is a hydraulic lift within the NSTTF solar tower capable of lifting a 400 ton payload from the ground level to the 300' level (tower top). The lift has historically been used for lifting large receiver systems to the 300' level, including the falling particle receiver prototype predecessor to the ongoing G3P3 project. The lift has multiple projects in the following year for which it will be used. While a recent cable inspection of the lift indicated that the cables were in good health, there are many hydraulic and other components which require periodic maintenance and troubleshooting to ensure reliable operation. Most components are the original systems installed during construction of the solar tower, and like any aging system, there is some potential that significant or total replacement could become necessary in the future.

- Passenger elevators: Passenger elevator additions or replacements at the NSTTF solar towers (original and G3P3 tower) may become needs. Upgrade of the lower passenger elevator in the solar tower is planned for FY25 Q1 and Q2, but the upper-level elevator does not currently have a planned upgrade. A passenger elevator for G3P3 may also become necessary as the utilization of the facility grows for future work.

- Lull telehandler: While it is not clear whether or not the cost of replacement of this asset would qualify to be considered capital equipment, this is a widely-used capability at the site that may need to be replacement in the future. Cost estimates and purchases of equipment of this nature must be coordinated with the Sandia Fleet department.

- Solar Furnace 2: The NSTTF solar furnace is the highest utilized capability at the site and experiences the longest customer wait times due to scheduling demand, despite being one of the most efficiently-run facilities at the site. The NSTTF has two pedestals and structures which previously were used for solar furnace systems, meaning there is opportunity to refurbish one to serve the growing customer base needing high-flux experiment-scale testing. While we do not have a cost estimate for such an upgrade, this would be a high-consequence and significant capability upgrade for the site which could rise to the level of a capital equipment expense.

#### 2.2.4.2. Explanation of Variance

N/a

## 2.3. Task 3 – Customer Engagement Concentrating Solar Thermal (CST) Collaboration Hub

### *2.3.1. Customer Engagement Tracking*

#### 2.3.1.1. Planned vs. Actual Activities

The NSTTF performs testing for external customers and collects testing fees based (typically) on hourly or daily rates. Funded projects awarded to the NSTTF are also charged a 10% O&M fee to reflect the cost of supporting these projects with NSTTF assets. These fees collectively are allocated to an NSTTF Site Fee Project which supports critical capabilities, including personal protective equipment and training, which cannot be supported solely by the DOE O&M Project budget. The site fees collected over the past decade are shown in Figure 8.

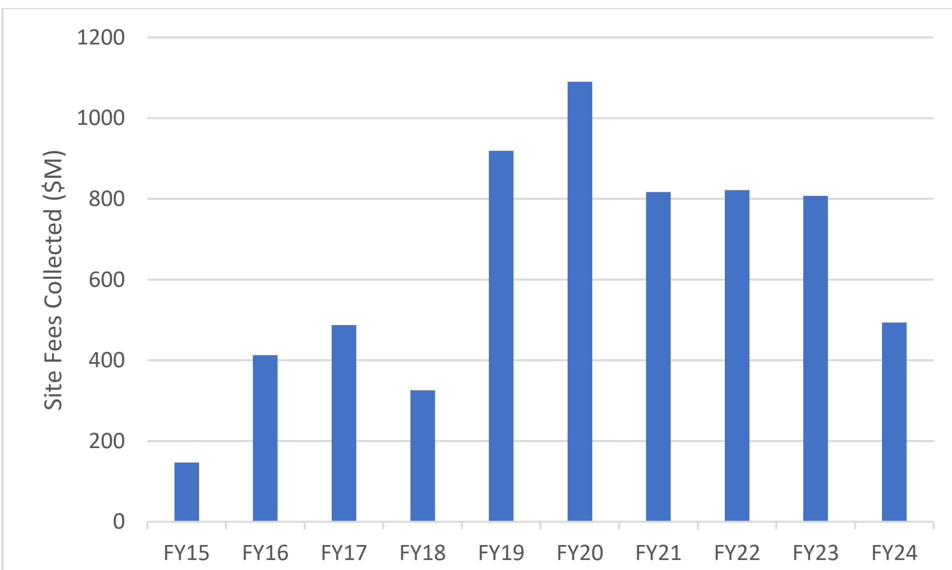


**Figure 8. Annual site fees collected (in thousands of dollars) since 2015, federal fiscal year basis.**

Site fees collected from FY22-24 from the solar tower testing were diverged from the increasing trend from previous years due partially to G3P3 construction, which was an anticipated effect of the project. Solar furnace testing and site fee collection was not impacted by the construction. Recent success in securing project funding somewhat mitigated construction impacts.

The NSTTF has a target customer base of 60% solar to 40% non-solar projects, with the goal of increasing the solar share relative to prior project periods (during which the customer base was a roughly 50/50 balance). To this end, the test campaigns are tracked in terms of number of solar and non-solar projects as well as solar vs. non-solar test and test setup days (not shown). Note that the numbers include both DOE directly, through funded projects awarded to NSTTF staff, and work for eternal customers. These numbers (Figure 9) represent the customer profiles since the beginning of FY24, as this was when the capability for hourly test tracking was established. CST testing had a strong presence at the NSTTF in the last budget period due in part to a range of long-duration tests supporting particle technologies, which enabled the facility to achieve >80% solar testing on a time basis. Solar furnace testing for other groups at Sandia made up the bulk of the non-solar testing as was a vital source of test fees.

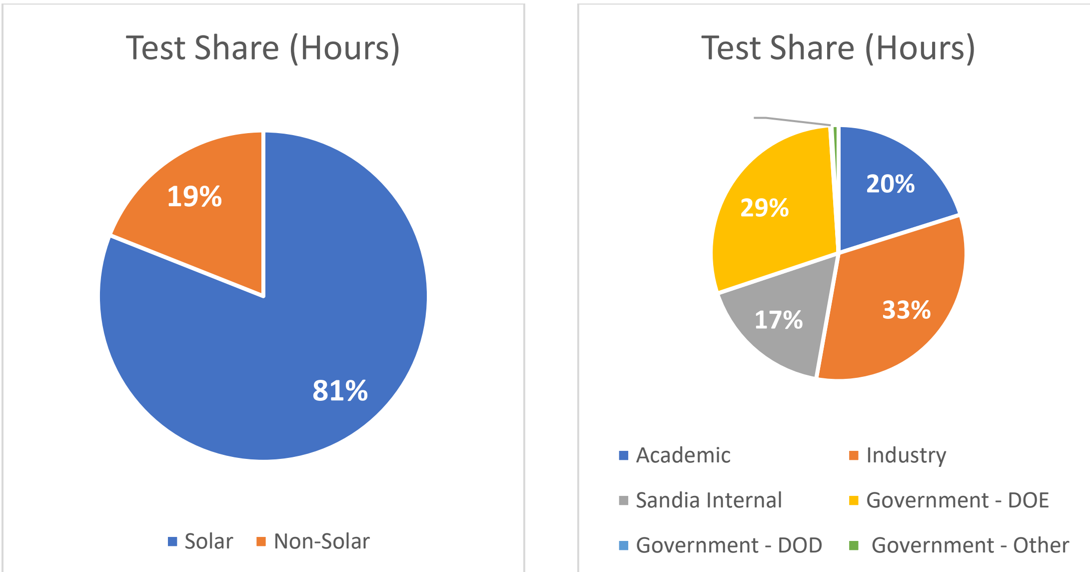


**Figure 9. Testing metrics in terms of total hours, reported as (left) the percentage of testing for CST-specific projects vs. non-CST projects and (right) testing hours classified by customer type.**

### *2.3.2. Expand CST Customer Base*

#### 2.3.2.1. Planned vs. Actual Activities

The NSTTF sought to improve customer engagement this budget period via outreach activities and improved advertisement of site capabilities through the Sandia Energy Website. Sandia sponsored the following presentations from concentrating solar subject matter experts as part of the sixth through eleventh installments of our Concentrating Solar Seminar Series:

- "System Advisory Model (SAM) for Concentrating Solar Power", Paul Gilman, Wednesday, November 30, 2022.
- "The Role of Engineering Management and Design for a Novel Parabolic Dish Solar Thermal Power Plant", Jonathan Swanepol, Thursday, December 15, 2022
- "High-Temperature Molten Salt Heat Transfer Systems", Sheng Zhang, Thursday, January 5, 2023
- "Experience with Calibrating Heliostats at Tonopah", Mark Ayers, Wednesday, February 15, 2023

- "Advances in Metrology & Standards for Central Receiver Systems – A German View", Marc Röger, and "Towards Deep Learning Based Airborne Monitoring Methods for Heliostats in Solar Tower Power Plants", Rafal Broda, Tuesday, August 29, 2023
- "Digital Twin Models and Internet 4.0 for Heliostat Fields", Michel Izygon, Thursday, December 21, 2023
- "Sustainable Aviation Fuels from Sunlight and Air", Aldo Steinfeld, Monday, July 8, 2024

A survey of the international CSP academic community was performed after the 2022 SolarPACES Conference held in Albuquerque, NM. The results are summarized in Figure 10 through Figure 13. Only around 25% of respondents had worked with Sandia previously, but the community communicated a high familiarity with the NSTTF. Respondents had the highest opinion of Sandia's expertise in solar power towers, with solar industrial process heat being the lowest rated (but still well-regarded) capability. While respondents generally felt Sandia's advertisement was sufficient, this result may suggest an opportunity to better engage the community on a new, rapidly growing subject area. Respondents mostly felt that all Sandia capabilities were highly useful, but the solar simulator received slightly lower ratings, partially motivating some capability enhancements to the system performed during the project period. The survey responses informed Sandia's strategy for customer engagement and updates to promotional materials (website, site pamphlet).

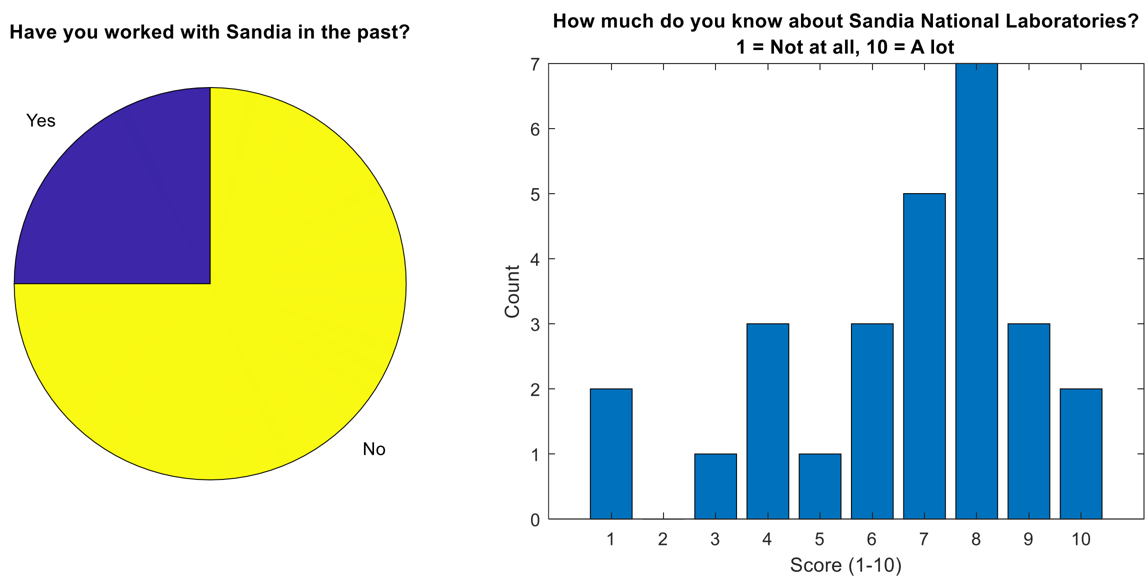


**Figure 10. Prior relationship and familiarity with the Sandia CSP department according to attendees of SolarPACES 2022.**

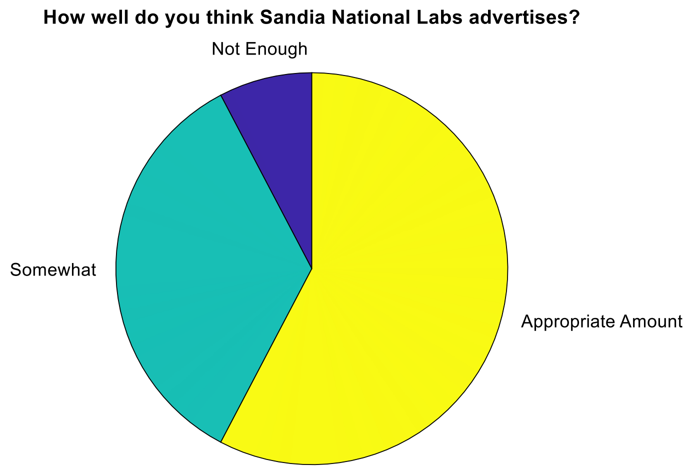


**Figure 11. Sandia CSP department's advertising effectiveness according to attendees of SolarPACES 2022.**

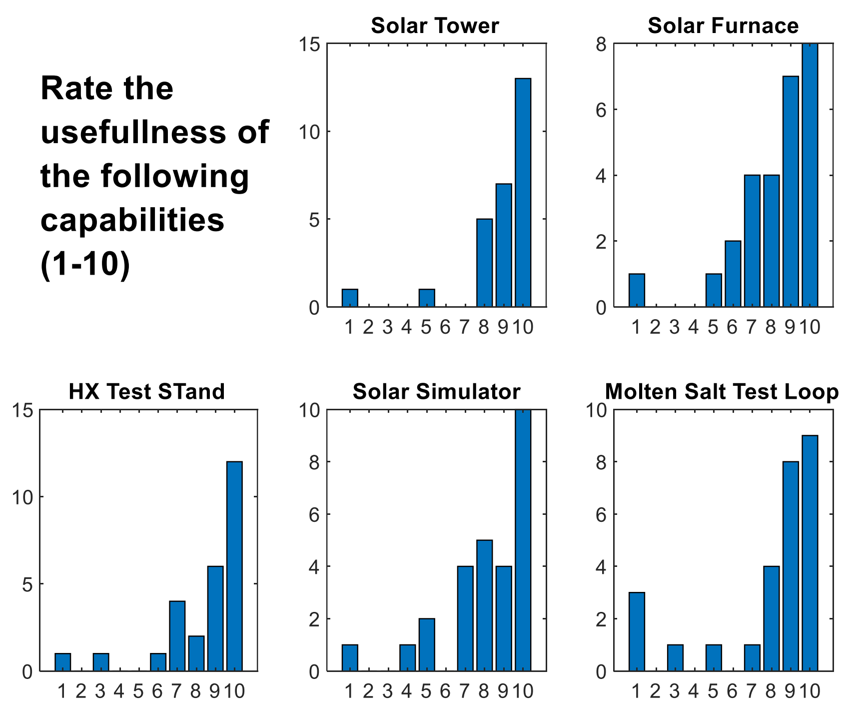


**Figure 12. Usefulness of NSTTF capabilities according to attendees of SolarPACES 2022.**

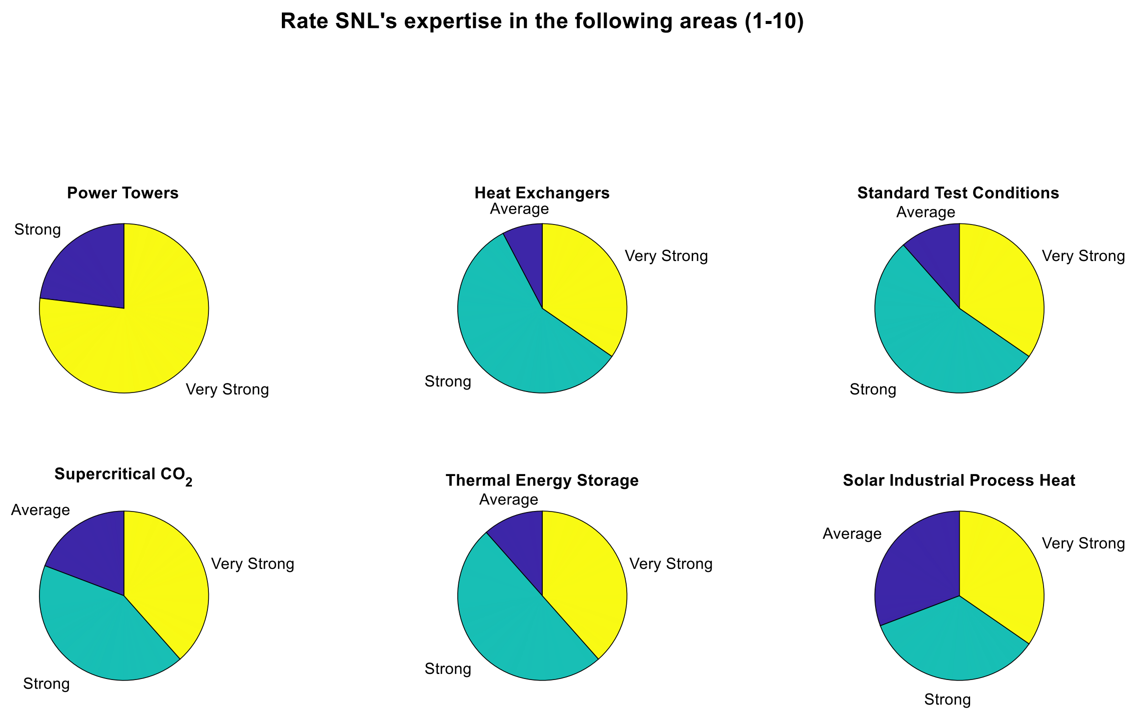


**Figure 13. Sandia CSP department's expertise in six different subject areas according to attendees of SolarPACES 2022.**

The NSTTF also conducted numerous tours and hosted numerous site visits throughout the year for academic, industrial, and government partners, as well as outreach events at the elementary, high-school, and university level. Significant events in FY23 included the G3P3 tower groundbreaking, the 2022 SolarPACES Conference and NSTTF tours, multiple visits from SETO and other DOE officials, visits from local high schools, and Sandia's Kids Day event at the NSTTF. In total, well over 1500 unique visitors experienced the NSTTF as part of these activities.

An update of the NSTTF pages on the Sandia energy website (https://www.sandia.gov/energy/home/national-solar-thermal-test-facility/) is currently underway in the effort to remove outdated information, cover new Sandia capabilities in areas such as high temperature particle transport and industrial process heat, and better highlight the uniqueness of the NSTTF's capabilities.

The previously named "engine test facility" (ETF) at the NSTTF was rebranded to the "electric-heating test facility" in recognition of the space's shifted purpose and capabilities from its original scope as a facility to test dish Stirling systems and other components of parabolic dish CSP technologies. The three test cells of the ETF, shown in Figure 14, include:

1. The heat exchanger test stand, which enables $sCO_2$ and particle loop operation and testing of prototype systems on the order of 10 $kW_t$,
2. The high temperature furnace facility, which offers a purge-capable box furnace and multiple tube furnaces for high temperature thermal and thermochemical processes,
3. The high flux solar simulator, for the high-throughput testing of materials and bench-scale concentrating solar components.

**Figure 14. From left to right: test cell one (heat exchanger test stand), two (high temperature furnaces), and three (solar simulator) in the electric-heating test facility.**

### *2.3.3. Explanation of Variance*

N/a

## 2.4. Task 4 – Procurement of Heat Exchanger

### *2.4.1. Planned vs. Actual Activities*

To support the procurement of a heat exchanger at the NSTTF for the CentRec noLimits project, funds in the amount of $520K were allocated. The request for quote, purchase, receipt, and invoicing of the heat exchanger were completed in FY22 and FY23 (primary year: FY22). The heat exchanger unit is stored outdoors, southwest of the NSTTF solar tower and currently still packaged in the shrink-wrapped plastic that it was transported, as shown in Figure 15. As the heat exchanger is constructed solely of 300 series stainless steel, no corrosion degradation is expected as result of storing outside and exposure to weather and atmosphere. A storage and utilization plan was prepared with the culmination of the task and reported separately to DOE.

**Figure 15. Solex heat exchanger stored at the NSTTF.**

## 2.5. Task 5 – Heliostat Refurbishment/Repair

### *2.5.1. Planned vs. Actual Activities*

Funds in the amount of $150K were allocated to support a scoping study to support the refurbishment of communications and other components in the NSTTF heliostat field to promote the long-term health of the facility and the compatibility of field communications and data with CSP industry and academic customers (primary year: FY23). This work culminated in a costing study and technical work proposal (TWP) detailing the requirements of the field and the cost to update heliostat and control room hardware consistent with these requirements. Additionally, the extraction of an unused heliostat base necessary for the G3P3 tower construction was leveraged as an opportunity to obtain a cost-efficient, qualitative inspection of heliostat base structural, power, and communication component aging (see Figure 16). The evaluation didn't indicate significant specific concerns for the field. The TWP for future work on a separate project was generated which contained overall cost estimates and a work plan.

**Figure 16. Heliostat base extraction depicting (left to right), concrete support, a more detailed view, and electrical cables.**

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