

# Mechatron SA PV Tracker

Performance Review

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20 pages

## Authors and Contributors

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## Summary

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PV Evolution Labs (now DNV GL PVEL LLC) has performed a preliminary technology and performance review of two (2) Mechatron Solar Inc. photovoltaic (PV) module tracking systems – the S140 single-axis tracker and the D170 dual-axis tracker. DNV GL PVEL LLC and Mechatron Solar Inc. partnered to install and commission the two trackers at PV-USA in Davis, CA in order to perform technical analyses of the designs, reliabilities, and performances of the Mechatron PV module tracking systems. Images of the installed S140 and D170 tracking systems are provided in Appendix A.

The design and reliability analyses in this report are based on information provided to DNV GL PVEL LLC by Michael Fakukakis, Chief Executive Officer (CEO) of Mechatron Solar Inc., an affiliate company of Mechatron SA. The analyses included in this report of the tracking systems include the following evaluations:

- Design
- Reliability
- Performance

### ***Conclusions***

PVEL has evaluated system design information and literature provided by Mechatron Solar Inc. regarding Mechatron's single- and dual-axis tracking systems. PVEL monitored and analyzed performance data relating to the tracking accuracy of Mechatron's D170 dual-axis tracker and the energy yields of Mechatron's tracking systems relative to a fixed-tilt PV system. The tracking accuracy data indicate that the D170 tracking system's maximum tracking errors are approximately 2° in azimuth and 6° in zenith. The azimuth errors are somewhat uniformly distributed throughout the solar day while the zenith tracking errors are larger during solar mornings when insolation is small. A comparison of the integrated normalized power output values of the S140 single-axis tracker, the D170 dual-axis tracker, and a fixed-tilt PV system indicates that system efficiency improvements of 40.06 % and 55.69 %, respectively, relative to a fixed-tilt PV array were recorded on 07/24/14.

## Design Review

### ***Rotation Mechanism***

DNV GL PVEL LLC has evaluated the design concepts of the proprietary Mechatron SA tracker drive technology. Literature provided by Mechatron SA states that the single-axis and dual-axis trackers have the rotational characteristics as listed in Table 1 below:

| Tracker Rotational Characteristics |                    |                            |                           |                           |
|------------------------------------|--------------------|----------------------------|---------------------------|---------------------------|
| Tracker                            | Degrees of Freedom | Azimuth Rotation Range [°] | Zenith Rotation Range [°] | Rotational Resolution [°] |
| S140                               | 1                  | 340                        | N/A                       | ≤ 0.1                     |
| D170                               | 2                  | 340                        | 60                        | ≤ 0.1                     |

**Table 1** Mechatron tracker rotational characteristics (per Mechatron SA)

Tracker movement along any axis is achieved via a hydraulic system charged by a single fluid pump. Azimuthal rotation is achieved by a combination of hydraulic pistons that serve in conjunction to achieve motion according to the following general order of operations:

1. Mechanical coupling (via the “grabber” piston) of the tracker rotational assembly to the motion driver (the “push-pull actuator” piston)
2. Release of the tracker position securing device (the “push-pull brake” piston)
3. Rotation of the tracker (via the “push-pull actuator” piston) to the desired position
4. Engagement of the tracker position securing device (the “push-pull brake” piston)
5. Mechanical decoupling (via the “grabber” piston) of the tracker rotational assembly from the motion driver (the “push-pull actuator” piston)
6. Return of the “push-pull actuator” piston to its standard position

Motion along the zenith is achieved using a single piston coupled to the hydraulic system.

### ***Structural Protection Mechanism***

Protection of the tracker system and its structure from excessive wind loads is achieved using three methods as follows:

1. Automatic tracker return to a stowed position is triggered by an integrated anemometer whenever wind speeds greater than the defined operational limit (typically thirty-eight miles/hour [38 mph]) are measured.
2. A passive hydraulic circuit permits the zenith tracking system (if applicable) to return to a stowed position in the event of power loss (e.g. due to grid power interruption) or detected system errors.
3. The “push-pull brake” piston is designed to slip upon excessive wind loads on the tracker platform (e.g. during brief but strong gusts of wind).

## Design Review

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### *Control Algorithm*

Automated positioning of the tracker system is achieved using a solar algorithm coupled with rotational position sensors (azimuth) and telemetry sensors that account for any system slippage or other errors. Typical accuracies are stated as  $\pm 1^\circ$  for flat-plate PV modules with accuracies of better than  $\pm 0.1^\circ$  achievable for solar concentrator applications.

## Reliability Review

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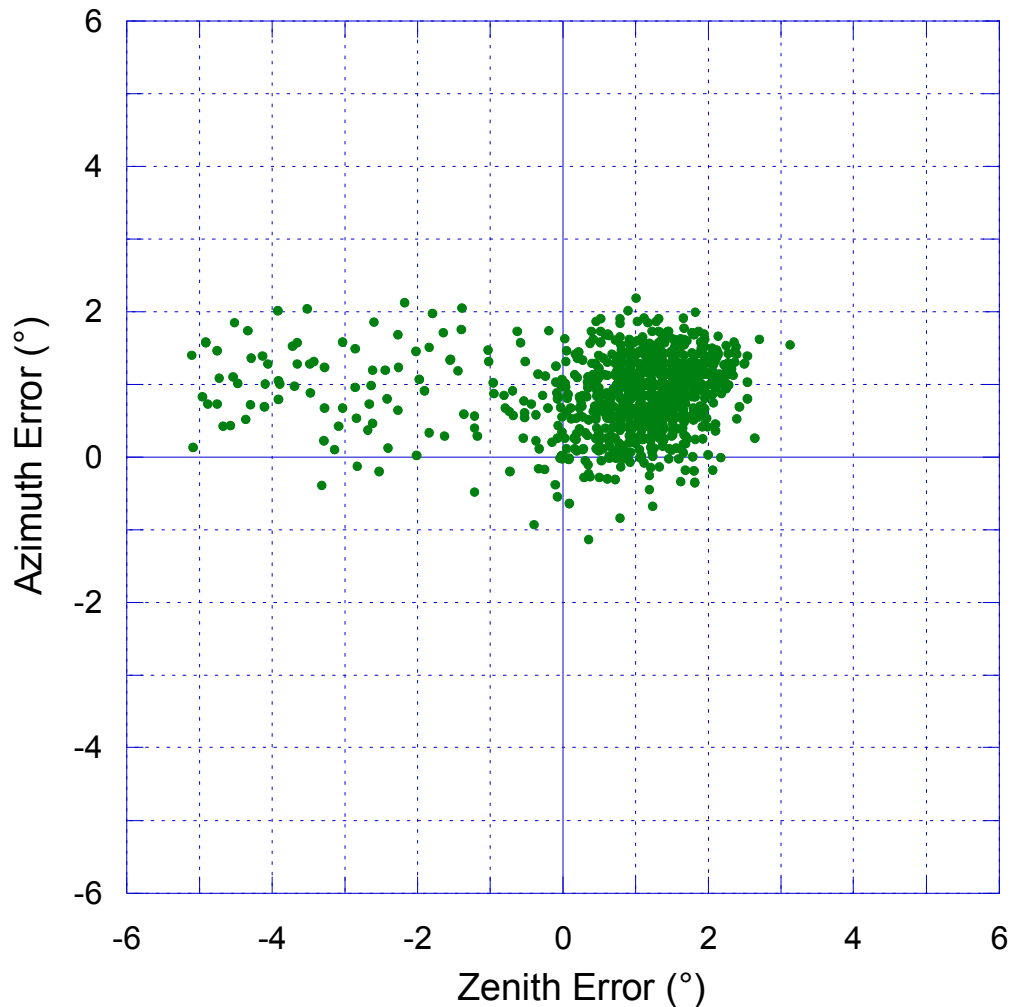
### *Accelerated Testing of Tracking Mechanism*

Mechatron Solar Inc. has provided data to DNV GL PVEL LLC indicating that accelerated testing of the D170 tracking system achieved sixty-six (66) full rotations in approximately three and one-half (3.5) days from 06/24/14 to 06/27/14. The log file output from the system's controller indicating the tracker rotation commands is provided in Table B of Appendix B.

## Performance Review

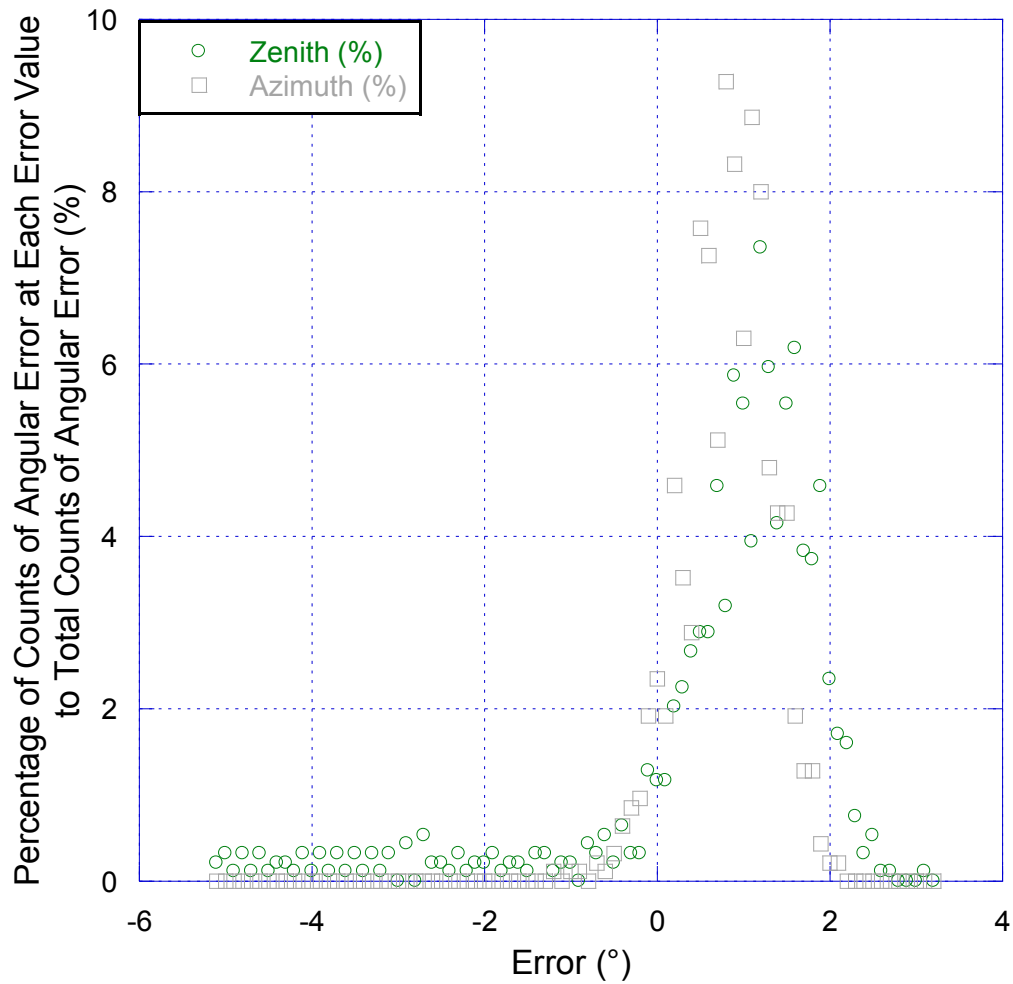
### *D170 Tracking Accuracy Characterization*

DNV GL PVEL LLC has characterized the tracking accuracy of the Mechatron D170 dual-axis tracker using the Trac-Stat SL-1, a state-of-the-art tracking accuracy measurement tool with a maximum error of  $\pm 0.05^\circ$ . The accuracy measurements were made over approximately fifteen (15) days from July 11, 2014 to July 25, 2014, and only include data from the Trac-Stat SL-1's primary sensor. Tracking error data were acquired every two (2) minutes during periods of direct normal irradiance (DNI) on the tracking accuracy measurement tool. The measurement tool was mounted directly to the D170's module platform at the center of the platform's surface in order to measure the accuracy of the tracking system with respect to a module in the average position on the tracker. A plot D170 tracking error over the test period is provided in Figure 1 below. It should be noted that the largest errors in zenith tracking accuracy occurred during the early mornings at times of low DNI. Figure 2 below is a plot



**Figure 1** D170 tracking error over the fifteen-day measurement period

## Performance Review



**Figure 2** D170 tracking error frequencies in percent – error bin width is 0.1°

of the frequencies of angular tracking errors at each error value for the zenith and azimuth angles. The total number of error points recorded over the period is approximately nine-hundred and thirty-eight (938). Table 2 below contains statistics of the tracking errors.

| Tracking Accuracy Statistics |                  |                   |
|------------------------------|------------------|-------------------|
| Statistic                    | Zenith Error (°) | Azimuth Error (°) |
| Average                      | 0.69             | 0.72              |
| Standard Deviation           | 1.34             | 0.47              |
| Median                       | 1.06             | 0.81              |
| Maximum                      | 2.26             | 1.66              |
| Minimum                      | -4.87            | -0.50             |

**Table 2** Tracking error statistics

## Performance Review

### ***Energy Yield Comparison***

DNV GL PVEL LLC has compared the normalized AC output powers from the Mechatron S140 and D170 trackers with a fixed-tilt PV array installed at the site of the Mechatron trackers' installation. The AC output of each PV array was connected to HiQ Solar's 8kW 3-phase inverters. Since the DC capacities of the PV arrays of the S140, D170, and fixed-tilt systems are not equivalent, it is necessary to evaluate the advantages of each tracking system with respect to the fixed-tilt system by normalizing the power output of each system to its peak power output during the day of generation to be analyzed (07/24/14). Table 3 below is a comparison of the integrated normalized power outputs of the three (3) systems given their orientation characteristics as listed.

| Systems Characteristics and Performance Comparisons |                    |                  |              |                                    |   |
|---|--------------------|------------------|--------------|------------------------------------|---|
| System  | Degrees of Freedom | Zenith Angle [°] | Azimuth [°]  | Integrated Normalized Power Output | Power Output Increase Relative to Fixed-tilt System [%] |
| S140  | 1                  | 35               | N/A          | 0.44                               | 40.06   |
| D170  | 2                  | N/A              | N/A          | 0.49                               | 55.69   |
| Fixed Tilt  | 0                  | 20               | South-facing | 0.31                               | N/A   |

**Table 3** Orientation characteristics and normalized integrated output power values recorded on 07/24/14

Plots of normalized AC output power from each system on 07/24/14 are provided in Figure 3 below.

## Performance Review

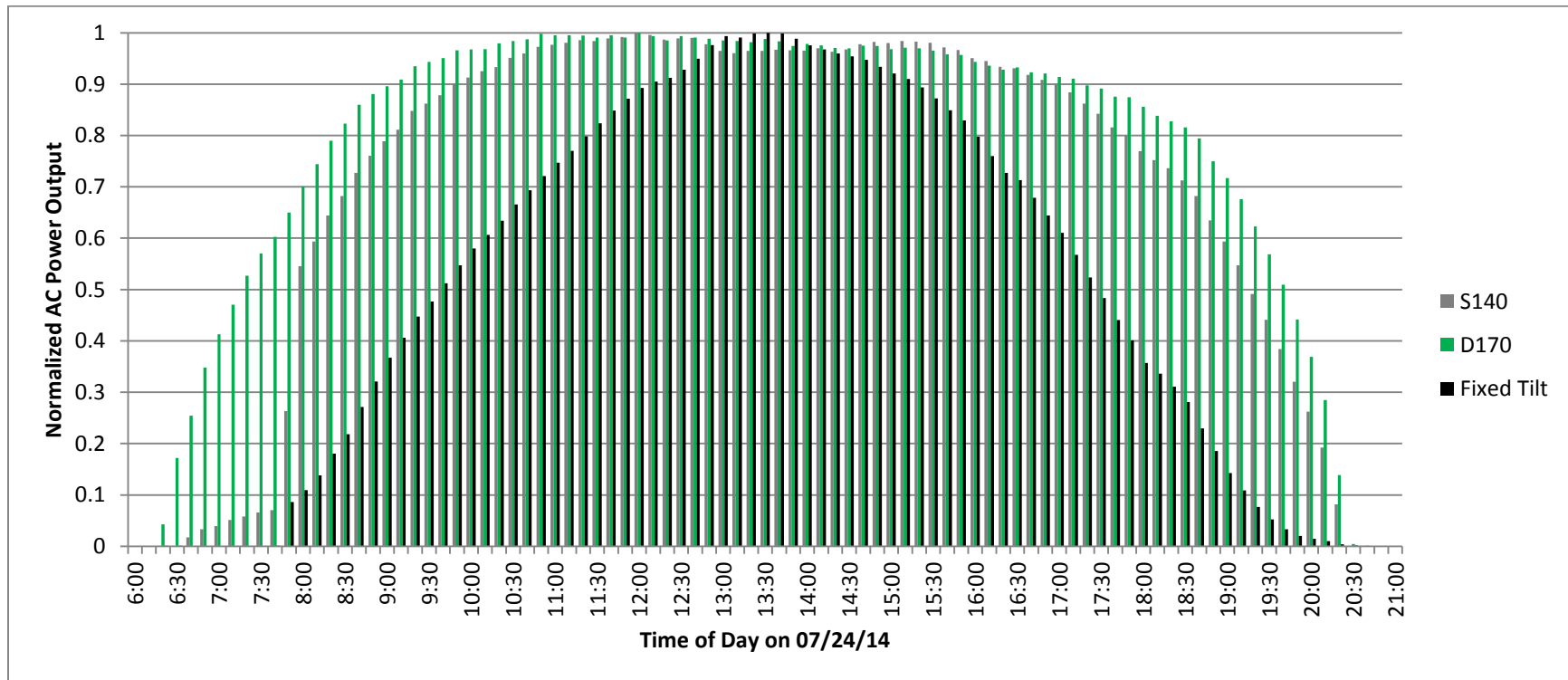
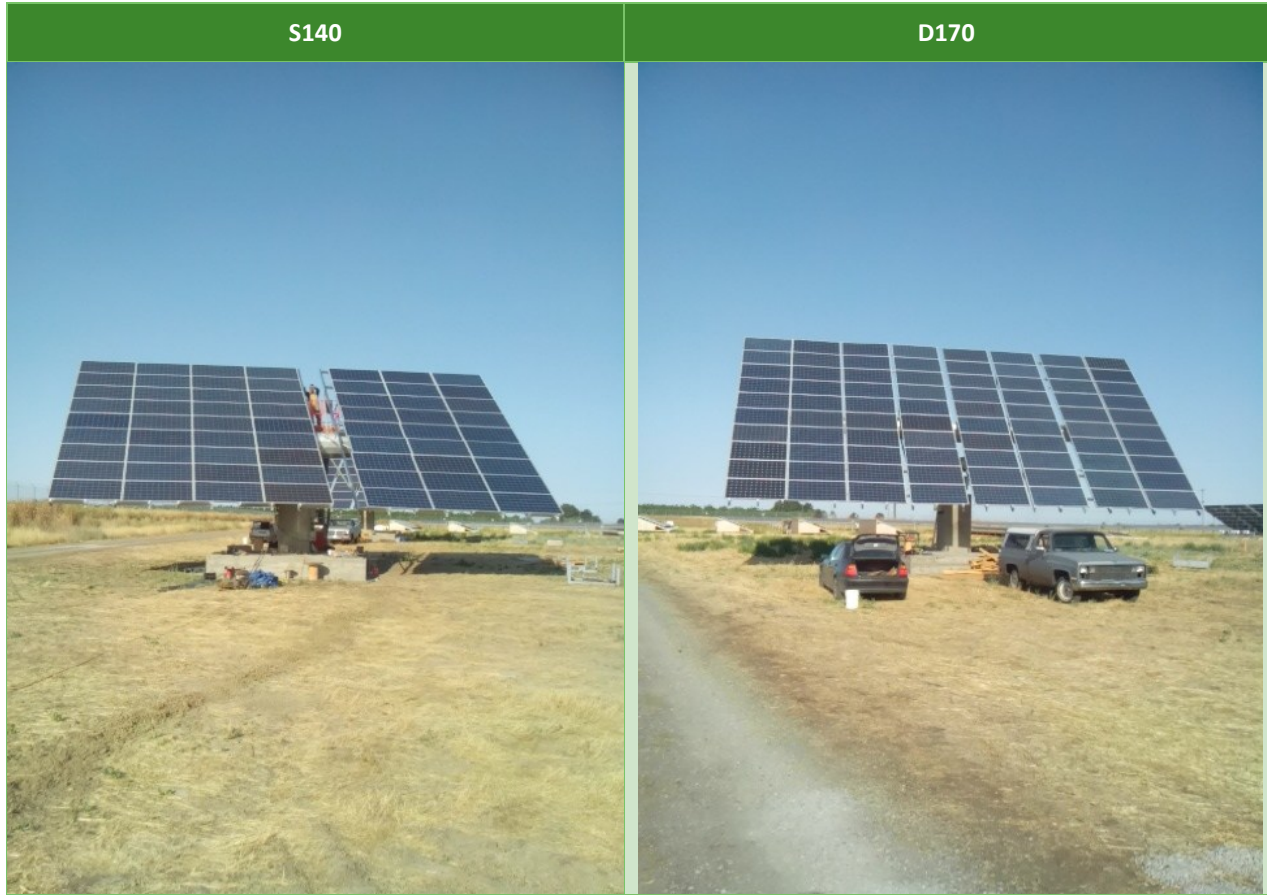


Figure 3 Normalized output power of the three systems on 07/24/14

## Appendix A



**Figure A** Images of the single-axis and dual-axis trackers installed by DNV GL PVEL LLC and Mechatron Solar Inc. at PV-USA in Davis, CA

## Appendix B

| Accelerated Testing - D170 Tracker Controller Log File Output |                 |               |                                       |
|---|-----------------|---------------|---------------------------------------|
| Date / Time   | Tracker Command | System Pulses | Cumulative Complete Tracker Movements |
| 24/06/14 14:27:54   | (103) at ElHome | 2             | 1                                     |
| 24/06/14 15:18:36   | (114) at Elev   | 58            |                                       |
| 24/06/14 15:18:36   | (113) at Azim   | 180           |                                       |
| 24/06/14 15:24:09   | (103) at ElHome | 0             |                                       |
| 24/06/14 15:39:13   | (100) go AzHome | 0             |                                       |
| 24/06/14 15:59:57   | (101) at AzHome | 0             | 2                                     |
| 24/06/14 16:33:12   | (114) at Elev   | 58            |                                       |
| 24/06/14 16:33:12   | (113) at Azim   | 180           |                                       |
| 24/06/14 16:38:44   | (103) at ElHome | 0             |                                       |
| 24/06/14 16:53:48   | (100) go AzHome | 0             |                                       |
| 24/06/14 17:15:04   | (101) at AzHome | 0             | 3                                     |
| 24/06/14 17:47:54   | (114) at Elev   | 58            |                                       |
| 24/06/14 17:47:54   | (113) at Azim   | 182           |                                       |
| 24/06/14 17:53:27   | (103) at ElHome | 0             |                                       |
| 24/06/14 18:08:31   | (100) go AzHome | 0             |                                       |
| 24/06/14 18:25:29   | (101) at AzHome | 0             | 4                                     |
| 24/06/14 18:58:11   | (114) at Elev   | 58            |                                       |
| 24/06/14 18:58:11   | (113) at Azim   | 180           |                                       |
| 24/06/14 19:03:44   | (103) at ElHome | 0             |                                       |
| 24/06/14 19:18:48   | (100) go AzHome | 0             |                                       |
| 24/06/14 19:39:21   | (101) at AzHome | 0             | 5                                     |
| 24/06/14 20:12:30   | (114) at Elev   | 58            |                                       |
| 24/06/14 20:12:30   | (113) at Azim   | 181           |                                       |
| 24/06/14 20:18:03   | (103) at ElHome | 0             |                                       |
| 24/06/14 20:33:07   | (100) go AzHome | 0             |                                       |
| 24/06/14 20:50:12   | (101) at AzHome | 0             | 6                                     |
| 24/06/14 21:23:18   | (114) at Elev   | 58            |                                       |
| 24/06/14 21:23:18   | (113) at Azim   | 180           |                                       |
| 24/06/14 21:28:51   | (103) at ElHome | 0             |                                       |
| 24/06/14 21:43:55   | (100) go AzHome | 0             |                                       |
| 24/06/14 22:04:21   | (101) at AzHome | 0             | 7                                     |
| 24/06/14 22:36:55   | (114) at Elev   | 58            |                                       |

## Appendix B

|                   |                 |     |    |
|-------------------|-----------------|-----|----|
| 24/06/14 22:36:55 | (113) at Azim   | 180 |    |
| 24/06/14 22:42:29 | (103) at ElHome | 0   |    |
| 24/06/14 22:57:32 | (100) go AzHome | 0   |    |
| 24/06/14 23:18:02 | (101) at AzHome | 0   | 8  |
| 24/06/14 23:51:07 | (114) at Elev   | 58  |    |
| 24/06/14 23:51:07 | (113) at Azim   | 180 |    |
| 24/06/14 23:56:39 | (103) at ElHome | 0   |    |
| 25/06/14 00:11:43 | (100) go AzHome | 0   |    |
| 25/06/14 00:32:16 | (101) at AzHome | 0   | 9  |
| 25/06/14 01:04:50 | (114) at Elev   | 58  |    |
| 25/06/14 01:04:50 | (113) at Azim   | 181 |    |
| 25/06/14 01:10:23 | (103) at ElHome | 0   |    |
| 25/06/14 01:25:27 | (100) go AzHome | 0   |    |
| 25/06/14 01:42:21 | (101) at AzHome | 0   | 10 |
| 25/06/14 02:14:52 | (114) at Elev   | 58  |    |
| 25/06/14 02:14:52 | (113) at Azim   | 180 |    |
| 25/06/14 02:20:25 | (103) at ElHome | 0   |    |
| 25/06/14 02:35:30 | (100) go AzHome | 0   |    |
| 25/06/14 02:56:00 | (101) at AzHome | 0   | 11 |
| 25/06/14 03:28:31 | (114) at Elev   | 58  |    |
| 25/06/14 03:28:31 | (113) at Azim   | 180 |    |
| 25/06/14 03:34:02 | (103) at ElHome | 0   |    |
| 25/06/14 03:48:06 | (100) go AzHome | 0   |    |
| 25/06/14 04:08:36 | (101) at AzHome | 0   | 12 |
| 25/06/14 04:41:05 | (114) at Elev   | 58  |    |
| 25/06/14 04:41:05 | (113) at Azim   | 180 |    |
| 25/06/14 04:46:36 | (103) at ElHome | 0   |    |
| 25/06/14 05:01:40 | (100) go AzHome | 0   |    |
| 25/06/14 05:22:10 | (101) at AzHome | 0   | 13 |
| 25/06/14 05:54:41 | (114) at Elev   | 58  |    |
| 25/06/14 05:54:41 | (113) at Azim   | 180 |    |
| 25/06/14 06:00:14 | (103) at ElHome | 0   |    |
| 25/06/14 06:15:18 | (100) go AzHome | 0   |    |
| 25/06/14 06:35:48 | (101) at AzHome | 0   | 14 |
| 25/06/14 07:08:08 | (114) at Elev   | 58  |    |

## Appendix B

|                   |                 |     |    |
|-------------------|-----------------|-----|----|
| 25/06/14 07:08:08 | (113) at Azim   | 180 |    |
| 25/06/14 07:13:40 | (103) at ElHome | 0   |    |
| 25/06/14 07:28:45 | (100) go AzHome | 0   |    |
| 25/06/14 07:49:15 | (101) at AzHome | 0   | 15 |
| 25/06/14 08:21:45 | (114) at Elev   | 58  |    |
| 25/06/14 08:21:45 | (113) at Azim   | 180 |    |
| 25/06/14 08:27:15 | (103) at ElHome | 0   |    |
| 25/06/14 08:42:20 | (100) go AzHome | 0   |    |
| 25/06/14 09:02:50 | (101) at AzHome | 0   | 16 |
| 25/06/14 09:35:20 | (114) at Elev   | 58  |    |
| 25/06/14 09:35:20 | (113) at Azim   | 180 |    |
| 25/06/14 09:40:50 | (103) at ElHome | 0   |    |
| 25/06/14 09:55:55 | (100) go AzHome | 0   |    |
| 25/06/14 10:16:25 | (101) at AzHome | 0   | 17 |
| 25/06/14 10:48:55 | (114) at Elev   | 58  |    |
| 25/06/14 10:48:55 | (113) at Azim   | 180 |    |
| 25/06/14 10:54:27 | (103) at ElHome | 0   |    |
| 25/06/14 11:09:31 | (100) go AzHome | 0   |    |
| 25/06/14 11:30:02 | (101) at AzHome | 0   | 18 |
| 25/06/14 12:02:32 | (114) at Elev   | 58  |    |
| 25/06/14 12:02:32 | (113) at Azim   | 180 |    |
| 25/06/14 12:08:04 | (103) at ElHome | 0   |    |
| 25/06/14 12:23:08 | (100) go AzHome | 0   |    |
| 25/06/14 12:43:38 | (101) at AzHome | 0   | 19 |
| 25/06/14 13:16:08 | (114) at Elev   | 58  |    |
| 25/06/14 13:16:08 | (113) at Azim   | 180 |    |
| 25/06/14 13:21:40 | (103) at ElHome | 0   |    |
| 25/06/14 13:36:44 | (100) go AzHome | 0   |    |
| 25/06/14 13:57:14 | (101) at AzHome | 0   | 20 |
| 25/06/14 14:29:44 | (114) at Elev   | 58  |    |
| 25/06/14 14:29:44 | (113) at Azim   | 180 |    |
| 25/06/14 14:35:16 | (103) at ElHome | 0   |    |
| 25/06/14 14:50:20 | (100) go AzHome | 0   |    |
| 25/06/14 15:10:50 | (101) at AzHome | 0   | 21 |
| 25/06/14 15:43:20 | (114) at Elev   | 58  |    |

## Appendix B

|                   |                 |     |    |
|-------------------|-----------------|-----|----|
| 25/06/14 15:43:20 | (113) at Azim   | 180 |    |
| 25/06/14 15:48:52 | (103) at ElHome | 0   |    |
| 25/06/14 16:03:56 | (100) go AzHome | 0   |    |
| 25/06/14 16:24:26 | (101) at AzHome | 0   | 22 |
| 25/06/14 16:56:56 | (114) at Elev   | 58  |    |
| 25/06/14 16:56:56 | (113) at Azim   | 180 |    |
| 25/06/14 17:01:28 | (103) at ElHome | 0   |    |
| 25/06/14 17:16:32 | (100) go AzHome | 0   |    |
| 25/06/14 17:37:02 | (101) at AzHome | 0   | 23 |
| 25/06/14 18:09:32 | (114) at Elev   | 58  |    |
| 25/06/14 18:09:32 | (113) at Azim   | 180 |    |
| 25/06/14 18:15:04 | (103) at ElHome | 0   |    |
| 25/06/14 18:30:08 | (100) go AzHome | 0   |    |
| 25/06/14 18:50:38 | (101) at AzHome | 0   | 24 |
| 25/06/14 19:23:08 | (114) at Elev   | 58  |    |
| 25/06/14 19:23:08 | (113) at Azim   | 180 |    |
| 25/06/14 19:28:40 | (103) at ElHome | 0   |    |
| 25/06/14 19:43:44 | (100) go AzHome | 0   |    |
| 25/06/14 20:04:14 | (101) at AzHome | 0   | 25 |
| 25/06/14 20:36:44 | (114) at Elev   | 58  |    |
| 25/06/14 20:36:44 | (113) at Azim   | 180 |    |
| 25/06/14 20:42:16 | (103) at ElHome | 0   |    |
| 25/06/14 20:57:20 | (100) go AzHome | 0   |    |
| 25/06/14 21:17:50 | (101) at AzHome | 0   | 26 |
| 25/06/14 21:50:20 | (114) at Elev   | 58  |    |
| 25/06/14 21:50:20 | (113) at Azim   | 180 |    |
| 25/06/14 21:55:52 | (103) at ElHome | 0   |    |
| 25/06/14 22:10:56 | (100) go AzHome | 0   |    |
| 25/06/14 22:31:26 | (101) at AzHome | 0   | 27 |
| 25/06/14 23:03:56 | (114) at Elev   | 58  |    |
| 25/06/14 23:03:56 | (113) at Azim   | 180 |    |
| 25/06/14 23:09:28 | (103) at ElHome | 0   |    |
| 25/06/14 23:24:32 | (100) go AzHome | 0   |    |
| 25/06/14 23:45:02 | (101) at AzHome | 0   | 28 |
| 26/06/14 00:17:32 | (114) at Elev   | 58  |    |

## Appendix B

|                   |                 |     |    |
|-------------------|-----------------|-----|----|
| 26/06/14 00:17:32 | (113) at Azim   | 180 |    |
| 26/06/14 00:23:04 | (103) at ElHome | 0   |    |
| 26/06/14 00:38:08 | (100) go AzHome | 0   |    |
| 26/06/14 00:58:38 | (101) at AzHome | 0   | 29 |
| 26/06/14 01:31:08 | (114) at Elev   | 58  |    |
| 26/06/14 01:31:08 | (113) at Azim   | 180 |    |
| 26/06/14 01:36:40 | (103) at ElHome | 0   |    |
| 26/06/14 01:51:44 | (100) go AzHome | 0   |    |
| 26/06/14 02:12:14 | (101) at AzHome | 0   | 30 |
| 26/06/14 02:44:44 | (114) at Elev   | 58  |    |
| 26/06/14 02:44:44 | (113) at Azim   | 180 |    |
| 26/06/14 02:50:16 | (103) at ElHome | 0   |    |
| 26/06/14 03:05:20 | (100) go AzHome | 0   |    |
| 26/06/14 03:25:50 | (101) at AzHome | 0   | 31 |
| 26/06/14 03:58:20 | (114) at Elev   | 58  |    |
| 26/06/14 03:58:20 | (113) at Azim   | 180 |    |
| 26/06/14 04:03:52 | (103) at ElHome | 0   |    |
| 26/06/14 04:18:56 | (100) go AzHome | 0   |    |
| 26/06/14 04:39:26 | (101) at AzHome | 0   | 32 |
| 26/06/14 05:11:56 | (114) at Elev   | 58  |    |
| 26/06/14 05:11:56 | (113) at Azim   | 180 |    |
| 26/06/14 05:17:28 | (103) at ElHome | 0   |    |
| 26/06/14 05:32:32 | (100) go AzHome | 0   |    |
| 26/06/14 05:53:02 | (101) at AzHome | 0   | 33 |
| 26/06/14 06:25:32 | (114) at Elev   | 58  |    |
| 26/06/14 06:25:32 | (113) at Azim   | 180 |    |
| 26/06/14 06:31:04 | (103) at ElHome | 0   |    |
| 26/06/14 06:46:08 | (100) go AzHome | 0   |    |
| 26/06/14 07:06:38 | (101) at AzHome | 0   | 34 |
| 26/06/14 07:39:08 | (114) at Elev   | 58  |    |
| 26/06/14 07:39:08 | (113) at Azim   | 180 |    |
| 26/06/14 07:44:40 | (103) at ElHome | 0   |    |
| 26/06/14 07:59:44 | (100) go AzHome | 0   |    |
| 26/06/14 08:20:14 | (101) at AzHome | 0   | 35 |
| 26/06/14 08:52:44 | (114) at Elev   | 58  |    |

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|                   |                 |     |    |
|-------------------|-----------------|-----|----|
| 26/06/14 08:52:44 | (113) at Azim   | 180 |    |
| 26/06/14 08:58:16 | (103) at ElHome | 0   |    |
| 26/06/14 09:13:20 | (100) go AzHome | 0   |    |
| 26/06/14 09:33:50 | (101) at AzHome | 0   | 36 |
| 26/06/14 10:06:20 | (114) at Elev   | 58  |    |
| 26/06/14 10:06:20 | (113) at Azim   | 180 |    |
| 26/06/14 10:11:52 | (103) at ElHome | 0   |    |
| 26/06/14 10:19:56 | (114) at Elev   | 58  |    |
| 26/06/14 10:19:56 | (113) at Azim   | 180 |    |
| 26/06/14 10:25:28 | (103) at ElHome | 0   |    |
| 26/06/14 10:26:56 | (100) go AzHome | 0   |    |
| 26/06/14 10:40:32 | (100) go AzHome | 0   |    |
| 26/06/14 10:47:26 | (101) at AzHome | 0   | 37 |
| 26/06/14 11:01:02 | (101) at AzHome | 0   | 38 |
| 26/06/14 11:33:32 | (114) at Elev   | 58  |    |
| 26/06/14 11:33:32 | (113) at Azim   | 180 |    |
| 26/06/14 11:39:04 | (103) at ElHome | 0   |    |
| 26/06/14 11:54:08 | (100) go AzHome | 0   |    |
| 26/06/14 12:14:38 | (101) at AzHome | 0   | 39 |
| 26/06/14 12:47:08 | (114) at Elev   | 58  |    |
| 26/06/14 12:47:08 | (113) at Azim   | 180 |    |
| 26/06/14 12:52:40 | (103) at ElHome | 0   |    |
| 26/06/14 13:07:44 | (100) go AzHome | 0   |    |
| 26/06/14 13:28:14 | (101) at AzHome | 0   | 40 |
| 26/06/14 14:00:44 | (114) at Elev   | 58  |    |
| 26/06/14 14:00:44 | (113) at Azim   | 180 |    |
| 26/06/14 14:06:16 | (103) at ElHome | 0   |    |
| 26/06/14 14:21:20 | (100) go AzHome | 0   |    |
| 26/06/14 14:41:50 | (101) at AzHome | 0   | 41 |
| 26/06/14 15:14:20 | (114) at Elev   | 58  |    |
| 26/06/14 15:14:20 | (113) at Azim   | 180 |    |
| 26/06/14 15:19:52 | (103) at ElHome | 0   |    |
| 26/06/14 15:34:56 | (100) go AzHome | 0   |    |
| 26/06/14 15:55:26 | (101) at AzHome | 0   | 42 |
| 26/06/14 16:27:56 | (114) at Elev   | 58  |    |

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|                   |                 |     |    |
|-------------------|-----------------|-----|----|
| 26/06/14 16:27:56 | (113) at Azim   | 180 |    |
| 26/06/14 16:33:28 | (103) at ElHome | 0   |    |
| 26/06/14 16:48:32 | (100) go AzHome | 0   |    |
| 26/06/14 17:09:02 | (101) at AzHome | 0   | 43 |
| 26/06/14 17:41:32 | (114) at Elev   | 58  |    |
| 26/06/14 17:41:32 | (113) at Azim   | 180 |    |
| 26/06/14 17:47:04 | (103) at ElHome | 0   |    |
| 26/06/14 18:02:08 | (100) go AzHome | 0   |    |
| 26/06/14 18:22:38 | (101) at AzHome | 0   | 44 |
| 26/06/14 18:53:08 | (114) at Elev   | 58  |    |
| 26/06/14 18:53:08 | (113) at Azim   | 180 |    |
| 26/06/14 18:58:40 | (103) at ElHome | 0   |    |
| 26/06/14 19:13:44 | (100) go AzHome | 0   |    |
| 26/06/14 19:34:14 | (101) at AzHome | 0   | 45 |
| 26/06/14 20:06:44 | (114) at Elev   | 58  |    |
| 26/06/14 20:06:44 | (113) at Azim   | 180 |    |
| 26/06/14 20:12:16 | (103) at ElHome | 0   |    |
| 26/06/14 20:27:20 | (100) go AzHome | 0   |    |
| 26/06/14 20:47:50 | (101) at AzHome | 0   | 46 |
| 26/06/14 21:20:20 | (114) at Elev   | 58  |    |
| 26/06/14 21:20:20 | (113) at Azim   | 180 |    |
| 26/06/14 21:25:52 | (103) at ElHome | 0   |    |
| 26/06/14 21:39:56 | (100) go AzHome | 0   |    |
| 26/06/14 22:00:26 | (101) at AzHome | 0   | 47 |
| 26/06/14 22:32:56 | (114) at Elev   | 58  |    |
| 26/06/14 22:32:56 | (113) at Azim   | 180 |    |
| 26/06/14 22:38:28 | (103) at ElHome | 0   |    |
| 26/06/14 22:53:32 | (100) go AzHome | 0   |    |
| 26/06/14 23:14:02 | (101) at AzHome | 0   | 48 |
| 26/06/14 23:46:32 | (114) at Elev   | 58  |    |
| 26/06/14 23:46:32 | (113) at Azim   | 180 |    |
| 26/06/14 23:52:04 | (103) at ElHome | 0   |    |
| 27/06/14 00:07:08 | (100) go AzHome | 0   |    |
| 27/06/14 00:27:38 | (101) at AzHome | 0   | 49 |
| 27/06/14 01:00:08 | (114) at Elev   | 58  |    |

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|                   |                 |     |    |
|-------------------|-----------------|-----|----|
| 27/06/14 01:00:08 | (113) at Azim   | 180 |    |
| 27/06/14 01:05:40 | (103) at ElHome | 0   |    |
| 27/06/14 01:20:44 | (100) go AzHome | 0   |    |
| 27/06/14 01:41:14 | (101) at AzHome | 0   | 50 |
| 27/06/14 02:13:44 | (114) at Elev   | 58  |    |
| 27/06/14 02:13:44 | (113) at Azim   | 180 |    |
| 27/06/14 02:19:16 | (103) at ElHome | 0   |    |
| 27/06/14 02:34:20 | (100) go AzHome | 0   |    |
| 27/06/14 02:54:50 | (101) at AzHome | 0   | 51 |
| 27/06/14 03:27:20 | (114) at Elev   | 58  |    |
| 27/06/14 03:27:20 | (113) at Azim   | 180 |    |
| 27/06/14 03:32:52 | (103) at ElHome | 0   |    |
| 27/06/14 03:47:56 | (100) go AzHome | 0   |    |
| 27/06/14 04:08:26 | (101) at AzHome | 0   | 52 |
| 27/06/14 04:40:56 | (114) at Elev   | 58  |    |
| 27/06/14 04:40:56 | (113) at Azim   | 180 |    |
| 27/06/14 04:46:28 | (103) at ElHome | 0   |    |
| 27/06/14 05:01:32 | (100) go AzHome | 0   |    |
| 27/06/14 05:22:02 | (101) at AzHome | 0   | 53 |
| 27/06/14 05:54:32 | (114) at Elev   | 58  |    |
| 27/06/14 05:54:32 | (113) at Azim   | 180 |    |
| 27/06/14 06:00:04 | (103) at ElHome | 0   |    |
| 27/06/14 06:15:08 | (100) go AzHome | 0   |    |
| 27/06/14 06:35:38 | (101) at AzHome | 0   | 54 |
| 27/06/14 07:08:08 | (114) at Elev   | 58  |    |
| 27/06/14 07:08:08 | (113) at Azim   | 180 |    |
| 27/06/14 07:13:40 | (103) at ElHome | 0   |    |
| 27/06/14 07:28:44 | (100) go AzHome | 0   |    |
| 27/06/14 07:49:14 | (101) at AzHome | 0   | 55 |
| 27/06/14 08:21:44 | (114) at Elev   | 58  |    |
| 27/06/14 08:21:44 | (113) at Azim   | 180 |    |
| 27/06/14 08:27:16 | (103) at ElHome | 0   |    |
| 27/06/14 08:42:20 | (100) go AzHome | 0   |    |
| 27/06/14 09:02:50 | (101) at AzHome | 0   | 56 |
| 27/06/14 09:35:20 | (114) at Elev   | 58  |    |

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|                   |                 |     |    |
|-------------------|-----------------|-----|----|
| 27/06/14 09:35:20 | (113) at Azim   | 180 |    |
| 27/06/14 09:40:52 | (103) at ElHome | 0   |    |
| 27/06/14 09:55:56 | (100) go AzHome | 0   |    |
| 27/06/14 10:16:26 | (101) at AzHome | 0   | 57 |
| 27/06/14 10:48:56 | (114) at Elev   | 58  |    |
| 27/06/14 10:48:56 | (113) at Azim   | 180 |    |
| 27/06/14 10:54:28 | (103) at ElHome | 0   |    |
| 27/06/14 11:09:32 | (100) go AzHome | 0   |    |
| 27/06/14 11:30:02 | (101) at AzHome | 0   | 58 |
| 27/06/14 12:02:32 | (114) at Elev   | 58  |    |
| 27/06/14 12:02:32 | (113) at Azim   | 180 |    |
| 27/06/14 12:08:04 | (103) at ElHome | 0   |    |
| 27/06/14 12:23:08 | (100) go AzHome | 0   |    |
| 27/06/14 12:43:38 | (101) at AzHome | 0   | 59 |
| 27/06/14 13:16:08 | (114) at Elev   | 58  |    |
| 27/06/14 13:16:08 | (113) at Azim   | 180 |    |
| 27/06/14 13:21:40 | (103) at ElHome | 0   |    |
| 27/06/14 13:36:44 | (100) go AzHome | 0   |    |
| 27/06/14 13:57:14 | (101) at AzHome | 0   | 60 |
| 27/06/14 14:29:44 | (114) at Elev   | 58  |    |
| 27/06/14 14:29:44 | (113) at Azim   | 180 |    |
| 27/06/14 14:35:16 | (103) at ElHome | 0   |    |
| 27/06/14 14:50:20 | (100) go AzHome | 0   |    |
| 27/06/14 15:10:50 | (101) at AzHome | 0   | 61 |
| 27/06/14 15:43:20 | (114) at Elev   | 58  |    |
| 27/06/14 15:43:20 | (113) at Azim   | 180 |    |
| 27/06/14 15:48:52 | (103) at ElHome | 0   |    |
| 27/06/14 16:03:56 | (100) go AzHome | 0   |    |
| 27/06/14 16:24:26 | (101) at AzHome | 0   | 62 |
| 27/06/14 16:56:56 | (114) at Elev   | 58  |    |
| 27/06/14 16:56:56 | (113) at Azim   | 180 |    |
| 27/06/14 17:02:28 | (103) at ElHome | 0   |    |
| 27/06/14 17:17:32 | (100) go AzHome | 0   |    |
| 27/06/14 17:38:02 | (101) at AzHome | 0   | 63 |
| 27/06/14 18:10:32 | (114) at Elev   | 58  |    |

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|                   |                 |     |    |
|-------------------|-----------------|-----|----|
| 27/06/14 18:10:32 | (113) at Azim   | 180 |    |
| 27/06/14 18:16:04 | (103) at ElHome | 0   |    |
| 27/06/14 18:31:08 | (100) go AzHome | 0   |    |
| 27/06/14 18:51:38 | (101) at AzHome | 0   | 64 |
| 27/06/14 19:24:08 | (114) at Elev   | 58  |    |
| 27/06/14 19:24:08 | (113) at Azim   | 180 |    |
| 27/06/14 19:29:40 | (103) at ElHome | 0   |    |
| 27/06/14 19:44:44 | (100) go AzHome | 0   |    |
| 27/06/14 20:05:14 | (101) at AzHome | 0   | 65 |
| 27/06/14 20:37:44 | (114) at Elev   | 58  |    |
| 27/06/14 20:37:44 | (113) at Azim   | 180 |    |
| 27/06/14 20:53:16 | (103) at ElHome | 0   |    |
| 27/06/14 21:08:20 | (100) go AzHome | 0   |    |
| 27/06/14 21:40:50 | (101) at AzHome | 0   | 66 |

**Table B** Log file output of D170 tracker controller during accelerated testing (provided by Mechatron Solar Inc.)

## About Us

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For companies developing PV products and projects, PV Evolution Labs (DNV GL PVEL LLC) is the premier solar panel performance and reliability testing lab. We provide secure, expert testing and validation services so you can be confident that you're making intelligent decisions based on the most reliable data.

PVEL is founded on the principle that understanding solar panel aging behavior through testing is a fundamental aspect of safety, cost reduction, and reliability – all of which are imperative to the growth, health, and evolution of the solar industry. PVEL is committed to increasing photovoltaic product quality while reducing product time to market.

Our dedicated environmental, mechanical, and electrical testing systems are designed specifically for the flat plate PV module form factor. Utilizing dedicated characterization systems ensures optimal data quality and repeatability. PVEL's calibrated equipment base is closely maintained to ensure optimal availability and reliability. Our specialized services are available for product and process qualification, raw material and supplier evaluation, ongoing reliability testing (ORT), risk assessment, lot acceptance, energy yield evaluation, and more.

The PVEL team possesses unparalleled expertise in test and measurement techniques for semiconductor devices and PV modules. Our highly qualified technical staff is dedicated to serving the needs of the solar industry with a commitment to excellence in test quality and customer service. PVEL aims to collaborate with our clients throughout the development cycle. By working with you from start to finish, we ensure the highest quality product with a faster time to market.

*Our mission at PVEL is to facilitate the dramatic growth of the North American solar industry.*