Performance of Amonix multijunction arrays

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ABSTRACT

After twenty years of commercial deployments of concentrator photovoltaic systems using silicon cells, Amonix has built a new generation of systems designed for III-V multijunction cells. The resulting 7th-generation systems yield a considerable performance dividend in the field-proven system design. The first systems, operating in Las Vegas, NV, achieve AC efficiencies in excess of 25%. Detailed modeling of the cell and system parameters provides a prediction of energy generation that is within 3% of the measured energy after seven months of operation. The predicted annual yield in this location is over 2600 kW-hr/kW.

Keywords: concentrator, III-V, multijunction, system, field, energy, performance, model

1. INTRODUCTION

1.1 Heritage

This year Amonix, Inc. celebrates twenty years of development of commercial, utility scale, high concentration photovoltaic (HCPV) systems. Founded in 1989, Amonix was established during a period of intense interest in concentrating PV systems employing high-efficiency silicon cells. In the years that followed, steady progress in performance, reliability, and cost reduction of six generations of system designs allowed for increasingly large field deployments. As of 2008, Amonix-designed systems (including those built and deployed by Guascor Fotón) accounted for over 70% of the ~18 MW of concentrator photovoltaic systems deployed worldwide [1]. Along the way, Amonix established the world record efficiency for a silicon cell: 27.6% under 92x concentration [2].

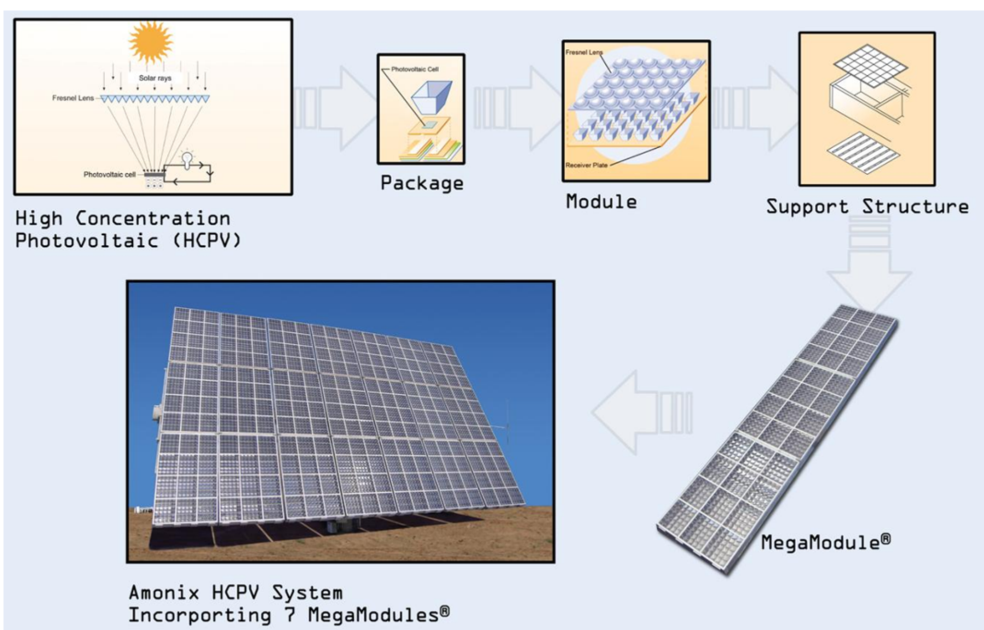

Figure 1. MegaModule® approach to utility-scale power generation.

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The key to commercial deployment at utility scale has been the MegaModule® design. The conventional module size of around 1 m^2, appropriate where modules are installed by hand, is no longer optimal when the systems migrate from rooftops into a field. A MegaModule® incorporates several dozen module-sized sections into a single, rigid frame sized for transportation by commercial tractor trailers. Most of the optical alignment therefore occurs within the controlled environment of the factory. In the field, thousands of cells are aligned to the tracker mount simultaneously with the installation of each MegaModule® (Figure 2).

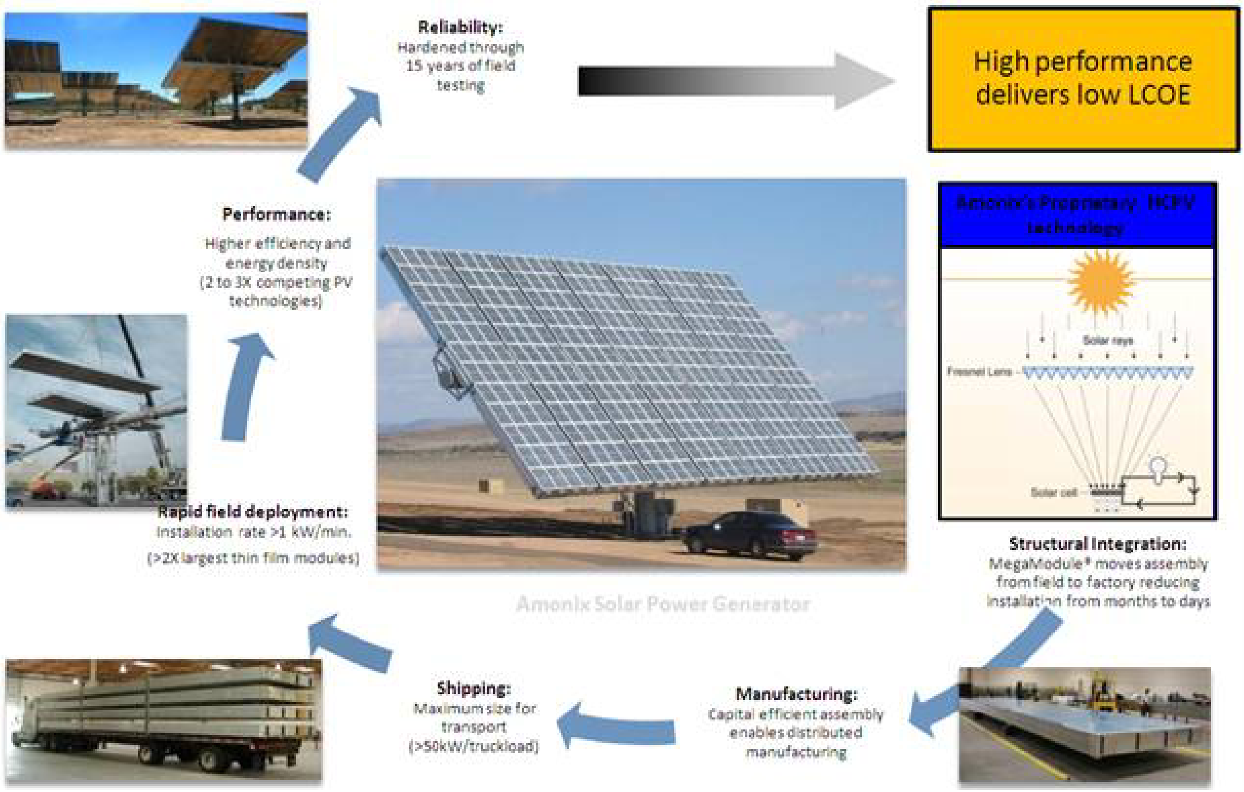


Figure 2. Field deployment using MegaModules®.

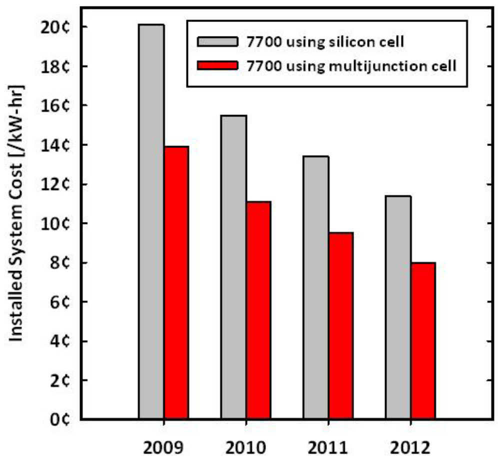
2. III-V MULTIJUNCTION SYSTEMS

2.1 Transition to III-V multijunctions

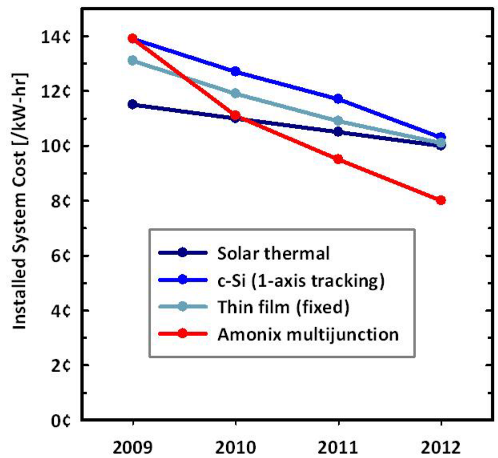
Despite the success of silicon-based Amonix systems, Amonix-designed capacity currently represents less than 0.2% of the world solar market, well below what the founders envisioned two decades ago. The benefits of HCPV systems for utility-scale generation in terms of annual energy yield and capacity factor have not yet been sufficient to offset concerns about the effect of long-term balance of systems costs in levelized cost of energy (LCOE) projections. In order to finally tip the balance in favor of HCPV, in 2000 Amonix began developing III-V multijunction cells for use in its HCPV systems. The present III-V multijunctions, at over 37% efficiency under standard test conditions, offer a >40% increase in efficiency with respect to the highest-efficiency silicon cells, as well as less sensitivity to higher operating temperatures and concentrations [2], [3].

These performance dividends more than offset the contribution of additional cell cost to the system LCOE. As an example, Figure 3a compares projected LCOE numbers for the next few years of systems using silicon and multijunction cells. Assuming reasonable dividends from economy of scale in the next few years, the leveraging effect of high-efficiency multijunction cells leads to a LCOE projection for HCPV below that of competing solar technologies (Figure 3b).

The 7000 series (seventh generation) of Amonix HCPV systems is the first to operate using all-multijunction MegaModules®. The first 7000-series system, a 7500 model composed of five MegaModules®, was deployed in cooperation with the University of Nevada-Las Vegas Center for Energy Research (CER) and reached first light in December of 2008. A 7700 system (consisting of seven MegaModules®) has recently been installed nearby. Students and faculty at CER are working with Amonix to monitor the performance of the 7500 and 7700 systems over time. Meteorological data and AC power generation data are collected at one-minute intervals. The system performance data has been tracked against a detailed parameter model developed to predict III-V multijunction-based HCPV system field performance.



(a)



(b)

Figure 3. High-efficiency multijunction cells have a leveraging effect on system LCOE.

2.2 Field performance prediction using parameter-based model

In order to predict the annual energy yield of fielded HCPV systems, a model has been developed that takes into account many of the variable parameters that affect system performance in the field. The performance of a silicon-based HCPV system can be expected to vary as a function of temperature, incident irradiance (DNI), cloud cover, wind speed, various system mismatch losses, soiling, and inverter efficiency. A multijunction-based system has additional cell-level mismatch due to its sensitivity to variations in the incident spectrum. The present three-junction cell is designed so that its top two sub-cells are current matched under a particular reference spectrum, such as the G173-03 (direct normal) spectrum, at 25° C. In field operation, current mismatch between the top two sub-cells will result from changes in temperature as well as daily and annual variations in the incident spectrum.

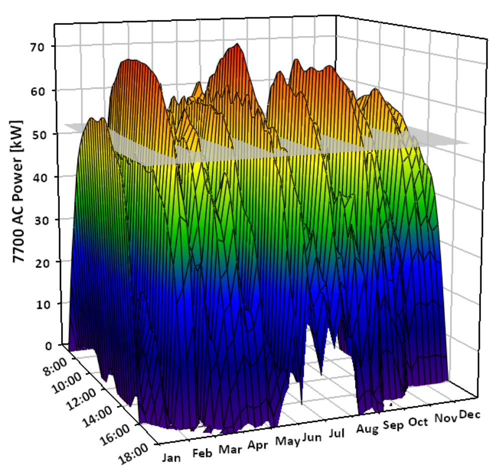


Figure 4. Predicted power output for a 7700 in Las Vegas, NV. The horizontal plane at 53 kW indicates the system PVUSA rating.

The spectra for a given location may be generated using NREL SMARTS [4]. The TMY3 database is used to supply parameters such as temperature, aerosol optical depth (AOD), and cloud cover [5]. Beginning with the temperature-corrected spectral response of multijunction cells, cell voltage and fill factor are also corrected for temperature and intensity. Details of the cell modeling approach have been described elsewhere [6], [7]. Once such system-level losses as optical transmission, current mismatch, soiling, and inverter efficiency are incorporated, a predicted system-level power profile emerges. As an example, the predicted power profile for a 7700 system in Las Vegas is shown in Figure 4. Due to the high DNI available in Las Vegas, a 7700 may be expected to operate well above its PVUSA rating for much of the year.

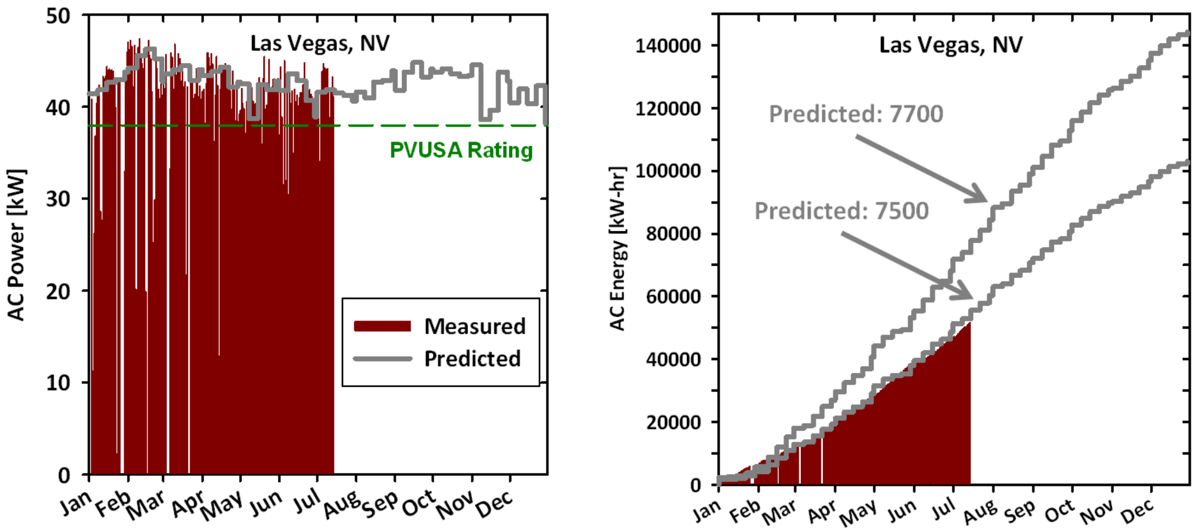
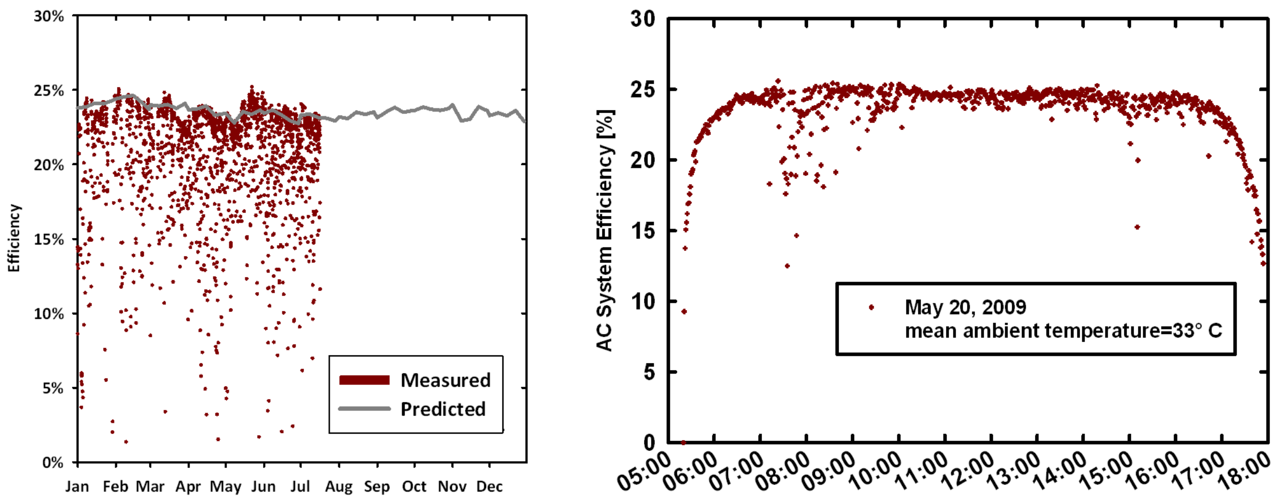


Figure 5. Daily peak power and cumulative energy of the 7500 in Las Vegas compared to the parameter model prediction.

2.3 Performance of the 7500 in Las Vegas, NV

Having operated for seven months, the 7500 system in Las Vegas provides a first look at the performance of a multijunction-based Amonix system. The measured daily peak power shown in Figure 5a tracks well with the envelope given by the parameter model prediction. Peak power is seen to dip, as expected, in the summer months due to higher temperatures and higher AOD. Despite vagaries of such factors as cloud cover, the cumulative energy to date (Figure 5b) is also within 3% of the predicted value. This suggests that a 7700 system at this location will generate around 140,000 kW-hr annually, corresponding to an annual yield of over 2600 kW-hr per kW.

AC system efficiency provides a useful means for detecting any system degradation that may occur over time. As indicated by Figure 6a, the measured AC efficiency of the 7500 to date follows the predicted efficiency envelope. The measured data points in Figure 6a consist of sixty-minute averages. Lower efficiency values occur early and late in the day and as a result of cloud cover. Figure 6b shows a recent clear day in which, despite a few intermittent clouds, the system maintained AC efficiency around 25% for over ten hours of the day. As predicted, efficiency has fallen slightly during the summer months, but is expected to rise again during the colder and less turbid (lower AOD) days of fall. To date, efficiency data does not provide an indication of performance degradation. Amonix will continue to track the progress of the 7500 to assess reliability and validate the parameter model for energy prediction.



(a) (b)

Figure 6. (a) Measured efficiency of the 7500 vs. prediction. (b) A daily snapshot of the AC system efficiency: the system is at or near 25% most of the day.

Figure 7. The 228-kW array at the Southern Nevada Water Authority's River Mountain Water Treatment Facility in Henderson, NV.

2.4 Future systems

In addition to the 7500 and 7700 installed at UNLV, six more 7500s have been installed nearby in Henderson, NV. The six 7500s achieved first light in July and began generating power for the Southern Nevada Water Authority. There are now over 300 kW of multijunction-based Amonix systems operating that are expected to produce over 840 MW-hr of clean energy to feed the Las Vegas grid. Amonix will use the experience gained with these systems as it deploys systems in other locations. The parameter model applied above for Las Vegas gives a sense of how 7000 series systems will operate at other locations as well. The effects of varying latitude, elevation, temperature, AOD, and cloud cover make a considerable impact on peak power and energy yield (Figure 8). The cold, high-elevation site of Alamosa, CO delivers predicted peak power approaching 70 kW, but the higher latitude and cloudier weather result in the lowest annual energy yield of the four sites evaluated. In contrast, Daggett, CA promises an energy yield 14% higher than that of Las Vegas. Such an increase bodes well for future Amonix systems in such locations. As Amonix systems are further optimized for multijunction operation, an additional 12% performance improvement is expected by 2012 (Figure 9). Combined with system cost reduction in progress, these improvements should result in rapid commercialization of the multijunction-based systems.

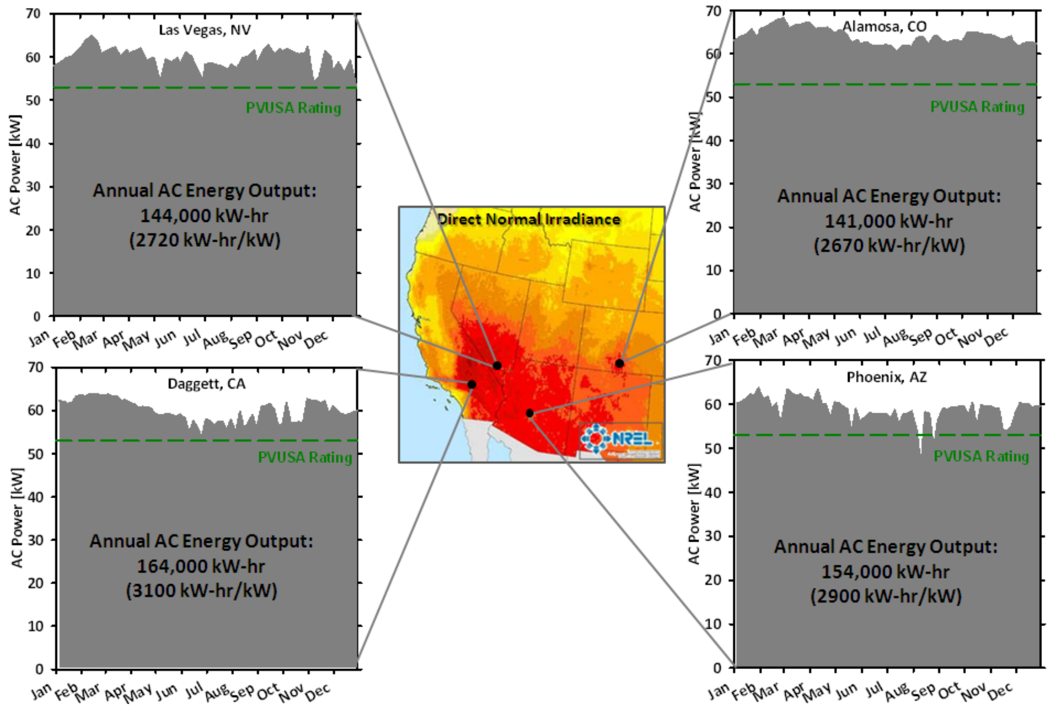


Figure 8. Parameter model prediction of peak power and energy yield at various locations in the American Southwest.

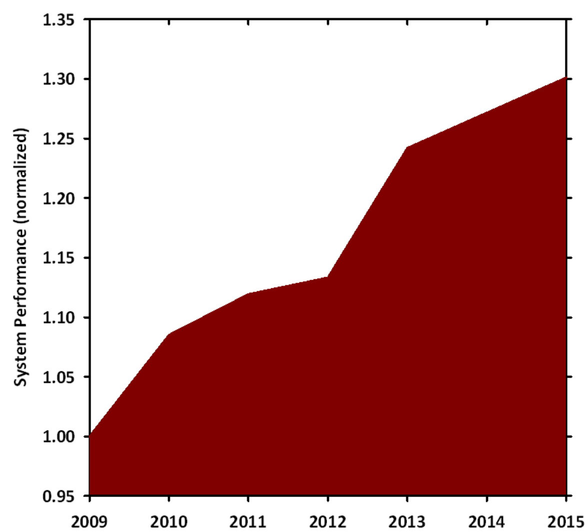


Figure 9. The Amonix performance road map. 12% improvement is expected by 2012.

3. CONCLUSION

The 7000 series of Amonix multijunction arrays brings together two decades of proven HCPV field performance with the world's highest efficiency solar cells. With reasonable production scale, the resulting reduction in LCOE is expected to make HCPV the cheapest form of solar energy within three years. The first 7000 series system has been operating for over seven months and its performance matches well with the prediction. Operating AC system efficiency of over 25% has been obtained. Seven other 7000-series systems have recently been deployed for a total installed capacity in excess of 300 kW of multijunction systems. This represents the beginning of large-scale energy generation by HCPV.

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REFERENCES

[1] New Energy Finance, www.newenergyfinance.com

[2] Kurtz, S., "Opportunities and Challenges for Development of a Mature Concentrating Photovoltaic Power Industry," NREL/TP-520-43208, www.nrel.gov/pv/pdfs/43208.pdf (2009).

[3] Kinsey, G.S., Hebert, P., Barbour, K.E., Krut, D.D., Cotal, H.L., Sherif, R.A. "Concentrator multijunction solar cell characteristics under variable intensity and temperature," Prog. Photovolt. Res. Appl. 16, 503-508 (2008).

[4] Gueymard, C., "SMARTS, a simple model of the atmospheric radiative transfer of sunshine: algorithms and performance assessment," Professional Paper FSEC-PF-270-95 (2001).

[5] http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

[6] Kinsey, G.S., Edmondson, K.M., "Spectral response and energy output of concentrator multijunction solar cells, Prog. Photovolt. Res. Appl., 17(5) (2009).

[7] Partain, L. and Fraas, L., editors, [Solar Cells and Their Applications, 2nd Edition], Wiley Publishers, New York, ch. 8 (2009).