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Concentrator PV (CPV): A Solar Seed Ready for Colorado

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Concentrator PV (CPV): A Solar Seed Ready for Colorado

by

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Abstract

This paper discusses a relatively new high technology photovoltaic concept utilizing high-efficiency space-flight solar cells in a concentrating mode for terrestrial applications. A proposal for power generation in Colorado is presented.

Introduction

I have always enjoyed working on high-risk projects. About 25 years ago I volunteered to direct a wind energy project for an electric utility and my peers stated that the project would end my career. It turns out that they were wrong, as wind energy has now become a viable form of renewable energy. The project I will discuss in this paper has similarities to wind energy in terms of its development status. The project is that of utility CPV. Has its time arrived?

A grid-connected concentrating photovoltaic (CPV) system schematic is shown in Figure 1. CPV systems use optical concentrators to focus direct solar radiation onto solar cells for conversion into electricity. By using optical concentrators to focus the solar radiation onto solar cells, the cell area, and consequently cell cost, can be reduced by a factor of up to 1000.

One issue is that PV electricity is expensive, currently costing 25 cents per kWh or more. A plant for manufacturing flat-plate PV would cost more that 1$/W. Hence a 100 MW plant would cost more than 100 million dollars. Also, the world PV market is currently less than 150 MW. If production of solar cells were substantially increased then costs would presumably decrease. However, there is a problem with a potential shortage of silicon. There may not be enough to produce more than 300 MW of silicon-based PV per year. A possible solution is to use CPV. A CPV electrical generation plant would require up to a factor of 1000 times less silicon. Further, a CPV manufacturing plant would cost less than 10 cents per watt. Thus a 100 MW manufacturing plant could cost on the order of ten million dollars, thereby significantly reducing investment risk in the manufacturing facility. An additional advantage is that the effluents resulting from cell manufacture would be reduced, by the concentration factor, from those for an equivalent flat-plate system.

Can CPV Leapfrog?

CPV has been "promising" for many years. However, the PV market has not been large enough to support the high volume sales of large systems needed by CPV companies to reduce costs. Nevertheless, to be successful CPV needs high efficiency cells and high direct solar radiation. NREL research has recently led to the development of high efficiency cells that are currently being used for space applications and Southern Colorado is rich in direct solar radiation. Satisfying these technology needs may ensure cost reductions if a high volume market opportunity appeared in Colorado.

NREL research led to the development of a two-junction GaInP/GaAs solar cell that is tuned to two different frequencies in the solar spectrum. The cell was invented in 1984 and was patented in 1988. The cell efficiencies rose from around 4% in 1985 to nearly 28% in 1990. The space program "got wind" of this development and began using the cells around 1995. Shown on Figure 2 [Kurtz and Friedman, 1998] is a pictoral history of the GaInP/GaAs cell. Projected efficiencies are seen to be as high as forty percent.

Production of these cells has increased significantly in recent years. Figure 3 [Kurtz and Friedman, 1998] is a graph depicting the percent of production of Si and III-V (so named for the columns in the periodic table) cells by one particular manufacturer. This manufacturer (TECSTAR) has increased its production of these cells by nearly an order of magnitude in the last five years. Another manufacturer (Spectrolab) has its cells flying on three satellites and current production is at 325 kW per year. This technology is clearly "taking off."

The issue of the need for a direct solar resource is not a problem for extraterrestrial applications. Although it could pose problems for terrestrial applications, it should not be a problem for Southern Colorado. Shown on Figure 4 is a map of direct normal solar radiation for Colorado. It is seen that Alamosa receives an average of 6.83 kWh/sq.meter/day. This is comparable with amounts in Arizona, a very sunny state, as shown in Figure 5.

The question, as usual, is one of economic viability. How soon can CPV compete with energy from natural gas or wind, costing around three cents per kWh? It turns out that there are production similarities between wind turbines and CPV such that costs can drop more rapidly for CPV than for flat-plate PV. A DOE/EPRI study [EPRI, 1997] has shown that CPV has a $1/W potential (at 40%cell efficiency), thus providing electricity at less than 4 cents per kWh.

The CPV module manufacturing process is a straightforward manufacturing and assembly operation, with components provided by a number of suppliers. This manufacturing and assembly operation is similar to that of wind systems. It is therefore reasonable to expect dramatic cost reductions concurrent with high volume CPV sales as happened with wind system costs in the 1980s.

What Else is Needed?

As with other developing systems, reliability of CPV systems has been poor. However, lessons have been learned from other areas, such as wind energy systems, that standards need to be developed up front and not later. Standards are currently being developed for CPV systems under the aegis of the IEEE Standards Association. Also, it is necessary to have experienced manufacturers. This is also happening, with the advent of manufacturers such as BP Solar and Honda, both of whom are developing concentrator technologies. BP Solar, the largest photovoltaic manufacturer in the world, has its EUCLIDES project due to come on line in November 1988. This is a 0.5 MWp plant for village power.

Another issue is that CPV needs a significant project opportunity. Based on the high direct solar resource in Colorado, why not develop a utility CPV system in Southern Colorado? It is important for utilities and communities concerned about risk to not ignore the possible reality of global climate change due to burning of fossil fuels. Much of Colorado's electricity comes from the burning of coal and when Colorado decides it is prudent to avoid the risk of global climate change, CPV systems in Colorado can contribute to this effort.

Conclusions

A CPV system for a utility has potential for Colorado. John F. Kennedy once stated the following: *The great French Marshall Lyautney once asked his gardener to plant a tree. The gardener objected that the tree was slow growing and would not reach maturity for 100 years. The Marshall replied, "In that case, there is not time to lose; plant it this afternoon!"*

Acknowledgment

I thank Professor C. Byron Winn for preparing this paper using the viewgraphs I presented at the 1998 Colorado Renewable Energy Society Conference.

References

Sarah Kurtz and D. J. Friedman, "Concentrator and Space Applications Of High-Efficiency Solar Cells - Recent Developments," presented at the NCPV review meeting, September 1998.

"Renewable Energy Technology Characterizations," EPRI TR-109496, Electric Power Research Institute, Palo Alto, CA, December 1997.

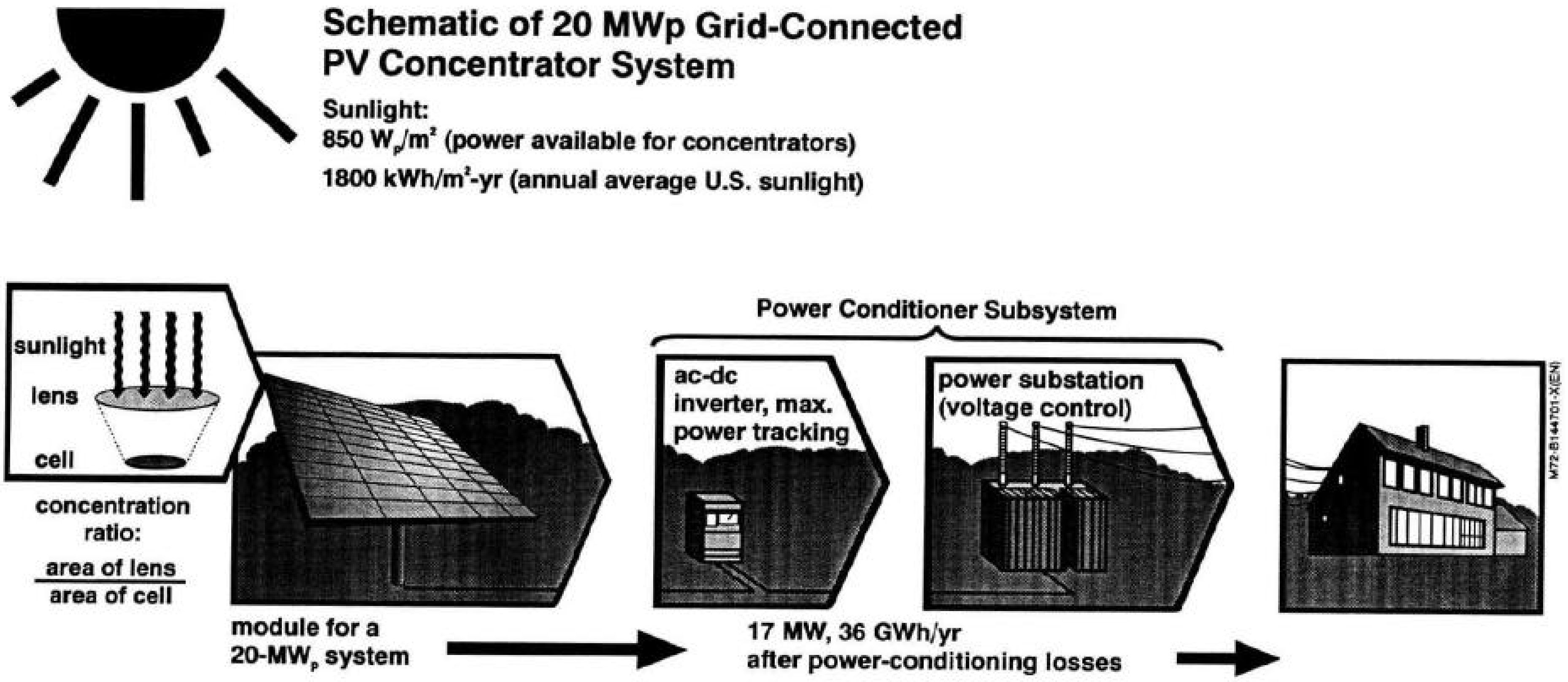
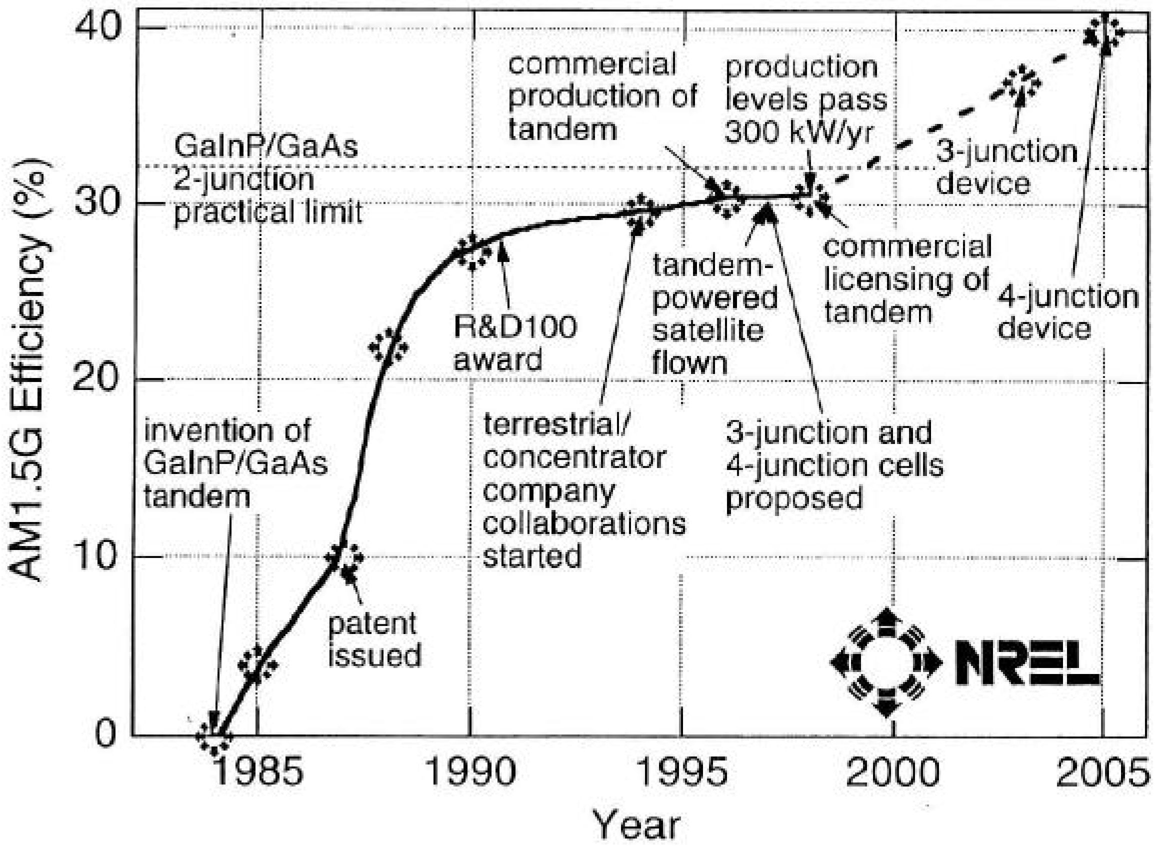

Schematic of 20 MWp Grid-Connected PV Concentrator System
Sunlight:
850 W_p/m² (power available for concentrators)
1800 kWh/m²-yr (annual average U.S. sunlight)
sunlight
lens
cell
concentration ratio: area of lens / area of cell
module for a 20-MW_p system
Power Conditioner Subsystem
ac-dc inverter, max. power tracking
power substation (voltage control)
17 MW, 36 GWh/yr after power-conditioning losses
M72-B144701-X(EN)

Figure 1

GaInP/GaAs Cell History



Kurtz, 9/10/98 NREL

Figure 2

Figure 3

Distribution of TECSTAR production between Si and III-V, reflecting an increase in production of close to a factor of 10. Dta courtesy of TECSTAR. (Abstractedf rom Kurtz and Friedman)

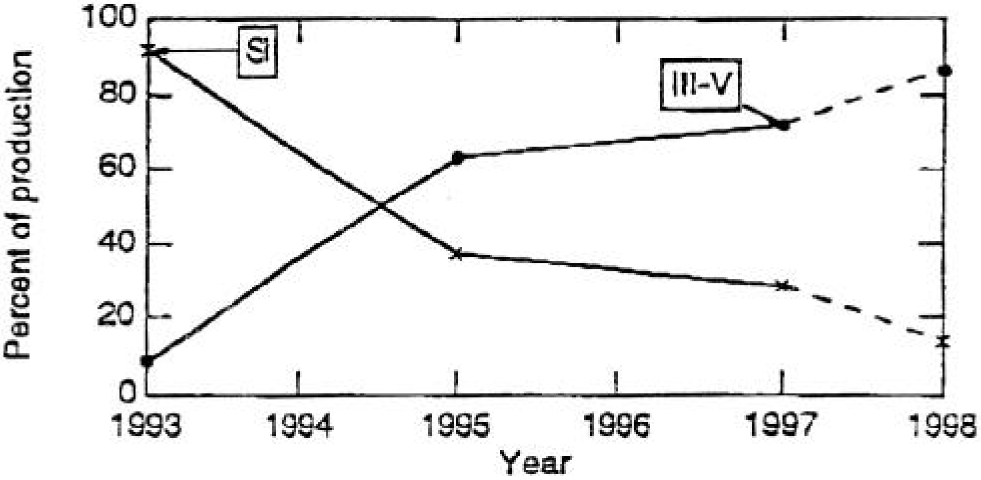
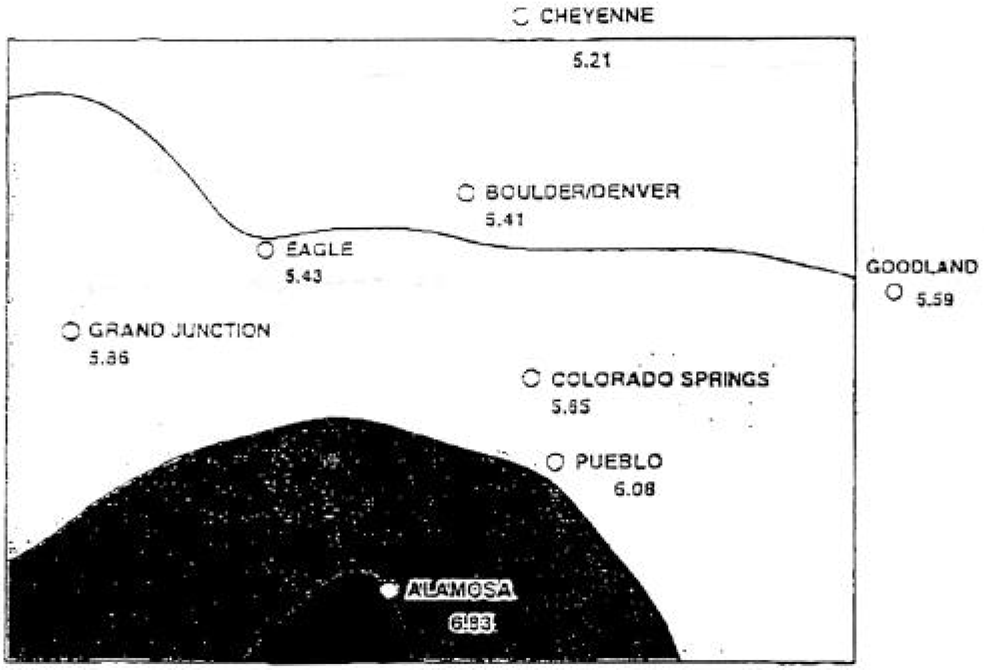


Figure 4

COLORADO

Direct Normal Solar Radiation

Solar Energy Available to Dish Concentrators



This map shows general trends via a spatial interpolation of solar radiation values from the 1961 - 1990 National Solar Radiation Data Base (NSRDB). The cities on this map are part of the 239 sites of the NSRDB.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

kWh/m²/day

■ 2.5 - 3.0
■ 3.0 - 3.5
▣ 3.5 - 4.0
☐ 4.0 - 4.5
☐ 4.5 - 5.0
☐ 5.0 - 5.5
☐ 5.5 - 6.0
■ 6.0 - 6.5
■ 6.5 - 7.0
■ 7.0 - 7.5

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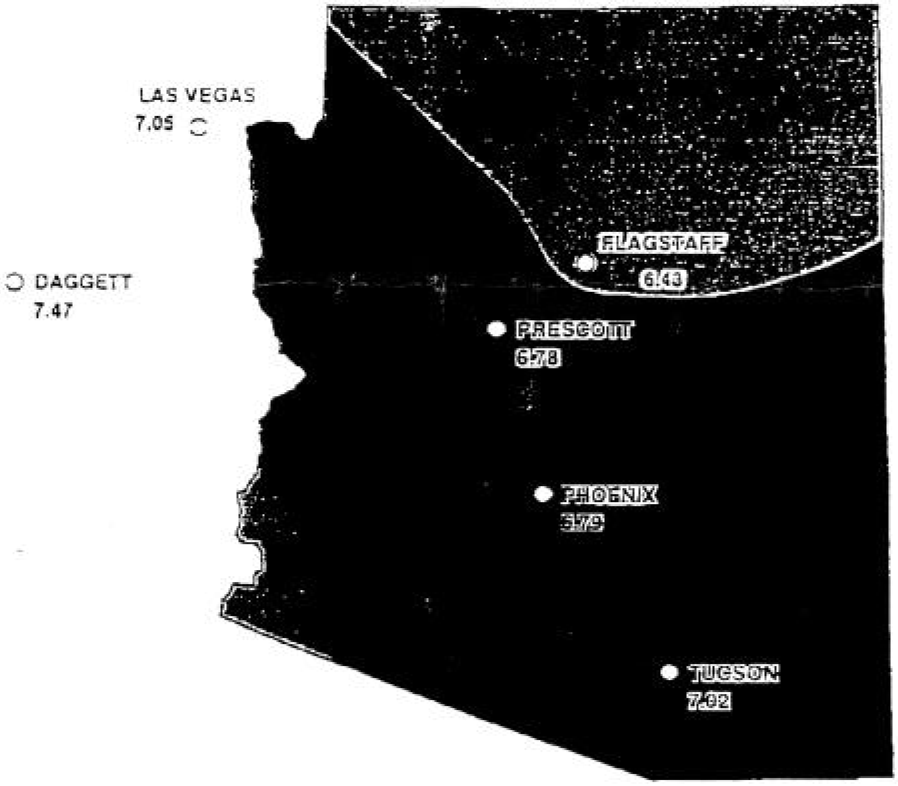
Figure 5

ARIZONA

Direct Normal Solar Radiation

Solar Energy Available to Dish Concentrators



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□ 4.5 - 5.0
□ 5.0 - 5.5
□ 5.5 - 6.0
■ 6.0 - 6.5
■ 6.5 - 7.0
■ 7.0 - 7.5