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# Technology Transfer through the Pipeline and Other Channels

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# TECHNOLOGY TRANSFER THROUGH THE PIPELINE AND OTHER CHANNELS

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## Abstract

Moving technology from the scientist's mind to a manufacturing facility is a process that can take many different paths. The traditional vision of a technology pipeline has been realized for a few instances in inventions by the National Center for Photovoltaics (NCPV). More numerous examples of transferred technology are found in other types of interactions. All pathes must overcome a number of barriers to the acceptance and eventual use of new technology developed by sources outside the manufacturer. This paper examines some success stories of technology transfer and lessons learned from these experiences. These lessons point to possible improvements needed to expedite transfer of future technologies.

## Introduction

For much of the public, a typical view of product development starts with the cartoon of the light bulb above the inventor signifying creation of an invention. With finger still in the air and "eureka" on his lips, the inventor begins a sequential process of turning this idea into a product. The invention is recorded. Research proceeds from basic science, through applied research, into engineering and process development. A handoff is made to the production people, who work through the pilot production and prototype stages. Adjustments to the plant design are finalized. Yield and throughput are optimized. Profitable quantities of product are shipped. By this time, the second generation of this product is well into the applied research phase or beyond. This process is the "technology pipeline." The analogy is carried further by comments such as the importance of keeping the pipeline full.

Most of us in research know that this vision of technology development is not typical. At least one study has shown a "rule of tens" related to inventions—10,000 ideas yield 1000 invention disclosures, 100 patent applications, 10 commercially significant products, and 1 technology that changes an industry [1]. These were the results for a decade of work by a group of 75 researchers. The NCPV is thus very fortunate to cite at least one success in this mode.

## Through the Pipeline

The demonstration of multiple-junction solar cells with efficiencies exceeding single-junction devices of the same materials family proved elusive for the first decade of research in the topic. In 1984, a newcomer to the field, Jerry Olson, and his colleagues invented a structure deemed an unlikely improvement by conventional wisdom of the time. The combination of a $Ga_{0.5}In_{0.5}P$ top cell and GaAs bottom cell was well known to not use the optimum bandgaps. Prior work in $Ga_xIn_{1-x}P$ had clearly demonstrated the gross deterioration of materials properties under the slightest tension, the condition needed for optimum bandgap. However, research on the basic properties of $Ga_xIn_{1-x}P$ and novel device designs paved the way for record-setting efficiencies [2]. During the same period, companies were developing single-junction GaAs PV technology for satellite power. Patents on the tandem cell structure were licensed from NREL. With NREL's technical assistance and on-site work with the industry's production tools, the concept became a product. By 1995, it dominated the space PV market. Further work advanced the device structure for use in concentrated sunlight. Spectrolab and NREL received an R&D100 Award in 2001 for the invention of the multiple-junction, terrestrial concentrator solar cell.

Several factors favored the success of this transfer of technology. First, the industry had an adaptable, fully functioning production process developed for the single-junction product. Second, the process used by NREL for material growth used chemistry similar to that of the production systems, ensuring a common language between partners. Third, NREL scientists worked at the industry site with the development and production personnel, eliminating guessing about differences in processes. Finally, the sizes of the research devices and initial production devices were within a factor of ten.

A second invention, during about the same period, may provide another example of this type of technology transfer. The invention is the three-stage, co-evaporation process for copper indium gallium diselenide solar cells. Again, NREL has set performance records for these solar cells using this process [3]. However, transfer of this technology has presented a greater challenge. Not only was a new product moving toward production, but the entire production process was in development.

### Through Other Channels

The most common process for technology transfer occurs in short-term collaborations. The NCPV staff performs research in all of the major PV areas and has developed a collective base of PV experience in excess of 1000 person-years, which is a resource unmatched anywhere. These interactions, which seek quick benefit from the experience, typically address a specific problem of limited scope. They may be completed in a single telephone call with a well-known colleague. Or, they may extend to multi-month studies drawing upon some of the unique tools in the lab and extensive exchange of samples. Frequently, the topic and results of these collaborations are held in confidence. On occasion, NREL serves only to perform measurements and return data. However, far more effective interactions are built on previous contacts that served to establish trust among the investigators. This permits analysis and discussion at a fundamental level, bringing the full scientific resources to bear on the problem.

Many of the topics selected for investigation by the NCPV have been identified through the National Thin-Film Teams planning meetings or by topical workshops such as the Silicon Point Defects and Processing or the recent Workshop on Moisture Ingress in PV Modules.

NCPV has designed and built apparatus to permit partners to apply our methods to their needs at their site. For example, Siemens Solar Industries routinely uses a tool for measuring minority-carrier lifetime in silicon ingots as a quality screen [4]. Another tool, PV Scan, is used to measure local dislocation density and photoresponse of silicon wafers at several sites [5]. Development of these tools presents a significant challenge to NCPV and its partners. The industry is not yet large enough to support an industry of equipment suppliers. This situation is compounded by the specialized needs of the diverse PV technologies. Past efforts to license the design for these tools to potential vendors have failed for these reasons. We are testing a new procedure that will circulate a “field unit” for industry testing, evaluation, and feedback. With positive guidance, one channel may be to solicit and fund a suitable vendor to fabricate units for distribution to the PV industry.

Another benefit of the experience base is the transfer of technology between PV materials systems. The best current example is the research of Xuanzhi Wu in developing CdTe solar cells. His most recent previous assignment was research on advanced transparent conducting oxides (TCO) for infrared filters in thermophotovoltaic converters [6]. Here, he developed processes for making $Cd_2SnO_4$ with excellent optical and electronic properties. When combined with a separately developed $Zn_2SnO_4$ buffer layer and the CdTe Team’s technology base, the dual-layer TCO helped to improve CdTe solar cells to record levels [7]. However, this example illustrates another challenge in applications of advanced technology—patience. Our industry partners have invested heavily in equipment to implement current processes. These investments and priority placed on other topics will delay adoption of the advanced processes, perhaps until second-generation equipment is procured. Industry decisions could be simplified and perhaps accelerated if the gap between the laboratory and production results could be reduced. Unlike the first example of the tandem concentrator cell, the industry processes here are not yet in full production, the NCPV processes are different, and the area of the laboratory devices are several orders of magnitude smaller. DOE and the NCPV are evaluating facilities that would permit more controlled process evaluation with improved diagnostics and integration of multiple process steps. Such tools could simplify technology transfer.

### Summary

The NCPV has learned many successful mechanisms for moving concepts from our laboratories to industrial production. The barriers to a successful transfer are many and varied. Some barriers include: Timing—the industry partner must be ready to adopt new technology. Individuals—both sides need an individual who collaborates well with the partner and is a champion for the technology within their organization. Communication—NCPV needs to speak the industry’s language in terms of processes and characterizing data that can be directly related to industrial tools.

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