FINAL REPORT

This is final report for the I & I project "High Throughput Continuous, Mass Production of Photovoltaic Modules".

Project Title: High Throughput, Continuous, Mass Production of Photovoltaic Modules

Covering Period: 9/30/2004 - 9/30/2007

Date of Report: February 6, 2008

Recipient:

AVA Solar Inc. 4557 Denrose Ct. Unit B Fort Collins, CO 80524	Formerly: AVA Technologies LLC 1612 Faraday Circle Fort Collins, CO 80525

Award Number: DE-FG36-04GO14333

Working Partners:

Acheson Industries 1600 Washington Ave. Port Huron, MI 48060	Colorado State University Materials Engineering Laboratory Mechanical Engineering Department Fort Collins, CO 80523

Cost Share Partners:

Acheson Industries 1600 Washington Ave. Fort Port Huron, MI 48060	AVA Solar Inc 4557 Denrose Ct. Unit B Fort Collins, CO 80522
Alpha Engineering and Design 1318 Blue Spruce Dr. Unit 5 Fort Collins, CO 80524	John G. Hill 2906 75th St. Boulder, CO 80301

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1. EXECUTIVE SUMMARY

AVA Solar has developed a very low cost solar photovoltaic (PV) manufacturing process and has demonstrated the significant economic and commercial potential of this technology. This I & I Category 3 project provided significant assistance toward accomplishing these milestones. The original goals of this project were to design, construct and test a production prototype system, fabricate PV modules and test the module performance. The original module manufacturing costs in the proposal were estimated at $2/Watt.

The objectives of this project have been exceeded. An advanced processing line was designed, fabricated and installed. Using this automated, high throughput system, high efficiency devices and fully encapsulated modules were manufactured. AVA Solar has obtained 2 rounds of private equity funding, expand to 50 people and initiated the development of a large scale factory for 100+ megawatts of annual production. Modules will be manufactured at an industry leading cost which will enable AVA Solar's modules to produce power that is cost-competitive with traditional energy resources. With low manufacturing costs and the ability to scale manufacturing, AVA Solar has been contacted by some of the largest customers in the PV industry to negotiate long-term supply contracts.

The current market for PV has continued to grow at 40%+ per year for nearly a decade and is projected to reach $40-$60 Billion by 2012. Currently, a crystalline silicon raw material supply shortage is limiting growth and raising costs. Our process does not use silicon, eliminating these limitations.

2. PROJECT ACCOMPLISHMENTS AND COMPARISON TO PROPOSED OBJECTIVES

The original goals of this project were to design, construct and test a production prototype system, fabricate solar photovoltaic (PV) modules and test the module performance. The original module manufacturing costs in the proposal were estimated at $2/Watt.

The objectives of this project have been significantly exceeded. An advanced processing line was designed, fabricated and installed for manufacturing cadmium telluride (CdTe) PV modules. Using this automated and high throughput system, high efficiency devices and fully encapsulated modules were manufactured. During the course of this project AVA Technologies has become AVA Solar Inc. AVA Solar is now a successful 50 person startup company with significant external investment to build large scale factories. AVA Solar is initiating development of a 100+ MW/yr manufacturing facility and intends to be in large scale manufacturing next year. Modules from AVA Solar's process will be manufactured at an industry leading cost which will enable power produced by AVA Solar's modules to be cost competitive with traditional energy resources. The DOE I & I support has been of great assistance and the program support is directly acknowledged on AVA Solar's website, http://www.avasolar.com/about/overview.php.

Figure 1: Some members of the AVA Solar team holding a CdTe solar cell

3. PROJECT ACTIVITIES

In the proposal, this project was organized into 20 detailed tasks. A brief summary is provided below.

3.1 Finalize the Design and Fabrication of the Manufacturing Systems:

Task 1, Finalize the Design of the Vacuum Chamber
Task 5, Fabricate the Vacuum Chamber
Task 8, Install and Initial Test of the Vacuum Chamber
Task 9, Integration of Different Chambers In the Vacuum Systems

The semiconductor fabrication processes are performed in a vacuum environment. With the support of this project, a vacuum system was designed and constructed. The system is over 50 feet long and was machined and welded by Alpha Engineering and Design. AVA Solar has successfully installed and tested the vacuum system. The system was able to achieve high vacuum and was tested for leaks and was found to be within specification.

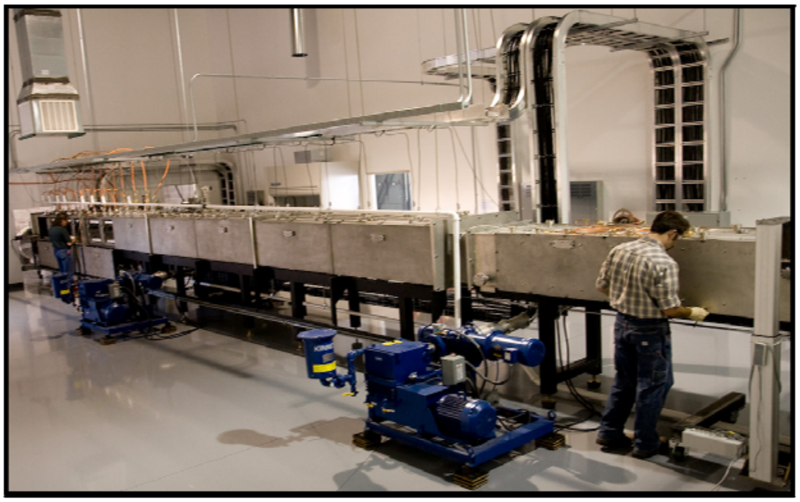


Figure 2: AVA Solar pilot system

Task 2, Finalize the Design of the HPD Process Modules
Task 6, Fabricate the HPD Process Modules
Task 11, Installation and Alignment of the HPD Process Modules

The Heated Pocket Deposition (HPD) process modules are a patented technology that performs the actual semiconductor deposition. The HPD sources reside in the vacuum chamber. The process modules were designed to maximize materials utilization, film uniformity and serviceability. Detailed thermal modeling and multiple design iterations were used to optimize the configuration. The vacuum system and process heads were successfully utilized to fabricate solar cells. Devices emerge from the process, one every 2 minutes with a total processing time of under an hour. A picture of the vacuum system with process heads installed is shown in Figure 2.

Task 3, Design Back Electrode Application System
Task 7, Fabricate Back Electrode Application System
Task 14, Implementation of the Spray Electrode Application System
Task 15, Optimize Electrode Application Equipment

The back electrode is formed from spray-applied conductive films on the CdTe surface. After consultation and assistance from Acheson Industries, Thierica Inc. was selected as the vendor for this system. The back electrode application system was designed and constructed. A design drawing is shown in Figure 3. The system accommodates the application of two conductive layers. The back electrode and has been installed and functions well.

Once the spray equipment was commissioned and initial testing completed, a full six sigma optimization study was performed. Film conduction, adhesion on the CdTe surface, and system throughput were maximized. Adhesion of the films was evaluated using ASTM 3359 test protocols and shown to be excellent after optimization. This system has been used to make high efficiency devices and modules.

Task 4, Design and Begin Fabricating Ancillary Components for the Prototype Manufacturing Line

AVA Solar completed the design and installed support equipment for module finishing. This equipment is used to perform the laser scribing, lamination, buss bar attachment and back hole sealing processes. Although purchased with non I & I funds, the equipment design and development activities were performed during this program and were used to help achieve the I & I milestones.

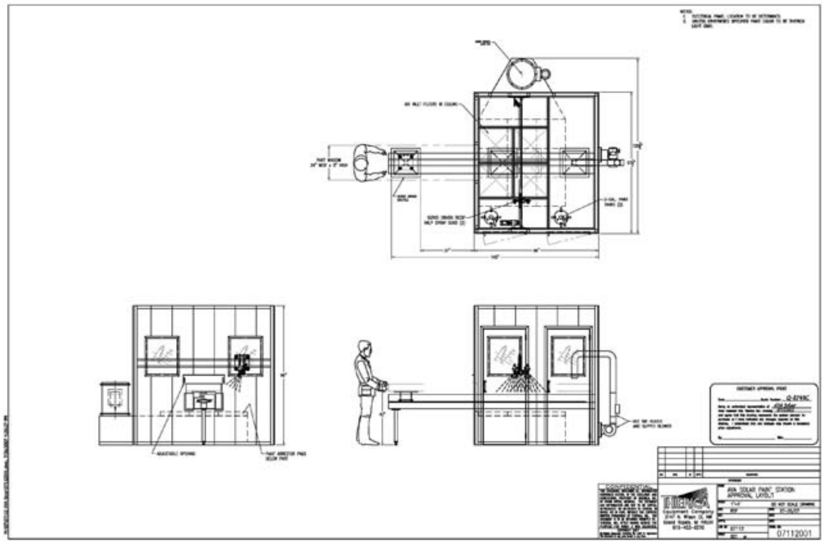
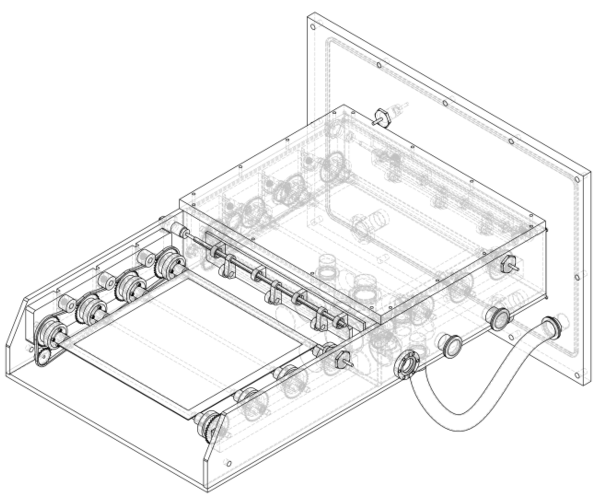


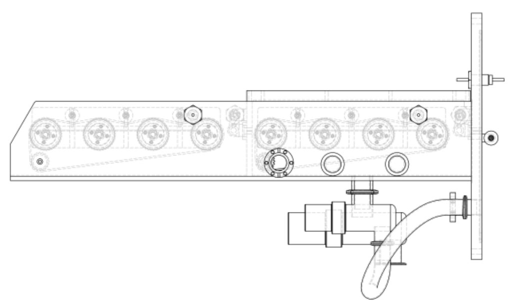
Figure 3: Blueprint of the back electrode spray application system installed at AVA Solar

3.2: Integrate Pilot Line and Preliminary Testing

Task 10, Integration of the Substrate Transport Belt

Within the vacuum system, substrates are indexed from one processing station to the next on an endless belt. Careful designs and precise hardware is needed to ensure that the belt indexes reliably and tracks straight. The belt was designed, installed and tested with good results. Automated load locks for moving substrates into and out of the vacuum environment were designed, constructed and installed early in the program. The load locks are designed to integrate into upstream and downstream automation. Shown below are some of the design details of the load lock systems.





Figures 4 and 5: Schematic of load lock systems for transporting PV substrates into and out of the production prototype system.

Task 12, Initial Operation and Determination of Optimum Process Conditions

Task 13, Fabricate and Characterize Small Area Devices

The prototype line was commissioned and deposition experiments initiated. The process settings required to produce suitable CdS and CdTe films were determined. Thickness was measured with a surface profilometer. It is noted that the process settings for this system processing 16.5 inch square substrates were very similar to those used in the prototype system (supported under the ERIP program) processing ~3 inch substrates. This demonstrates the inherent scalability of AVA Solar's process. After semiconductor processing, the back electrode was applied. Small area devices were then cut from these larger substrates. The devices were characterized for current/voltage (JV) performance. Excellent performance was demonstrated, with devices efficiencies over 11% are routinely seen using unmodified Pilkington TEC 15 glass substrates.

3.3: Run the Production Prototype and Test Modules
Task 16, Full Module Fabrication

Utilizing the semiconductor and the electrode application systems and the "ancillary" equipment described in Task 4, fully encapsulated modules were manufactured. In the original proposal, it was anticipated that an outside vendor be used for encapsulation. However, during the course of this project, AVA Solar has acquired all the capability and hardware needed to manufacture modules in-house. Many interconnected 16.5 inch square modules have been fabricated to date. These modules are glass/glass laminates and have complete buss bar and back box wiring. Modules are currently undergoing accelerated testing to ensure reliability.

Figures 6 and 7: Pictures of encapsulated modules. The edge seal around perimeter and series interconnection lines are visible.

Task 17, Preliminary Evaluation of Outdoor Module Performance

Encapsulated modules have been measured for initial efficiency by JV measurement. This was done outdoors using a calibration cell to measure the solar isolation intensity and a Kiethley source meter to provide bias voltage and current measurement. These initial, prototype modules have a higher efficiency then many commercially available modules currently in the market.

Task 18, Expert Consultation

During the course of this project, our key business advisor was John Hill. Mr. Hill is a nationally recognized venture capitalist. He started the first venture fund in Colorado and his firm has launched 75 companies, and he has served on the board of 25 companies, both public and private. While active in the mid-late 80's, Hill Carman Ventures was one of the top perfuming funds in the industry. Mr. Hill was named director of the National Venture Capital Association in Wash. DC. Mr. Hill is now the chairman of AVA Solar. Representatives from NSC, DOE, I&I Program, and numerous international companies were given full technology demonstrations and consulted for inputs on future strategic directions. This input was beneficial in forming AVA Solar Inc.

Task 19, Determination of Manufacturing Cost Estimates

Manufacturing cost of sales analyses have been performed and show AVA Solar's manufacturing costs are significantly below the current PV industry levels. These costs are approximately one half the manufacturing costs projected in the original proposal. The analysis was performed with a 120 x 60 cm (approximately 48 x 24 inches) substrate size. These numbers have been verified by external independent reviews from companies interested in AVA Solar's technology[1]. Based on these costs, AVA Solar's panels will be able to provide power at costs that are competitive with traditional energy resources.

Task 20, Ongoing Business Activities

During the course of this project, AVA Technologies has incorporated and become AVA Solar. We have grown from the original 3 founders to a nearly 50 person company with engineering, finance, HR and business professionals. AVA Solar has relocated to new facilities. This new space includes approx 20,000 sq. ft. of manufacturing bay and approximately 6,000 sq. ft. of office space. AVA Solar has received 2 rounds of private equity investment. AVA Solar is also pleased to have been awarded a $3 million DOE Solar America Initiative (SAI) Incubator project. The DOE I & I support has been of great assistance and the program is directly acknowledged on AVA Solar's website, www.avasolar.com/about/overview.php.

The current market for PV has continued to grow at more than 40% per year for nearly a decade and is projected to reach $40-$60 Billion by 2012. Currently, a crystalline silicon raw material supply shortage is limiting growth and raising costs. Our process does not use silicon, eliminating these issues. With the recent growth in the solar market and the significant expansion of our available funds, AVA Solar has modified the original business plan. Based on market analysis, AVA Solar does not intend to sell significant quantities of 16.5 inch square modules. We intend to enter the market with a large format, 120 x 60 cm product manufactured at extremely large production volume. With low manufacturing costs and the ability to scale manufacturing, AVA Solar has been contacted by some of the largest customers in the PV industry to negotiate long-term supply contracts for the 120 x 60 cm modules. A manufacturing facility for 100+ megawatt of annual capacity is being developed.

4. PRODUCTS DEVELOPED DURING PROJECT

4.1 Technologies

The most significant product developed during the course of this project is the PV pilot manufacturing line which demonstrates the company's capability to produce solar panels that can provide electricity at a price competitive with traditional fossil fuel sources.

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[1] Details of the interactions between these companies and AVA Solar are covered under non-disclosure agreements

4.2 Websites

AVA Solar has developed a corporate website outlining our values, technology and products. www.avasolar.com

4.3 Publications / Presentations

Since the start of this project, a significant number of publications and presentations have been made by members of AVA Solar. Some members our group also participated in the Thin Film Partnership Program of NREL through Colorado State University. This focus of this NREL-supported effort was the development of a more fundamental understanding of our manufacturing process. This effort dovetailed with this I & I effort. The publications that are associated with the CSU/NREL activity are listed here for completeness.

Thermal model for a superstrate cooling apparatus for an integrated in-line manufacturing process for thin film PV devices , R.A. Enzenroth, K. L. Barth, W. S. Sampath, and V. Manivannan, J.Vac. Sci. Technol. B 25 (6) (2007) 1.

Stable Cu-based back contacts for CdTe thin-film PV devices, R.A. Enzenroth, K. L. Barth, W. S. Sampath, V. Manivannan and P. Noronha, Journal of Solar Energy Engineering (Under Review)

Effect of chemical treatment on the optical properties of CdTe solar cells probed by spectroscopic ellipsometry, S. Kohli, V. Manivannan, J. N. Hilfiker, P. R. MCCurdy, R.A. Enzenroth, K. L. Barth and W. S. Sampath, Journal of Vac. Sci. Tech (Under review).

Enzenroth, R. A. T. Takamiya, K. L. Barth, and W. S. Sampath, "Photocapacitance Study of Deep Levels in Thin CdTe PV Devices", Volume 515, Issue 15, 31 May 2007

R. A. Enzenroth, K. L. Barth, and W. S. Sampath, "Transient Ion Drift Measurements of Polycrystalline CdTe PV Devices", presented at the 2006 IEEE 4th World Conference on Photovoltaic Energy Conversion (WCPEC-4), (2006)

R. A. Enzenroth, T. Takamiya, K. L. Barth, and W. S. Sampath, "Photocapacitance Study of Deep Levels in Thin CdTe PV Devices", Spring EMRS (2006)

Barth, K. L, R. A. Enzenroth, and W. S. Sampath, "Advancing Thin Film CdTe PV Manufacturing", Thin Film PV Kickoff Meeting, April 4, 2006.

Barth, Kurt L., Robert A. Enzenroth and W. S. Sampath, "Brief Update of Progress at AVA Technologies LLC", National CdTe Team Meeting, Sponsored by the DOE through the National Renewable Energy Laboratory, Golden, CO, March 7 and 8, 2006

R. A. Enzenroth, K. L. Barth, and W. S. Sampath, "Observations of Cu Diffusion in CdTe PV Devices", National CdTe Team Meeting, Sponsored by the DOE through the National Renewable Energy Laboratory, Golden, CO, March 7 and 8, 2006

Barth, K. L., "Very Low Cost Solar Photovoltaic Manufacturing" Talk given to Clean Technologies meeting at the Denver area Chamber of Commerce, 3/27/06.

Barth, Kurt L, "Thin Film Photovoltaic Manufacturing", Presentation to executives and managers at Acheson Industries, Port Huron Michigan, February 16, 2006.

Barth, Kurt L., R. Albert Enzenroth and W. S. Sampath, "Progress at AVA Technologies LLC" National CdTe Team Meeting, Sponsored by the DOE through the National Renewable Energy Laboratory, Golden, CO, May 5 and 6, 2005. Available at NREL website: www.nrel.gov/ncpv/thin_film/docs/Ind-AVA%20Tech.ppt#366,1,Progres

Sampath, W. S, R. Albert Enzenroth, and Kurt L. Barth, "Advances in Continuous In-Line Processing of CdTe PV Devices" National CdTe Team Meeting, Sponsored by the DOE through the National Renewable Energy Laboratory, Golden, CO, May 5 and 6, 2005. Available at NREL website: www.nrel.gov/ncpv/thin_film/docs/Sp-top-Sampath.ppt

Enzenroth, R. A., K.L. Barth, and W.S. Sampath "Estimation of Acceleration Factors by Comparison of Performance During Accelerated Stress and in Outdoor Conditions", National CdTe Team Meeting, Sponsored by the DOE through the National Renewable Energy Laboratory, Golden, CO, May 5 and 6, 2005. Available at NREL website: www.nrel.gov/ncpv/thin_film/docs/Stab-Al%20Enzenroth.ppt

Enzenroth, R. A. T. Takamiya, K.L. Barth, and W.S. Sampath, "Steady State Photocapacitance (PHCAP) Study of CdS/CdTe PV Devices", National CdTe Team Meeting, Sponsored by the DOE through the National Renewable Energy Laboratory, Golden, CO, May 5 and 6, 2005. Available at NREL website: www.nrel.gov/ncpv/thin_film/docs/Mat-chem-Al%20Enzenroth.ppt

Barth, Kurt, "Mass Production of Thin Film Solar Photovoltaics", Invited talk for US DOE Golden Field Office March 17, 2005.

Sampath, W. S., Robert. A. Enzenroth and Kurt L. Barth, "Mass Production of Thin Film Solar Photovoltaics", Presentation, Discussion and Facility Tour with the Fort Collins Utilities, and CSU Facilities, March 3, 2005.

Enzenroth, R. A., K. L. Barth and W. S. Sampath, "Thermal Admittance Spectroscopy Study: Preliminary Observations of a Meyer-Neldel Relationship in CdTe Devices", Invited talk to senior Researchers and managers, NREL Golden CO, February, 16, 2005.

Barth, K. L., R. A. Enzenroth, and W. S. Sampath, "Consistent Processing and Long Term Stability of CdTe Devices", presented at the 31 IEEE PVSC, January 3-7, 2005, Lake Buena Vista, Florida.

Enzenroth, R. A., K. L. Barth and W. S. Sampath, "Thermal Admittance Spectroscopy Study: Preliminary Observations of a Meyer-Neldel Relationship in CdTe Devices", presented at the 31 IEEE PVSC, January 3-7, 2005, Lake Buena Vista, Florida.

Sampath, W. S., R. A. Enzenroth and K. L. Barth, "Mass Production of CdTe Solar Photovoltaics", American Society of Mechanical Engineers (ASME), Centennial Section Laboratory tour and presentation, Nov. 18, 2004.

Malhotra, C. P, R. L. Mahajan, W.S. Sampath, K. L. Barth, R. A. Enzenroth, "Control of Temperature Uniformity during the Manufacture of Stable Thin-film Photovoltaic Devices", Submitted to the 2004 ASME International Mechanical Engineering Congress & Exposition, (IMECE 2004), November 13-19, 2004, Anaheim, California

Barth, K. L., R. A. Enzenroth, and W. S. Sampath, "Advances in Continuous In-Line Processing of CdS/CdTe Devices: Stability and Scale-Up", DOE Solar Energy Technologies Program Review Meeting, October 25-28, 2004, Denver, Colorado.

Sampath, W. S. and K. L. Barth, "Mass Production of CdTe Solar Photovoltaics", Mechanical Engineering Seminar, University of Wyoming, October 22, 2004.

Barth, K. L., "Mass Production of CdTe Solar Photovoltaics", Mechanical Engineering Seminar Series, Colorado State University, October 15, 2004.

Enzenroth, R. Albert, K. L. Barth, W. S. Sampath, "Correlation of Stability to Varied $CdCl_2$ Treatment and Related Defects in CdS/CdTe PV Devices as Measured by Thermal Admittance Spectroscopy", 14th International Conference on Ternary and Multinary Compounds, September 27-October 1, 2004, Denver, Colorado, USA.

4.4 Patents

During the course of this project, AVA Solar submitted a patent application on an invention not directly supported by this project. The patent title is "Apparatus and Method and for Rapid Cooling of Large Area Substrates in Vacuum".

4.5 Other products

AVA Solar has produced a significant number of thin-film and photovoltaic samples. The fabrication of these samples were not directly supported by this project, but were enabled by this development.

Appendix A

Final Task Schedule

Task Schedule (Including one year extension)

Task Number	Tasks Description	Original planned task completion date	Revised task completion date	Percent complete
1	Design back contact (BC) vacuum. chamber	6/30/05	5/15/06	100%
2	Design BC process modules	6/30/05	5/30/06	100%
3	Design electrode application system	6/30/05	5/30/07	100%
4	Design ancillary pieces	12/31/05	5/30/07	100%
5	Fabricate. BC vacuum. chamber	12/31/05	8/30/06	100%
6	Fabricate. BC process mod.	12/31/05	3/30/07	100%
7	Fabricate. electrode app system	12/31/05	6/30/07	100%
8	Inst/test BC vacuum sys	3/31/06	2/14/07	100%
9	Integrate. two vacuum systems	3/31/06	3/1/07	100%
10	Integrate Sub Transport Belt	3/31/06	3/31/07	100%
11	Install/Align of the HPD process Modules	3/31/06	3/31/07	100%
12	Initial operation of full production prototype (PP)	6/30/06	6/30/07	100%
13	Fabricate / test small area devices from PP	6/30/06	6/30/07	100%
14	Implement electrode app. sys.	6/30/06	8/30/07	100%
15	Optimize electrode app. sys.	6/30/06	9/30/07	100%
16	Fabricate full modules with PP	6/30/06	9/30/07	100%
17	Prelim test outdoor performance	9/30/06	9/30/07	100%
18	Expert consultation	9/30/06	9/30/07	100%
19	Determine cost estimates for full PV manufacturing	9/30/06	9/30/07	100%
20	Ongoing business activities	ongoing	ongoing	100%

Appendix B

Final Spending Schedule

Budget period	**Approved Budget See note below**	**Project Expenditures**
Total	1,080,000	1,148,745.97
DOE Share	500,000	$500,000
Cost Share	580,000	$648,745.97

Note: Award does not break down budget by task only by period in Statement of Objectives,

Appendix C

Final Cost Share Contributions

Funding Source	**Approved Cost Share**		**Cumulative to Date**	
	Cash	**In-Kind**	**Cash**	**In-Kind**
Acheson Industries		500,000		$193,963.08
AVA Technologies		80,000		$332,054.09
Other (John Hill)		-		$69,000.00
Alpha Engineering		-		$53,729.00
Total		**580,000**		**$648,746.**
Cumulative Cost Share Contributions			**$648,746**	

It is noted that cost share requirements for this project have been exceeded.