Demonstration of the Benefits of Silicone Encapsulation of PV Modules in a Large Scale Outdoor Array

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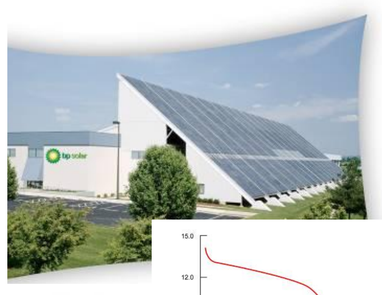
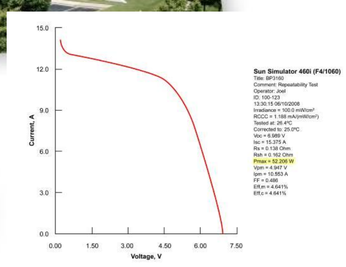
Abstract: Based on the historical performance of silicones in both the construction and electronic industries, silicones are known for their superior performance in outdoor applications. This performance makes silicone materials well suited for solar photovoltaic (PV) modules in their application as a semiconductor device made for outdoor use. Silicone applications within the module include encapsulants, potting materials, and junction box and frame sealants. Dow Corning has developed a number of silicone-based products for use in PV module construction including the Dow Corning® PV-6100 Cell Encapsulant Series product line launched in 2009. To demonstrate the product line performance in real-world conditions, 15 kilowatts of mono-crystalline matrices were purchased from SunPower Corporation, San Jose, California, USA under the United States Department of Energy Solar America Initiative Program. The matrices were encapsulated on the Pilot Line in Dow Corning's USA Solar Application Center in Freeland, MI USA. The silicone-encapsulated modules were installed as part of a 30 kW PV array at the Dow Corning corporate headquarters in Auburn, Michigan in 2009. The balance of the array was constructed using 15 kW of EVA modules purchased from SunPower Corporation, using identical cell and glass technology to compare efficiency and durability.

Proven Durability Using Silicone Encapsulants



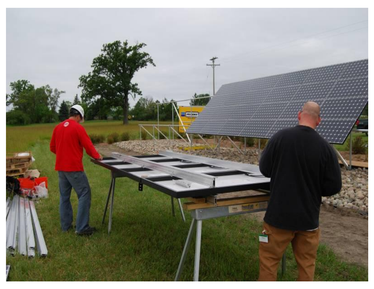


Silicone encapsulated crystalline silicon PV modules have been in service in large scale arrays for over 25 years.

Module Production, Installation and Observations

Automated Cell Press

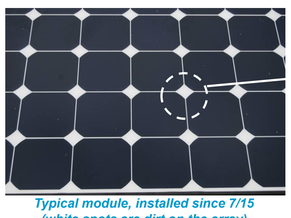
To demonstrate the *Dow Corning*® PV 6100 Cell Encapsulant Series improved manufacturing throughput at an industrial scale, a pilot line was designed and installed in Freeland, Michigan USA.



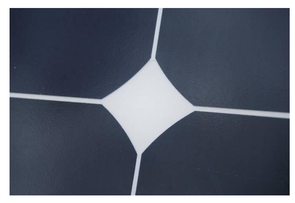
Silicone array being installed

Fronius Invertors (4)

Array erected in two halves in same location, 45º angle, no shading, East (EVA): Inv #1: 4x9 modules; Inv #2: 4x8 modules, West (Si): Inv #3: 4x8 modules; Inv #4: 4x9 modules, Four Fronius 7.5 kW Inverters
Data acquisition using Fronius software.



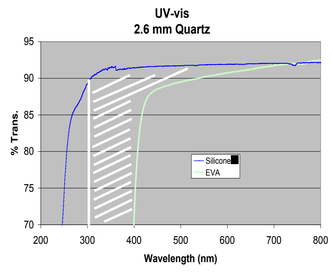
Typical module, installed since 7/15 (white spots are dirt on the array)

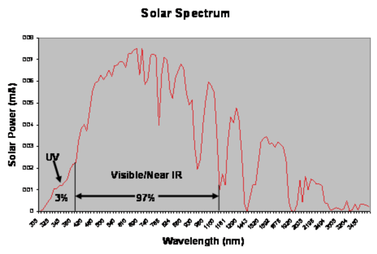


Close-up of "diamond" showing no delamination or bubbles

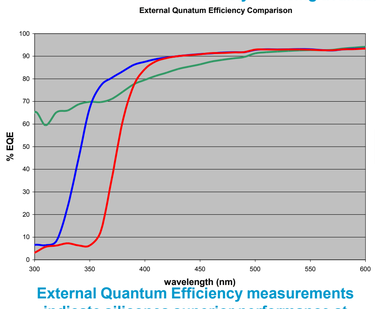
- **Modules have experienced temperatures of ~ 95ºF to -10ºF, sun, rain and snow**
- **Appearance of all Silicone modules is "excellent"**
- **No evidence of delamination or yellowing for either Silicone or EVA**

Measurements for Efficiency Gains

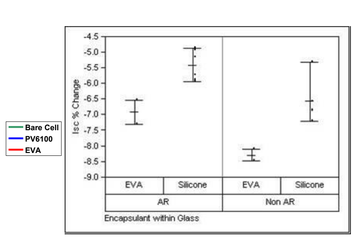




Transmission measurements shows that EVA absorbs light below 400 nm effectively reducing available light for silicon PV cells by 3%.



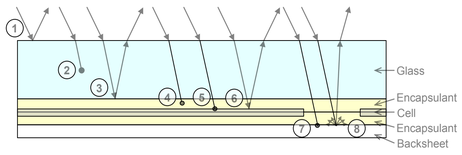
External Quantum Efficiency measurements indicate silicones superior performance at wavelengths below 400 nm.



Data Provided Courtesy of SunPower Corporation

Comparative flash test measurements at STC of encapsulated SunPower Cells shows superior silicone improved Isc response

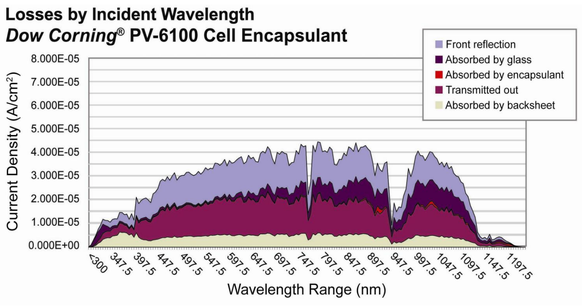
Modeling Efficiency Gains
Australia National University Ray Trace Modeling



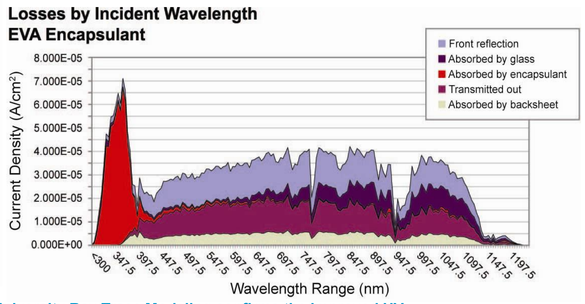
Optical loss mechanisms in a PV module

Loss mechanism	Main dependence
1. Reflection from glass	n_{glass}
2. Absorption in glass	α_{glass} & t_{glass}
3. Refl at glass-encapsulant & escape	n_{glass} & n_{encaps}
4. Absorption in encapsulant	α_{encaps} & t_{encaps}
5. Absorption in ARC	n_{encaps}; n_{ARC}, k_{ARC} & t_{ARC};
6. Reflection from ARC and escape	$n_{silicon}$ & $k_{silicon}$; morphology
7. Absorption in backsheet	R_{bsheet} (when encapsulated)
8. Reflection from backsheet and escape	R_{bsheet} & n_{encaps}

Losses by Incident Wavelength
***Dow Corning*® PV-6100 Cell Encapsulant**

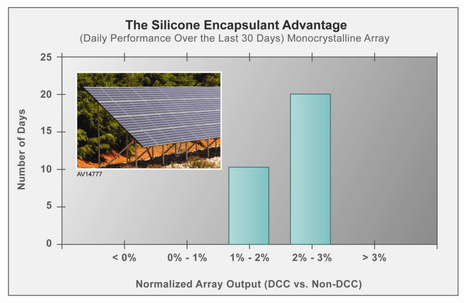


Losses by Incident Wavelength
EVA Encapsulant



In a collaborative study with Australia National University Ray Trace Modeling confirms the improved UV response of silicon PV cells when encapsulated with silicone.
Originally Presented at 24th © 2009 IEEE PVSEC - AN OPTICAL COMPARISON OF SILICONE AND EVA ENCAPSULANTS FOR CONVENTIONALSILICON PV MODULES: A RAY-TRACING STUDY
Keith R. McIntosh, James N. Cotsell, Ann W. Norris, Nick E. Powell, and Barry M. Ketola

Array Level Efficiency Gains



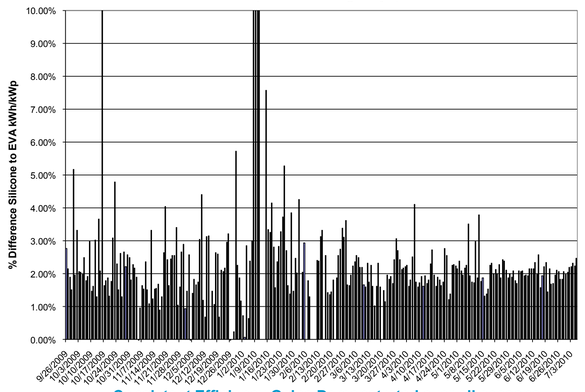
	Dow Corning 12,342W Capacity	Non-Dow Corning 12,466W Capacity	System 24,808W Capacity
Watts produced at 2:45 PM	7,312W	7,130W	14,442W
Yesterday's KWh Produced	63.8 kWh	63.1 kWh	126.9 kWh
Total KWh Produced			29,533 kWh
Normalized KWh/Wp	0.1629	0.1596	
Total Advantage DCC vs. Non-DCC	2.06%		

Monocrystalline Array at Dow Corning Corporation, Midland, Michigan

Summary of Efficiency Gains over a 30 day period.

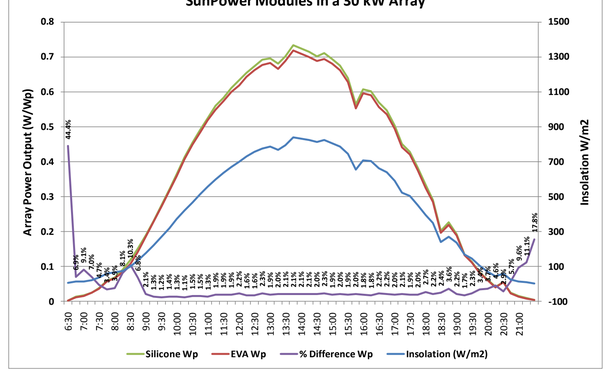
SunPower Corporation makes no warranties, express, implied or otherwise, regarding the sufficiency, accuracy or completeness for any data it has provided herein.

SunPower Array Comparison Si-EVA % Difference Silicone to EVA kWh/Wp
September 26 through July 6, 2010



Consistent Efficiency Gains Demonstrated over all seasons.

Power Output Comparison of Silicone and EVA Encapsulated SunPower Modules in a 30 kW Array



Typical array performance on a sunny summer day in Michigan.

Conclusions: A 30 kW array to compare the performance of EVA to Silicone encapsulated modules was constructed at Dow Corning Corporation at the Corporate Center in Auburn Michigan USA using EVA modules and matrices purchased from SunPower Corporation under the United States Department of Energy Solar America Initiative program under Award Number DE-FC36-07GO17043. The silicone modules were encapsulated using Dow Corning® PV-6100 Cell Encapsulant Series at Dow Corning's pilot line in Freeland, Michigan, USA. The array was installed in July of 2009. Data collection on the array has been underway from September 2009. The data collection has shown silicone encapsulated modules outperform EVA encapsulated modules at greater than 2% kW/kW_p relative efficiency gain. The modules have been exposed to all seasons experiencing temperatures from approximately 95ºF to -10ºF, and sun, rain and snow. Regular inspections have shown that the appearance of the Silicone and EVA modules continues to be very good. The array continues to be monitored for performance and appearance.

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