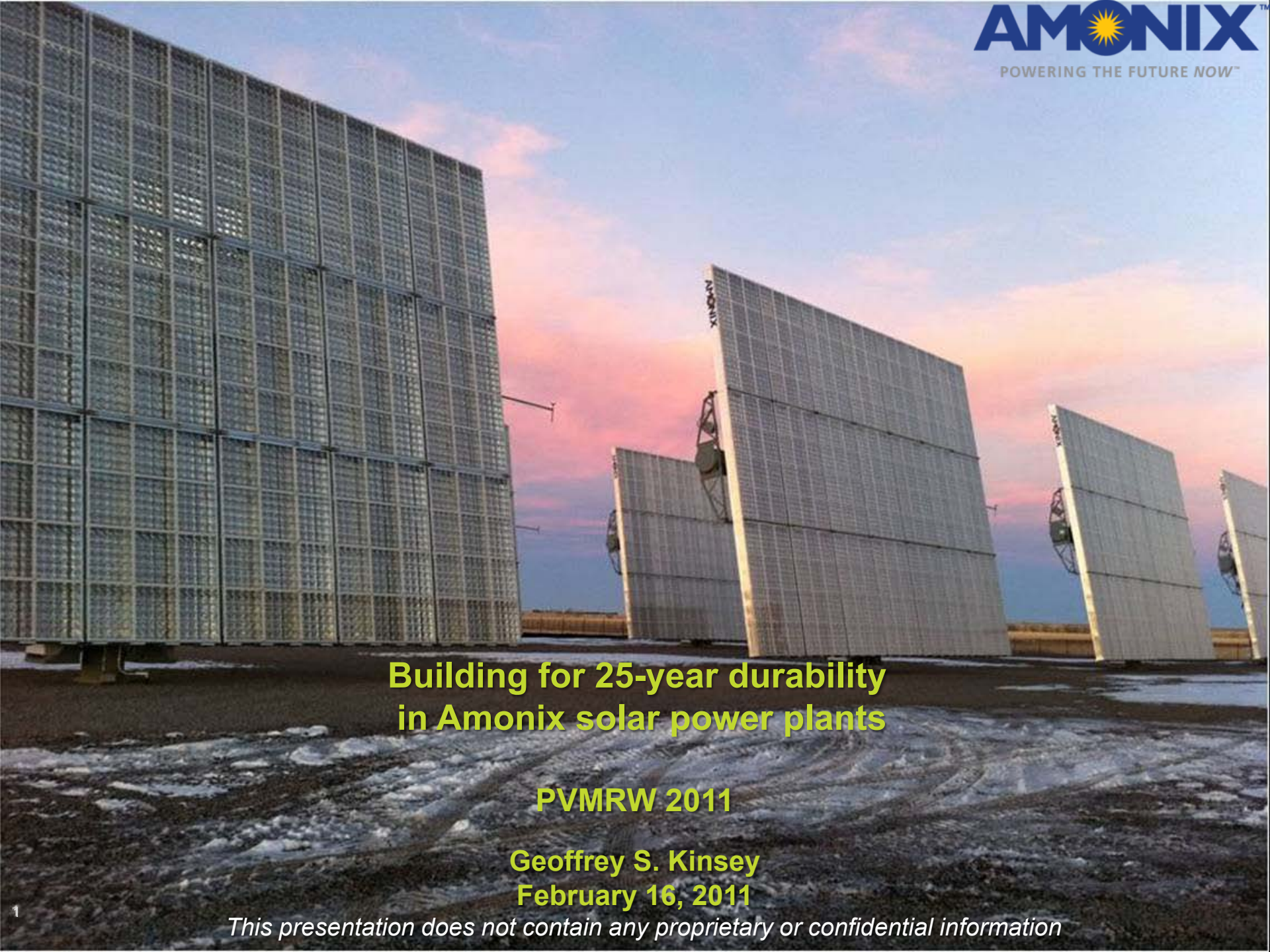


Building for 25-year durability in Amonix solar power plants

PVMRW 2011

Geoffrey S. Kinsey

February 16, 2011

This presentation does not contain any proprietary or confidential information

The solar landscape

SUNPOWER
Q.CELLS
SUNTECH
SHARP
SOLON Don't leave the planet to the stupid

nanosolar
HelioVolt
First Solar.
PrimeStar Solar Making It Happen

SOLAR

Silicon PV

Thin-Film PV

DIFFUSE

CONCENTRATED

Concentrating Solar Power

ABENGOA SOLAR
acciona Energía
ausra
BrightSourceEnergy

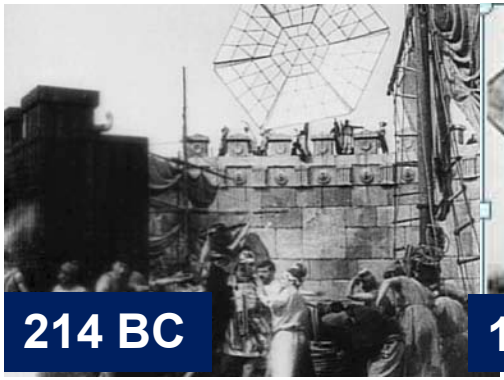
Concentrating PV (CPV)

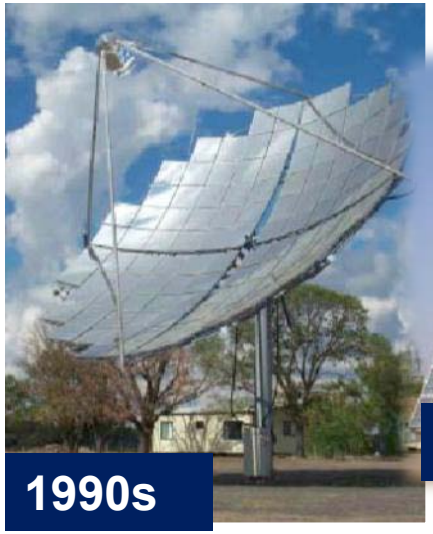
Arima Eco Energy
sol3g
isofoton
SolFocus Innovation Inspired by Nature
Concentrix solar

AMONIX POWERING THE FUTURE NOW

History of CPV

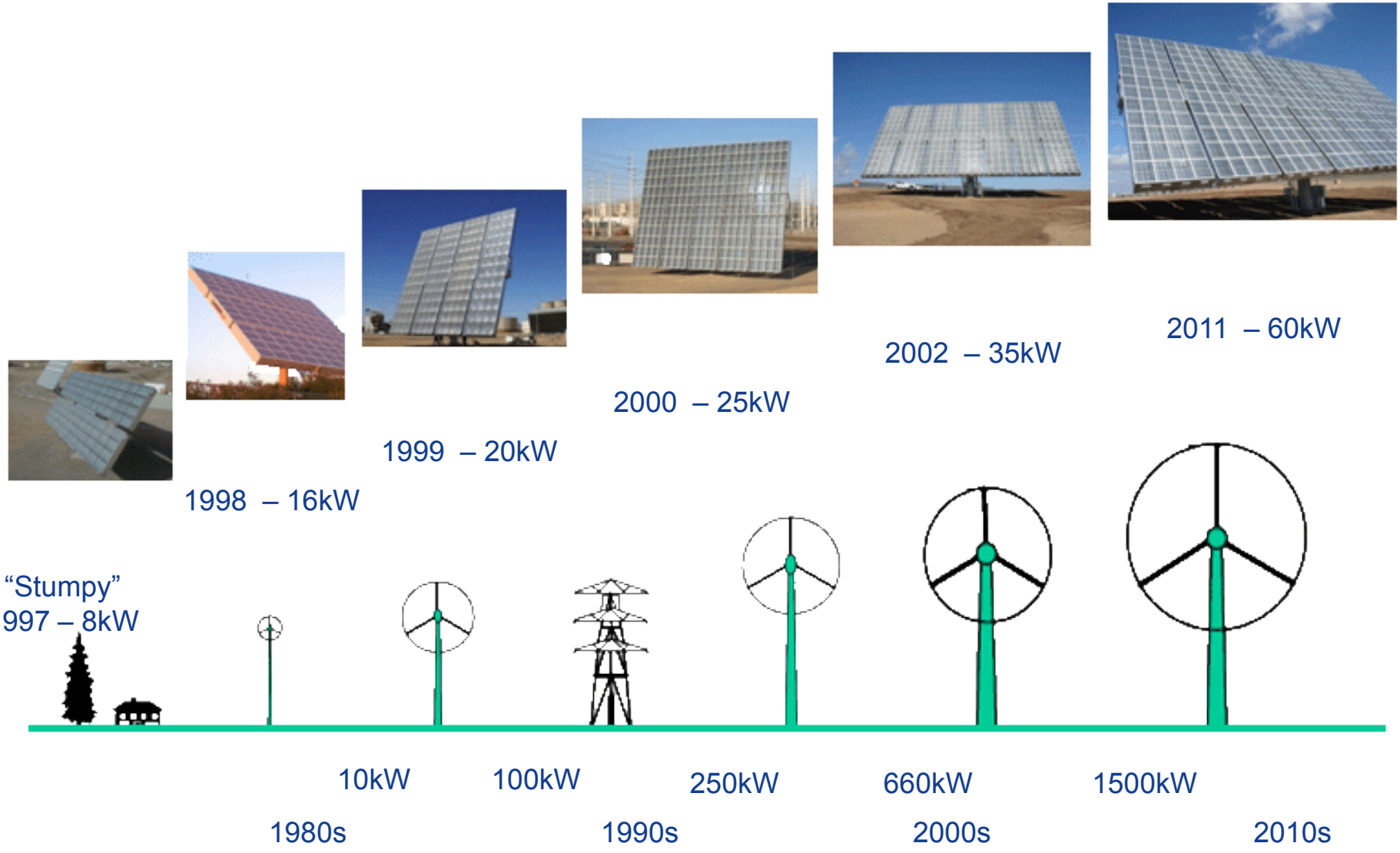
CPV Progression





AMONIX
POWERING THE FUTURE NOW

Size supports durability



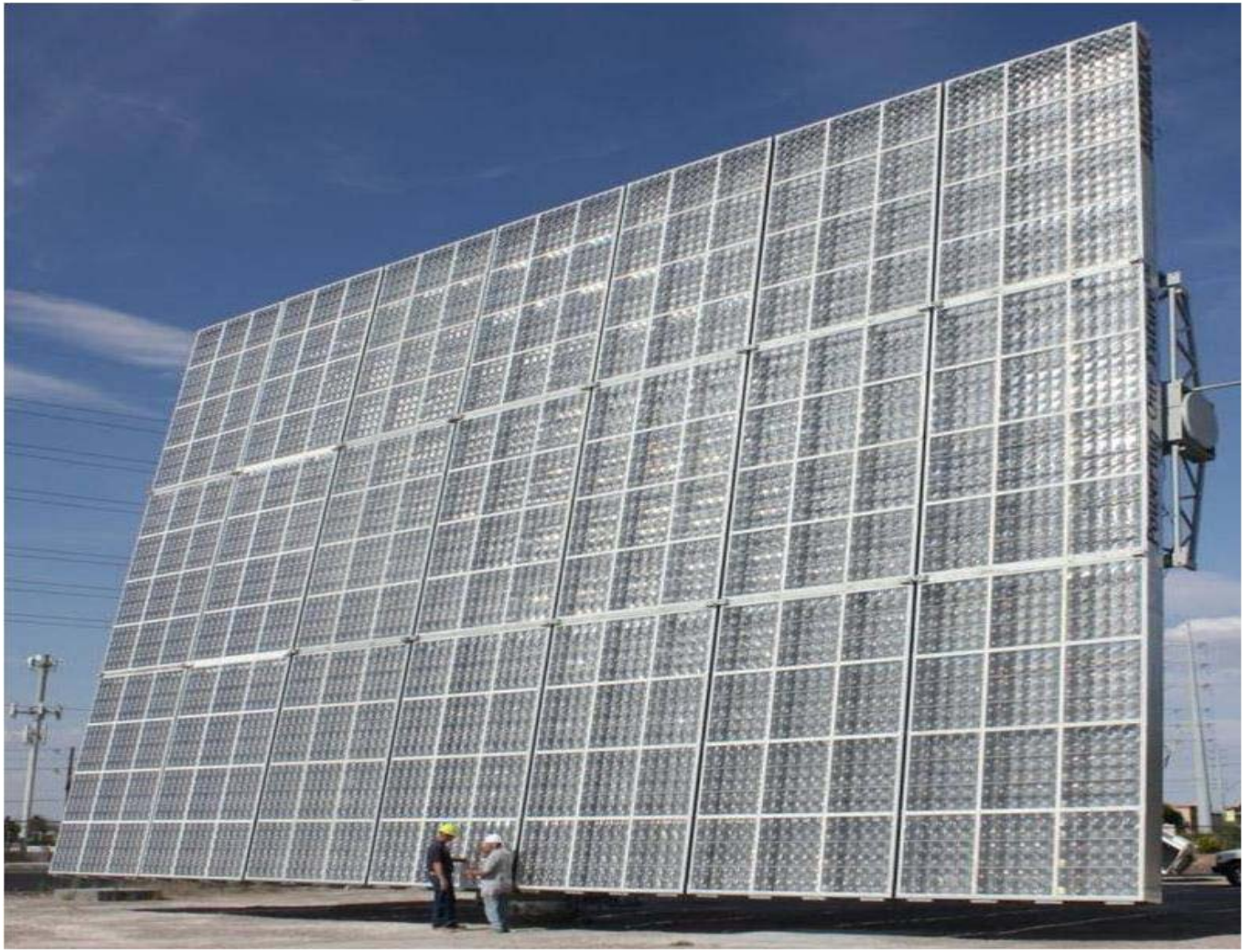
Multijunction Solar Cell Transition

Same footprint almost doubles energy output

35kW Silicon Cell
(16% AC Efficiency)

60kW Multijunction Solar Cell
(27% AC Efficiency)

Competitive today with established PV technologies



Amonix 7700 Solar Power Generator: 60 kW, 27% AC_{PVUSA}

CPV community

DAIDO STEEL

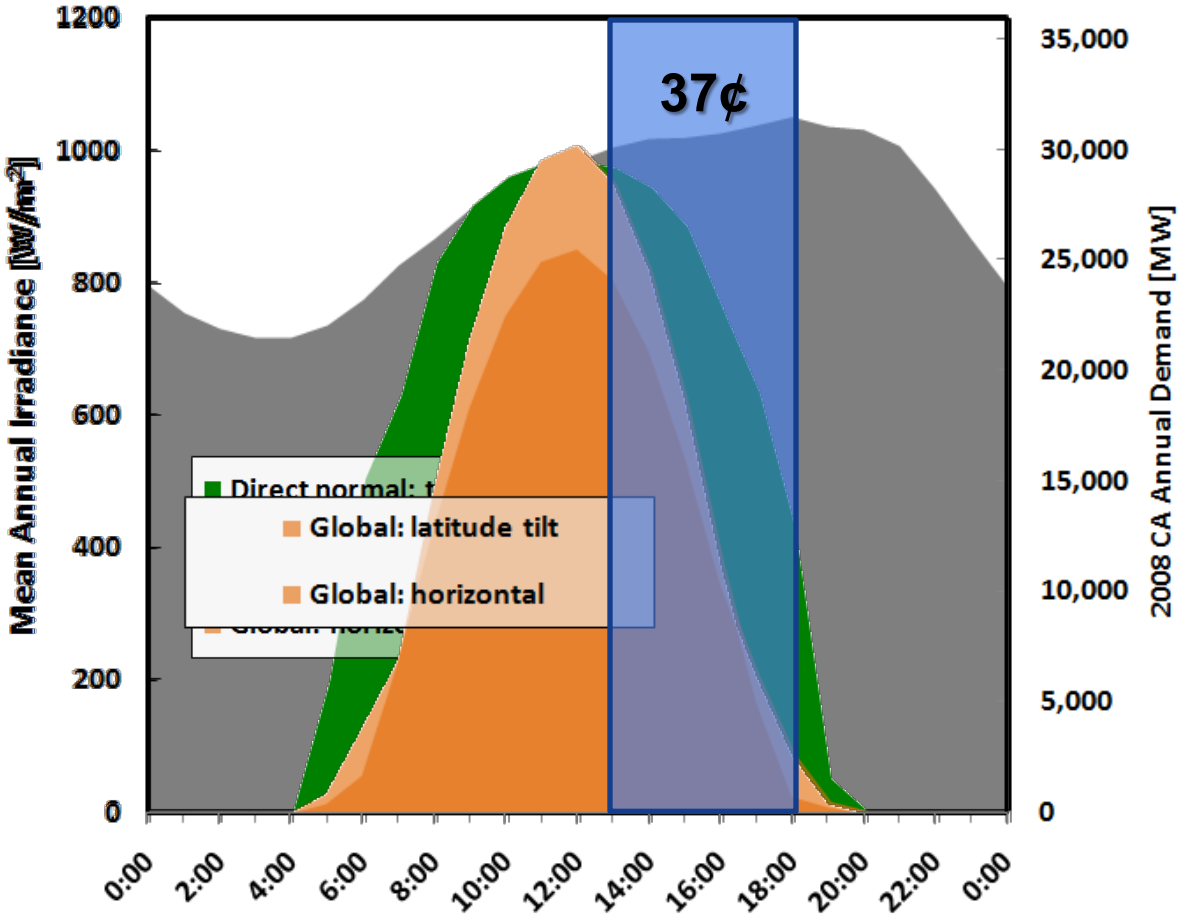
Concentrix solar
Division of Soitec

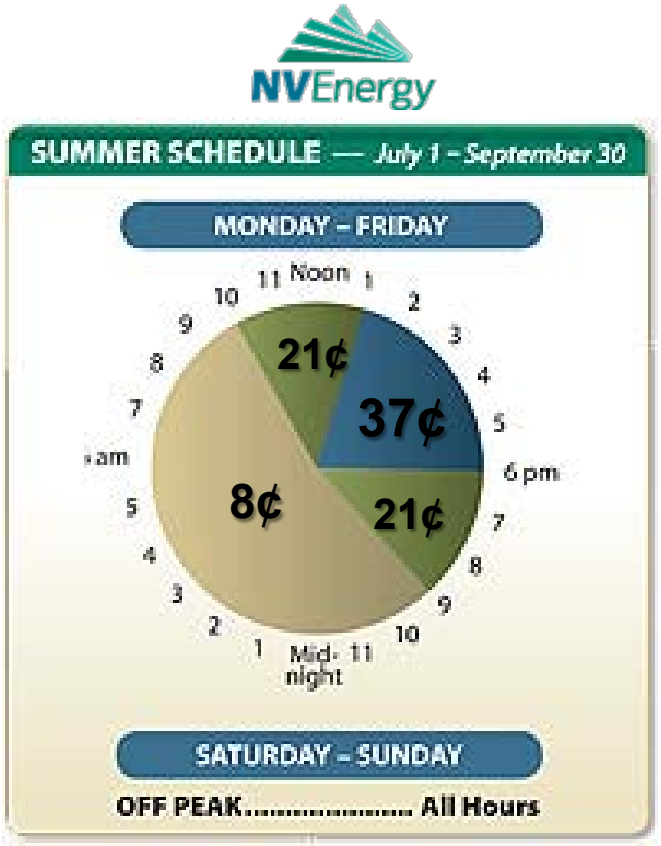
SolFocus
Innovation Inspired by Nature

emcore
empower with light™

3-15 kW systems

From power to *energy*





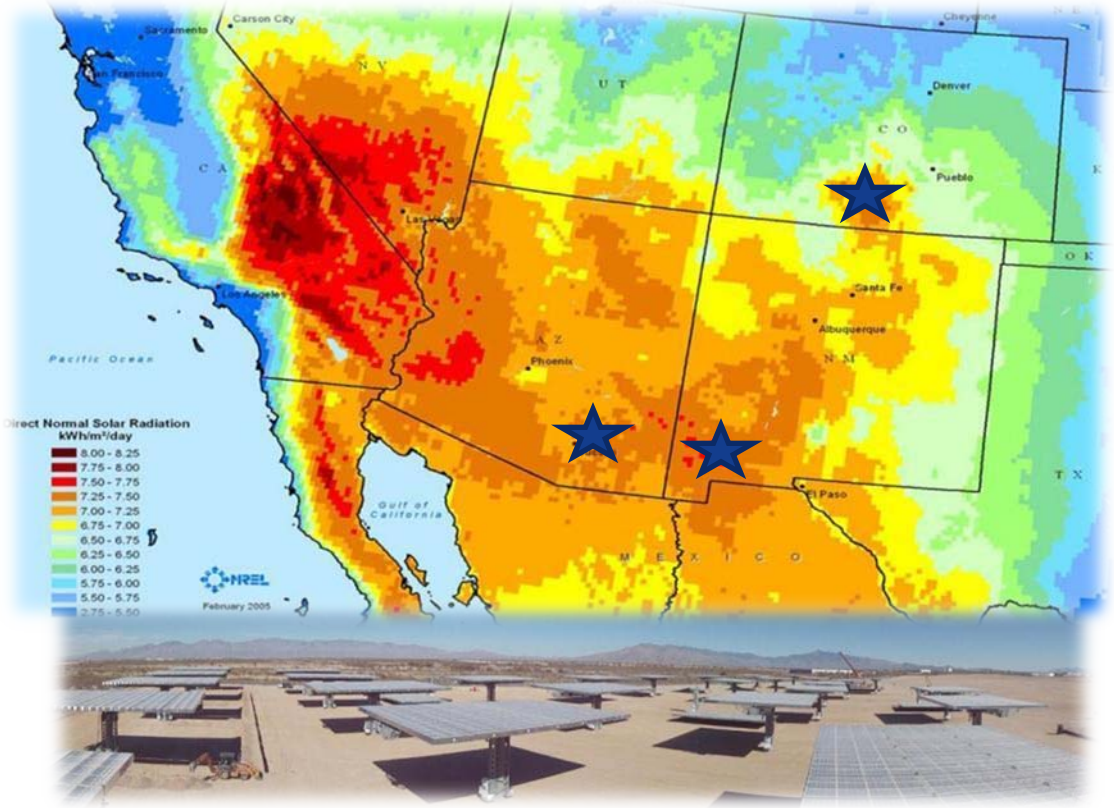
Rates per kW-hr

- Utility demand: flat output & high capacity factor.
- Two-axis tracking delivers a “flatter” output.
- CPV justifies the cost of dual-axis tracking

AMONIX
POWERING THE FUTURE NOW

Amonix CPV Projects

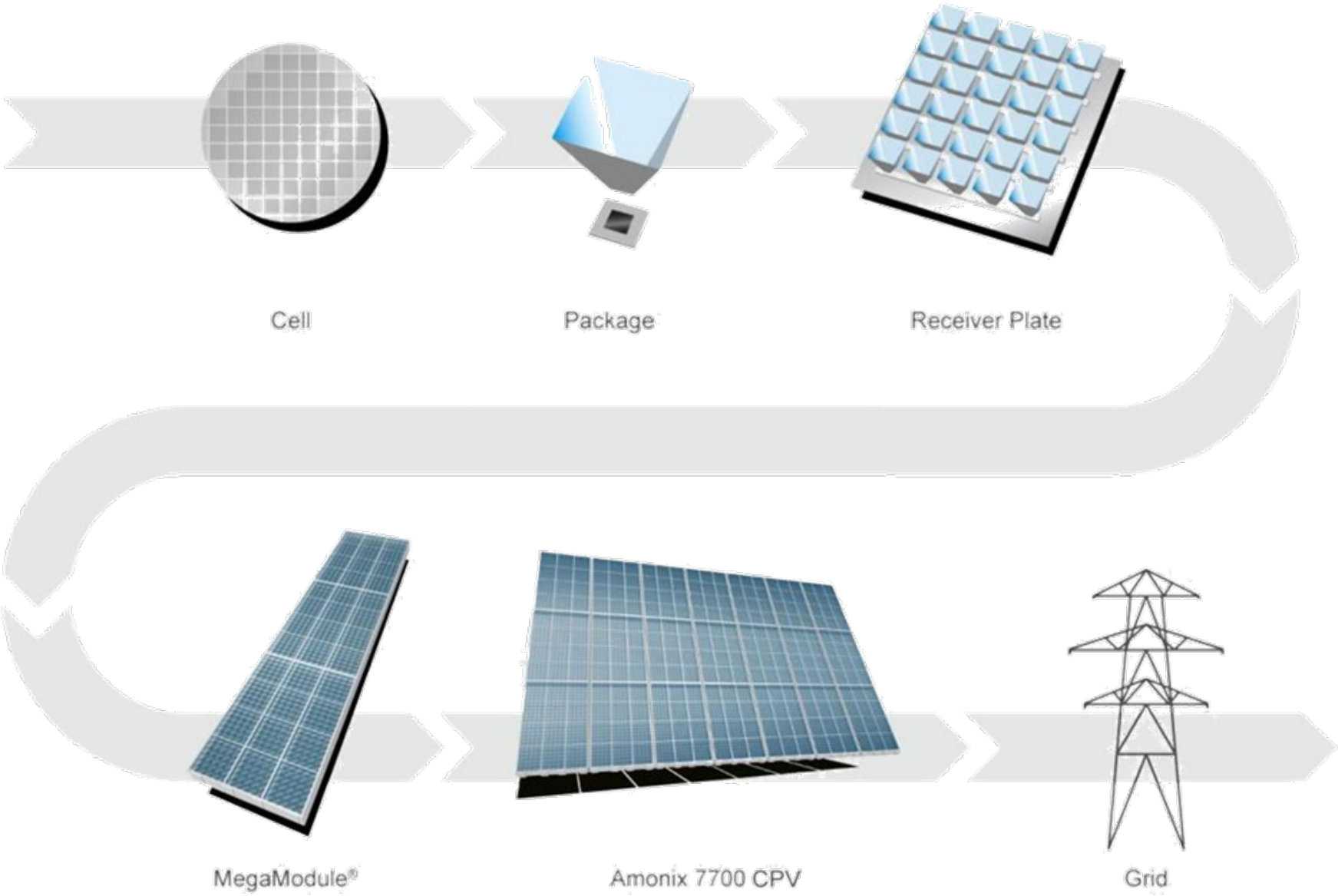
Robust Pipeline



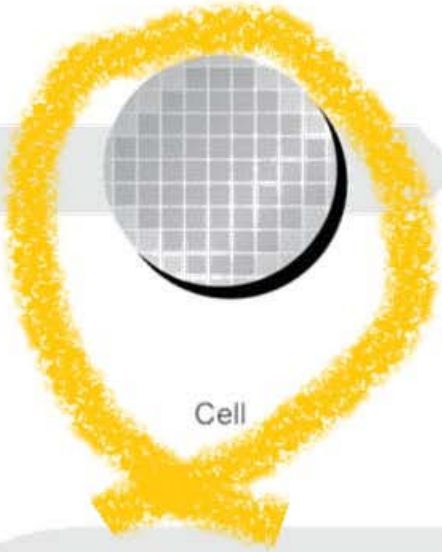
3MW Installed Last Quarter	50MW Under Construction

AMONIX
POWERING THE FUTURE NOW

Component levels

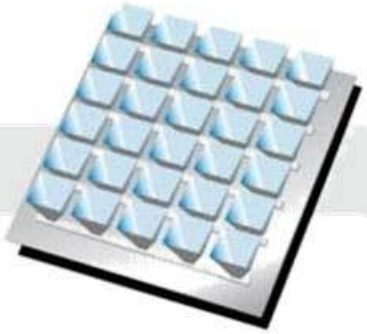


AMONIX
POWERING THE FUTURE NOW



Cell

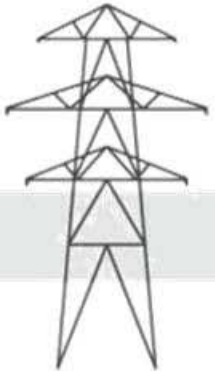
Package



Receiver Plate

MegaModule®

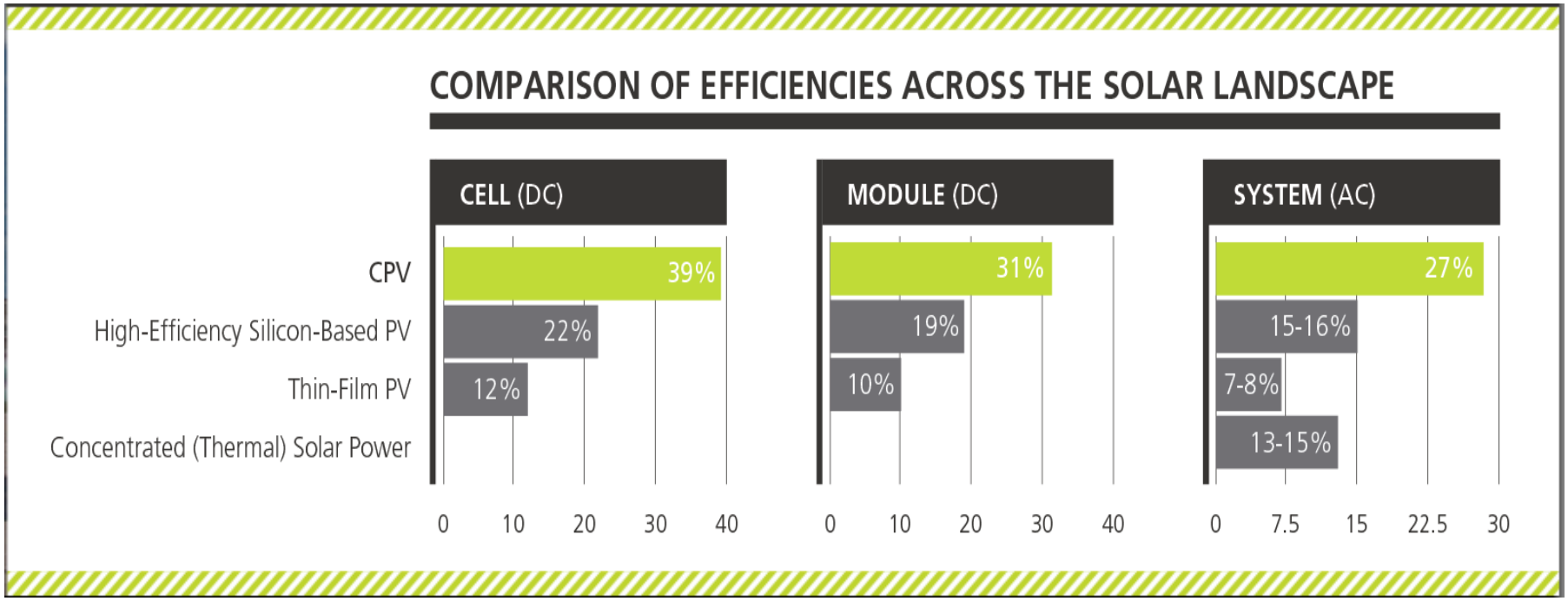
Amonix 7700 CPV



Grid

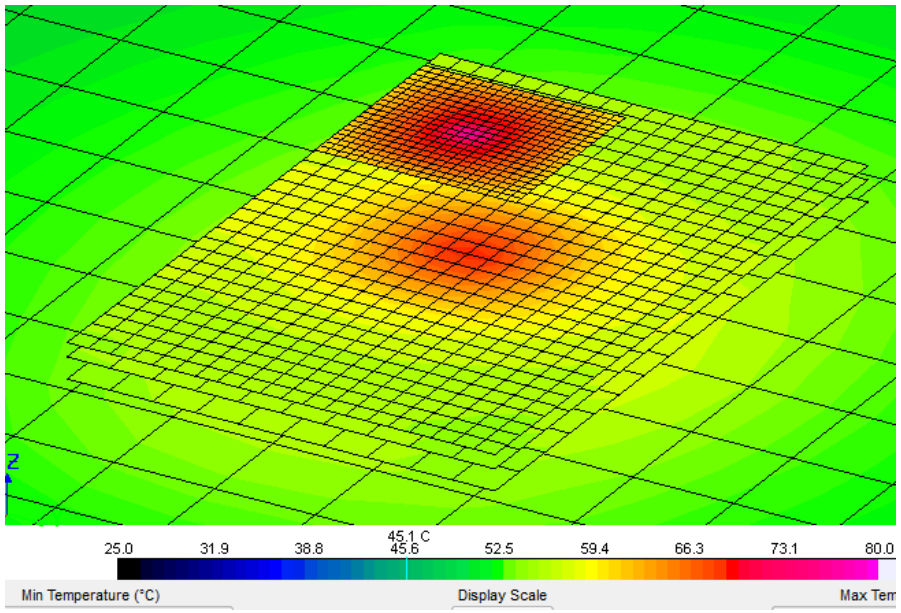
III-V multijunctions deliver the highest efficiency

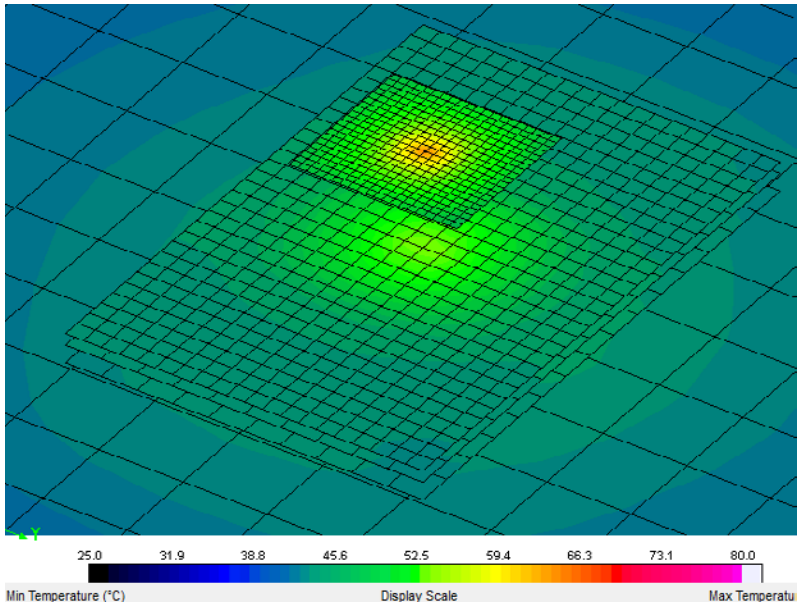
- 27% System, 31% Module, 39% Cell Efficiencies



Higher efficiencies support reliability

Thermal management





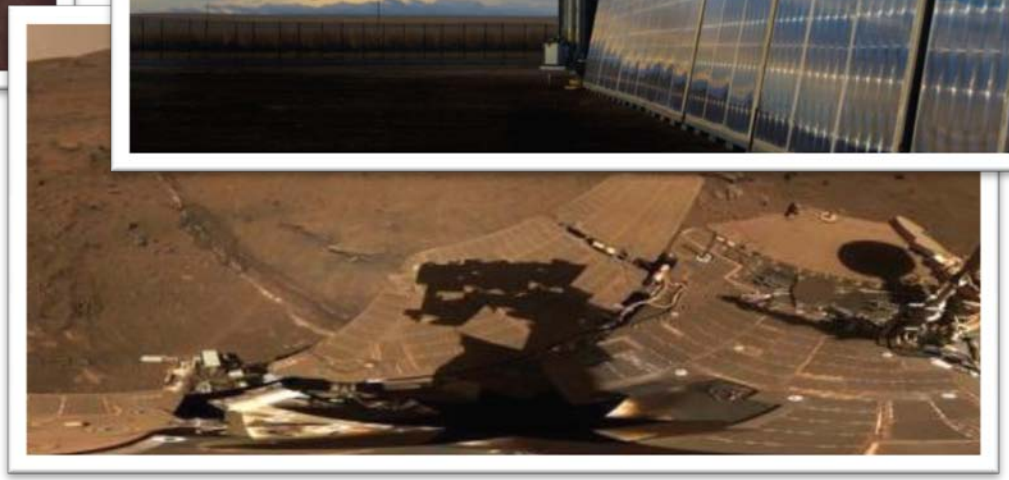
aggressive thermal management

high efficiency

durability

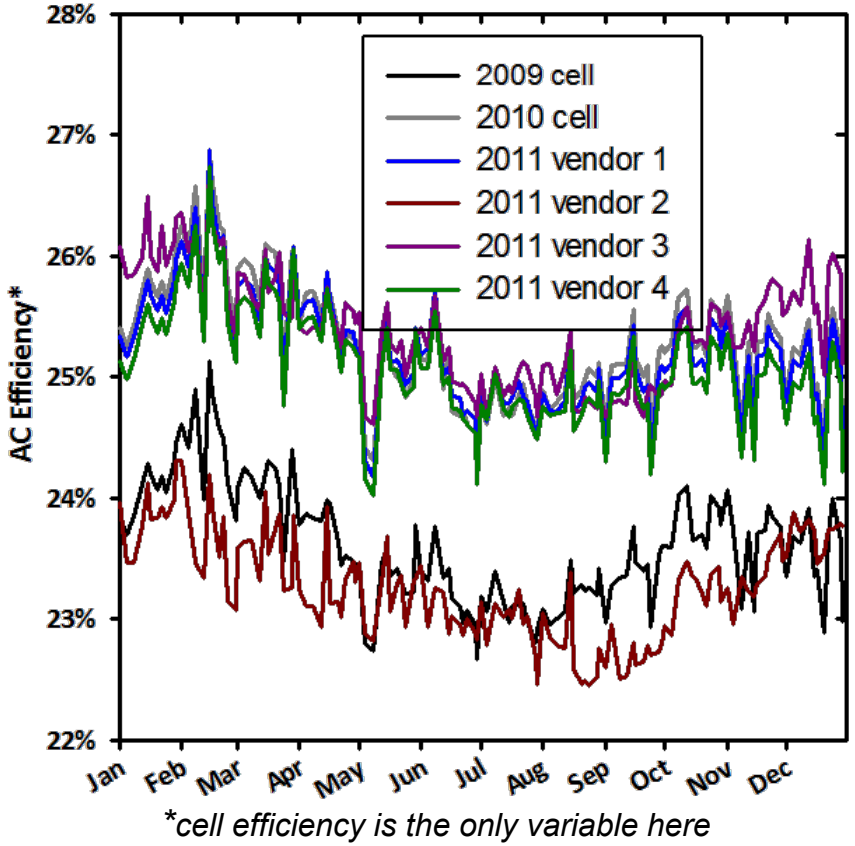
III-V multijunction solar cell: space heritage

Proven reliable in off- and on-planet operation

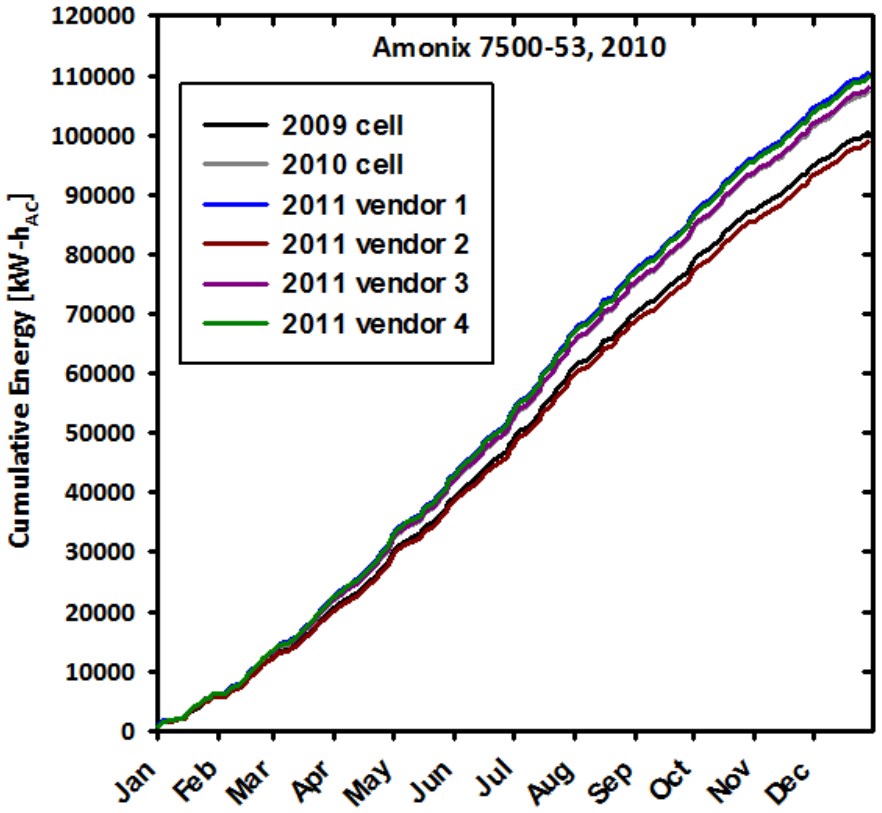


Multiple III-V multijunction cell vendors

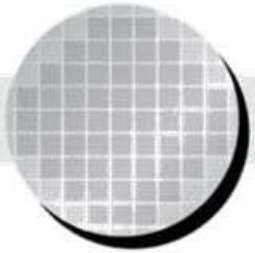
Model of 7700-53 performance in Las Vegas



*cell efficiency is the only variable here

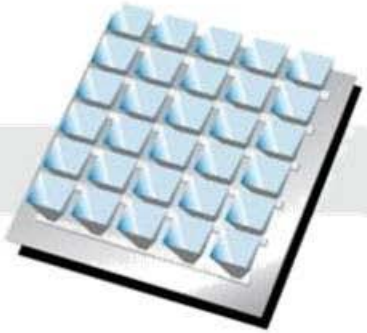


- field of vendors provides new insights in process improvements, design for reliability, & testing



Cell

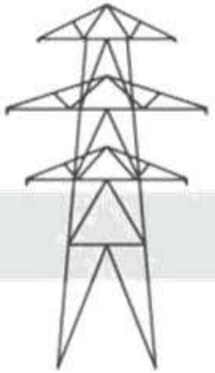
Package



Receiver Plate

MegaModule®

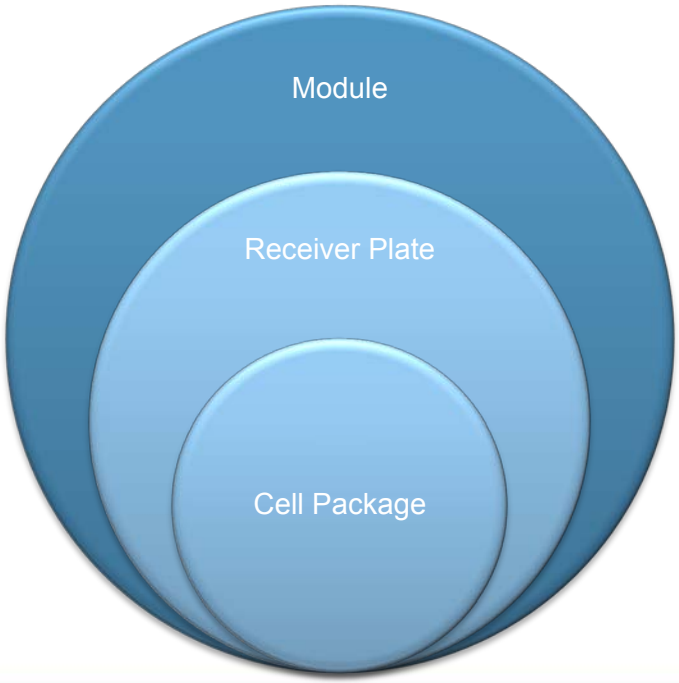
Amonix 7700 CPV



Grid

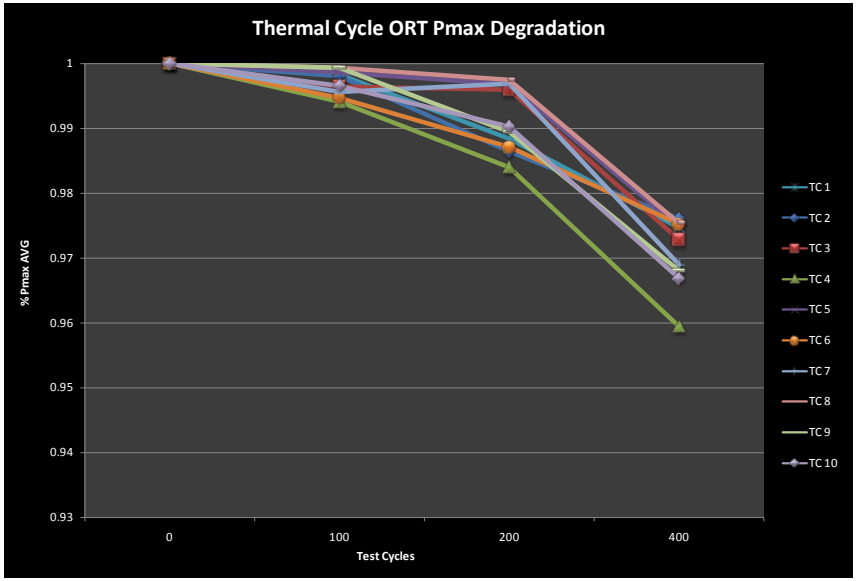
On Going Reliability

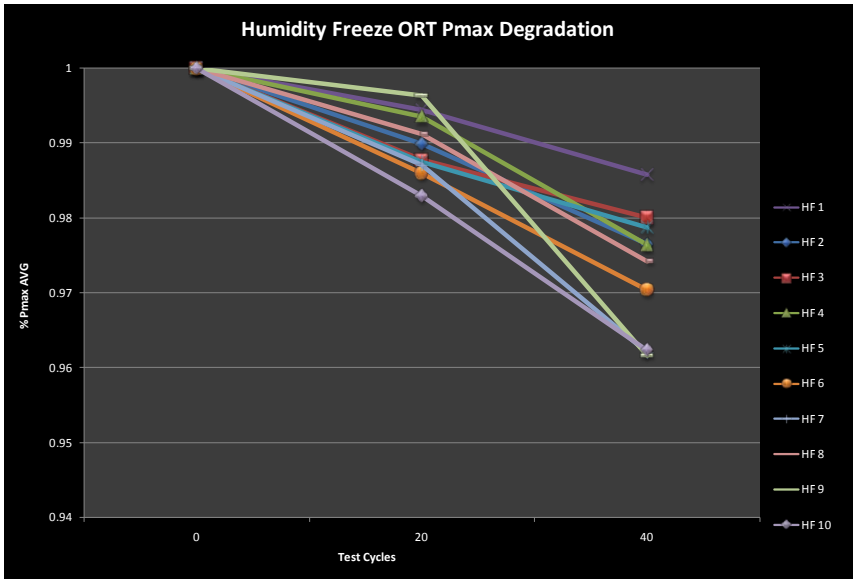
- Ongoing Reliability Testing is performed to monitor product reliability throughout manufacturing
- A comprehensive ORT will provide ongoing life data for the product, along with advance warning of dangerous shifts in manufacturing quality

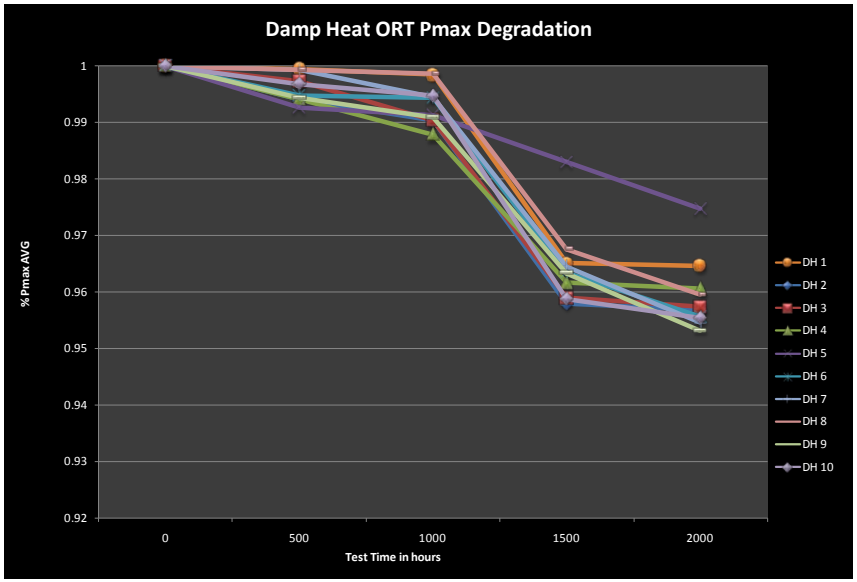


Cell Package ORT

Test	Test Specification	Pass Criteria
Visual Inspection	IEC 62108 10.1	0 failures
Thermal Cycle (200 cycles)	IEC 62108 10.6	0 failures
Humidity Freeze (40 cycles)	IEC 62108 10.8	0 failures
Damp Heat (1000 hours)	IEC 62108 10.7	0 failures

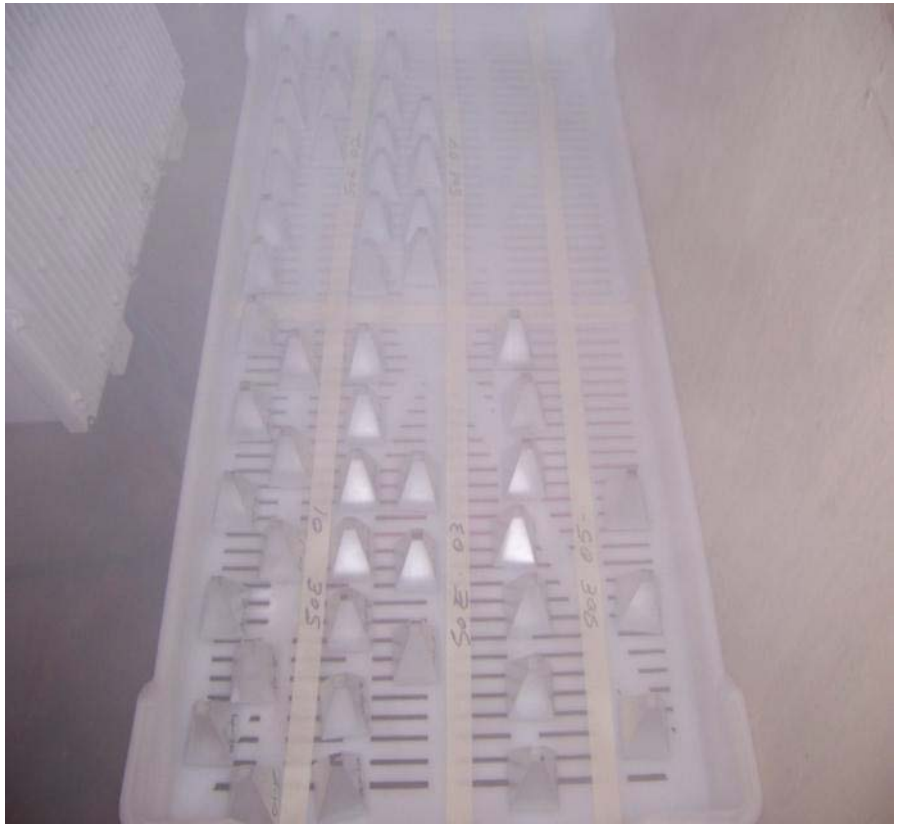
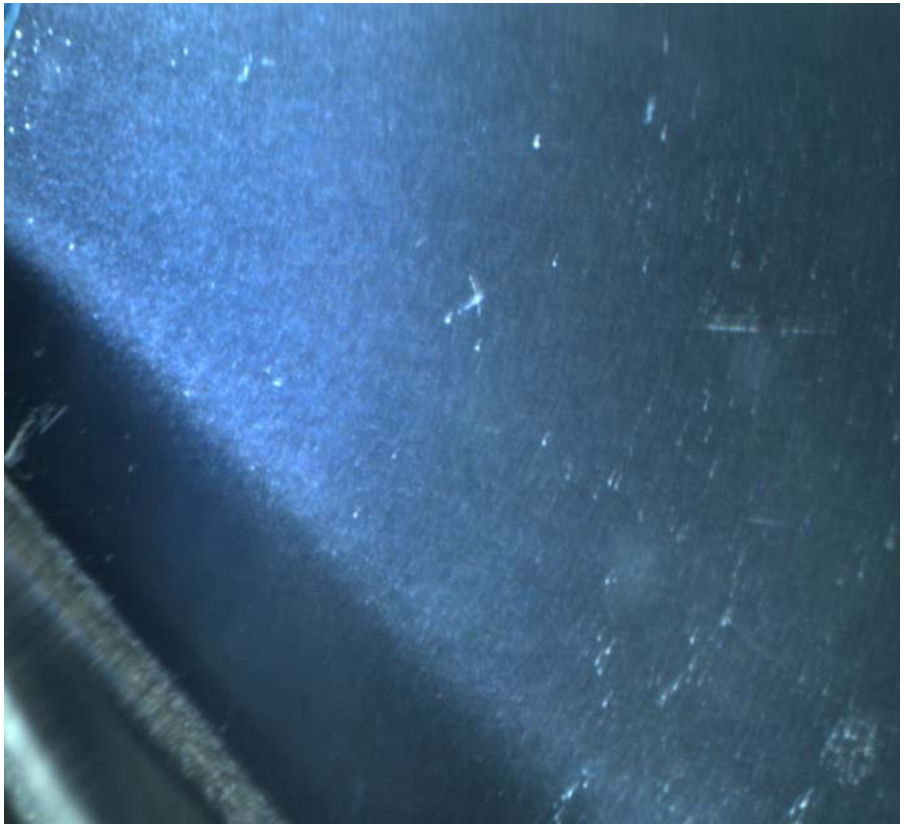






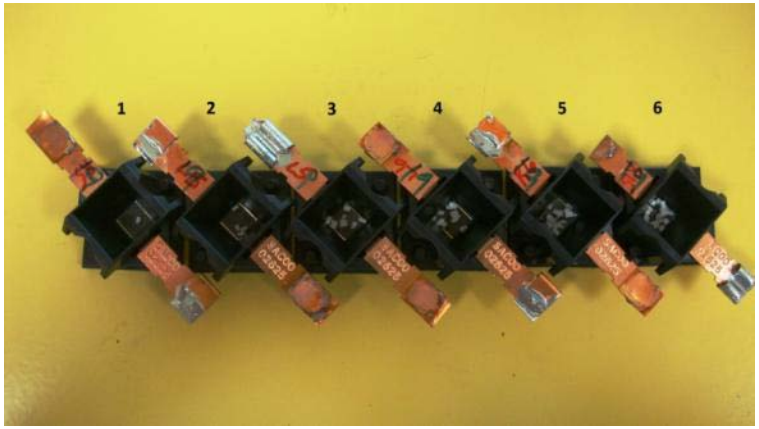
Secondary Optics

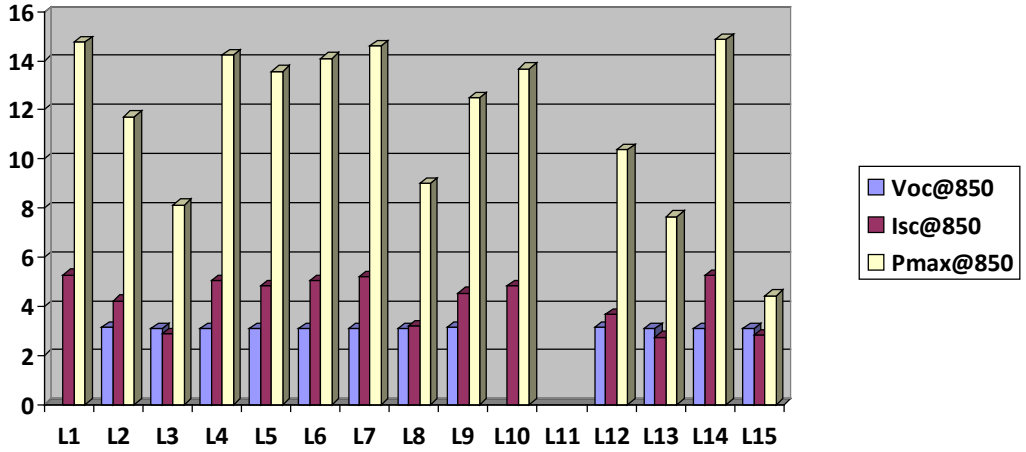
Extreme Salt Fog Conditions

Stress to 2X Mil-Std Requirements	Post Stress Analysis- No Tarnishing
	

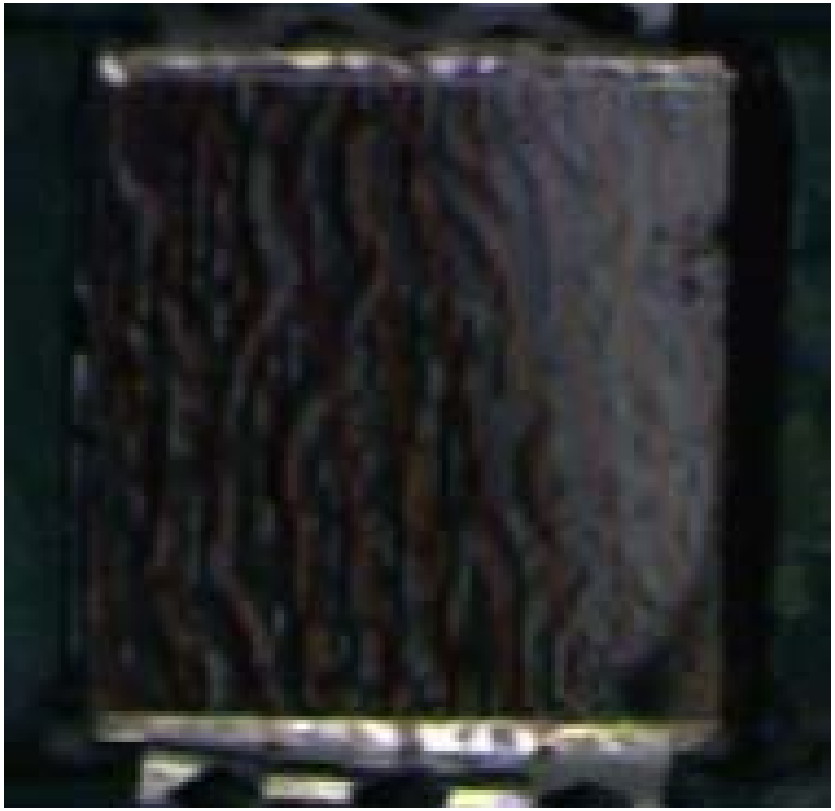
Receiver Plate Debris Study

- Determine the amount of debris that causes a failure

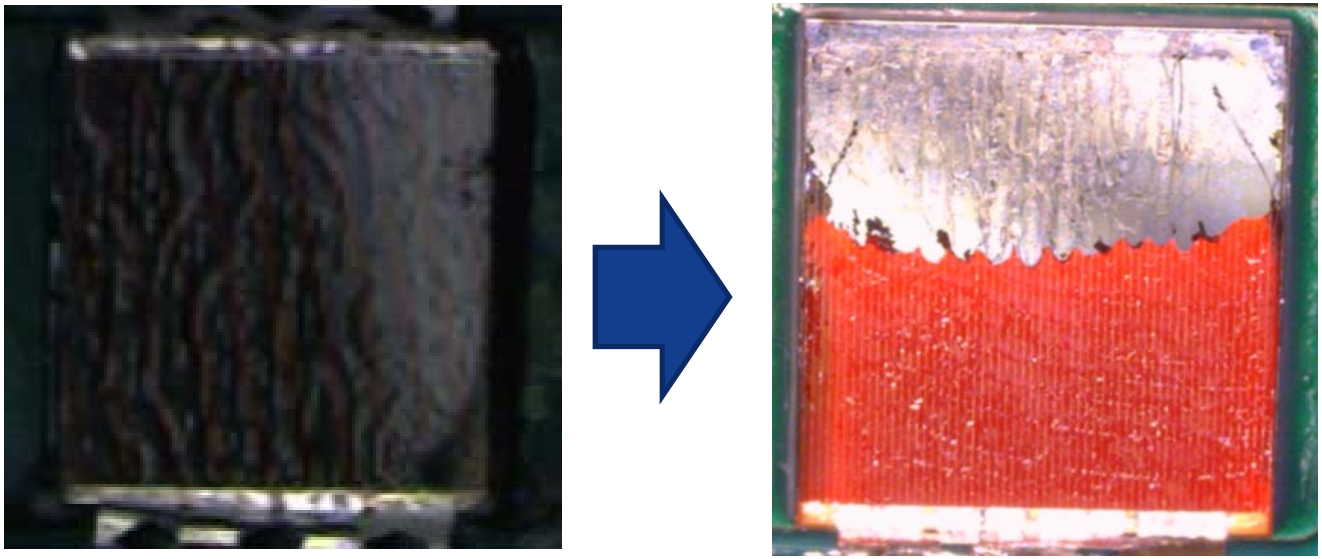


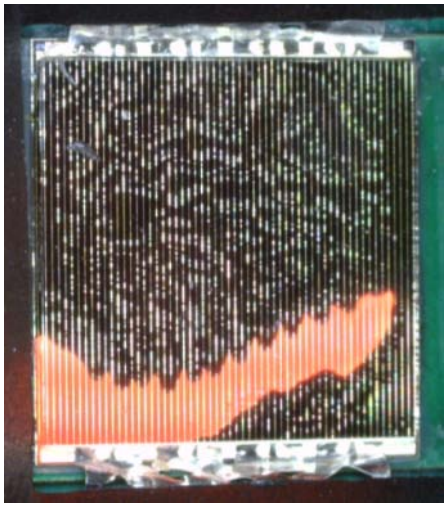


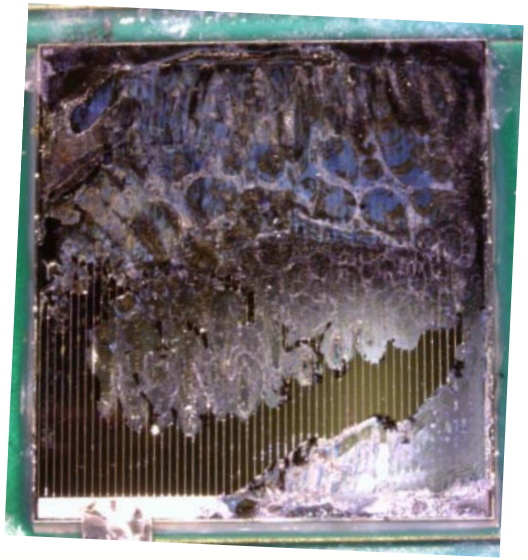
?

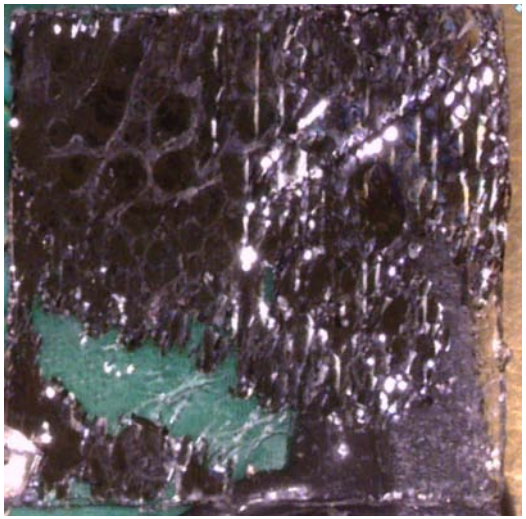


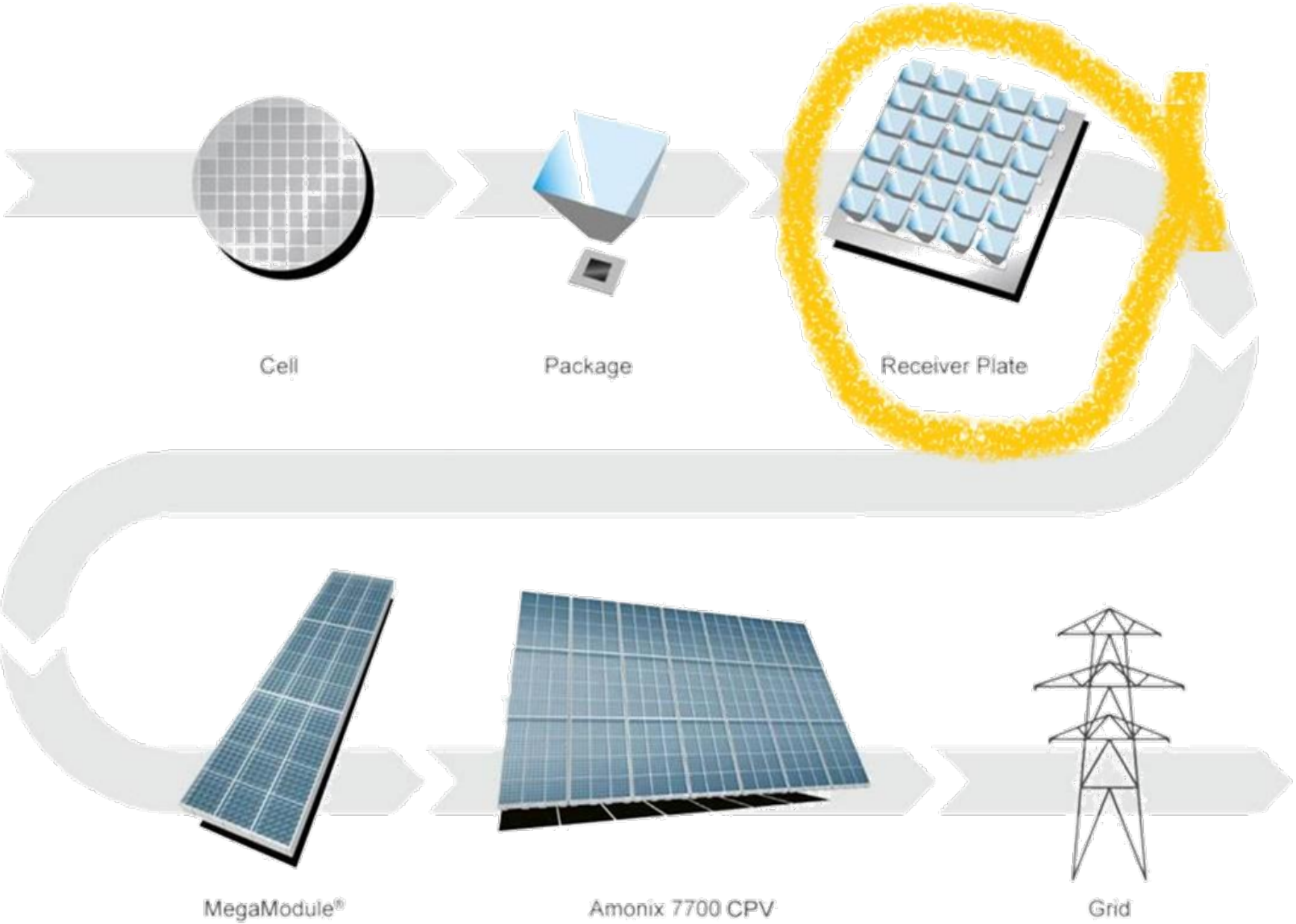
Epitaxial exfoliation







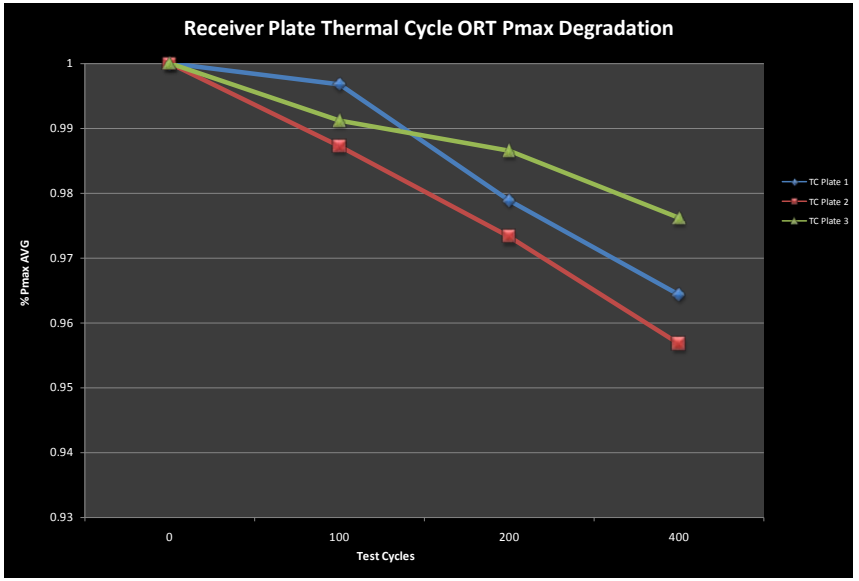


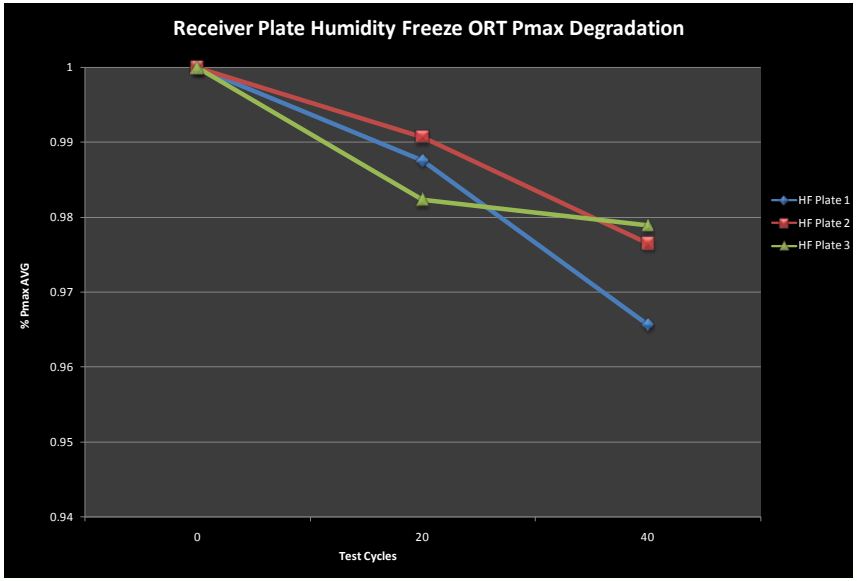


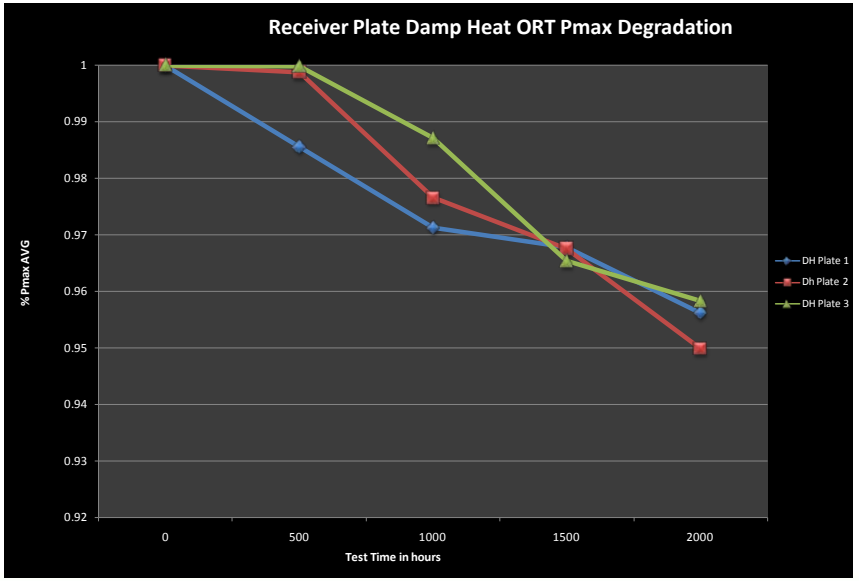
AMONIX
POWERING THE FUTURE NOW

Mini Module ORT

Test	Test Specification	Pass Criteria
Visual Inspection	IEC 62108 10.1	0 failures
Thermal Cycle (200 cycles)	IEC 62108 10.6	0 failures
Humidity Freeze (40 cycles)	IEC 62108 10.8	0 failures
Damp Heat (1000 hours)	IEC 62108 10.7	0 failures







Material background: PMMA

- Amonix uses a Fresnel lens composed of PMMA acrylic

- Acrylic originally developed for aircraft canopies:
  - high broadband transmittance (~92%), superior to glass
  - good UV durability
  - one of the hardest plastics: resistant to soiling

- Different formulations of PMMA are now available:
  - recent use of UV inhibitors in PMMA extends the lifetime relative to pure PMMA material

Description

Poly(methyl methacrylate) (PMMA) is a clear, colorless polymer used extensively for optical applications. It is available commercially in both pellet and sheet form. Outstanding properties include weatherability and scratch resistance. The most serious deficiencies are low impact strength and poor chemical resistance

Properties

Glass transition temperature: 114°C.

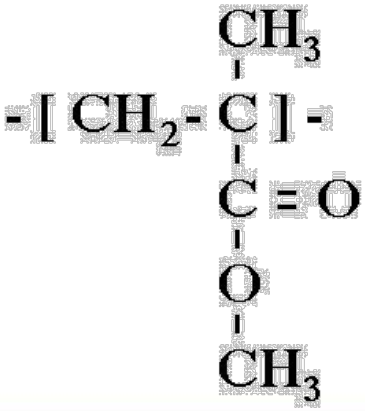
Amorphous density at 25°C: 1.17 g/cm^3.

Molecular weight of repeat unit: 100.12 g/mol.

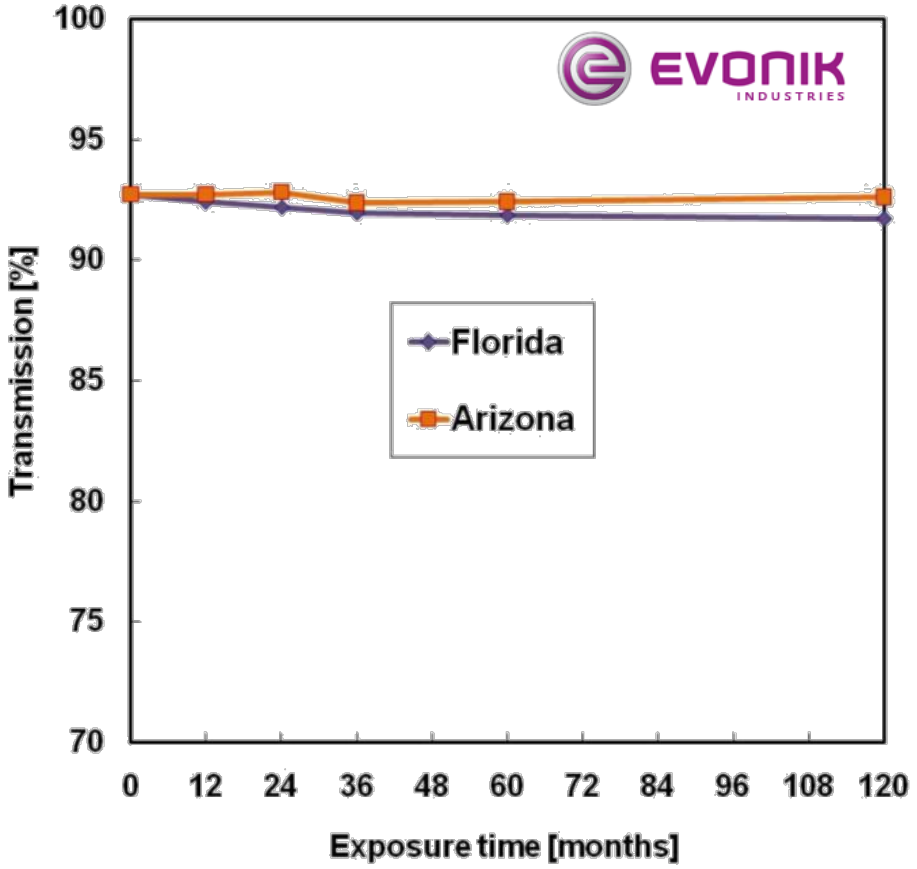
Typical physical properties

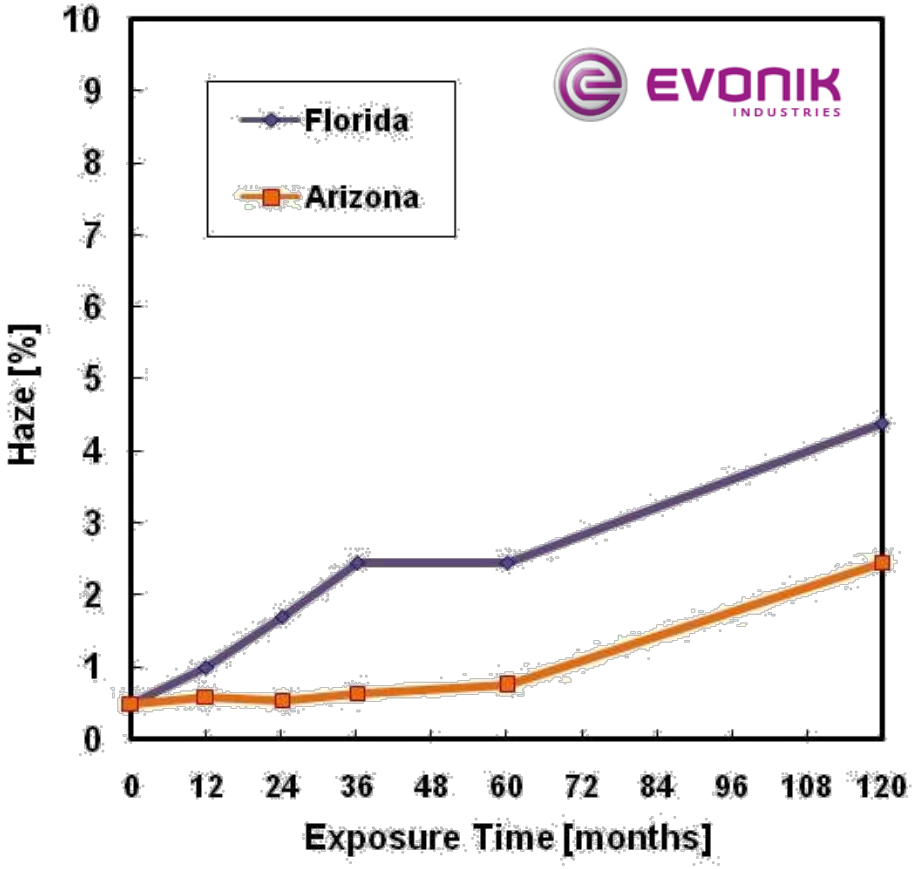
Repeat Unit

$C_5H_8O_2$



PMMA in outdoor exposure





- arid climate reduces rate of degradation

NREL study of PMMA for CPV

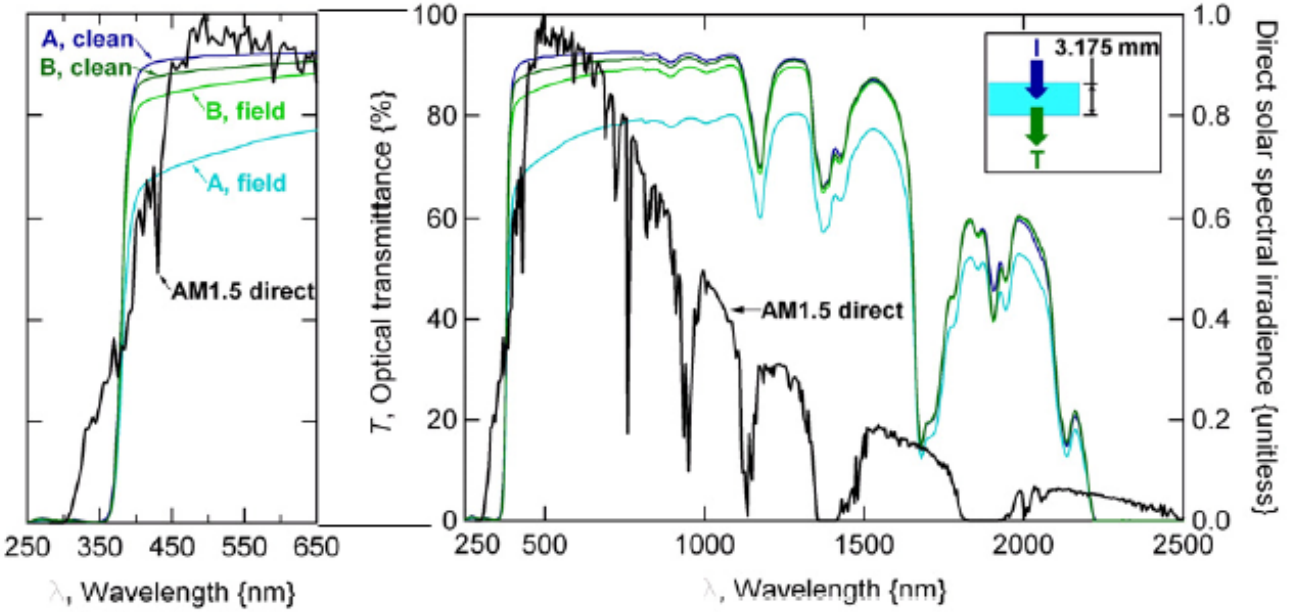


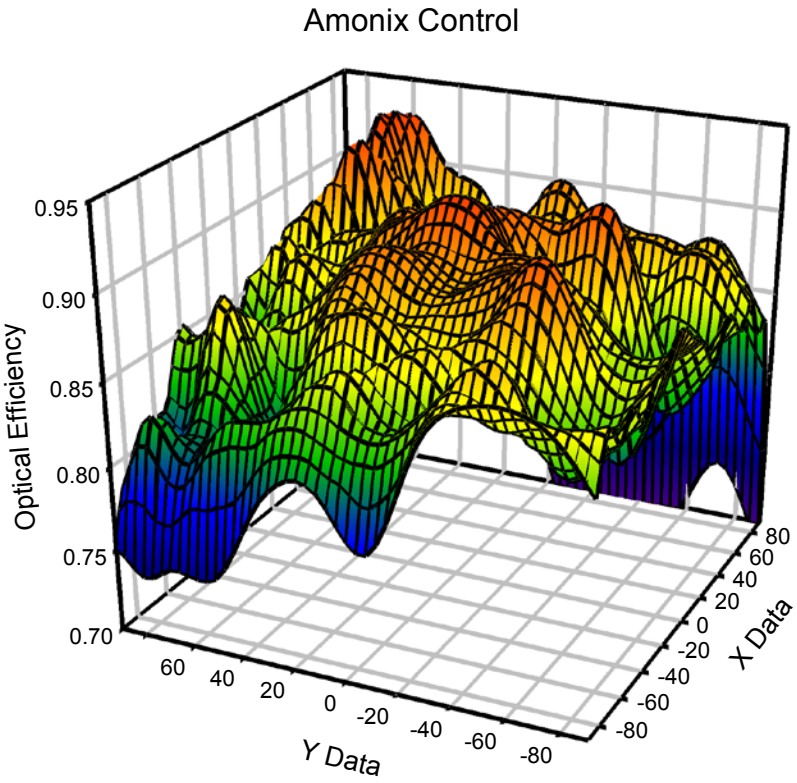
Figure 2: Measured optical transmittance (in air, compensated to h = 3.175 mm) for the most-soiled (fielded 22 years outdoors, "A") and next-most-soiled (fielded 8 years, "B") veteran lenses, relative to the normalized standard direct solar spectral irradiance [5]. Measurements were first made in the as-received condition and then after cleaning.

Strong attenuation of the blue region is not apparent for either of the cleaned sets in Figure 2. Use on a tracker tends to reduce exposure to airborne contamination, particularly if the module is maintained ≥2 meters above the ground [11].

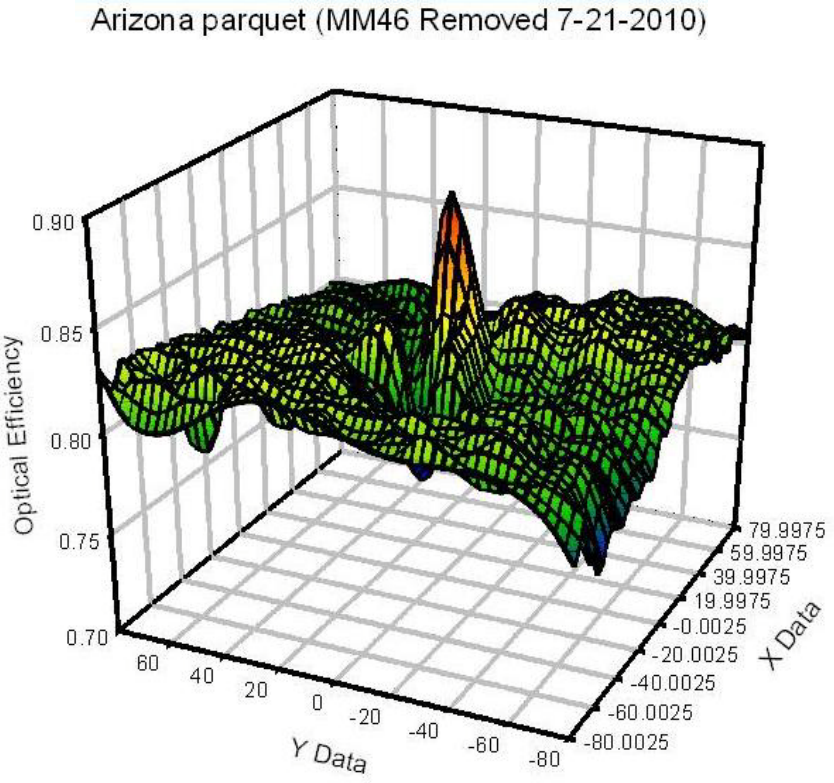
David C. Miller, Lynn M. Gedvilas, Bobby To , Cheryl E. Kennedy, and Sarah R. Kurtz, "Durability of Poly(Methyl Methacrylate) Lenses Used in Concentrating Photovoltaics", Proc. SPIE, 2010, 7773-02.

- **after cleaning, degradation in transmission is modest, <0.3%/year**

Amonix lenses fielded in Arizona



new lens: mean optical efficiency=85%



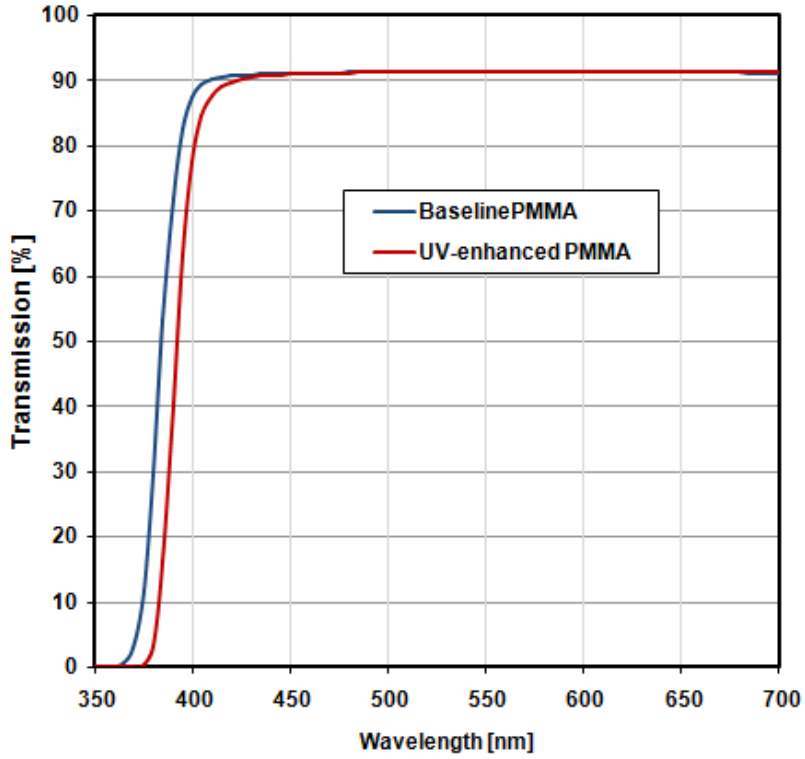
fielded lens: mean optical efficiency=81%

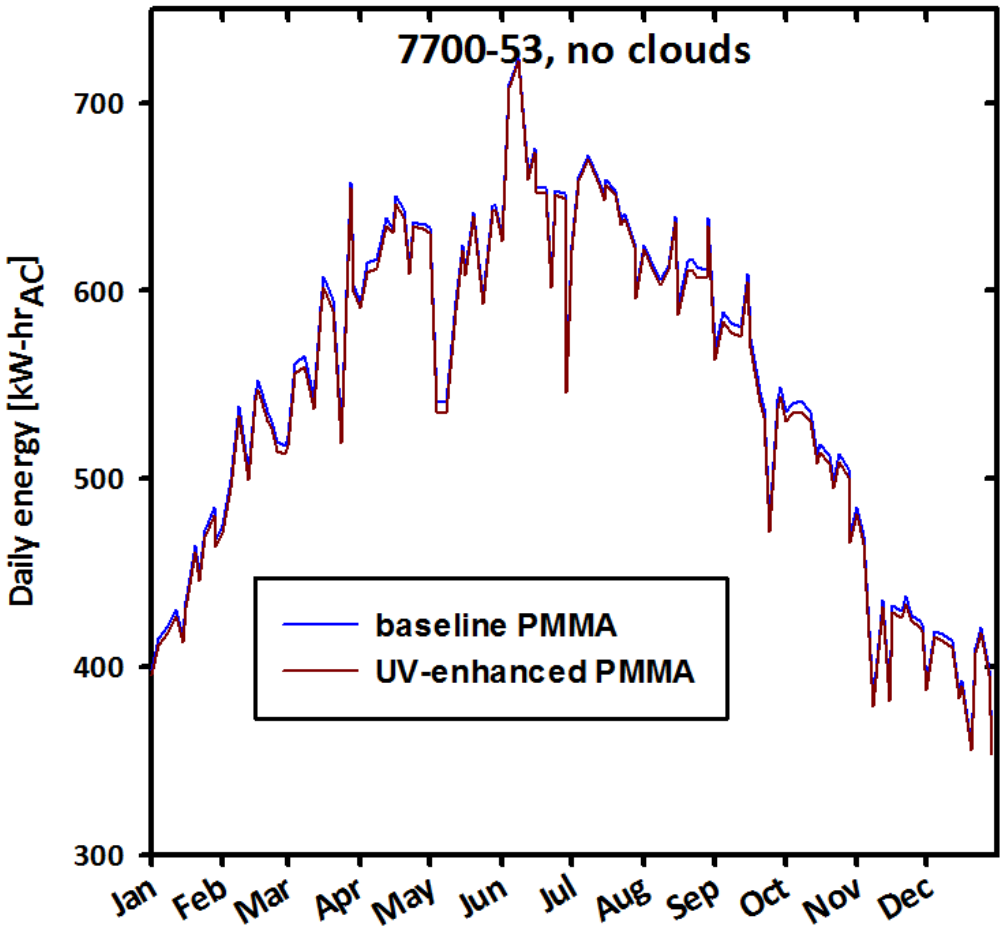
- laser map of lens surface quantifies mean optical efficiency
- lens from MM46 was installed c. 2001: decrease in optical efficiency of <0.4%/year

Lens Qualification

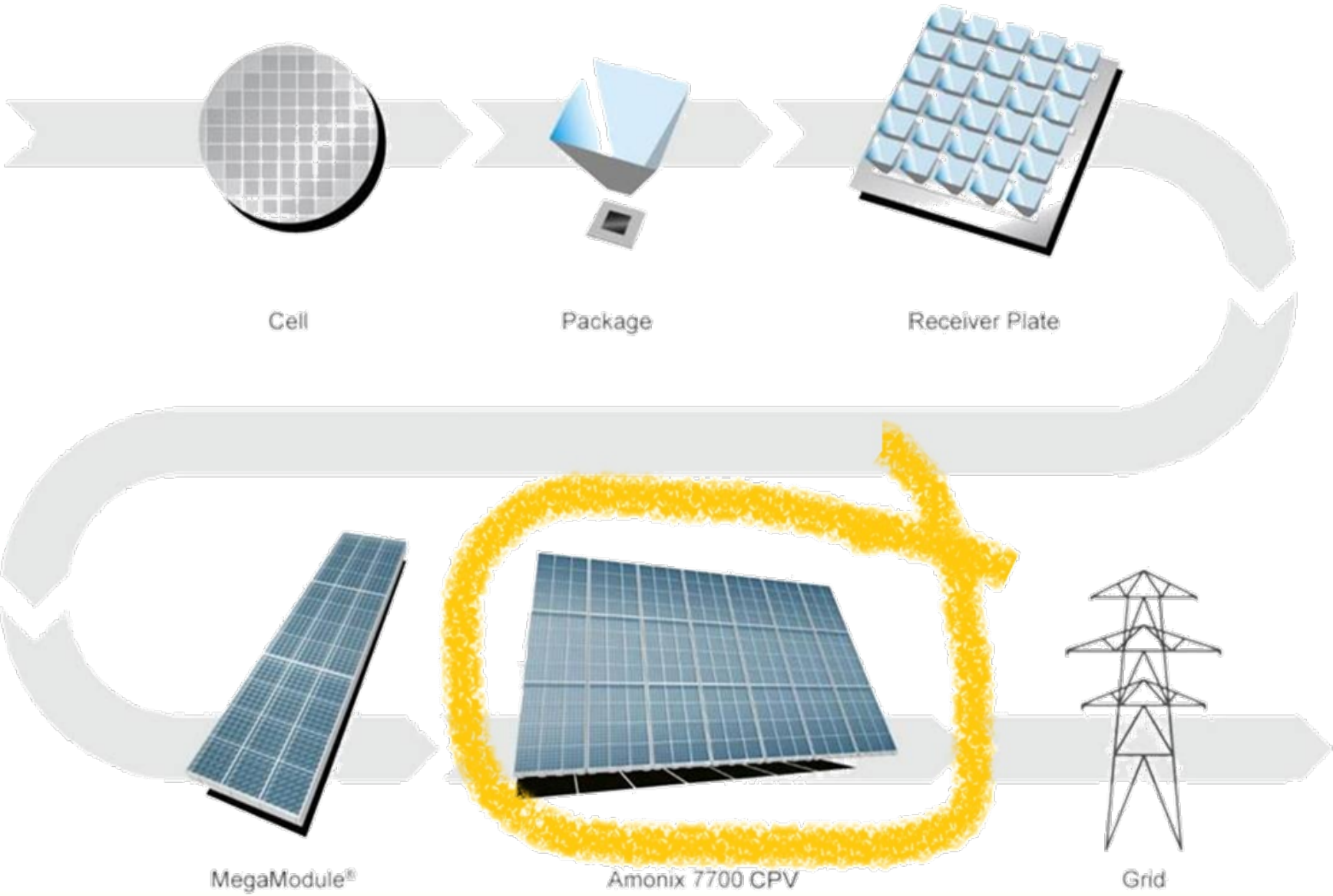
Test	Conditions	Configuration	Threshold
Performance	0°, 20°, 40° tilt	module	P_{mp}, characterization only
Damp heat	60° C, 60% relative humidity for 1000 hours	single lens element	$D_{optical\ efficiency}$<1%
		module	NP_{MP}>0.98
Temperature cycle	-40° to 110° C, 500 cycles	mounted to frame	$D_{optical\ efficiency}$<1%
Humidity freeze	after temperature cycle test: -40° to 60° C, 85% relative humidity, 20 cycles	mounted to frame	$D_{optical\ efficiency}$<1%
Abrasion resistance		single lens element	$D_{optical\ efficiency}$<1%
Impact test	per IEC 62108	mounted to frame	$D_{optical\ efficiency}$<1%
			no cracks (1x inspection)
UV test	Weather-Ometer, 1000 hours	bare lens sheet	$D_{optical\ efficiency}$<1%
		single lens element	NP_{MP}>0.98
	Outdoor concentrated test, 1000 hours	unpatterned sample	$DT_{350\text{-}1800nm}$<1%

Enhanced UV durability





- small decrement in energy generation provides substantial extension of lifetime



AMONIX
POWERING THE FUTURE NOW

Mega Module Transportation Qualification

- During shipment, the Mega Module can experience shock, vibration and compression which impact reliability

Test Condition	Test Description	Test Standard
Atmospheric Conditioning	Controller Temperature and Humidity	Mil-Std 810
Compression	Machine Apply and Release	Mil-Std 810
	Machine Apply and Hold	
	Weight and Load Spreader	
Vibration	Fixed Displacement	Mil-Std 810
	Random	
Shock	Drop	Mil-Std 810
	Incline Impact	
	Horizontal Impact	

Competitive Advantages

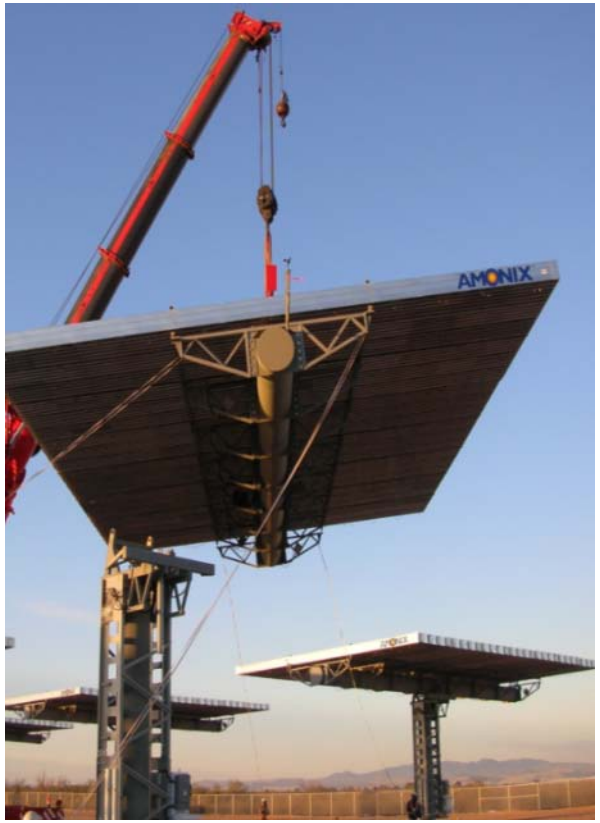
Highest Efficiency, Low LCOE	Proven & Practical	Rapid & Flexible Deployment	Highest Energy Density
			
40% Cell, 31% Module	~20MW Deployed WW	"Drop and Connect" Deployment	Water-Free Power Production 5 acres per MW

Low Factory Capital Investment

Leverages Existing Commodity and Fabrication Infrastructure

Distributed manufacturing

MegaModule® fabrication



Truck bed to field

Height provides wear & soiling resistance

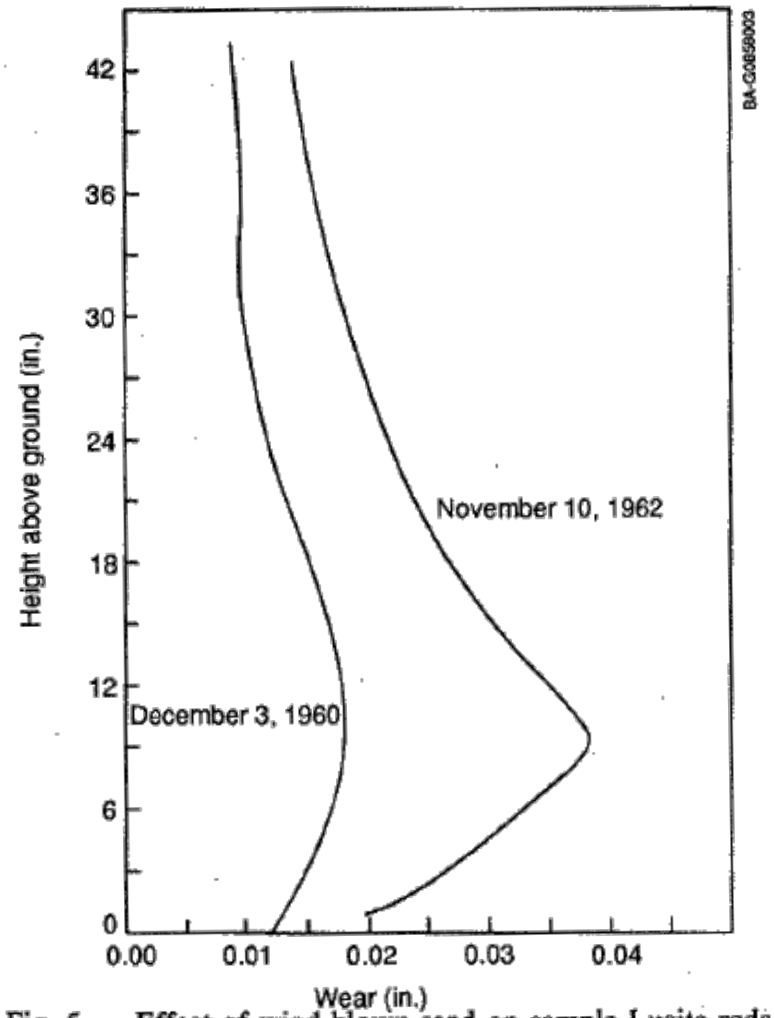
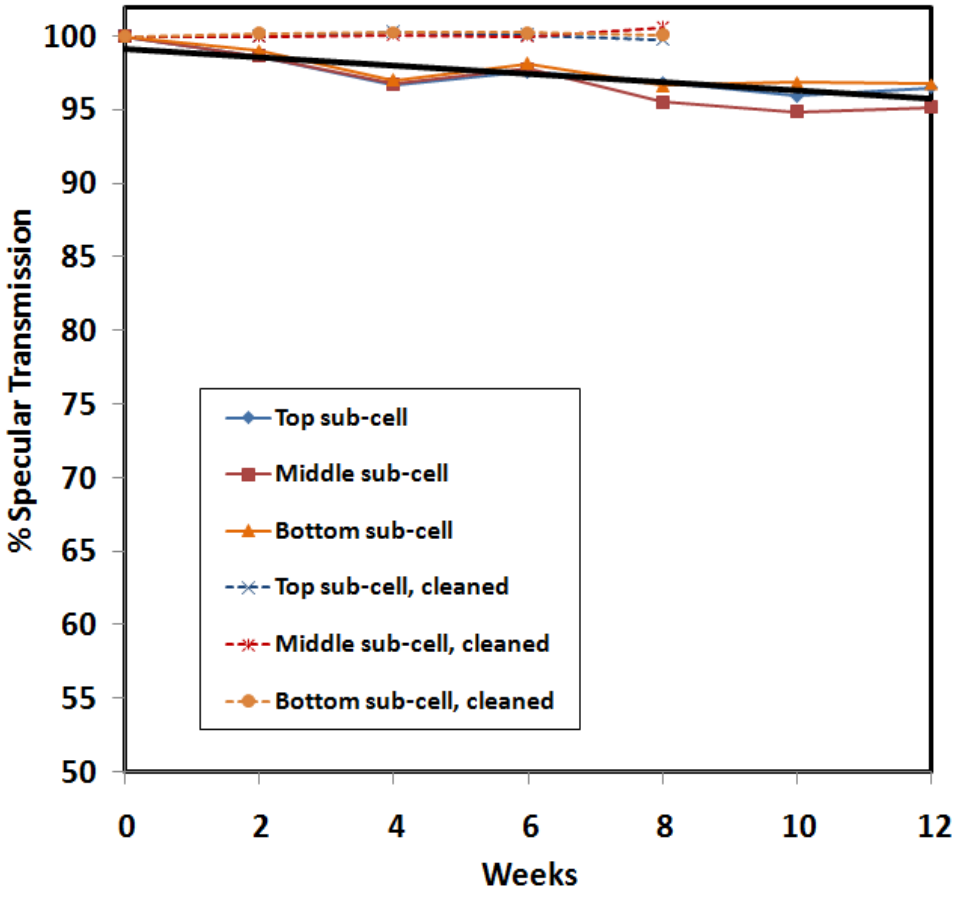


Fig. 5. Effect of wind-blown sand on sample Lucite rods

THE EFFECT OF SANDSTORMS ON PV ARRAYS AND COMPONENTS

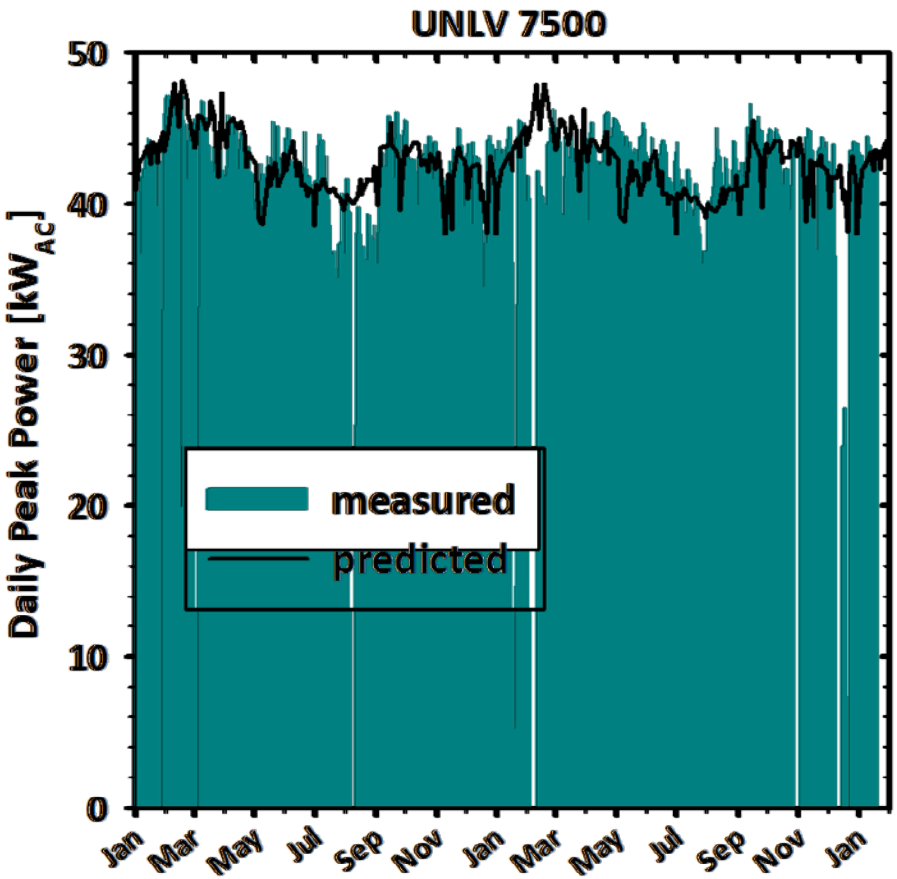
John P. Thornton, P.E.
National Renewable Energy Laboratory, Golden, Colorado, U.S.A.

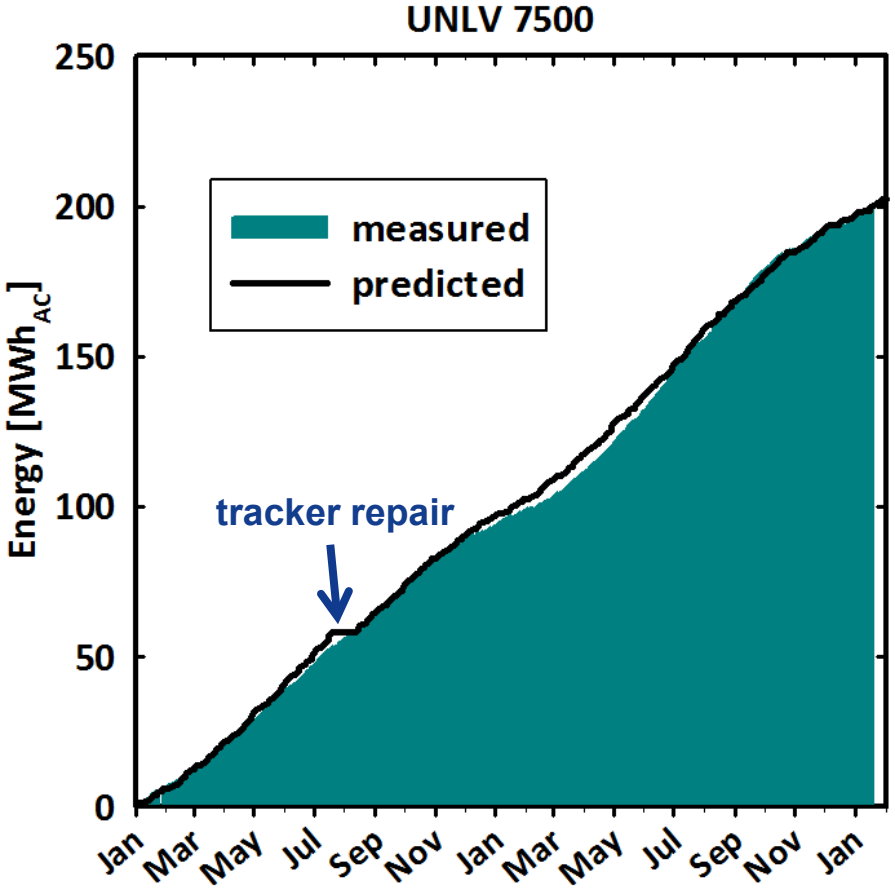
Soiling in Las Vegas



- mean soiling is around 2% near the Las Vegas strip

Performance prediction: 2009-2011





- Generation is variable, but *predictable*
- <1% deviation from energy prediction after 2 years

Rapid Installation and Deployment

- **CPV is utility grade**

From truck bed to tracking in days

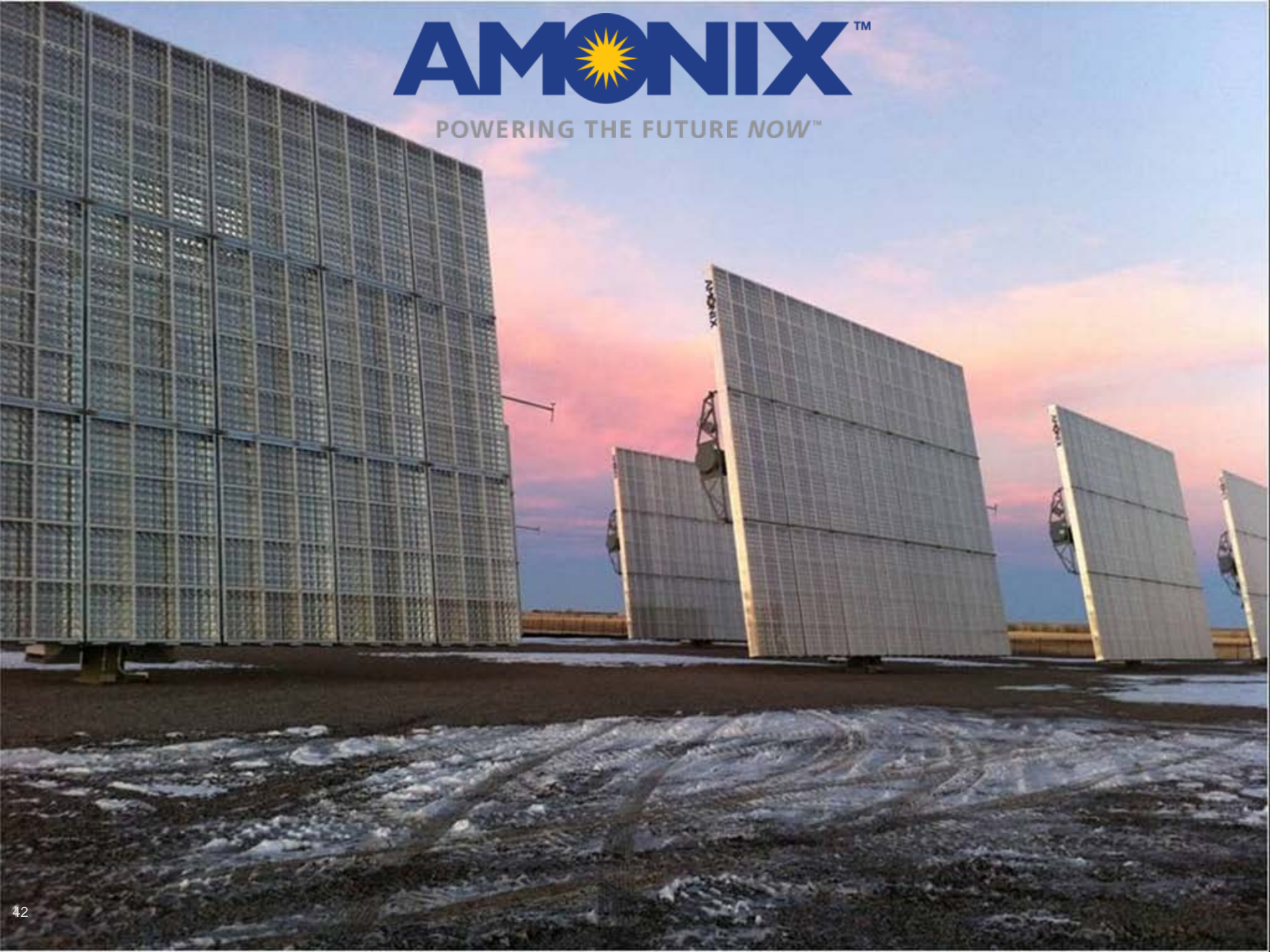
- New, efficient installation process

Problems remain:

Solution: “RCMs”

RCMs: Rodent Counter Measures

One more reason to install in the desert!


AMONIX™
POWERING THE FUTURE NOW™


AMONIX™
POWERING THE FUTURE NOW™