Research and product development at DuPont Photovoltaic Solutions

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UNSW Public Research Seminar

10-March-2016

Outline

- DuPont Introduction
- DuPont Photovoltaics
- Solamet® PV Metallization Pastes
  - Metal Induced recombination
- Holistic Reliablitiy program
  - Advanced module encapsulation

Let me introduce myself

- UNSW:
  - Undergrad (PV)
  - Worked at Pacific Solar on student project
  - Worked for thin-film group as lab assistant
  - PhD – thin-film c-Si solar cells
- IBM: Postdoc
- Silexos: Device team leader
- Innovalight: Process Engineering
- DuPont: Current

Understanding Materials, Cells, Modules – Under One Roof

DuPont Silicon Valley Technology Center

Our Purpose

DuPont is a Science Company

We work collaboratively to find sustainable, innovative, market-driven solutions to solve some of the world's biggest challenges, making lives better, safer, and healthier for people everywhere.

DuPont Has Evolved Over Two Centuries

EXPLOSIVES

CHEMICALS

INTEGRATED SCIENCE

1800

1802 – E.I. DUPONT

1804 – FIRST POWDER MILL

1805 – CORE VALUES

1850

1880 – FIRST DYNAMITE

1900

1903 – EXPERIMENTAL STATION

1915 – PLASTICS

1917 – MAKING DYES

1923 – CELLOPHANE®

1924 – RAYON®

1924 – FILMS BUSINESS BEGINS

1928 – CHEMICAL EXPANSION

1935 – NYLON®

1936 – LUCITE®

1949 – ENGINEERING POLYMERS

1950

1952 – MYLAR®

1961 – TEDLAR®

1962 – LYCRA®

1965 – KEVLAR®

1966 – TYVEK®

1967 – NOMEX®

1972 – ELECTRONICS EXPANSION

1986 – CORIAN®

1999 – ACQUIRES PIONEER HI-BRED

2000

2000 – SORONA® BIO BASED POLYMER

2003 – SOLAE JOINT VENTURE

2011 – ACQUIRES DANISCO

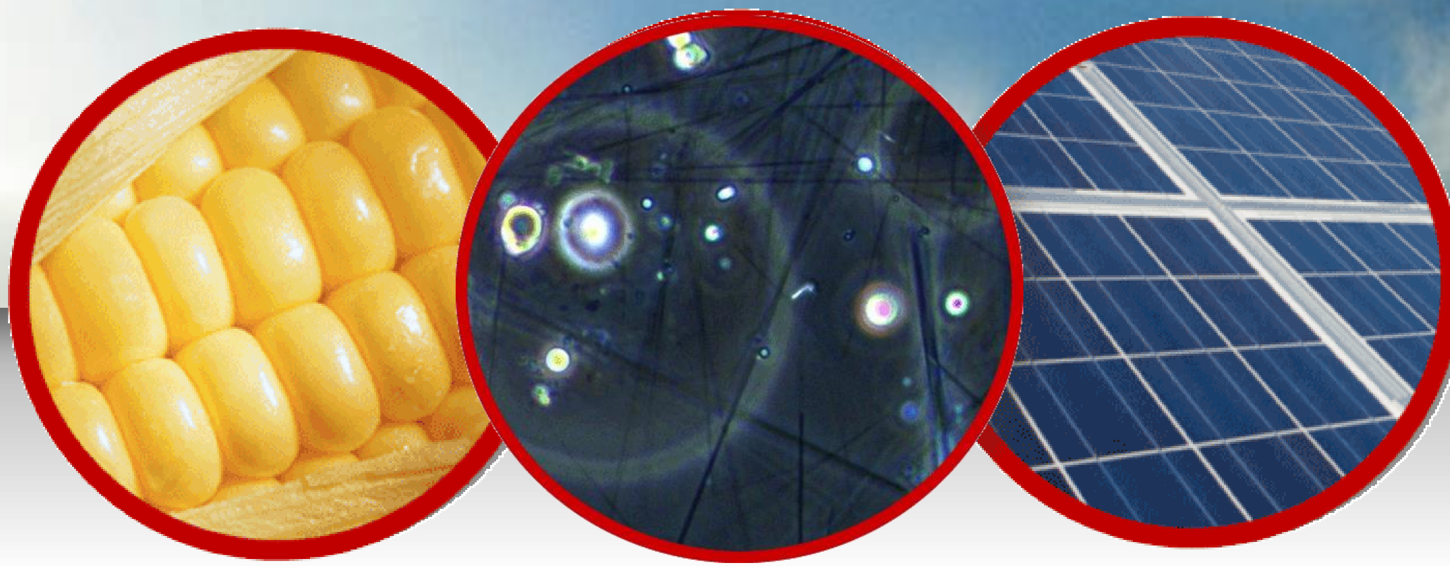
2012 – ACQUIRES 100% OF SOLAE

2013 – COMPLETES SALE OF PERFORMANCE COATINGS BUSINESS AND ANNOUNCES PLANS TO SEPARATE PERFORMANCE CHEMICALS

2050

Our Strategic Priorities

Our strategy is to be a premier market-driven science company and generate superior shareholder returns.



AGRICULTURE & NUTRITION

BIOBASED INDUSTRIALS

ADVANCED MATERIALS

THE DUPONT PORTFOLIO OF INNOVATIVE MATERIALS FOR SOLAR MODULES

CRYSTALLINE SILICON MODULE

A PHOTOVOLTAIC ENCAPSULANTS
DuPont™ PV5400 Series encapsulant sheeting
DuPont™ PV8600 Series encapsulant sheeting

B PHOTOVOLTAIC METALLIZATIONS
DuPont™ Solamet® photovoltaic metallizations

C SILICON DOPING TECHNOLOGIES
DuPont™ Innovalight™ silicon inks

D ELECTRICAL AND STRUCTURAL COMPONENT MATERIALS
DuPont™ Rynite® PET thermoplastic polyester resins
DuPont™ Crastin® PBT polybutylene terephthalate resins

E BACKSHEET MATERIALS
DuPont™ Tedlar® PVF films

DuPont: The Leading Specialty Material Supplier in PV

Solamet® metallization pastes

Driving higher energy conversion efficiency

Tedlar® backsheet films

Protecting PV modules

Elvax® and Ionomer encapsulants

Delivering long-term protection of cells

Rynite® PET Zytel® Nylon composite materials

Reducing system costs and speed up installation

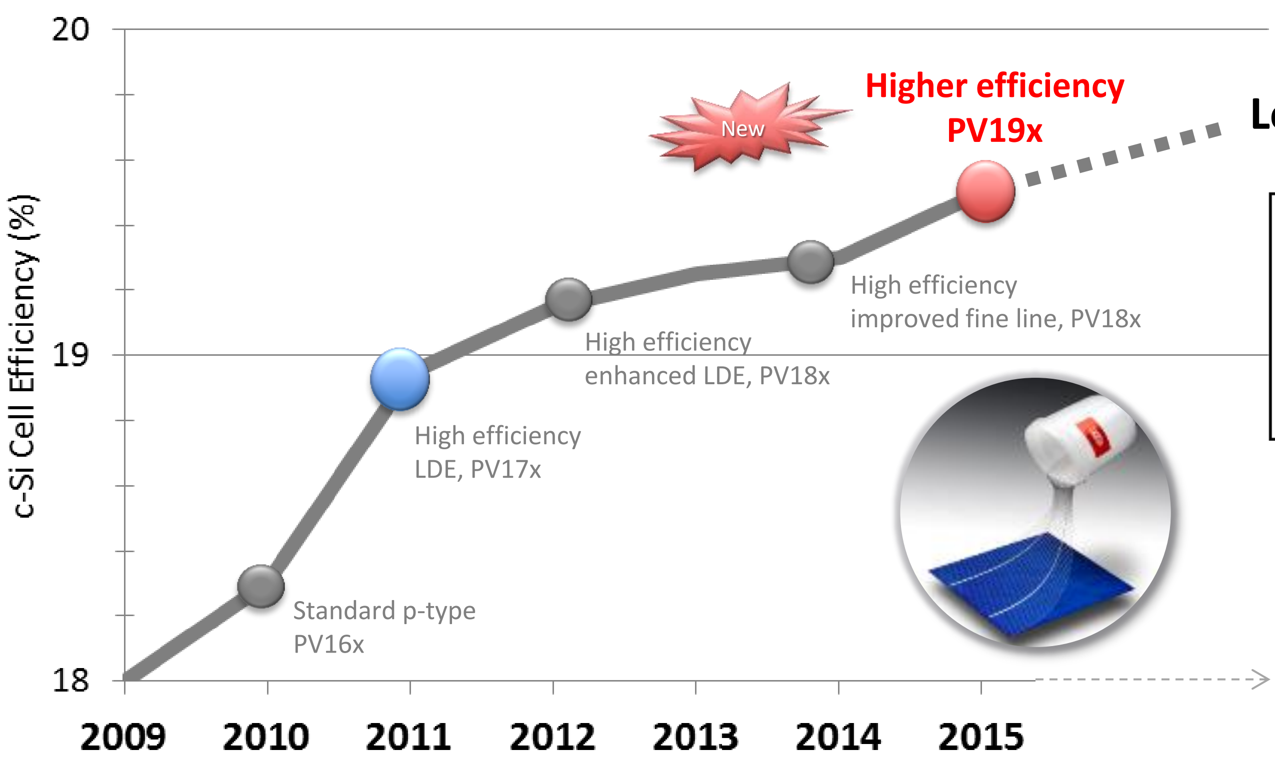
Three Areas Driving The Growth in PVs

Efficiency	Cost	Lifetime
Improve efficiency with innovative materials and cells architectures	Reduce panel and installation cost with improvements in materials and processes	Safe power generation for > 25 years

All Three Drivers are Inseparable

Solamet® Metallization Paste – Delivering Higher Electrical Power

DuPont™ Solamet® Driving Cell Performance Evolution



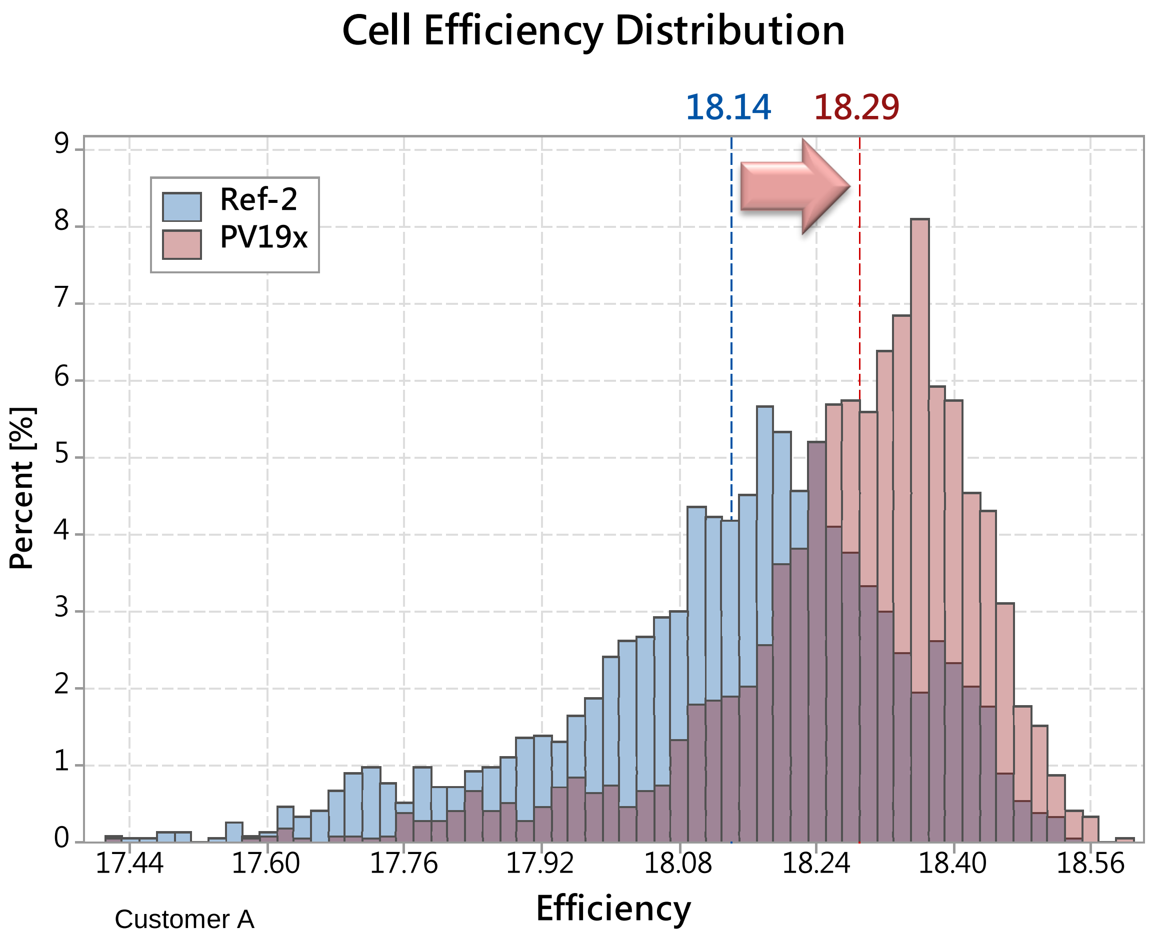
Looking to the future:

Fine line aspect ratio will be key focus in metallization development to improve p-type cell efficiency

First to introduce LDE with Solamet® PV17x achieving a step change in efficiency

New Gen. Solamet® PV19x enabling extreme LDE with excellent fine line capability

DuPont™ Solamet® PV19x Industry Collaboration: Superior Performance and Yield Demonstrated on mc-Si

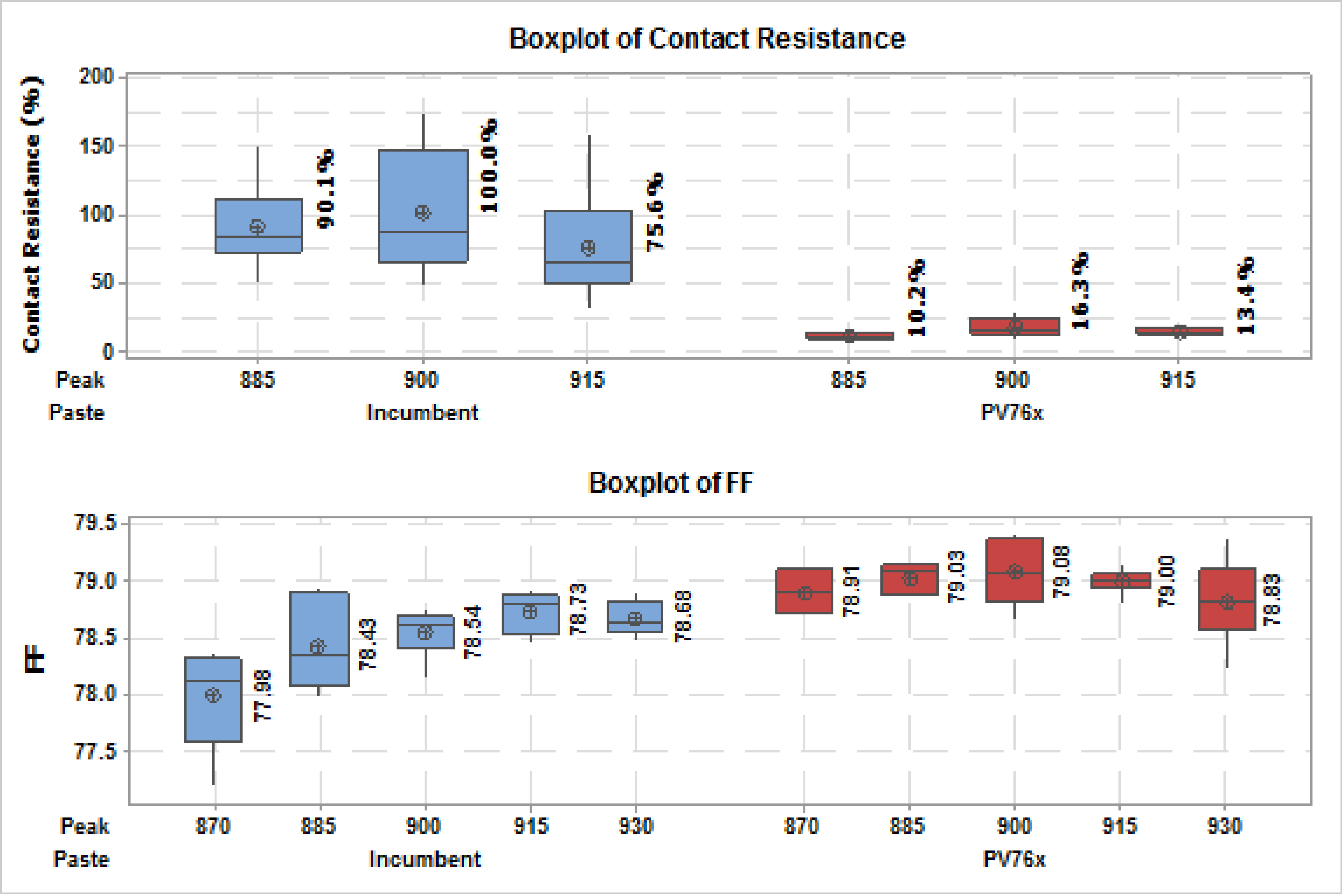


Customer A
N=2500pc

- **>0.15% efficiency gain** on multi proven in pilot run
- **Robust processing latitude** allowing tighter cell distribution to reduce low efficiency binning <17.8%
- **Production yield increased** from 93% to 98.5% for >260W power output

DuPont™ Solamet® PV76x

Front Side Silver Paste Series Designed for PERC



- Excellent contact performance at lower peak firing temperatures
- Lower firing temperature reduces voids and passivation damage
- >0.15% cell efficiency gain vs. conventional front side pastes

Proven Performance on Industry Leading Mono PERC

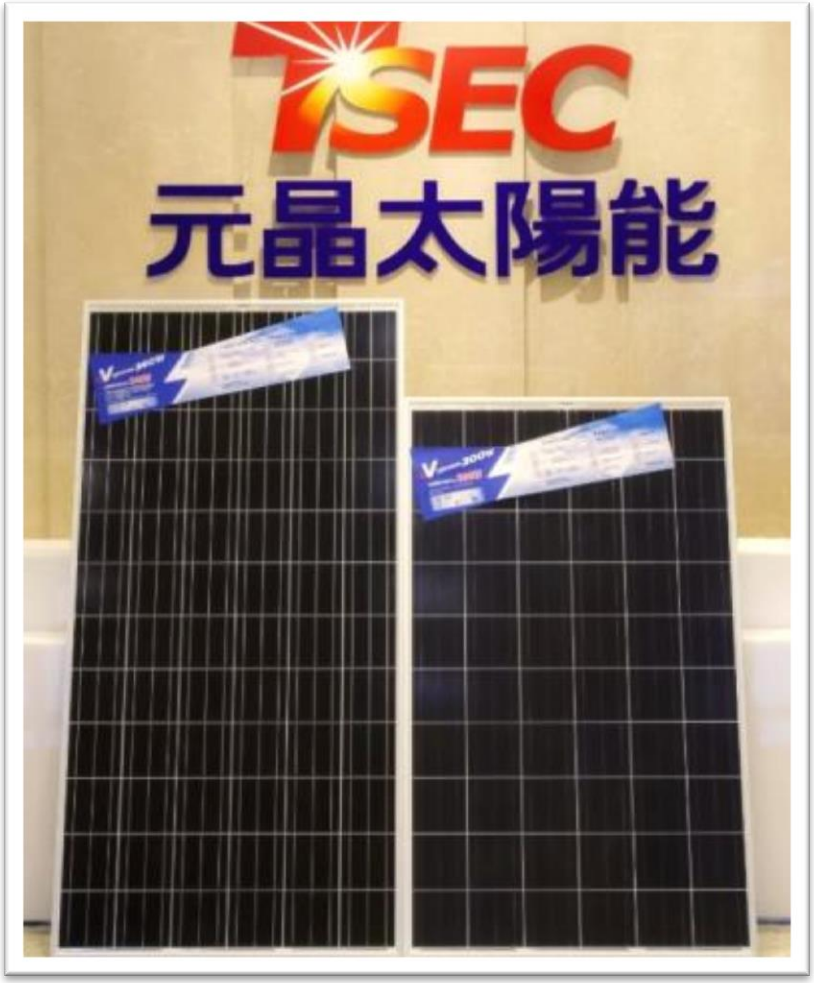
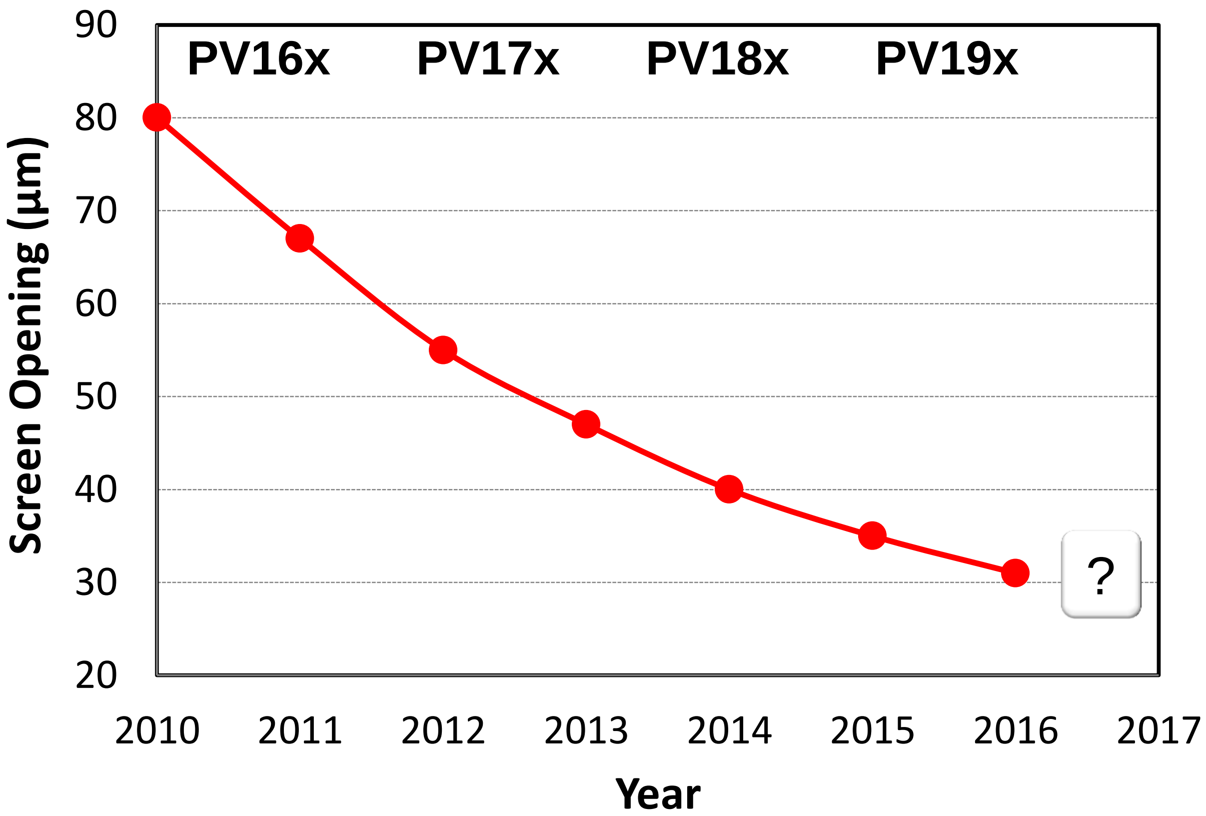


Image courtesy of TSEC

- DuPont collaborated with TSEC to develop front and rear side silver pastes optimized to maximize PERC cell performance
- With the new PERC pastes TSEC gained 0.15% cell efficiency to reach over 21%
- The power output of TSEC's newest "V-Series" panels is more than 300Wp and 360Wp in 60-cell and 72-cell configuration respectively

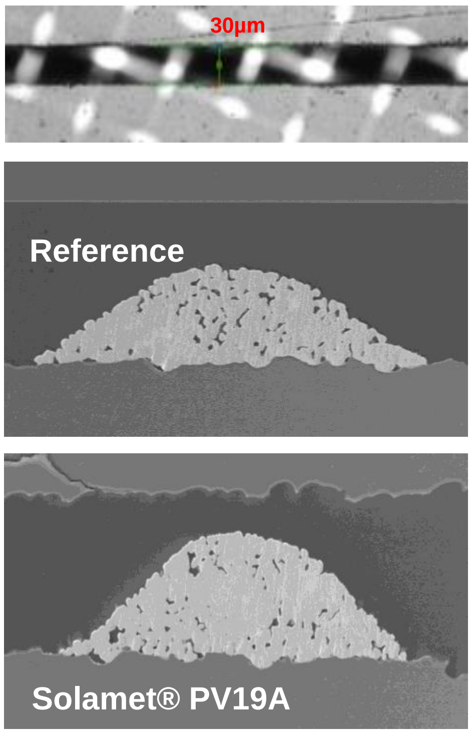
Read more at: http://www.dupont.com/products-and-services/solar-photovoltaic-materials/media/press-releases/20150224-dupont-tsec-high-efficiency-solar-panels.html

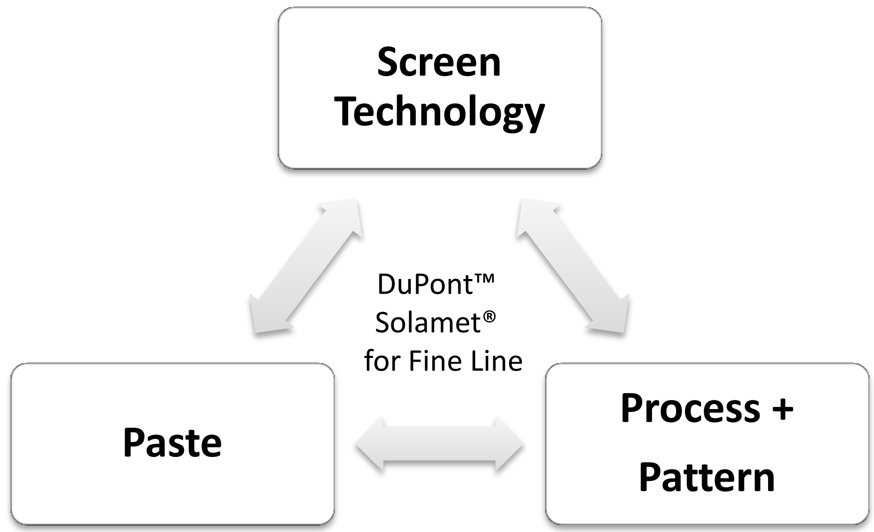
Fine Line Evolution by Solamet® Paste



35µm finger lines are now possible with PV19X

DuPont™ Solamet® Driving Cell Performance Evolution

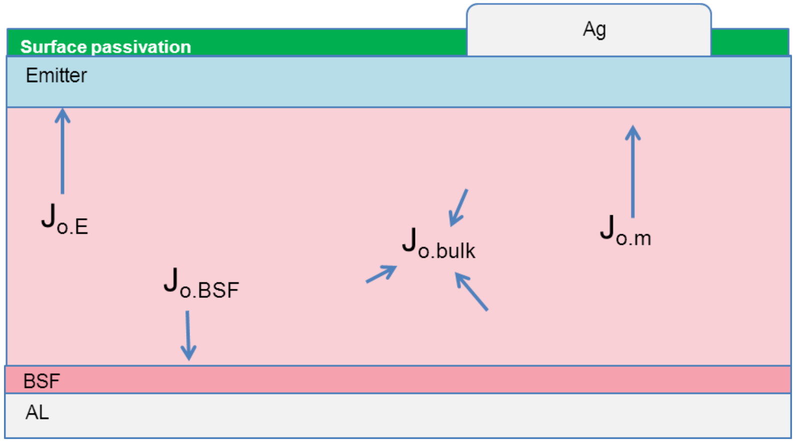


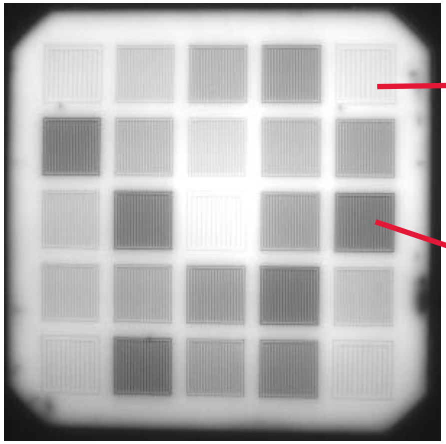


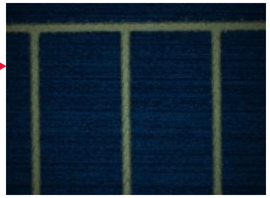
Advance fine line innovations achieved by synergy from screen technology, paste and pattern design

Metal induced recombination: Jo.m

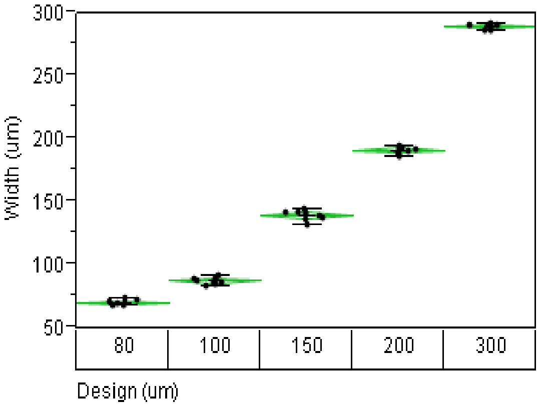
Solar cell Jo is the sum of all component, including Jo.m



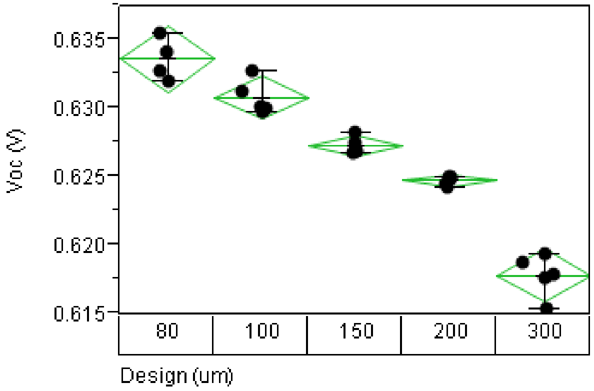




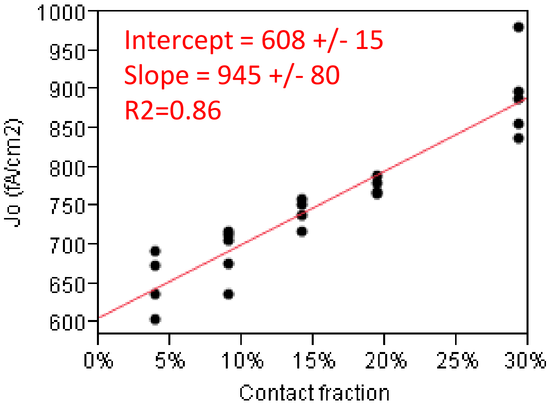
Line width / shading / J_L



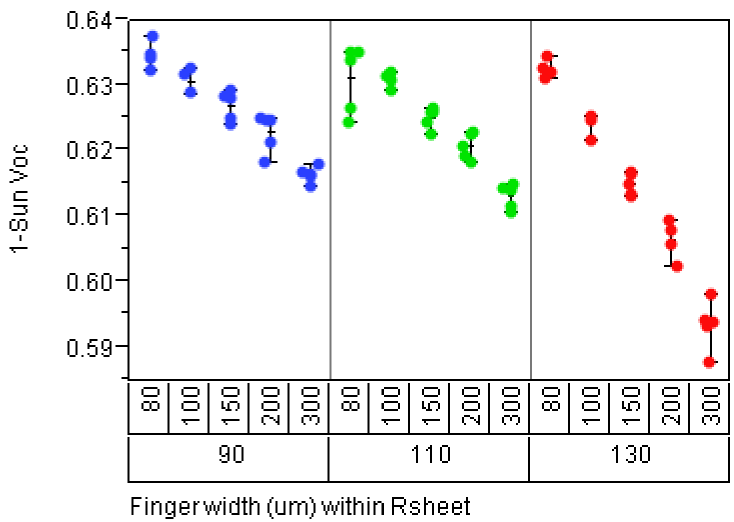
Voc

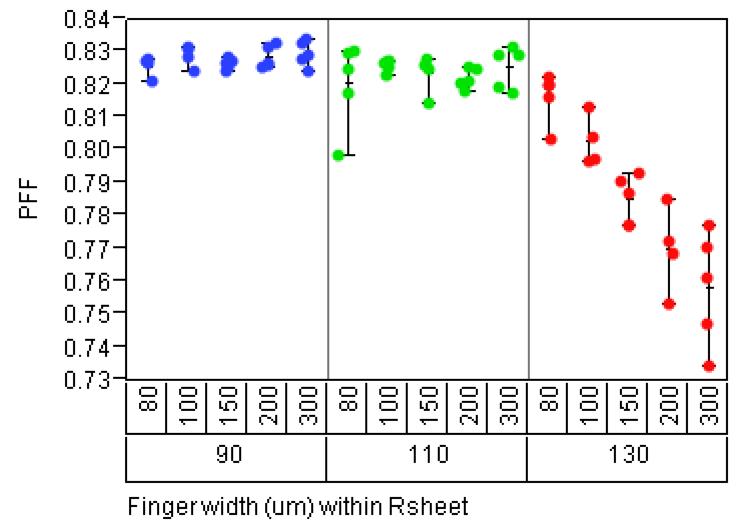


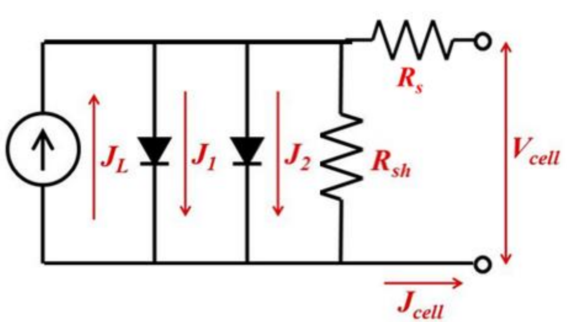
Jo.m = 1015 fA/cm²



- Non idealities stem from many places: Shunts, Schottky contacts, edges
  - Lighter and shallower emitters = high risk





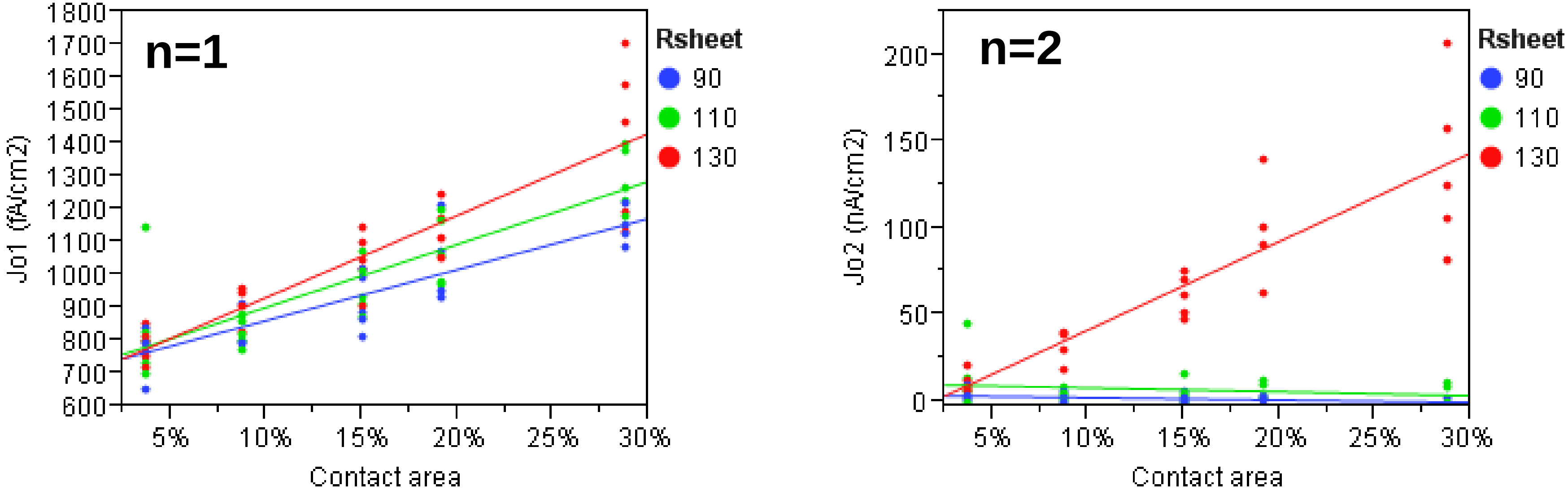


Use the two diode model for non-idealities

-Suns-Voc tester + fit

Image: PV Lighthouse
https://www2.pvlighthouse.com.au/calculators/EC%20calculator/EC%20calculator.aspx

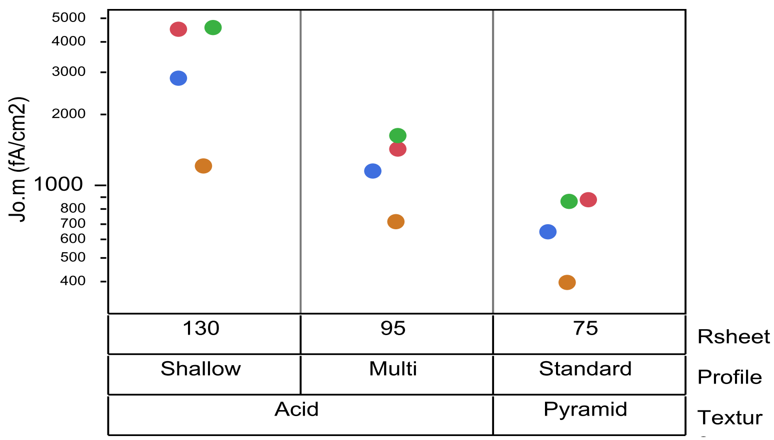
- Jo1.m increases for shallower / higher Rsheet emitters
- n=2 recombination is quantified for very shallow emitter



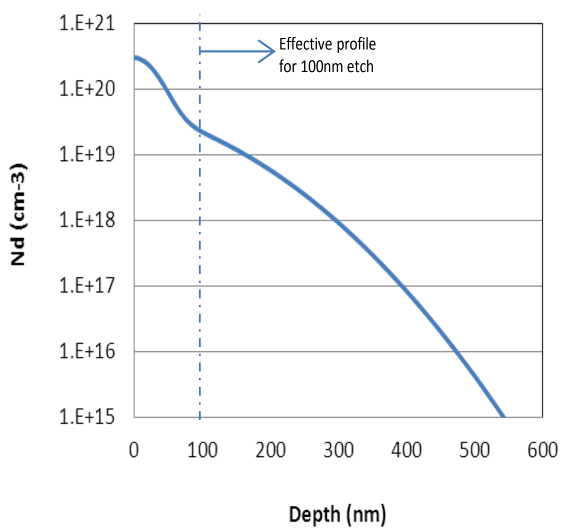
Rsheet (Ω/sq)	Jo1.m (fA/cm2)	Jo2.m (nA/cm2)
90	1420 +/- 200	-12 +/- 6
110	1820 +/- 260	-20 +/- 20
130	2390 +/- 290	510 +/- 80

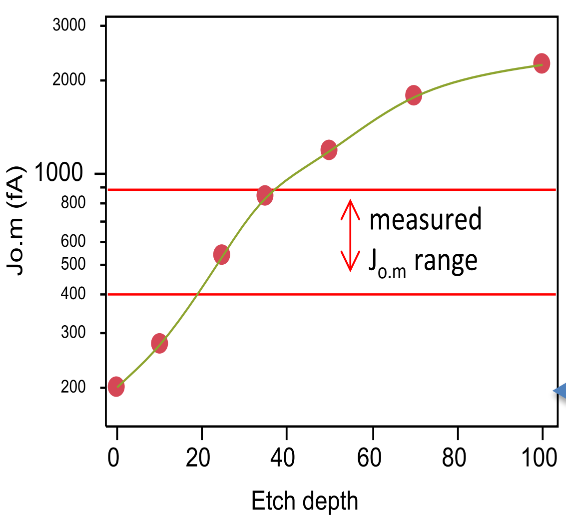
EDNA emitter recombination model

- After M. Abbott et al, IEEE PVSC Denver 2014



EDNA model indicates 20-40nm silicon etch by metal would deliver the Jo.m we measure

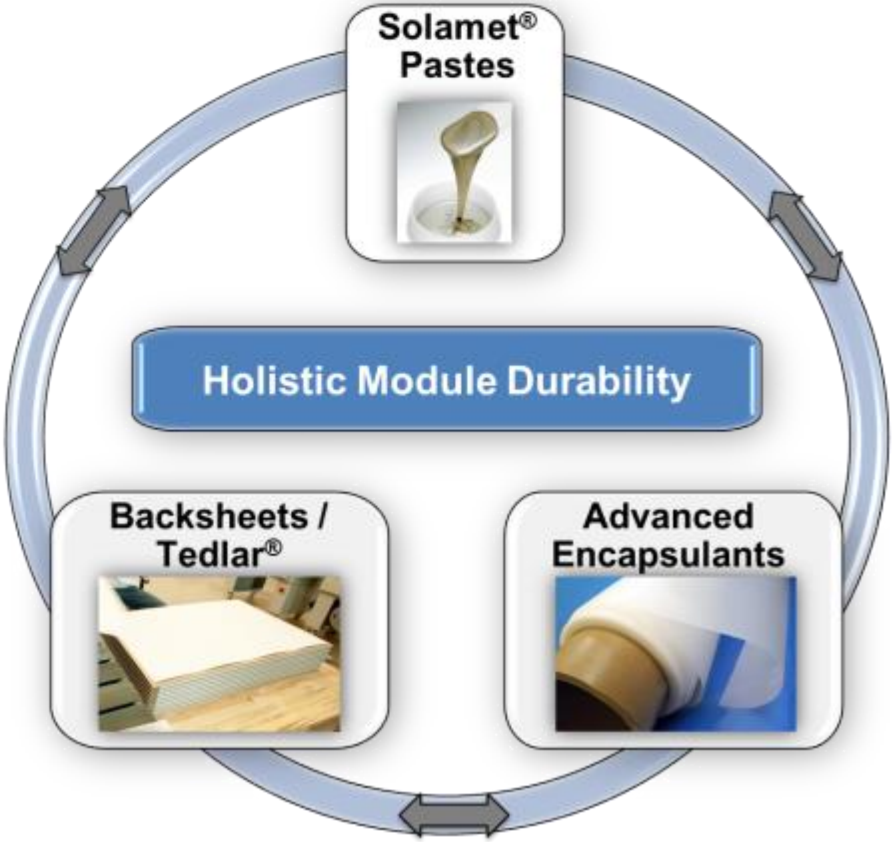




Fundamental limit?

Holistic Cell and Module Durability Program

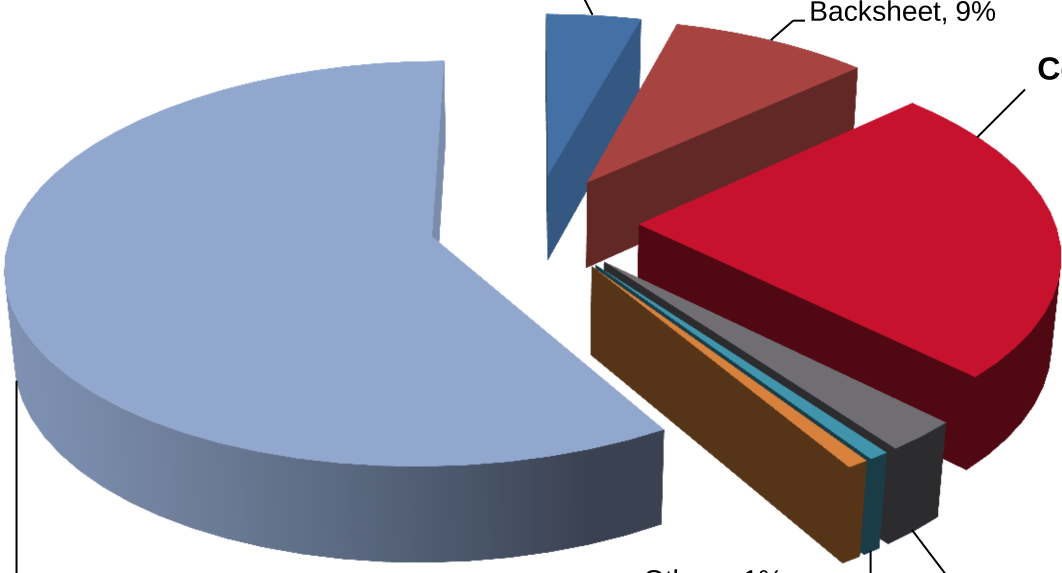
- Evaluate durability for PV materials and their interactions and synergies in module
- Provide science-based understanding of materials-related lifetime performance
- Develop products with highest durability to deliver more power output



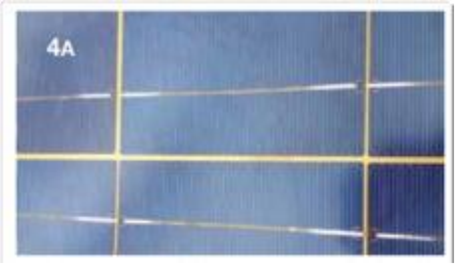
Proven Track Record of Paste Reliability in Various Industries

- More than 40 years thick film composition experiences in high reliable requirement industries e.g., automotive, telecom, military…
- Over 30 years engagement in solar applications

Field Studies Reveal Quality Issues



Subcomponent degradation mode pareto based on visual inspection



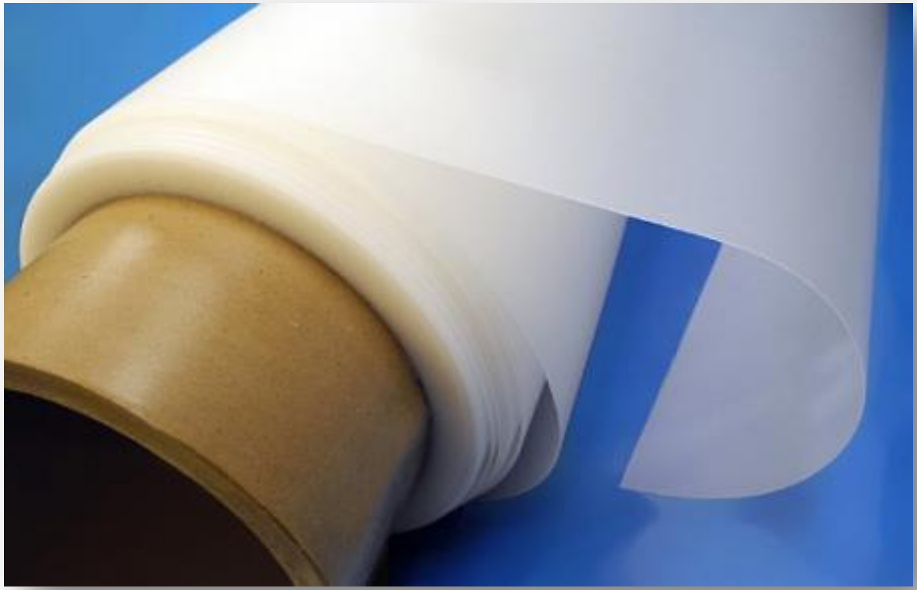
DuPont Field Module Program

- Inspected >60 global installations (>200 MW & 1.5 million modules) in NA, EU, & AP ranging from 0-30 years installed
- Data includes c-Si modules from > 45 module manufacturers

IEEE PVSC (New Orleans, 2015, A. Bradley et al)

41% of inspected modules exhibited some visual defect
Findings consistent with BP and SunPower data

Advanced Encapsulants



Modules with Ionomer encapsulant provide superior reliability

Modules with Ionomer encapsulant are free of snail trails

Modules with Ionomer encapsulant are PID free

EVA as encapsulant

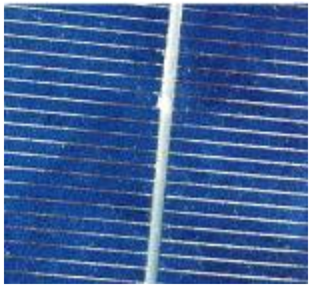
Ionomer as encapsulant

Modules with Standard types of EVA show snail trails, while Ionomers Prevent the Failure Mode

Snail Trails

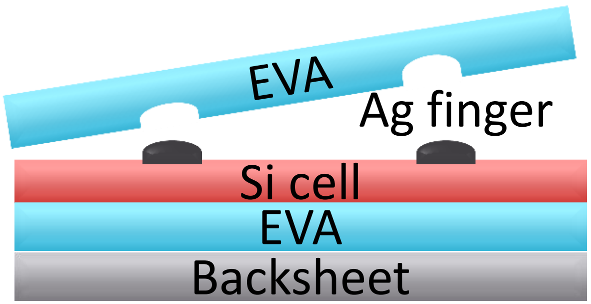
- Mysterious dark lines criss-crossing PV modules
- First occurrence in Spain in March 2007
- Rapid increase in occurrence over past few years

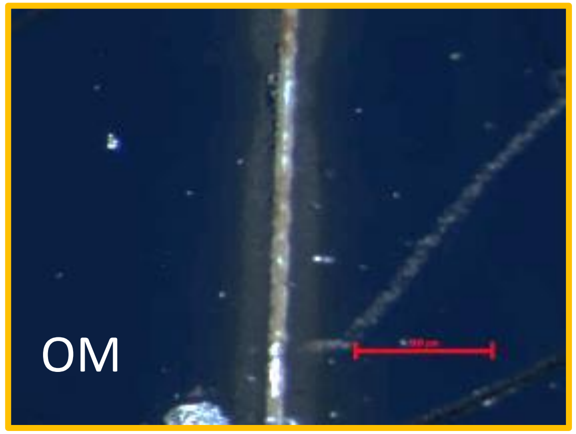


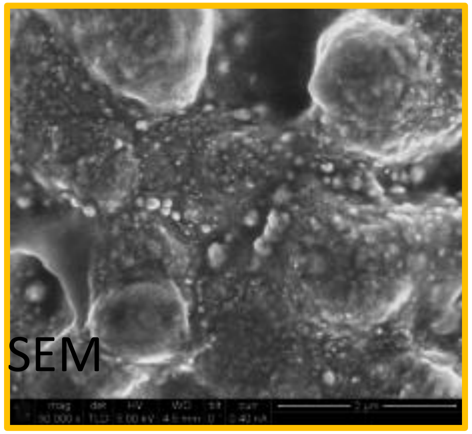



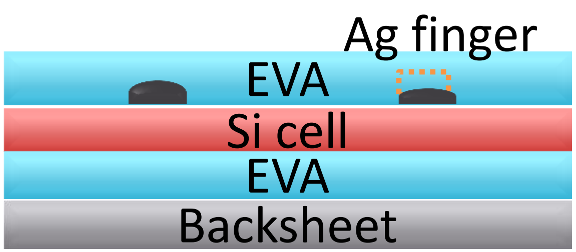
- Location is at the interface of cell and EVA
- Always form on top of **micro-cracks**
- Have affected a large number of module makers

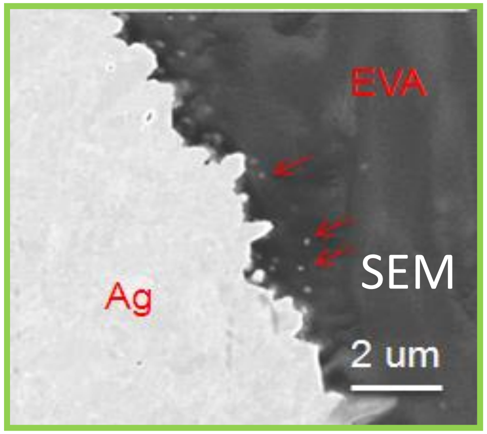
Root Cause of Snail Trail









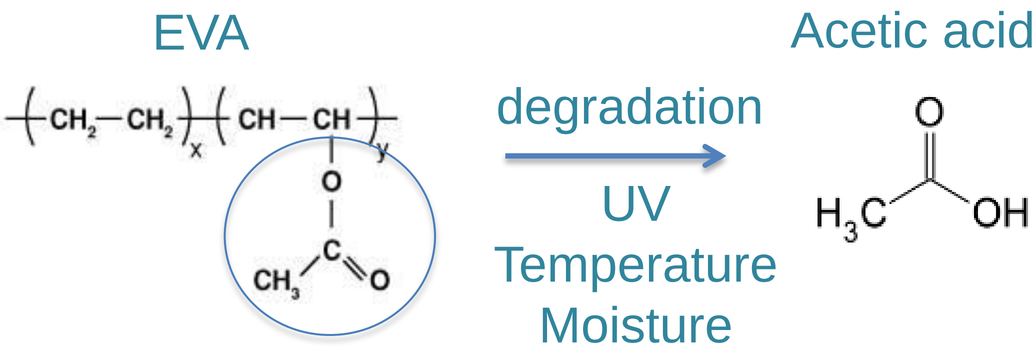


Microscopy analysis showed ***nano-particles*** of different sizes and densities exist on the surface of Ag finger, caused by an interaction between Ag finger and chemistry in EVA.

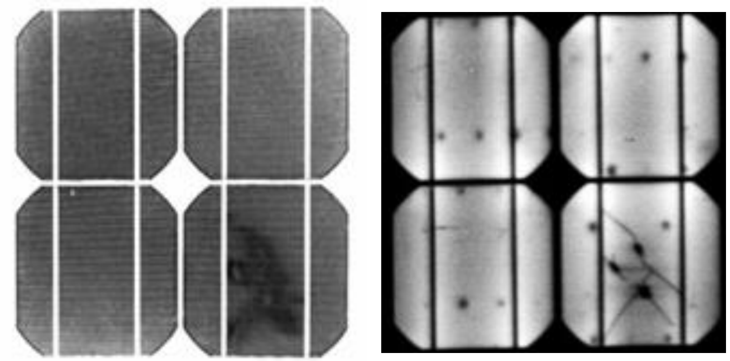
Combined experiments (XPS, Raman and ionic chromatography) revealed that the dark nanoparticle in the snail trail region is ***silver compound***.

Root cause of snail trail is interaction between Ag finger and chemistry in EVA

Acetic Acid in EVA Accelerates Snail Trail Formation



Field test: EVA+AcOH

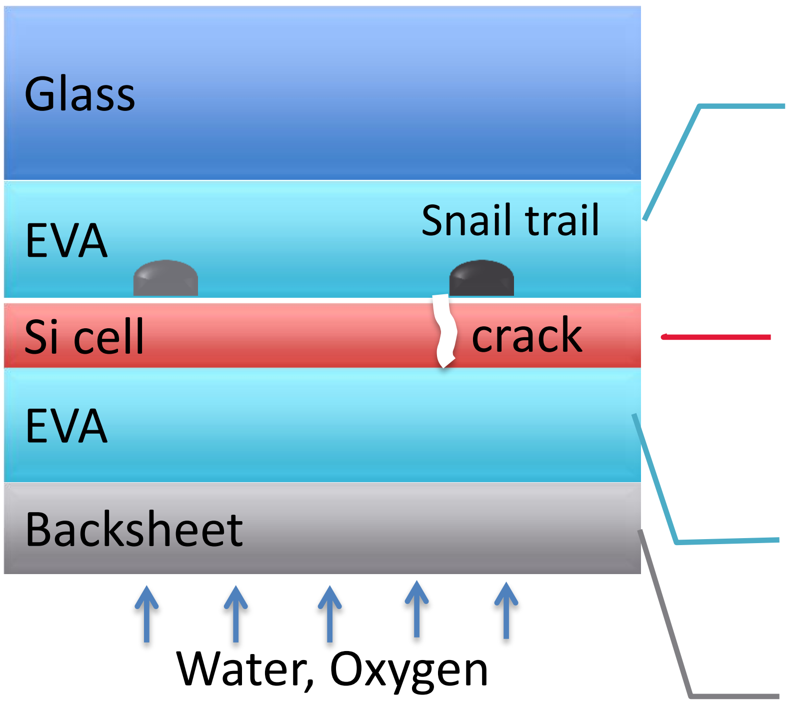


Visual image EL image

EVA			Ionomer
EVA 1#	EVA 2#	EVA 3# with 0.1% acetic acid	
Snail trails After ~4 months	Snail trails After ~5-6 months	Snail trails after ~14 days	No snail trails after 12 months

Acetic acid generated from EVA degradation can significantly accelerate formation of snail trail

Micro-cracks and Water Ingression



Usually takes ~ 1 year to saturate, but local areas with cracks can reach saturation far more quickly

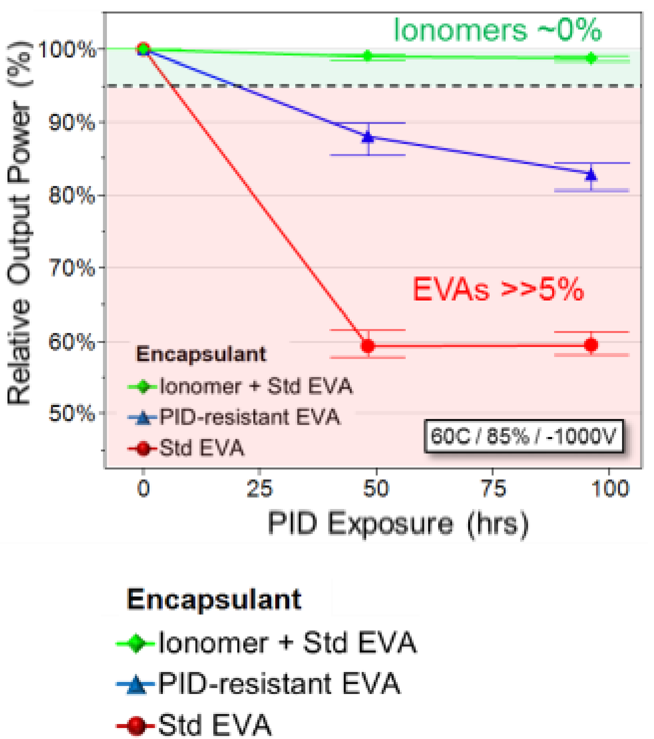
Without cracks ~ 0.06 $g/m^2/d$: Water diffusion mainly through cell edges.
With cracks > 5 $g/m^2/d$: Cracks act as additional moisture diffusion pathway

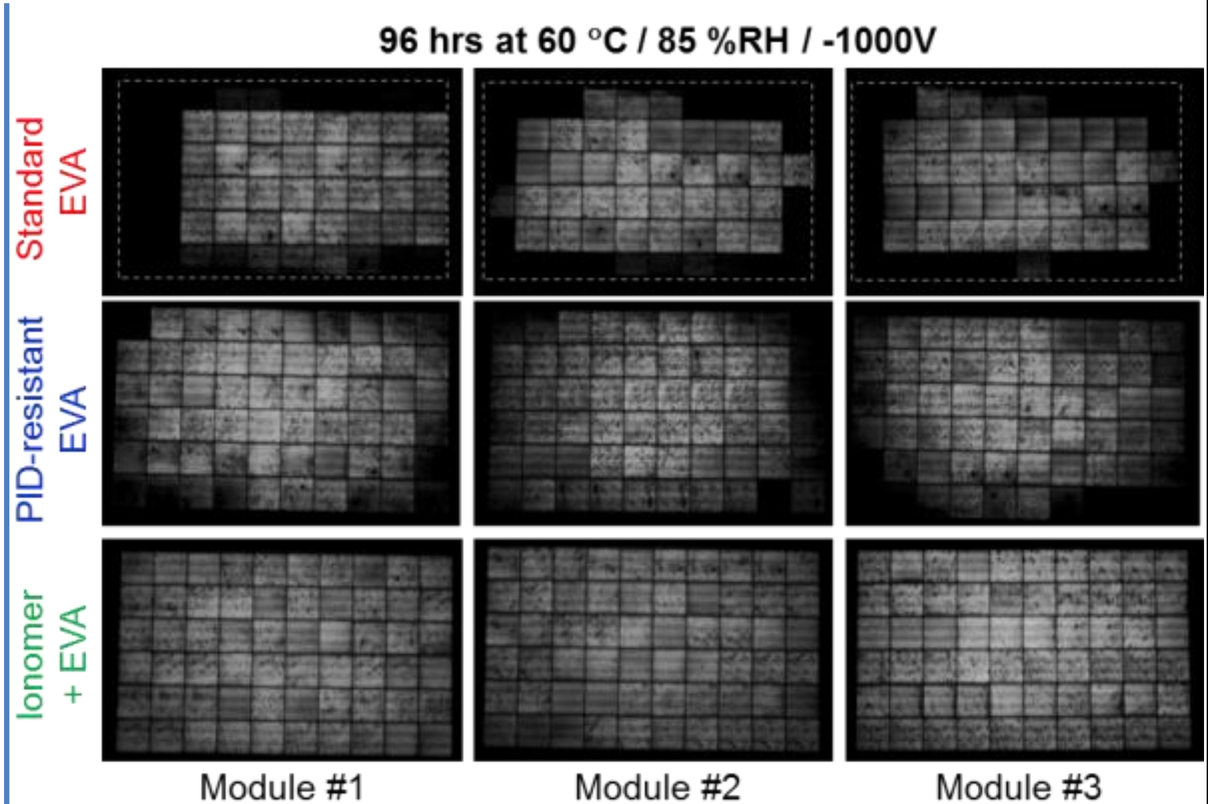
Saturation with water ~ 1 day

0.3~4.5 $g/m^2/d$: Main diffusion path for moisture and gas

Micro-cracks play a more important role than backsheet in the water ingression and snail trail formation.

PID Degradation





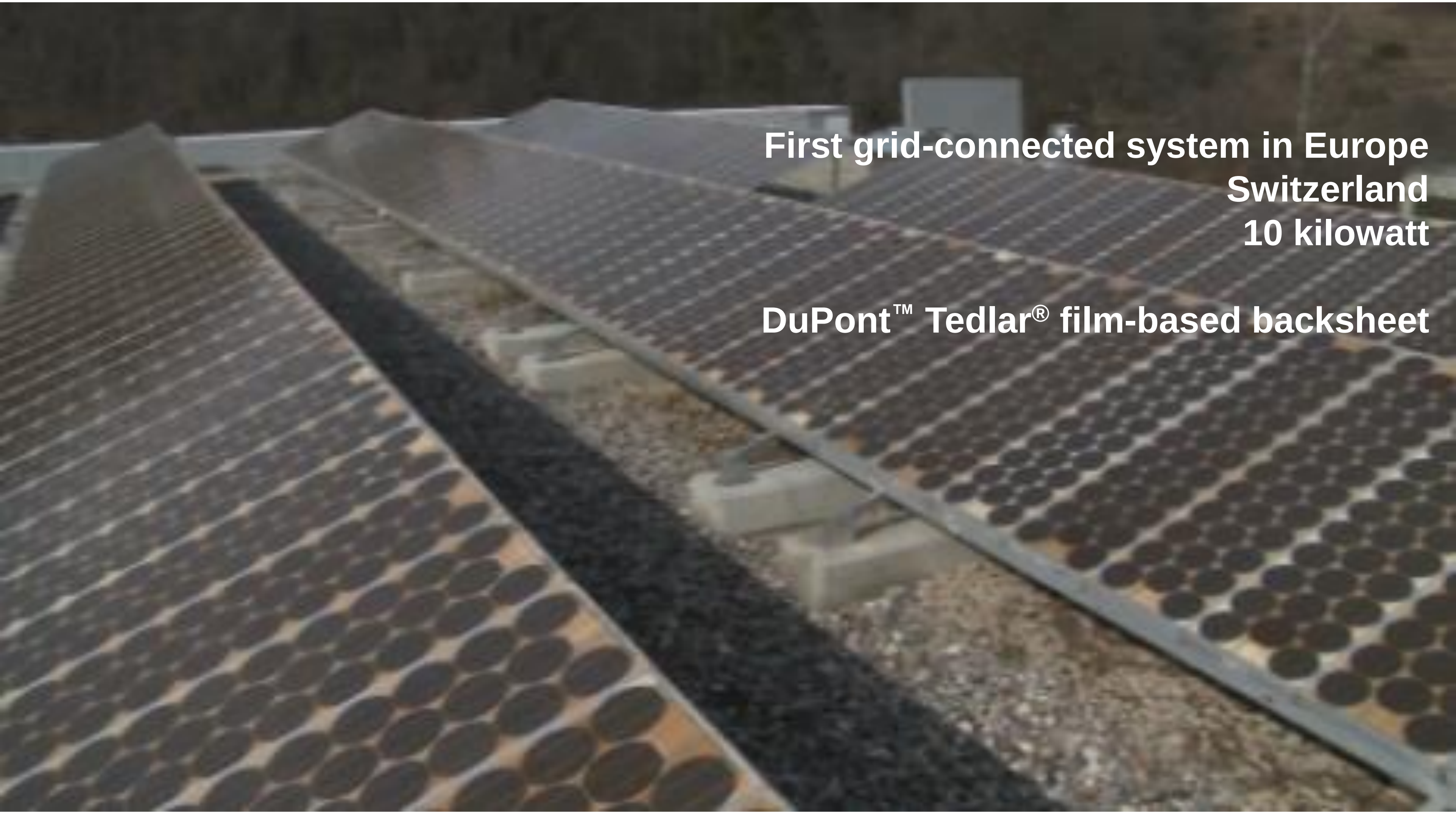
Methodology*:

- Three encapsulants: (a) Strd EVA, (b) "PID-resistant" EVA, (c) **Thin Ionomer+Strd EVA**
- Nine full-size modules, PID-prone cells. Fabricated on industrial module line.
- 60C / 85% / -1000V for 100 hours (also done: 85/85 for >500 hours)

→ **Ionomers do not show any degradation after PID testing, while EVAs degrade**

*) Sergio Pop *et al.*, Presented at PVSEC 2014 in collaboration with Yingli

Powering Reliably Since 1982

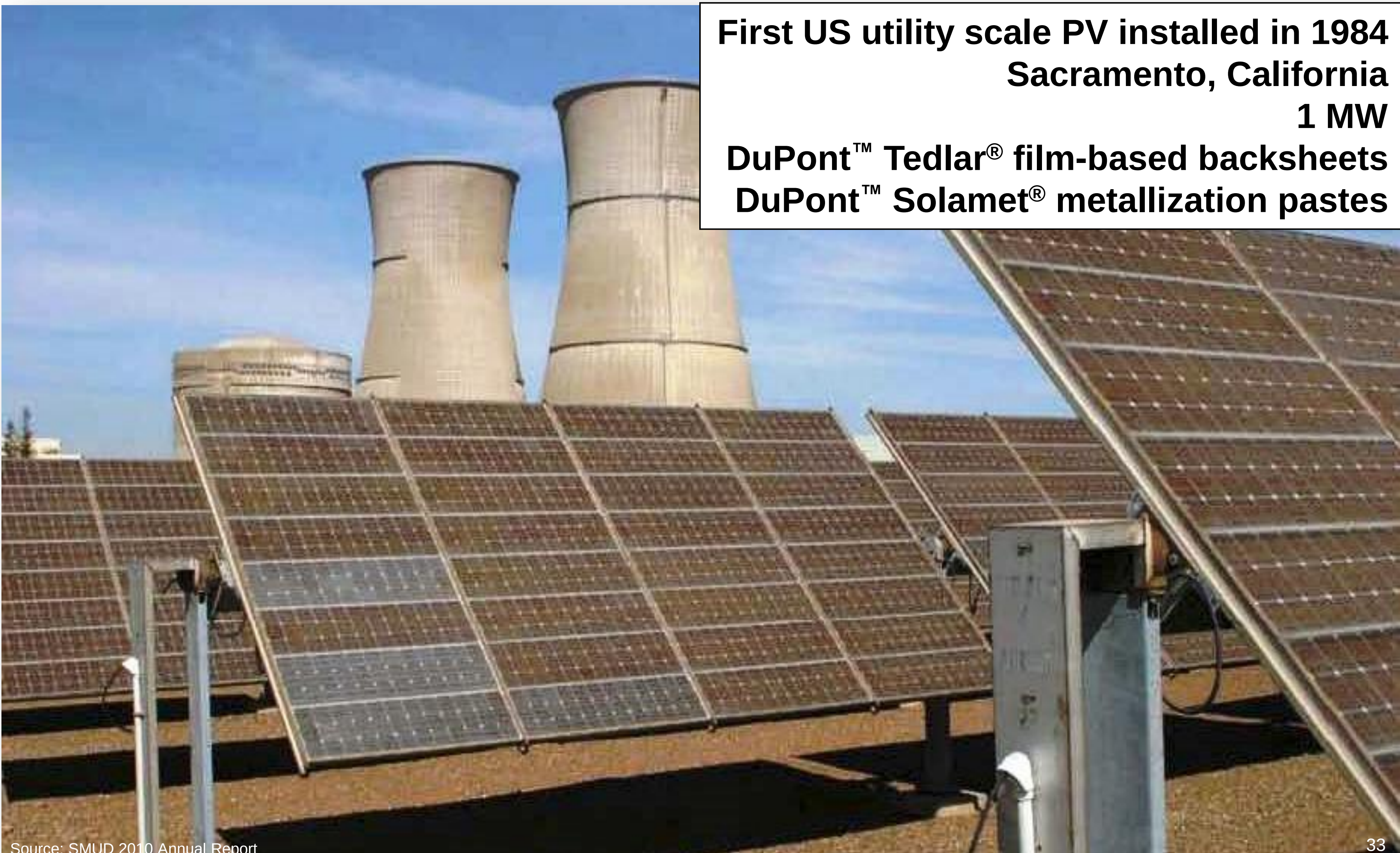


First grid-connected system in Europe
Switzerland
10 kilowatt

DuPont™ Tedlar® film-based backsheet

DuPont Materials Powering Reliably for Decades

First US utility scale PV installed in 1984
Sacramento, California
1 MW
DuPont™ Tedlar® film-based backsheets
DuPont™ Solamet® metallization pastes



Source: SMUD 2010 Annual Report

Summary

- Choice of materials significantly impacts solar panel performance and financial returns - Materials Matter™

- DuPont™ Solamet® PV19x delivers efficiency improvement
  - Excellent fine line printability down to 30µm screen opening with improved aspect ratio
  - Integrated PERC Solutions with DuPont™ Solamet® PV76x/PV56x/PV36x delivers gains exceeding 0.15% in production
  - Low voltage losses

- Advanced Ionomer encapsulants
  - Snail trails can be corrected
  - Resistant to PID

photovoltaics.dupont.com

The miracles of science™