NREL National Renewable Energy Laboratory | Sandia National Laboratories | U.S. Department of Energy — Energy Efficiency & Renewable Energy

Utility/Lab Workshop on PV Technology and Systems

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Tempe, Arizona

NREL/PR-5200-49854

Survey of PV Field Experience

Dirk Jordan
NREL

SEPA solar electric power association | SRP Delivering more than power.™ | EPRI Electric Power Research Institute

Outline

- ♦ Introduction
- ♦ Historical component failures

  20 years ago – Modules ; Today - Inverters
- ♦ Historical degradation rates (R_d)

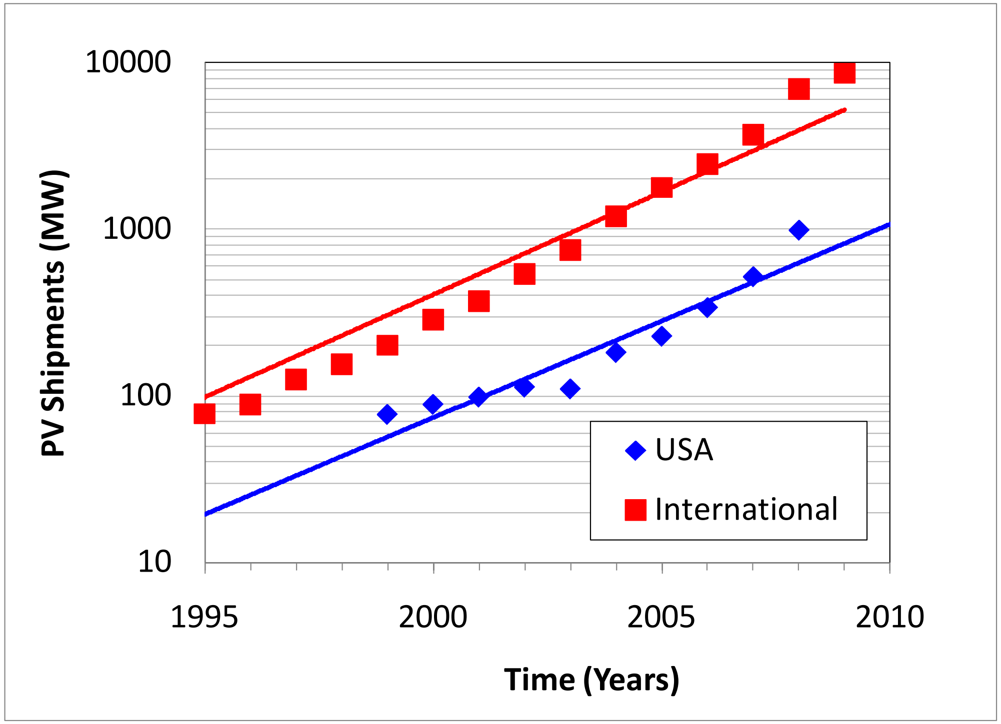
  Most modules degrade at 0.5%/year & are improving
- ♦ Connection Degradation rate uncertainty & risk

  Higher uncertainty leading to higher risk

Growth of PV Industry

Photo credit: Steve Wilcox, NREL PIX 15548

Alamosa Plant in Colorado

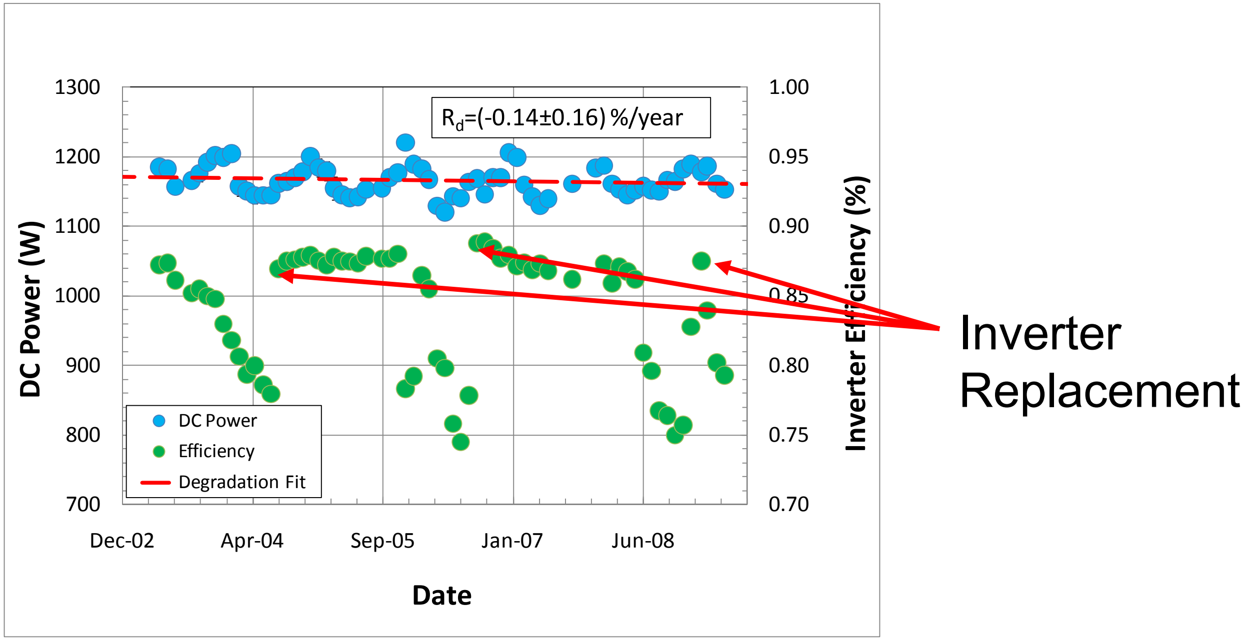


Sources:
International: PV News, April 2009
USA: http://www.eia.doe.gov/emeu/international/contents.html

Reliability required to sustain exponential growth of industry

Reliability & Durability

- **Reliability:** Ability to perform designed task without failure → discrete, disruptive events
- **Durability:** Ability to perform task without significant deterioration → continuous, gradual decline



Extreme example of inverter failure

Both important for cost of electricity

PV for Utility Scale Application (PVUSA)

The plant was originally constructed by the Atlantic Richfield oil company (ARCO) in 1983.

Provided electricity, research opportunity, data & experience through the 1980s and 1990s.

Plant was dismantled in the late 1990s.

Location: Carrisa Plains
Size: 5.2 MW
Data: 1988

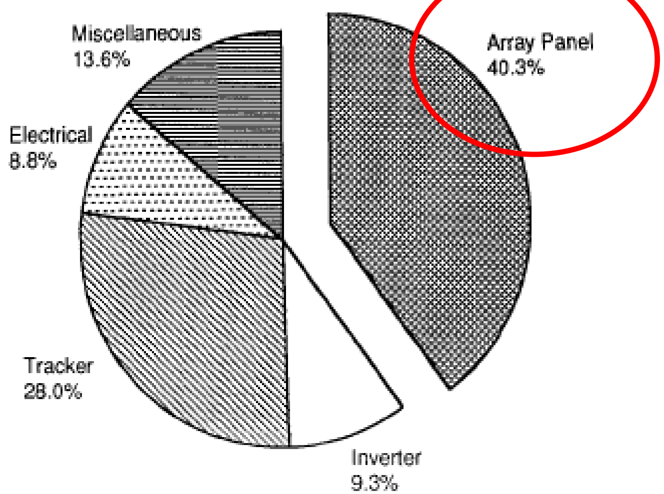


Figure 7. Maintenance labor hours, 1988. Percent of 3,100 total labor hours allocated by plant subsystem.

Some Research Publications

- Emerging Modules at PVUSA_Townsend_PG&E_1995.pdf
- Irradiance & Temp Effects on PV power_Whitaker_Endecon_IEEE_1991.pdf
- New performance index PVUSA_Townsend_PG&E_IEEE_1994.pdf
- New PV performance model_Whitaker_Sandia_PVSC_1997.pdf
- Outdoor PV perfromance at PG&E_Jennings_PVSC_1990.pdf
- PG&E Research_Weinberg_PG&E_PVSC_1989.pdf
- PV module performance_Jennings_PVSC_1988.pdf
- PV Power performance_Wenger_PG&E_PVSC_1990.pdf
- PV research PG&E_Jennings_PG&E_PVSC_1990.pdf
- PVUSA 1st decade_Jennings_PG&E_IEEE_1996.pdf
- PVUSA beginning_Hester_PG&E_1988.pdf
- PVUSA early lessons_Hester_1996.pdf
- PVUSA for PV plant_Dows_PVUSA_1995.pdf
- PVUSA progress report 1989.pdf
- PVUSA progress report 1991.pdf

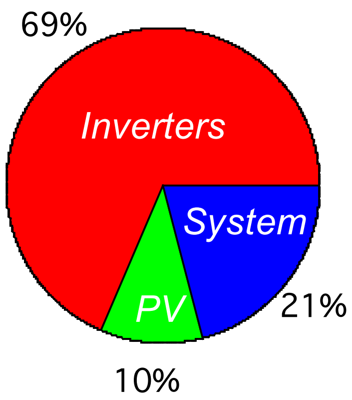
"CARRISA PLAINS PV POWER PLANT PERFORMANCE", Wenger et al., PG&E, PVSC 1990.

Plant contained engineering modules.

Panels showed the highest maintenance

Tucson Electric Power - Springerville

"Five Years of Operating Experience at a Large, Utility-scale Photovoltaic Generating Plant", L. M. Moore et al., Prog. Photovolt: Res. Appl. 2008; 16:249–259



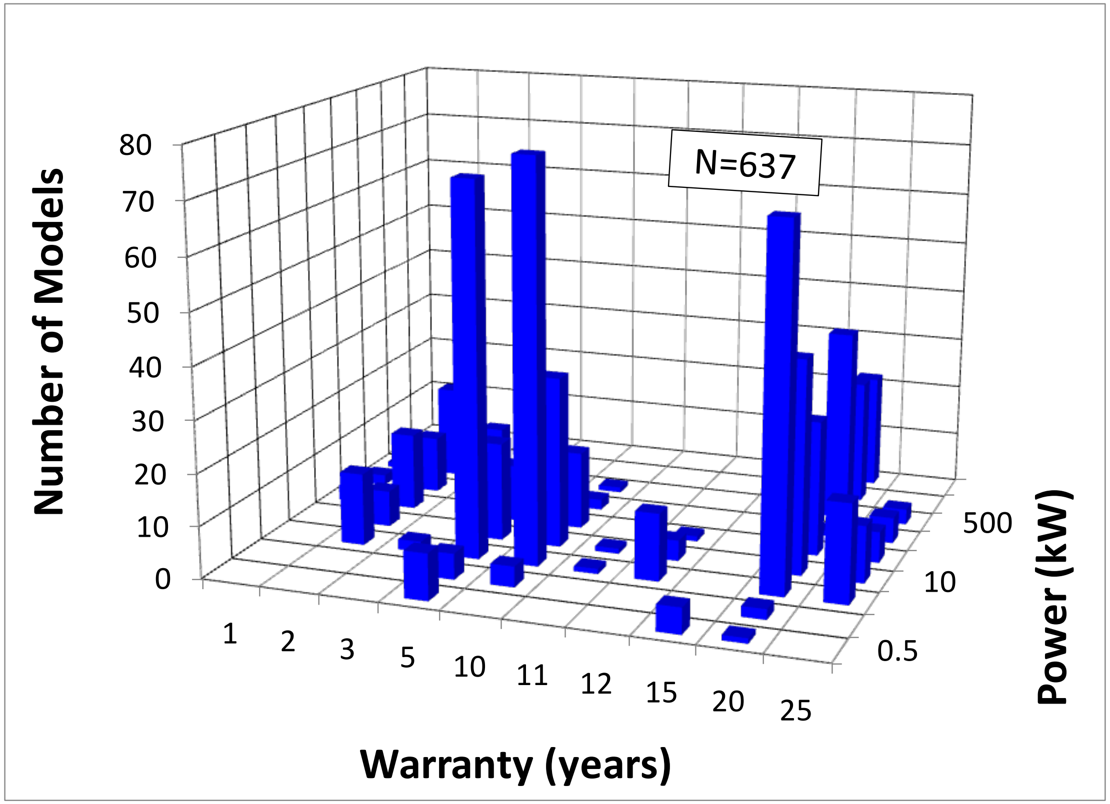
Unscheduled maintenance costs for PV system operation

Category	No. Events (%)	Cost (%)	Notes
Inverter	37	59	25% from 1 lightning storm
DAS	7	14	90% from 1 lightning storm
AC Disconnect	21	12	50% due to dirt accumulation
Module/ J Box	12	3	60% due to failed blocking diode
PV Array	15	6	45 % from 1 lightning storm
System	8	6	All utility meter

Module stability has improved over the last 20 years → the next component requiring improvement is the inverter.

Inverters seem to dominate O&M cost now

Maximum Warranties - Inverters



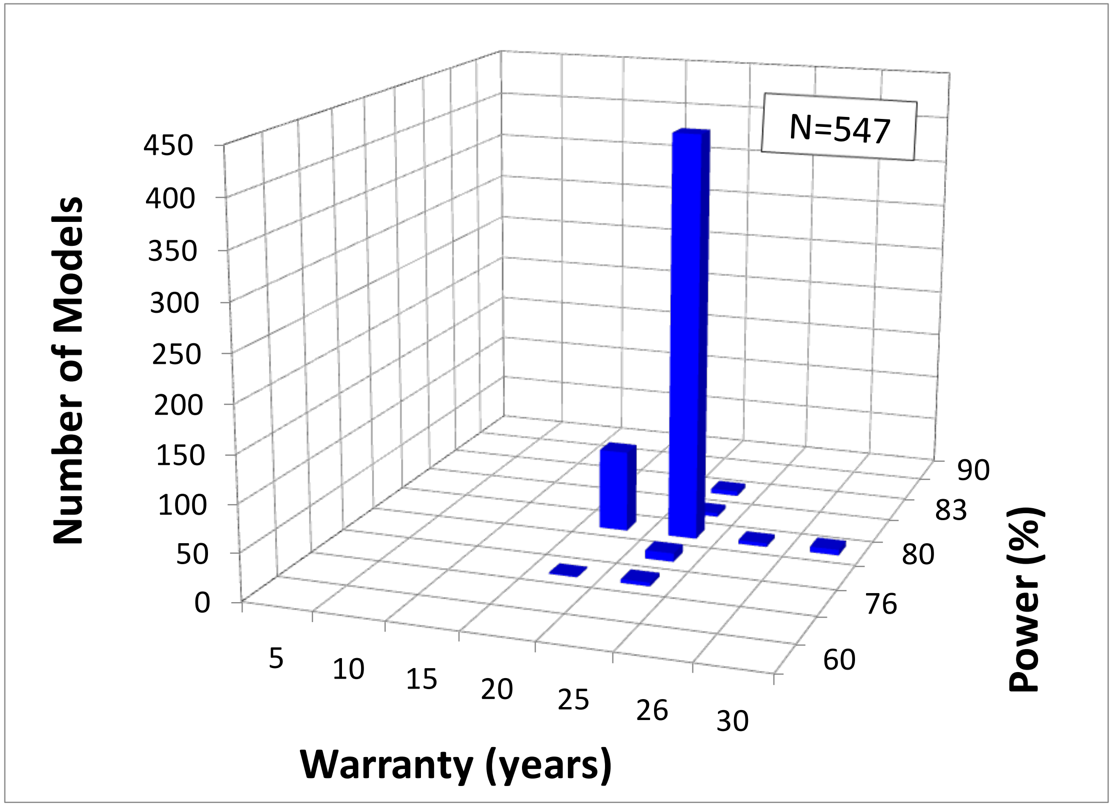
Source:
Photon International,
April 2010

Inverters suffer from early failures in the field due temperature-related issues, mismatch between PV voltage and inverter window.

Qualification and performance standards for inverters and BOS are not well-defined

Inverters are improving but still have wide distribution

Maximum Warranties - Modules



Source: Photon International, Feb 2010

Solarex/BP module Warranty Period

Date	Length of Warranty
Before 1987	5 Years
1987 – 1993	10 Years
1993 – 1999	20 Years
Since 1999	25 Years

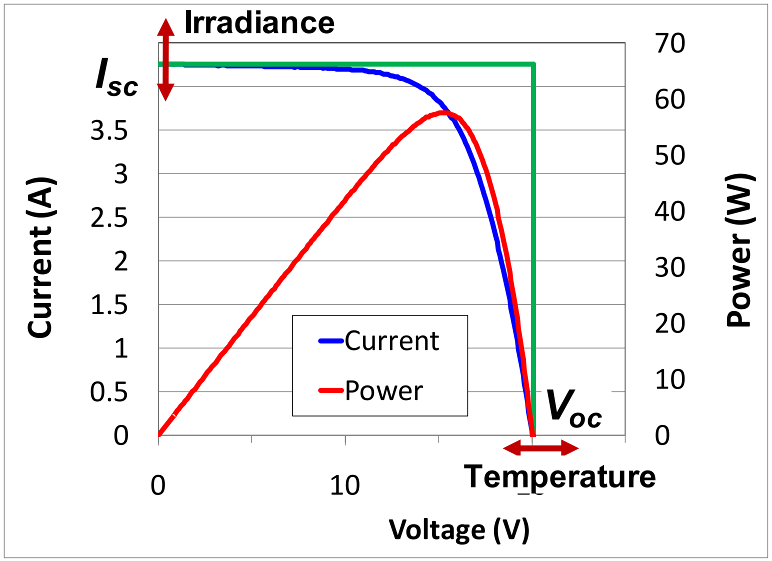
"Long Term Photovoltaic Module Reliability", J.Wolgemuth, NCPV and Solar Program Review Meeting 2003

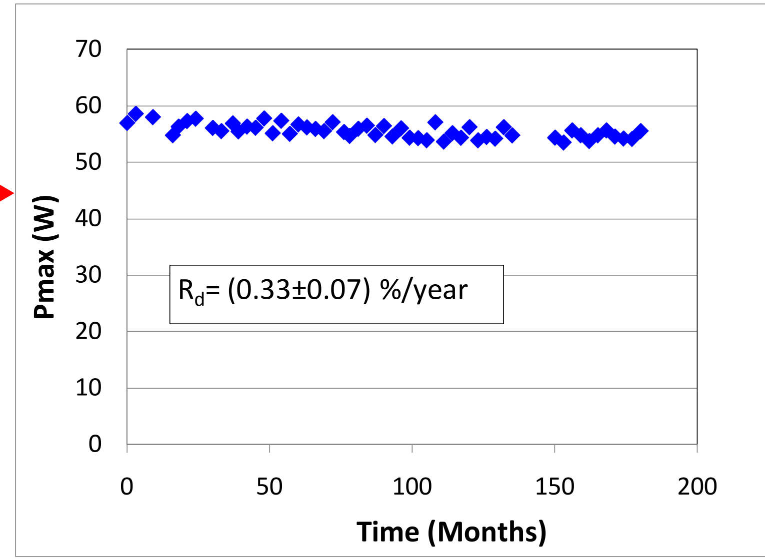
Module maximum warranties typically greater than inverters

PV modules show smaller distribution

Degradation Rate (R_d)- Discrete Points

1. Translation to reference conditions (IEC60891)
2. Time series to determine degradation rate

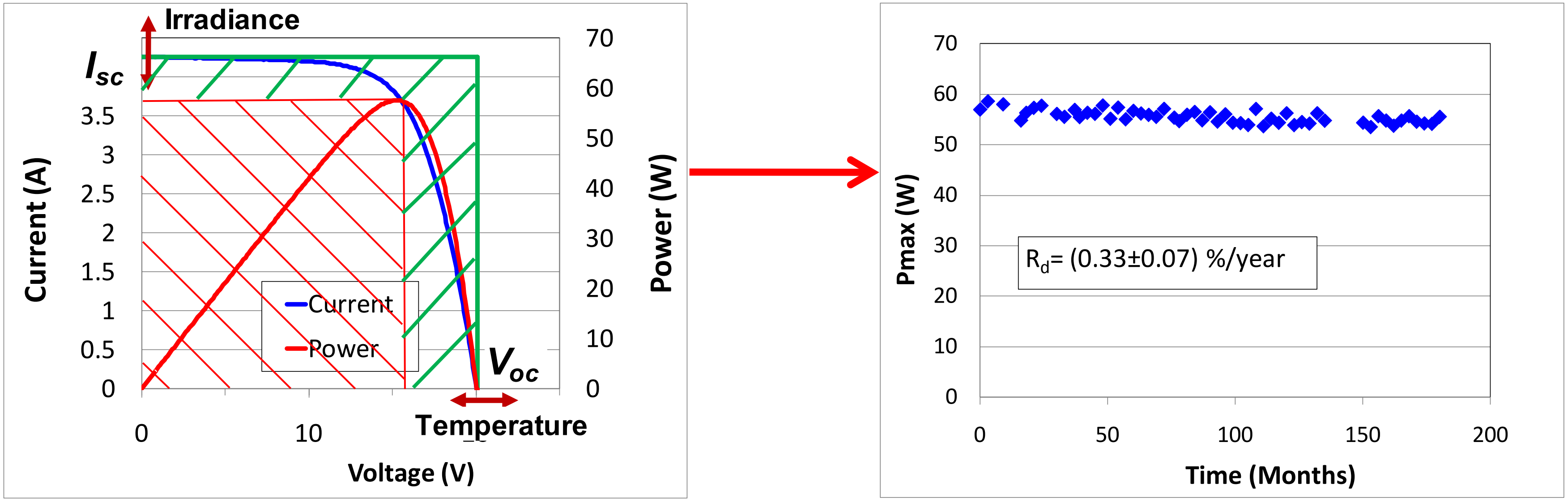




Quarterly taken I-V curves for degradation

Degradation Rate - Discrete Points

1. Translation to reference conditions (IEC60891)
2. Time series to determine degradation rate

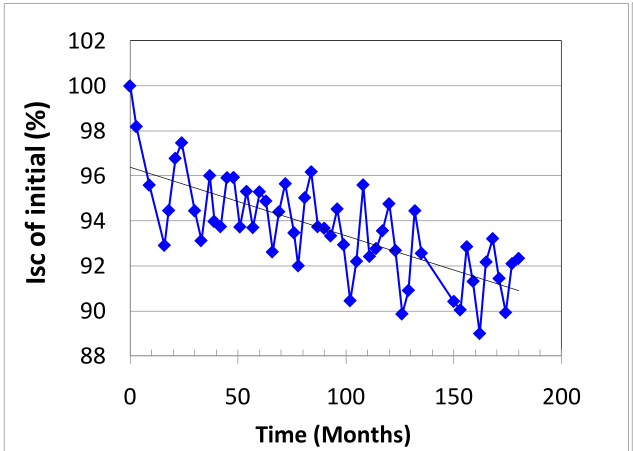


$$FF = \frac{P_{\max}}{I_{sc} \cdot V_{oc}} = \frac{I_{\max} \cdot V_{\max}}{I_{sc} \cdot V_{oc}}$$

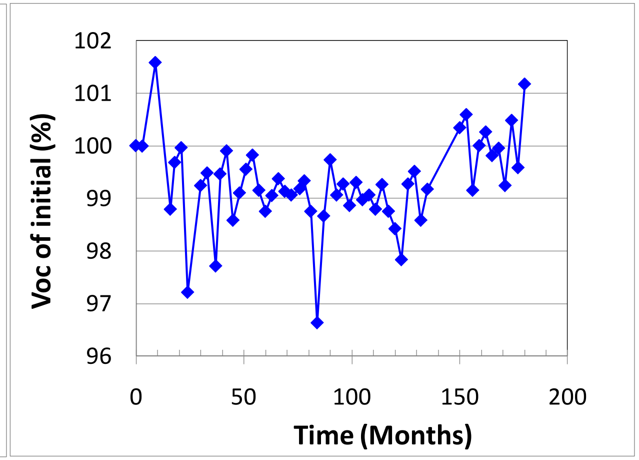
Quarterly taken I-V curves for degradation

Degradation Rate - Discrete Points

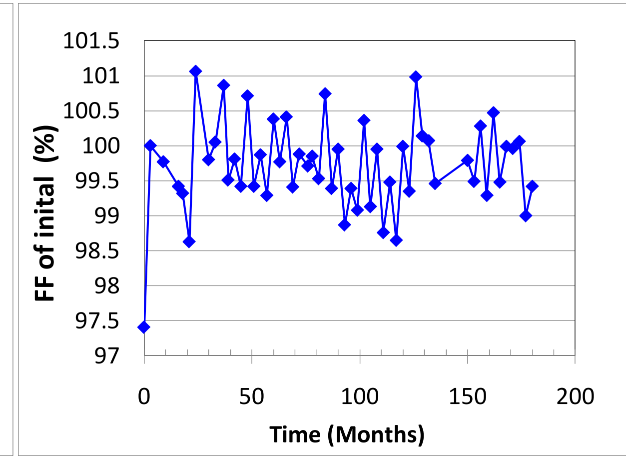
Short-circuit Current



Open-circuit Voltage



Fill Factor



Degradation is due to decline in I_{sc}, (V_{oc} & FF are stable) → clues to failure mechanism

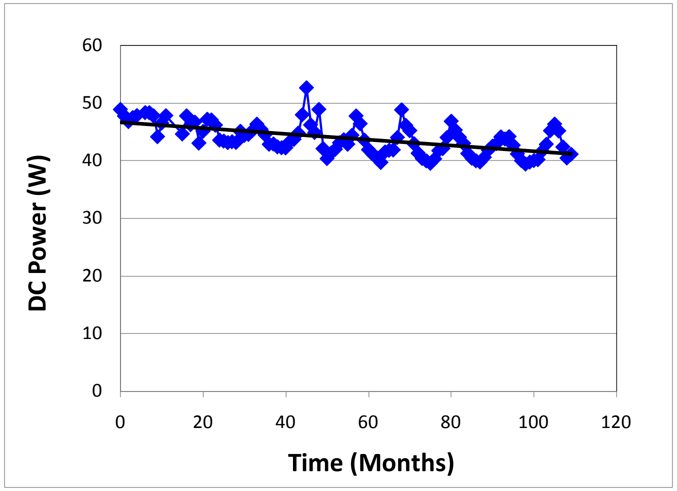
Problem: 1. Labor-intensive, has to be clear sky
2. Large arrays → portable I-V tracer may not be available
3. Typically not available

I-V curves provide clues to underlying failure mechanism

Degradation Rate - Continuous Data

1. Translation to reference conditions (use a multiple regression approach)
2. Time series to determine degradation rate

DC, AC Power



PVUSA – multiple regression

$$P = E \cdot \left(a_1 + a_2 \cdot E + a_3 \cdot T_{ambient} + a_4 \cdot ws\right)$$

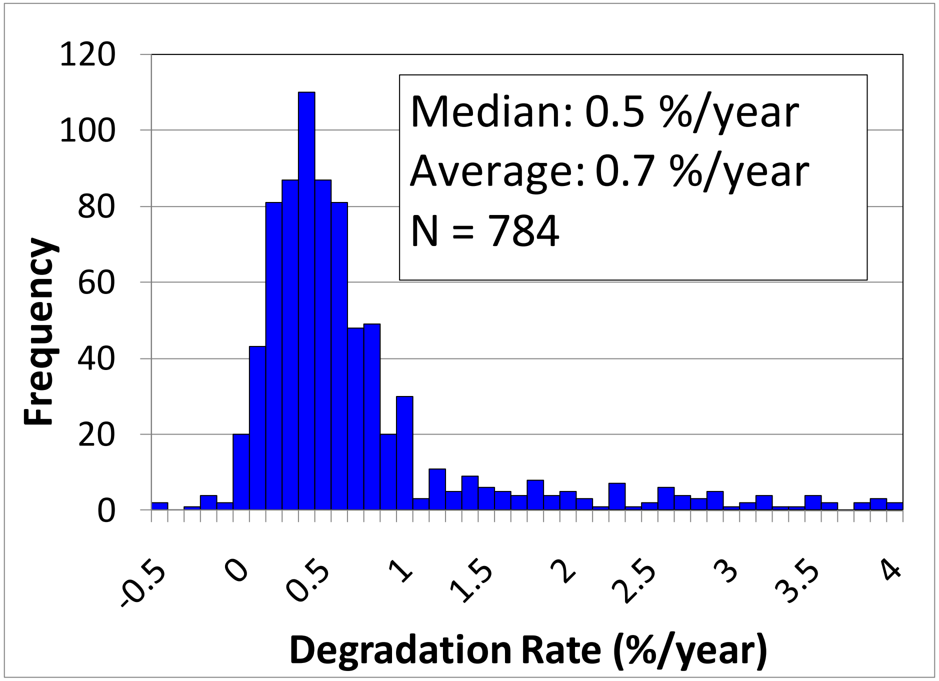
Standard Test Conditions (STC): E=1000 W/m^2, Tmodule=25ºC
PVUSA Test Conditions (PTC): E=1000 W/m^2, Tambient=20ºC, wind speed=1 m/s

Seasonality leads to required observation times of 3-5 years → long time in today's market

Long time required for accurate R_d

Historical Degradation Rates

Published R_d in literature

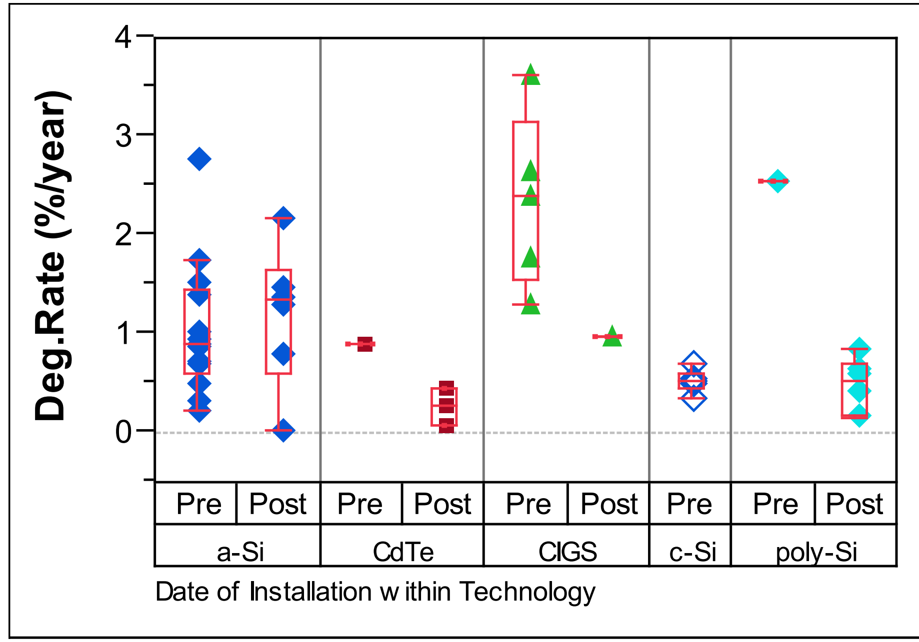


Technology, age, packaging, geographic location

Most modules degrade by ca. 0.5 %/year

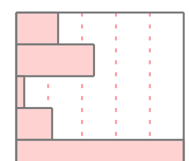
PERT – Degradation Rates

Performance Energy Rating Testbed = PERT



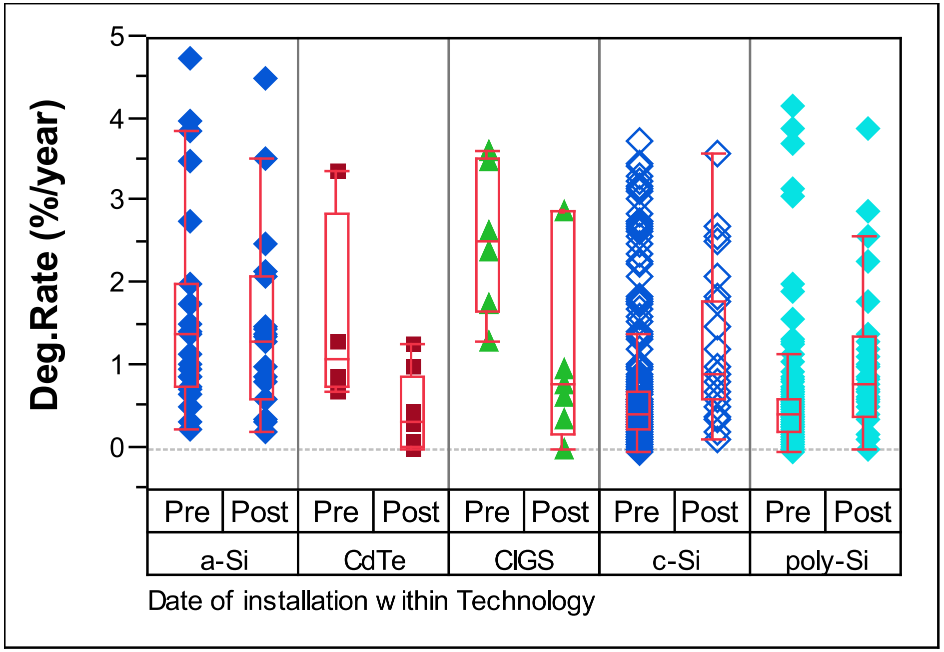
Pre: Installed before year 2000
Post: Installed after year 2000

More than 40 Modules,
> 10 manufacturers,
Monitoring time: 2 yrs-16 yrs



Appears that CdTe, CIGS & poly-Si improved

Historical Degradation Rates



Historical degradation rates are analyzed in a similar way

Similar tendency found as with the PERT modules

While the Si technologies remain stable, thin-films seem to have improved.

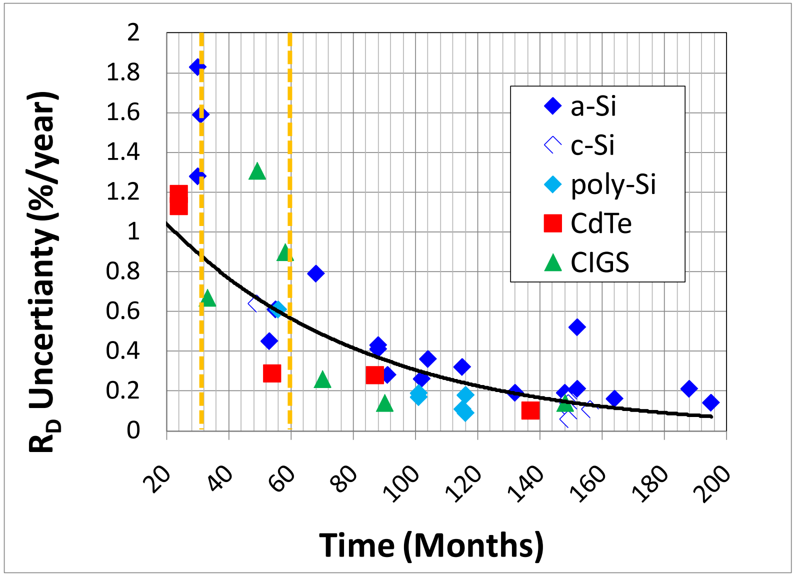
c-Si and Poly-Si show an uptick in R_d → could be from new manufactures pushing into market*

*G. TamizhMani et al., "Failure Analysis of Module Design Qualification Testing", Proc. 35th PVSC, Honolulu, HI, June 20-25 2010.

Appears that CdTe, CIGS & poly-Si improved

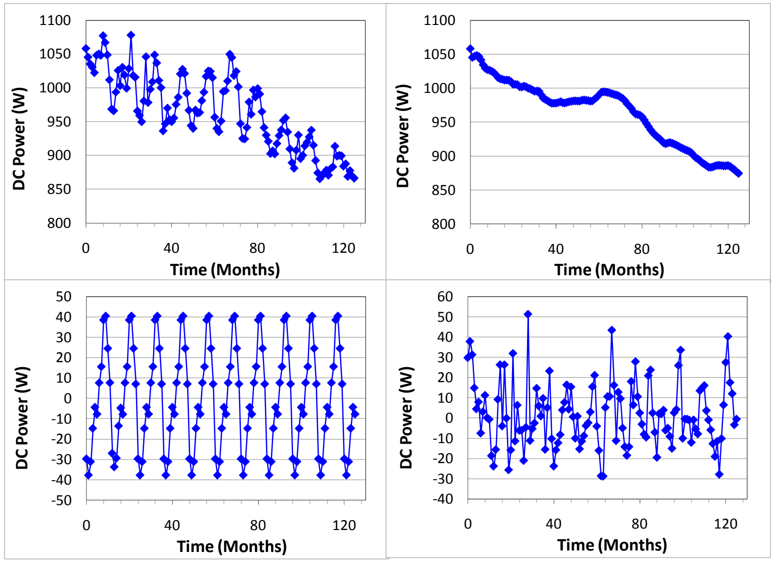
Degradation Rate Uncertainty

PERT Data



Original

Trend



Seasonality

Irregular

Traditionally: need 3-5 years to determine R_d*.

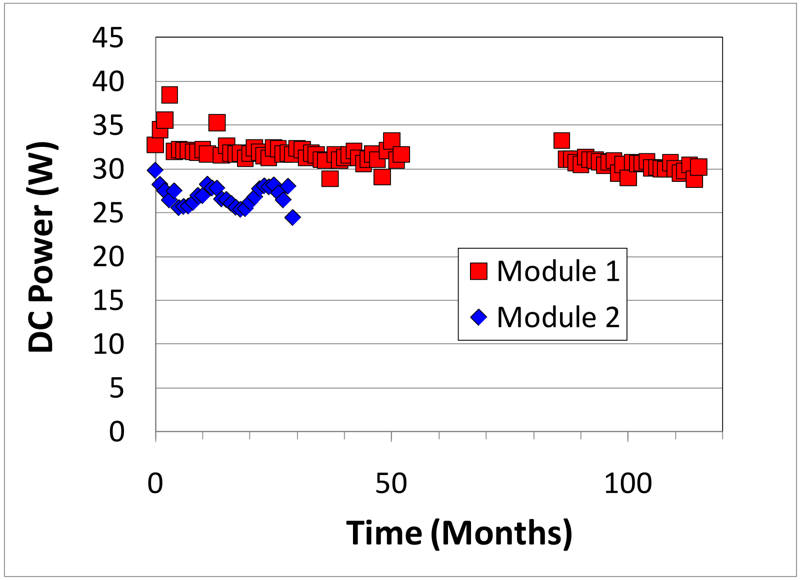
Modeling: (i) Classical Decomposition
(ii) ARIMA**

Accurate Determination of R_d takes time

Modeling can shorten required time

*Osterwald CR, Adelstein J, del Cueto JA, Kroposki B, Trudell D, Moriarty T. Proc. of the 4th IEEE World Conference on Photovoltaic Energy Conversion, Hawaii, 2006.
** D.C.Jordan et al., "Analytical Improvements in PV Degradation Rate Determination", Proc. 35th PVSC, Honolulu, HI, June 20-25 2010.

Consequences of R_d Uncertainty



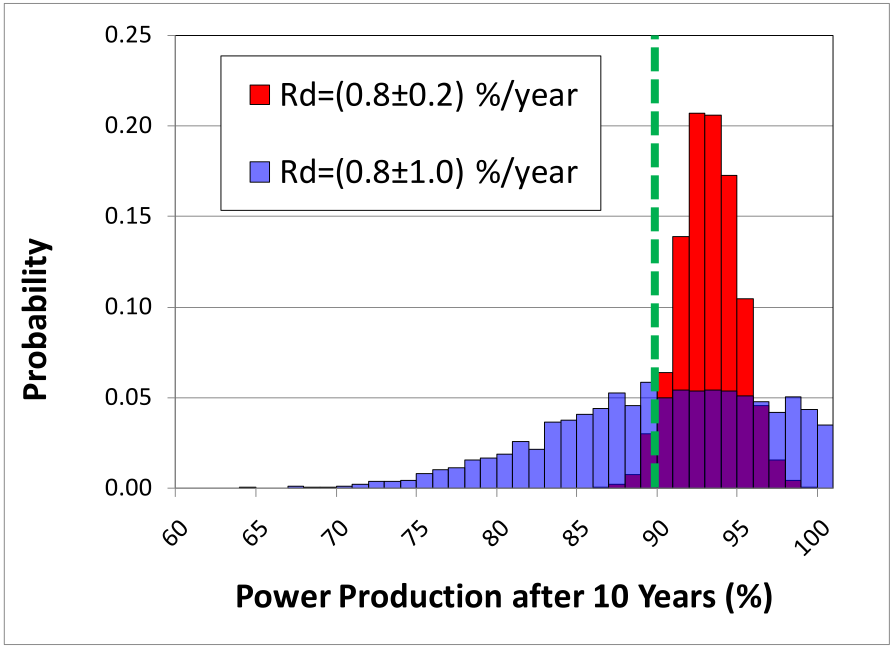
2 examples from NREL:
Different observation lengths, seasonality etc. → Leads to different uncertainties

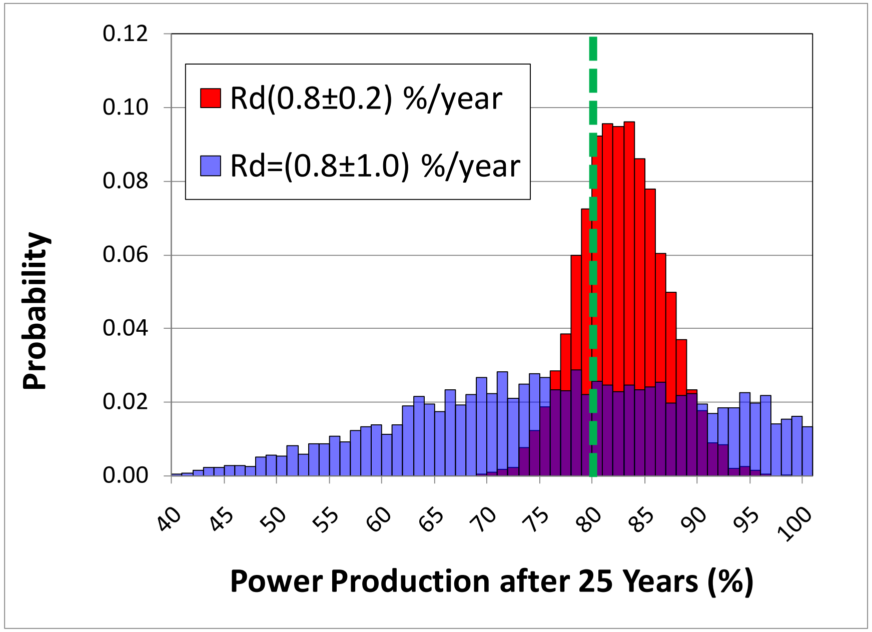
R_d (Module 1) = (0.8 ±0.2) %/year
R_d (Module 2) = (0.8 ±1.0) %/year

Same R_d but very different uncertainty

R_D Uncertainty Impact on Warranty

Manufacturer Warranty often twofold: 90% after 10 years, 80% after 25 years





Probability to invoke warranty:

1.0 %/year uncertainty = 46%
0.2 %/year uncertainty = 4%

$$Energy(Year_N) = \sum_{n=1}^{N} \frac{Energy(Year_1) \cdot (1 - R_D)^n}{(1+r)^n}$$

Probability to invoke warranty:

1.0 %/year uncertainty = 57%
0.2 %/year uncertainty = 24%

Higher R_d uncertainty significantly increases warranty risk

Thank You!