

# Comparison of Degradation Rates of Individual Modules Held at Maximum Power

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# Outline

- Purpose
- Published degradation rates
- NREL measurement procedure
- Degradation rate results
- Discussion and conclusions

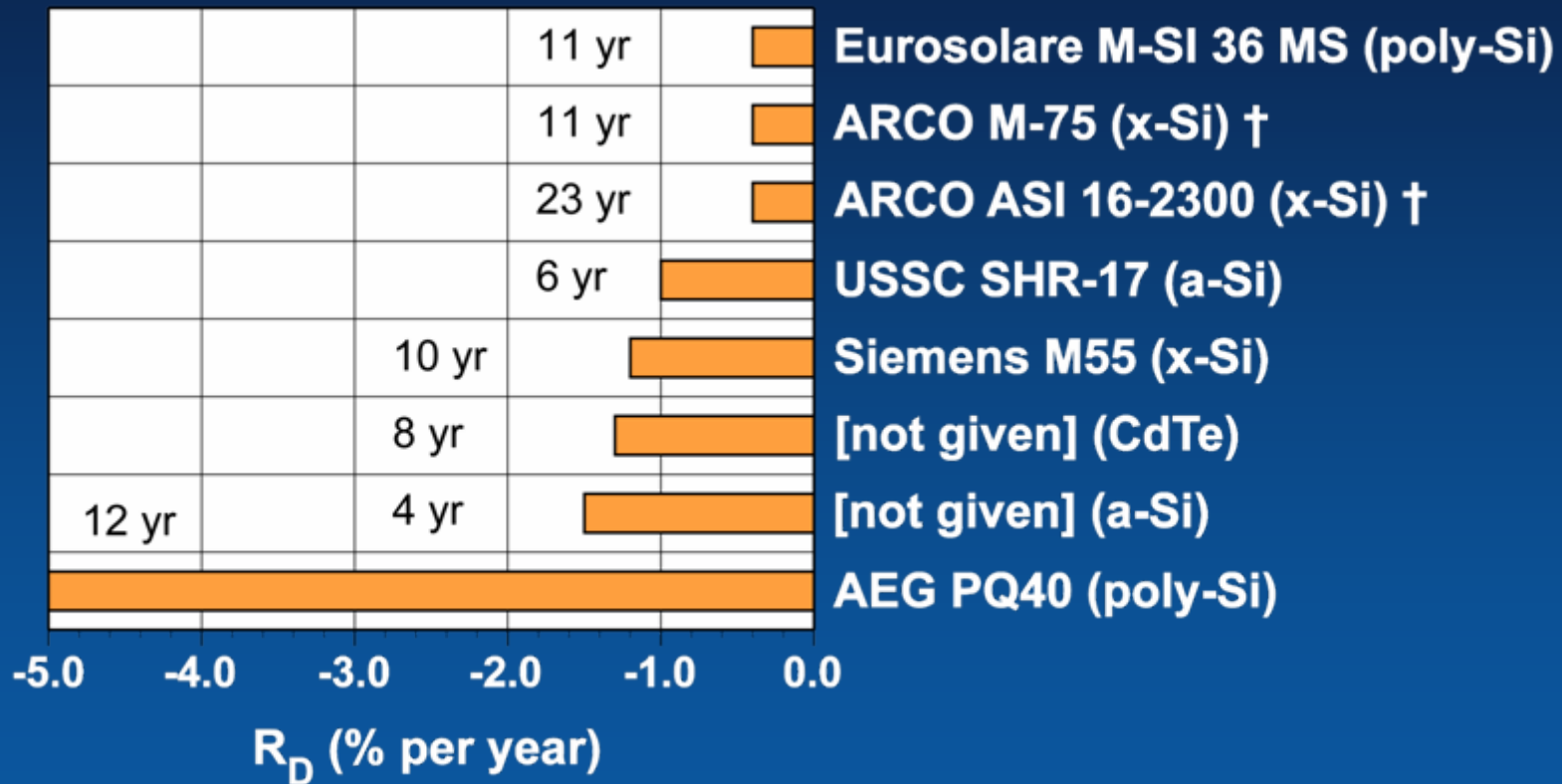
# Purpose

- Module degradation rates ( $R_D$ ) needed for accurate PV system energy delivery calculations
- Time-consuming measurement
- $R_D$  data are generally unavailable
- System sizing software PVWATTS:
  - Has an input for aging loss, but defaults to no loss
  - Recommends using the common rule-of-thumb 1% per year
- Attempt to quantify PV module  $R_D$

# Published Degradation Rates

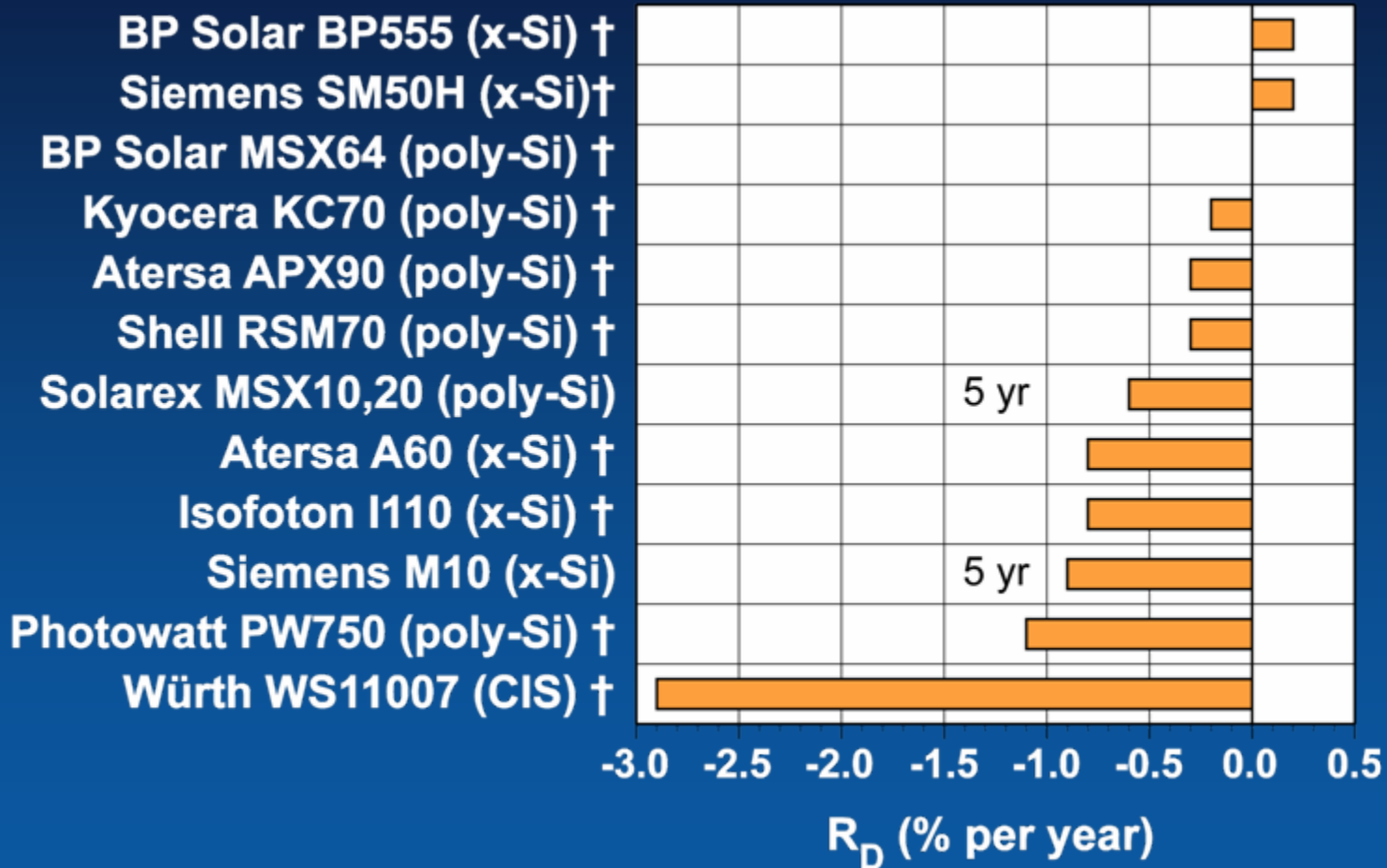
- PV literature search for published  $R_D$  values
- Only nine references since 2000 found
- Indication of measurement difficulties
- All but two are from modules exposed in systems
- $R_D$  values derived from system data can include factors unrelated to modules, such as:
  - Inverter operation; max. power tracking
  - Wiring degradation
- System exposures provide more statistics

# Published $R_D$ — Systems



† Based on individual module performance measurements

# Published $R_D$ — Modules



† N. Cereghetti, et. al., 3rd WCPEC, Osaka, May 2003

# NREL $R_D$ Measurements

- Performance & Energy Ratings Testbed (PERT) on roof of Outdoor Test Facility
- Operational since 1994
- Currently 35 modules under test





# PERT Data Acquisition

- 3 Raydec Multi-Tracer II max-power tracking loads
- 15 module channels each
- I-V curves every 15 min.
- Irradiance and back-of-module temperature measurements



# PTC Power Rating Calculations

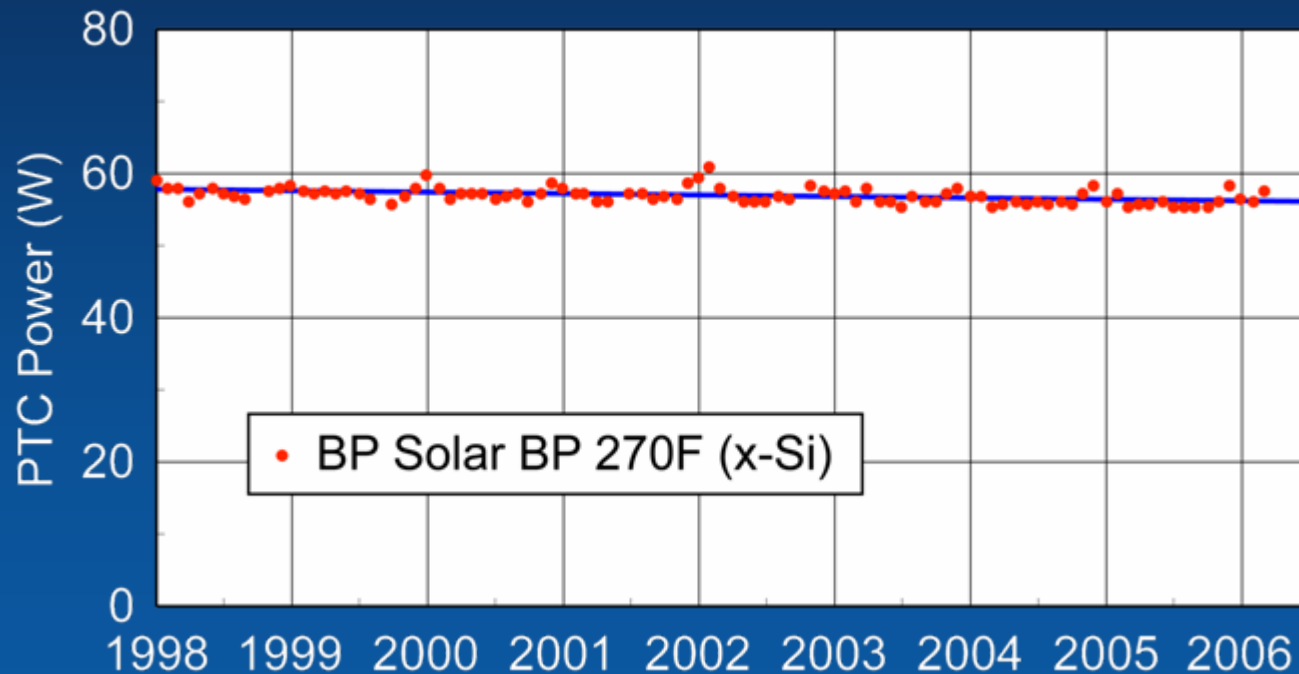
- $P_{\max}$  extracted from I-V curves and combined with E, T, and s
- For  $E > 800 \text{ W/m}^2$ , 1 month of data fit to Performance Test Conditions (PTC)
- Using regression results, power rating @ STC calculated

$$P = E \left[ a_1 + a_2 E + a_3 T + a_4 s \right]$$

PTC:  $E = 1000 \text{ W/m}^2$ ,  $T = 20^\circ\text{C}$ ,  $s = 1 \text{ m/s}$

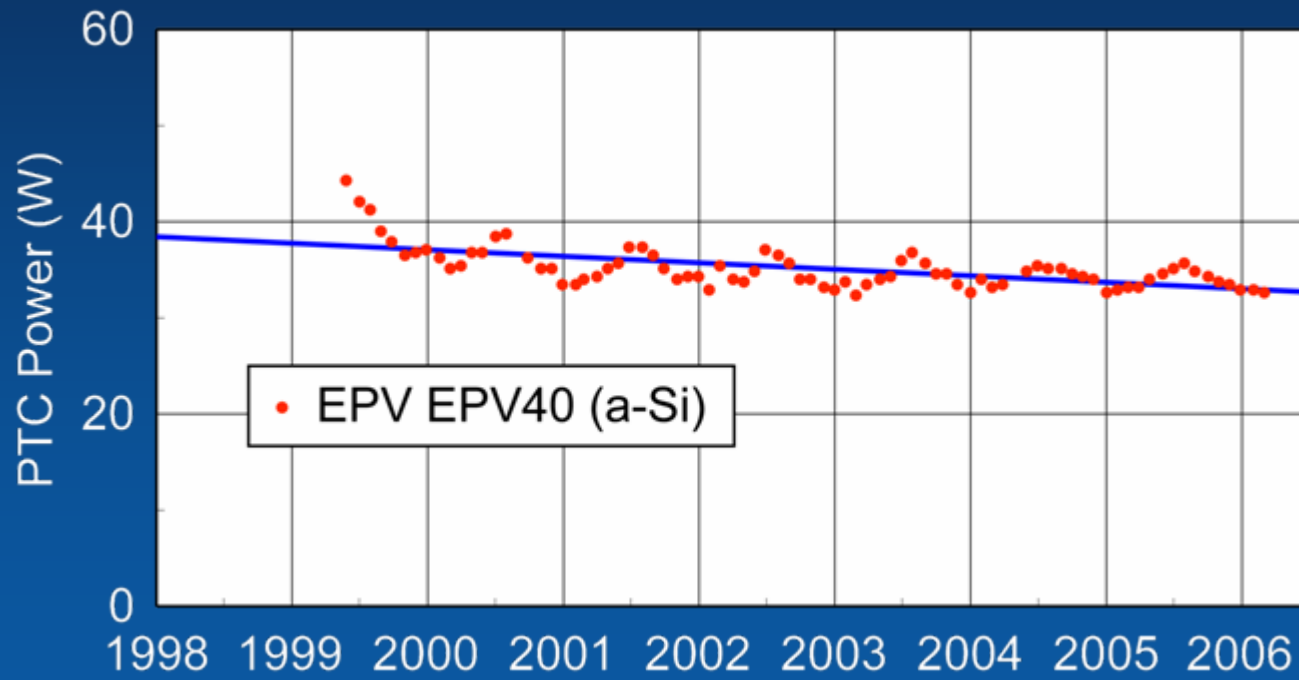
# $R_D$ Determination

- PTC ratings plotted versus time
- Slope of linear fit gives  $R_D$  (-0.35 %/yr)

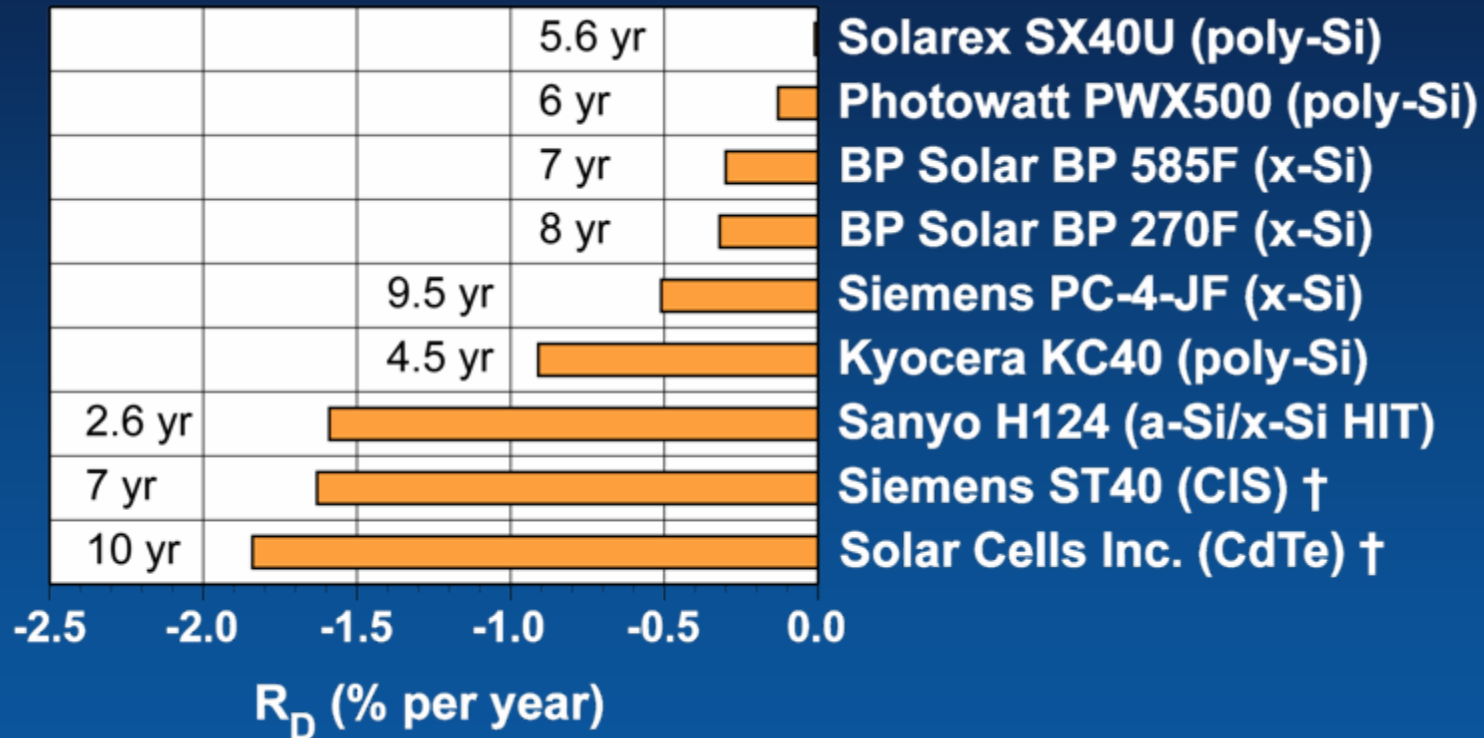


# Pitfalls

- a-Si initial stabilization
- Seasonal variations

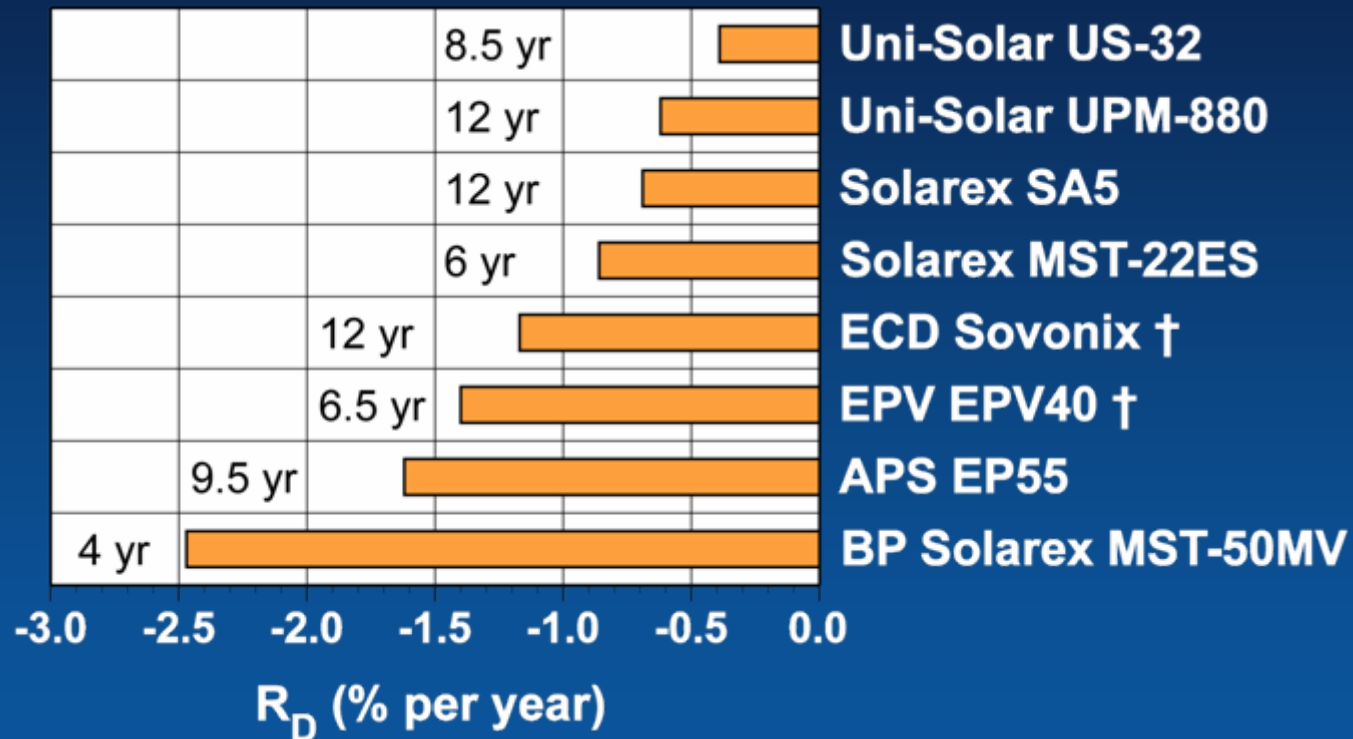


# PERT $R_D$ Results — Crystalline



† Non-commercial prototype modules

# PERT $R_D$ Results — a-Si



† Non-commercial prototype modules

# Discussion and Conclusions

- Many Si  $R_D$  values  $< 1\%/year$
- Some thin-film  $R_D$  values  $< 1\%/year$
- Recommend  $0.5\%$  per year for Si
- $R_D > 2\%/year$  likely indicative of serious module or system problems
- $R_D$  values vary over wide range; accurate data should be available for system designers