

Experience with Qualification and Safety Testing of Photovoltaic Modules

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Outline

Test Results @ TÜV Rheinland PTL

- **Qualification Test Results of PV Modules (IEC 61215/61646)**
(3636 modules [87% c-Si]; 20 different countries; 1997-2009 [13 years of data])
 - **c-Si: 1997-2005 vs. 2005-2007 vs. 2007-2009**
 - **Thin-film: 1997-2005 vs. 2005-2007 vs. 2007-2009**
- **Safety Test Results of PV Modules (IEC61730; ANSI/UL1703)**
 - **c-Si: Temperature test – 140 modules (2006-2009)**

Qualification Standards for PV Modules

- IEC 61215: c-Si
- IEC 61646: Thin-film
- IEC 62108: CPV

Qualification Testing – **Sequence** – A Quick View

(Initial)
Visual Inspection
Insulation (dry & wet)
Performance (P_{max})

Stress 1

(Intermittent)
Visual Inspection
Insulation (dry & wet)
Performance (P_{max})

Stress 2

(Final)
Visual Inspection
Insulation (dry & wet)
Performance (P_{max})

Pass Verdict:

- Functional
- Safe

Safety Standards for PV Modules

- IEC 61730: Both technologies
- ANSI/UL 1703: Both technologies

Safety Testing – **Test** -A Quick View

(Initial)
Visual Inspection
Insulation (dry & wet)
~~Performance (P_{max})~~

Stress 1

(Final)
Visual Inspection
Insulation (dry & wet)
~~Performance (P_{max})~~

Pass Verdict:

- ~~Functional~~
- Safe

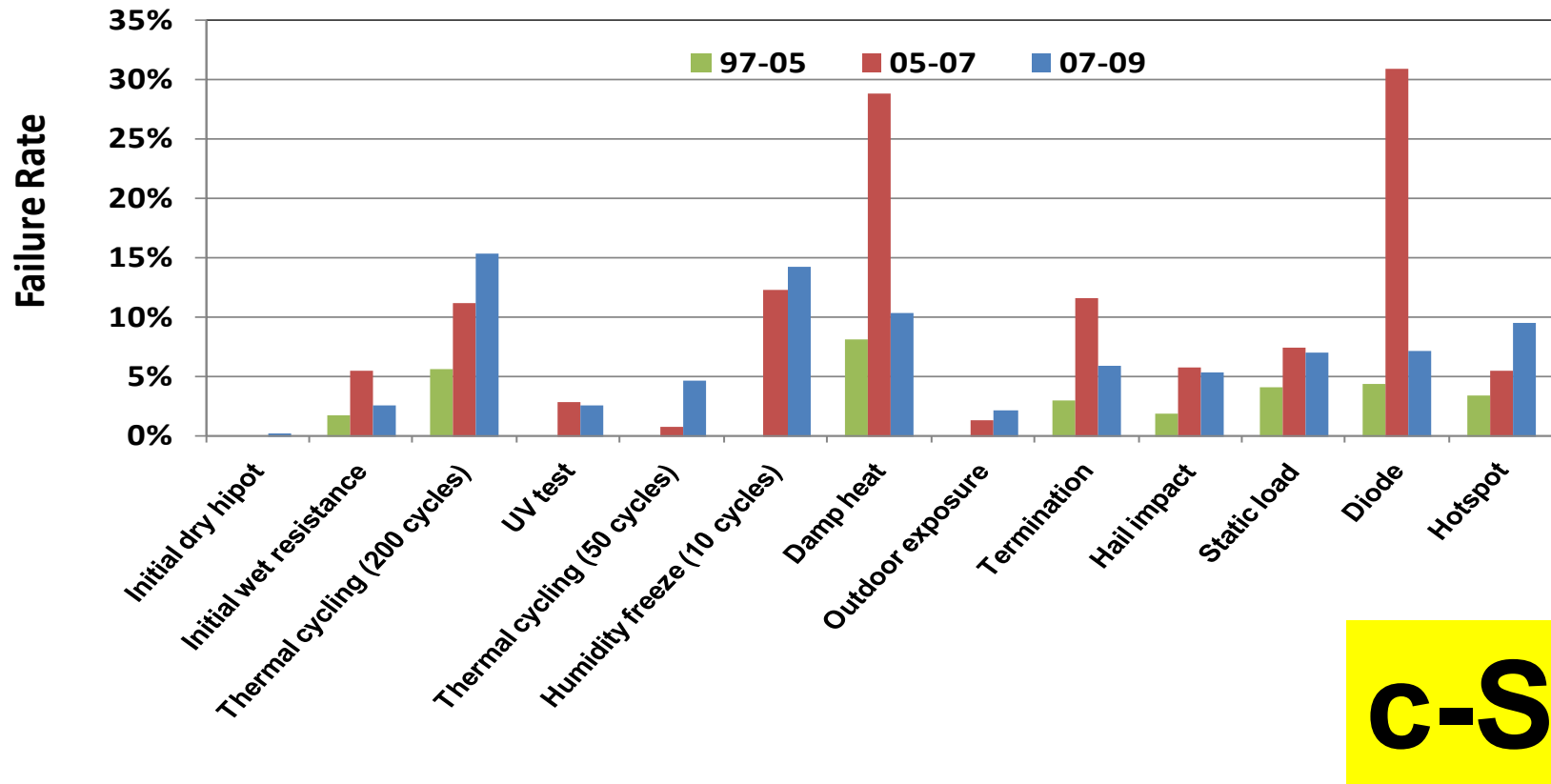
Accelerated Testing

- **Qualification Testing:** The qualification testing is a **short-duration** (typically, 60-90 days) accelerated testing and it may be considered as a **minimum requirement to undertake reliability testing**. The primary goal in the qualification testing is to identify the **initial short-term reliability issues** in the field.
- **Reliability/Lifetime Testing:** The primary goal in the accelerated reliability or lifetime testing is to **identify the initial, use and ultimate reliability** issues in the field so that the lifetime can be predicted and warranty can be protected. A rigorous, **long-term** reliability testing of PV modules would be extremely time consuming and very expensive.
- **Test-to-Failure:** The test-to-failure (TTF) testing is a **compromise and it falls between** these two extremes of qualification testing and lifetime/reliability testing. The primary goal in the TTF testing is to **improve the current design as compared to previous or competitors' designs**.

➤ **Qualification Test Results of PV Modules (IEC 61215/1646)** (3636 modules [87% c-Si]; 20 different countries; 1997-2009 [13 years of data])

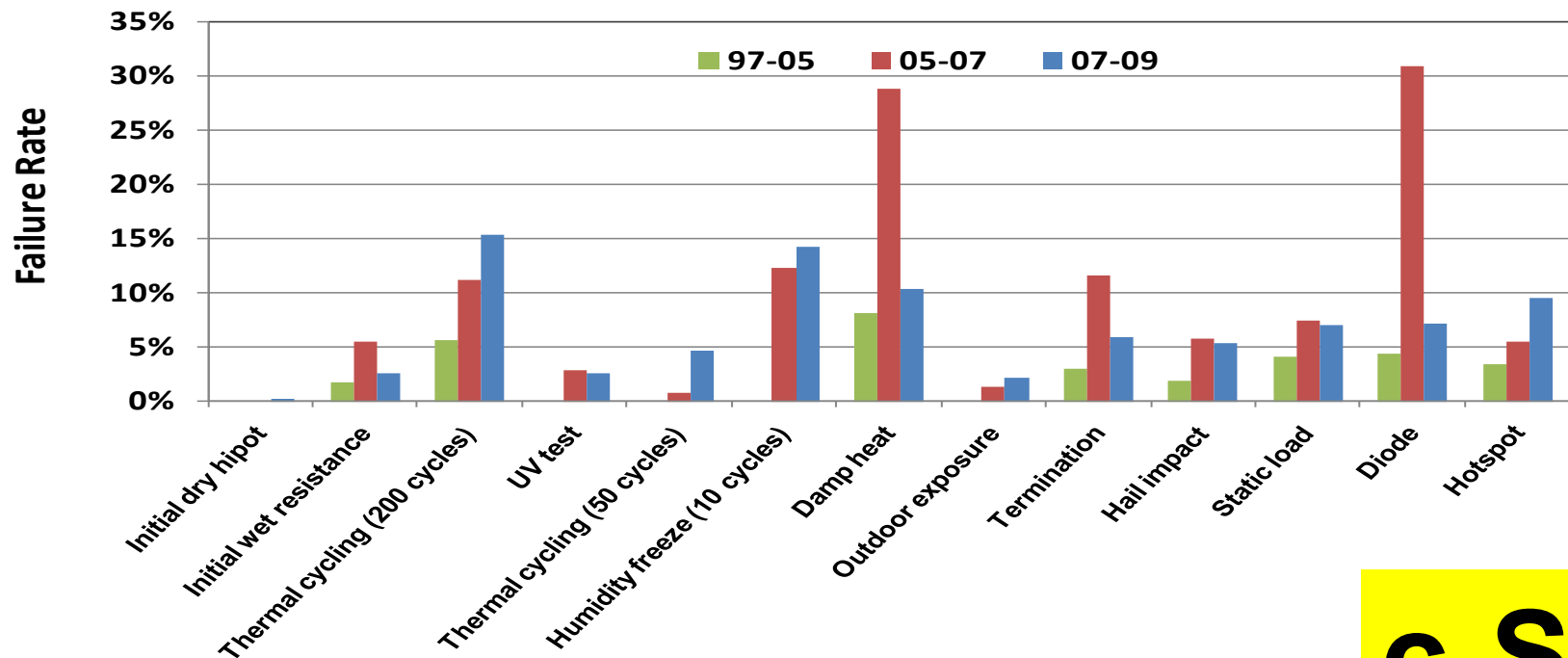
- **c-Si: 1997-2005 vs. 2005-2007 vs. 2007-2009**
- **Thin-film: 1997-2005 vs. 2005-2007 vs. 2007-2009**

Qualification Testing of 3169 c-Si Modules at TÜV Rheinland PTL (1997-2009)



- 1997-2005: 1012 c-Si modules
- 2005-2007: 932 c-Si modules (New manufacturers in both c-Si and thin-film technologies: 52%)
- 2007-2009: 1225 c-Si modules (New manufacturers in both c-Si and thin-film technologies: 39%)

Qualification Testing of 3169 c-Si Modules at TÜV Rheinland PTL (1997-2009)

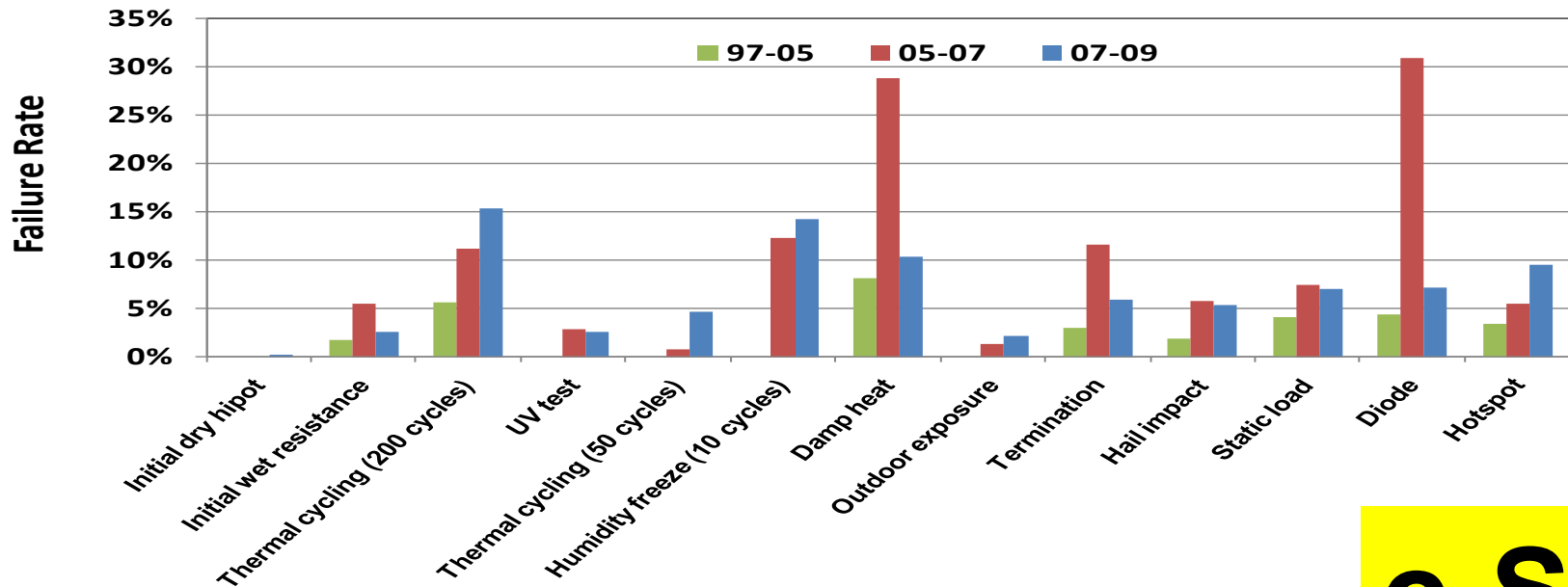


c-Si

Top 3 Failure Rates

- 1997-2005: # 1 Damp heat; # 2 Thermal cycling (200 cycles); # 3 Diode
- 2005-2007: # 1 Diode; # 2 Damp heat; # 3 Humidity freeze
- 2007-2009: # 1 Thermal cycling (200 cycles); # 2 Humidity freeze; # 3 Damp heat

Qualification Testing of 3169 c-Si Modules at TÜV Rheinland PTL (1997-2009)



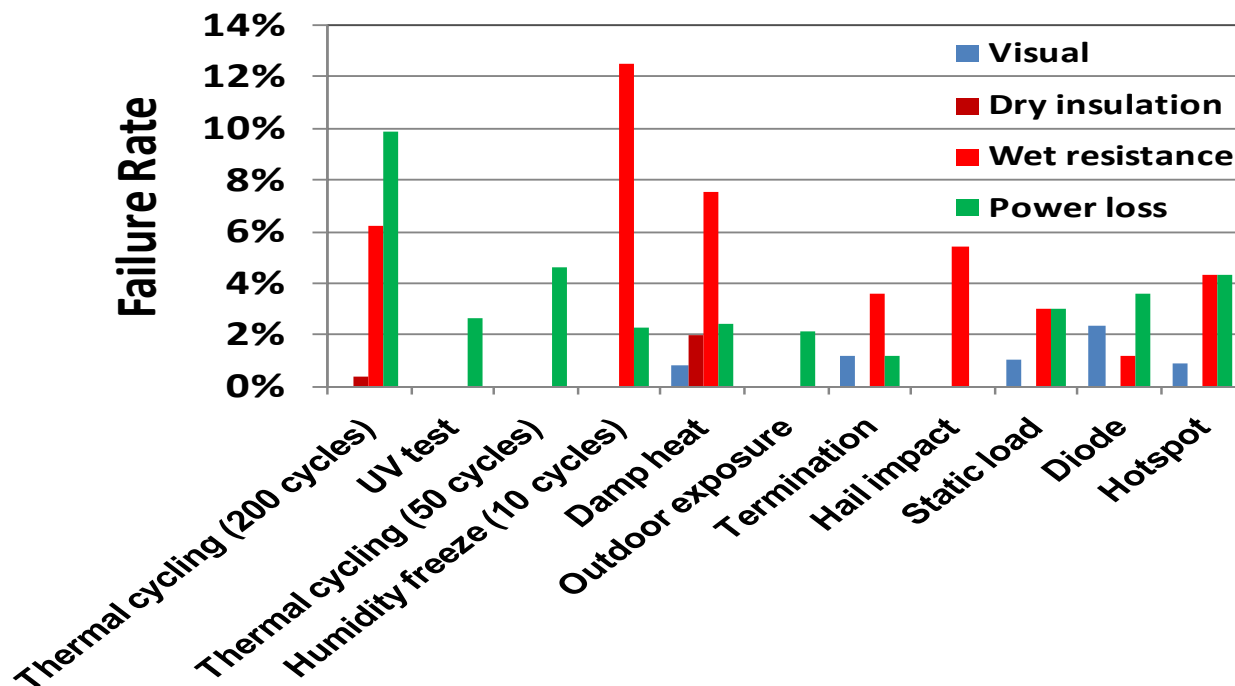
c-Si

• 1997-2009 (13 years): **Top 4 failure rates**

- Damp heat failure rates: 2007/2005 = **increased**; 2009/2007 = **decreased**
- Thermal cycling failure rates: 2007/2005 = **increased**; 2009/2007 = **increased**
- Humidity freeze failure rates: 2007/2005 = **increased**; 2009/2007 = **increased**
- Diode failure rates: 2007/2005 = **increased**; 2009/2007 = **decreased**

Out of the box (initial) wet resistance failure (!!!) : 2005 – 2%; 2007 – 5%; 2009 – 3%

Qualification Testing of 1225 c-Si Modules at TÜV Rheinland PTL Distribution of Failure Criteria (2007-2009)

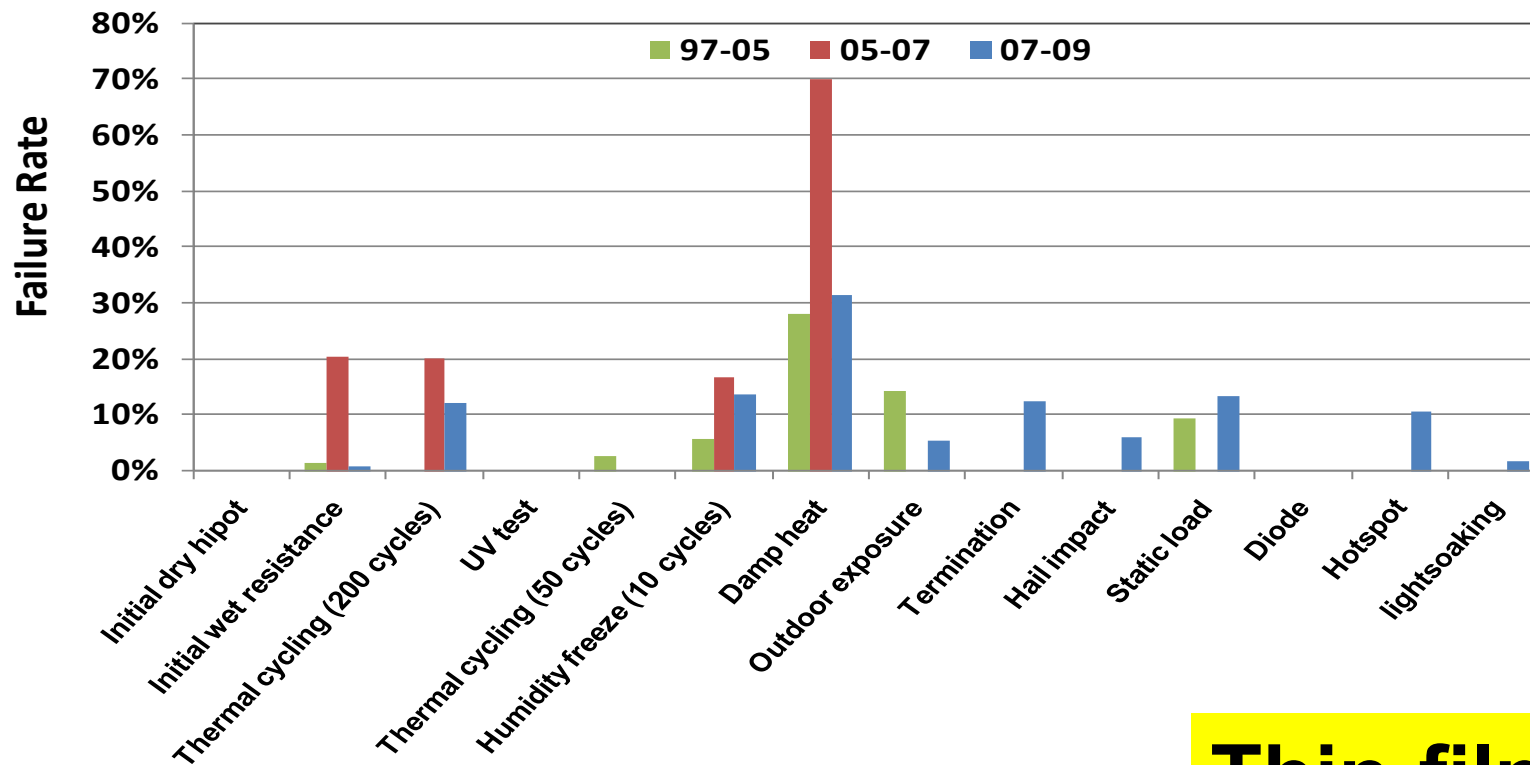


c-Si

Order of post-stress failure

- **Visual:** Diode (2.4%) > Termination > Static load > Hot spot / Damp heat (0.9%)
- **Dry insulation:** Damp heat (2%) > Thermal cycling-200 (0.4%)
- **Wet resistance:** Humidity freeze (12.5%) > Damp heat > Thermal cycling-200 > Hail impact > Hot spot > Termination > Static load > Diode (1.2%)
- **Power loss:** Thermal cycling-200 (9.9%) > Thermal cycling-50 > Hotspot > Diode > Static load > UV > DampHeat ~ HumidityFreeze ~ OutdoorExposure > Termination (1.2%)

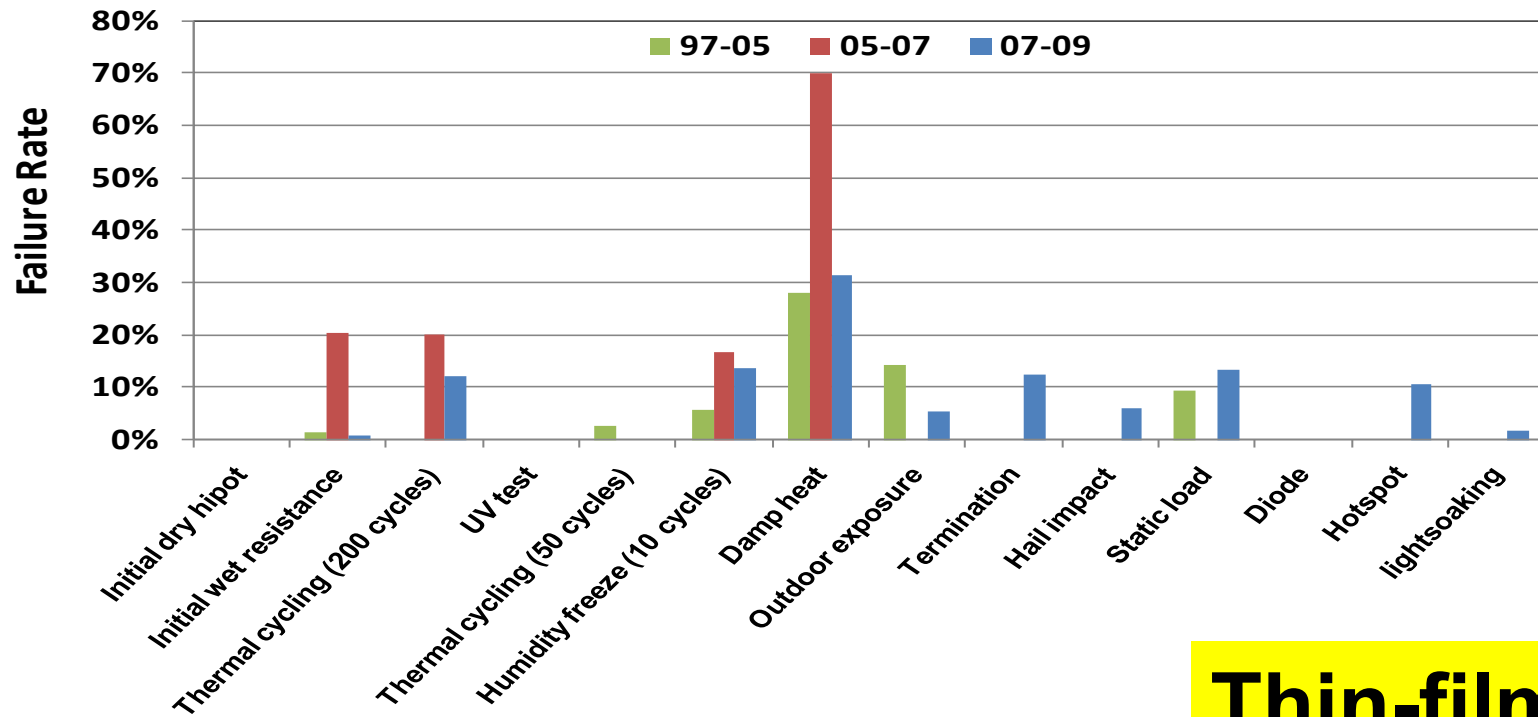
Qualification Testing of 467 Thin-Film Modules at TÜV Rheinland PTL (1997-2009)



Thin-film

- 1997-2005: 150 thin-film modules
- 2005-2007: 69 thin-film modules (New manufacturers in both c-Si and thin-film technologies: 52%)
- 2007-2009: 248 thin-film modules (New manufacturers in both c-Si and thin-film technologies: 39%)

Qualification Testing of 467 Thin-Film Modules at TUV Rheinland PTL (1997-2009)

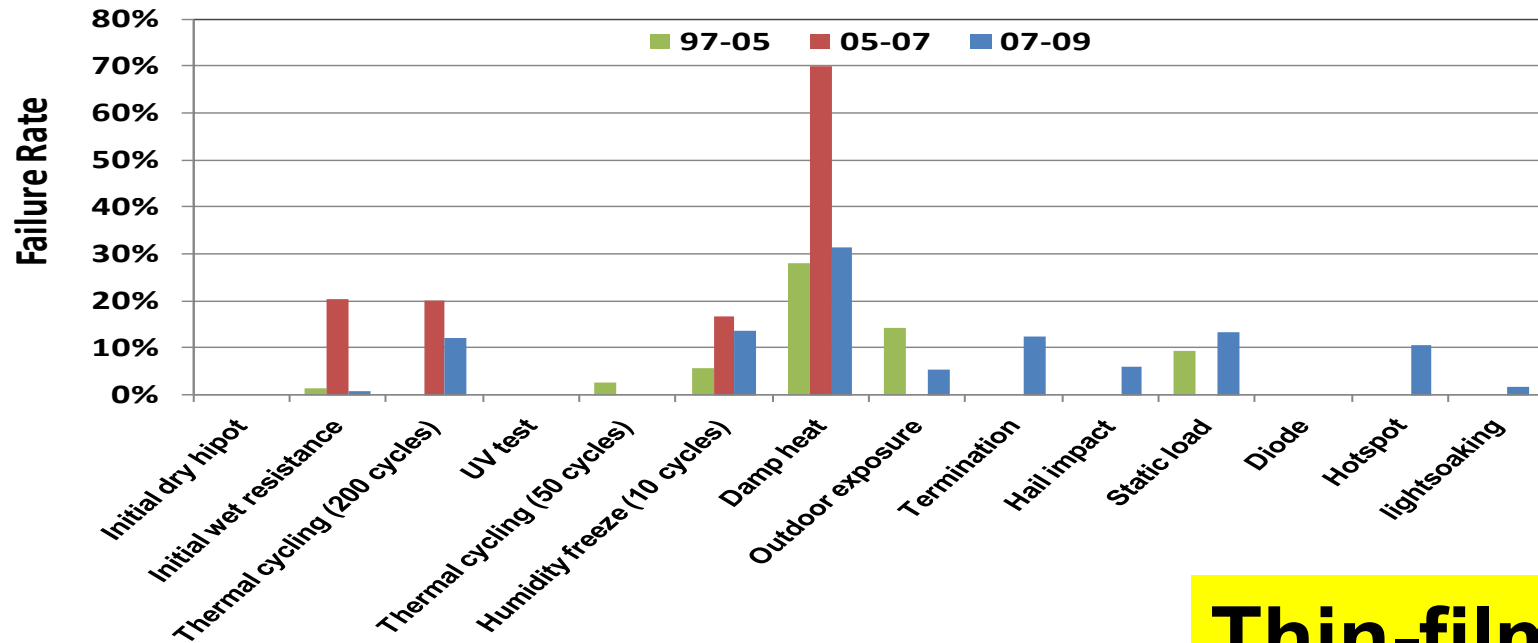


Thin-film

Top 3 Failure Rates

- 1997-2005: # 1 Damp heat; # 2 Outdoor exposure; # 3 Static load
- 2005-2007: # 1 Damp heat (**disaster!**) ; # 2 Thermal cycling (200); # 3 Humidity freeze
- 2007-2009: # 1 Damp heat; # 2 Humidity freeze; # 3 Static load

Qualification Testing of 467 Thin-Film Modules at TUV Rheinland PTL (1997-2009)



Thin-film

• 1997-2009 (13 years): **Top 4 failure rates**

- Damp heat failure rates: 2007/2005 = **increased**; 2009/2007 = **decreased**
- Thermal cycling failure rates: 2007/2005 = **increased**; 2009/2007 = **decreased**
- Humidity freeze failure rates: 2007/2005 = **increased**; 2009/2007 = **decreased**
- Static load failure rates: 2007/2005 = **decreased**; 2009/2007 = **increased**

Out of the box (initial) wet resistance failure (!!!) : 2005 – 1%; 2007 – **20%**; 2009 – 1%

➤ **Safety Test Results of PV Modules (IEC61730; ANSI/UL1703)**

- **c-Si: Temperature test – 140 modules (2006-2009)**

Purpose of Temperature Test:

This temperature test is designed to determine the maximum reference temperatures for various components and materials used to construct the module, in order to establish the suitability of their use.

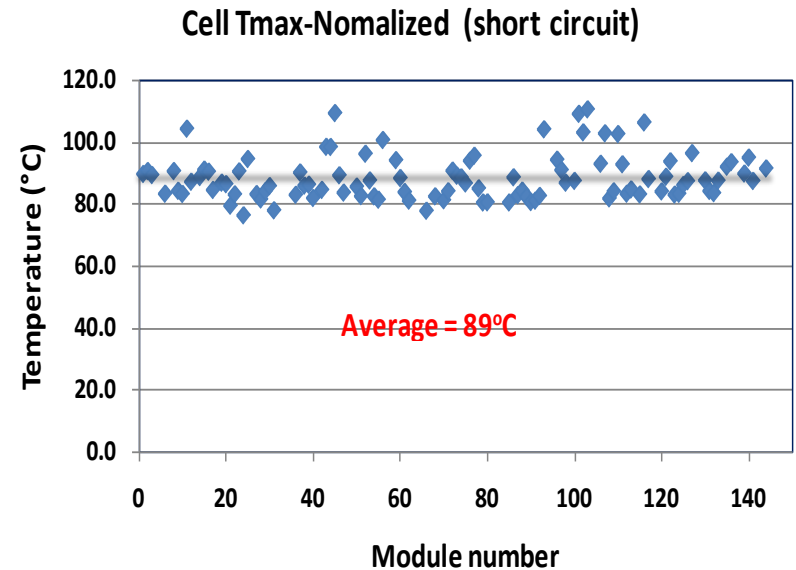
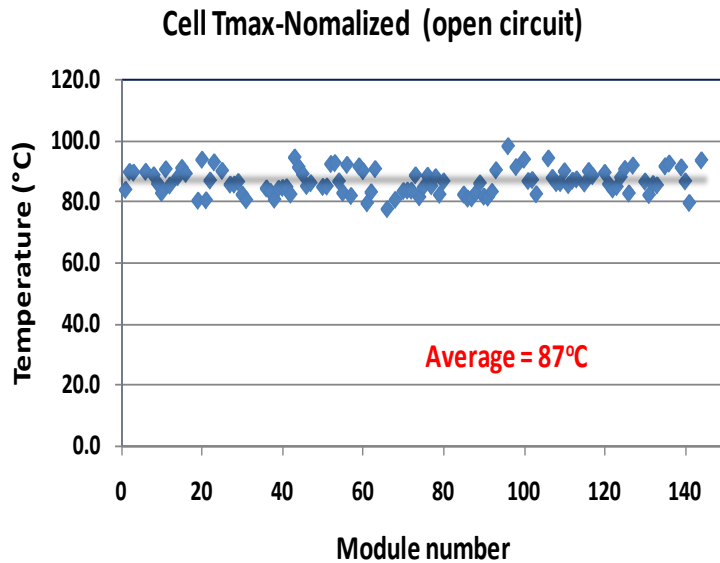
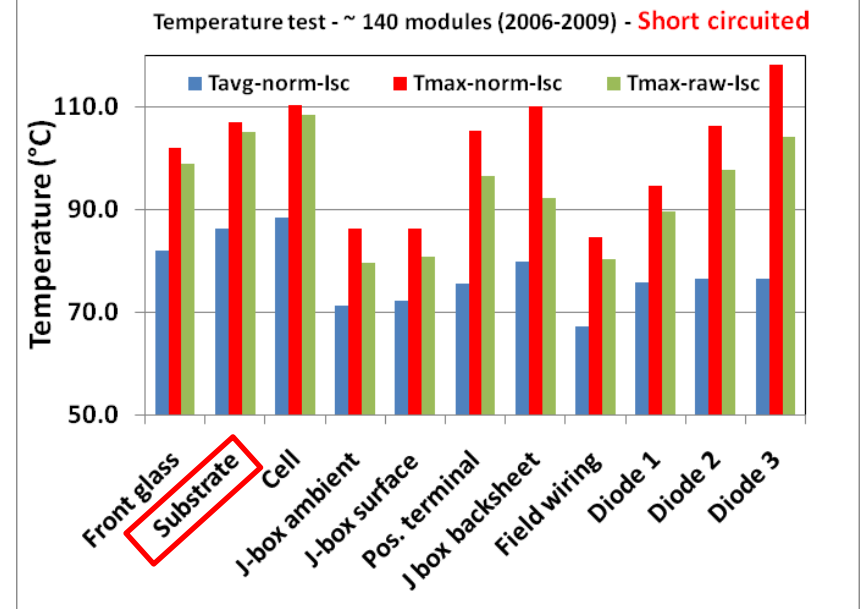
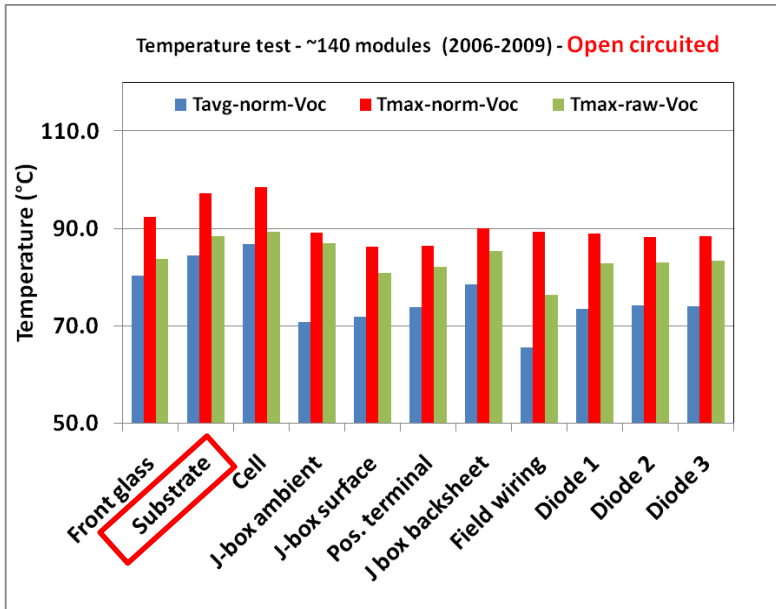
Insulating polymeric material requirement:
Relative thermal index > (T_{norm} + 20°C)

$$T_{norm} = (T_{max} - \text{Mean } T_{amb}) \times \frac{1000}{\text{Mean Irradiance}} + 40$$

Where

T_{norm} is the normalized temperature, T_{max} is the maximum component temperature during the test, and T_{amb} is the ambient temperature during the test.

1	Front glass
2	Substrate
3	Cell
4	J-box ambient
5	J-box surface
6	Positive terminal
7	J-box backsheet
8	Field wiring
9-1	diode 1
9-2	diode 2
9-3	diode 3



Summary

Qualification Testing: c-Si

• Damp heat failure rates:	2007/2005 = increased ; 2009/2007 = decreased
• Thermal cycling failure rates:	2007/2005 = increased ; 2009/2007 = increased
• Humidity freeze failure rates:	2007/2005 = increased ; 2009/2007 = increased
• Diode failure rates:	2007/2005 = increased ; 2009/2007 = decreased

Qualification Testing:Thin-Films

• Damp heat failure rates:	2007/2005 = increased ; 2009/2007 = decreased
• Thermal cycling failure rates:	2007/2005 = increased ; 2009/2007 = decreased
• Humidity freeze failure rates:	2007/2005 = increased ; 2009/2007 = decreased
• Static load failure rates:	2007/2005 = decreased ; 2009/2007 = increased

Safety - Temperature Testing: Polymeric Substrate (c-Si)

- **T**_{avg-norm-Voc}: 84°C
- **T**_{max-norm-Voc}: 97°C