Impact of temperature and moisture stability for packaging choices of perovskite solar cells

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Overview

- Operating conditions for different markets
- Fabrication and testing conditions
- Lifetime predictions for different activation energies
- Moisture hardening of modules
- Examples of accelerated humidity testing
- Recommendations for early module development

Operating conditions for different markets

Market	Insolation	Temperature range	Humidity range	Desired lifetime
Utility/C&I	AM1.5	-40C to 65C	0% to 90%	>30 years
Residential/BIPV	AM1.5	-40C to 85C	0% to 90%	>20 years
VIPV	AM1.5	-40C to >100C	0% to 90%	> 7 years
Aerospace	AM0	-65C to 65C	0%*	> 5 years
Space - orbit	AM0	-100C to 70C	0%*	> 2 years
Space - off orbit	AM0	-220C to 50C	0%*	> 10 years

- Temperature and humidity limitations can make markets with lower temperatures and shorter lifetime attractive as entry points.
- UVB (280-315nm) exposure can be more significant for aerospace and space applications.

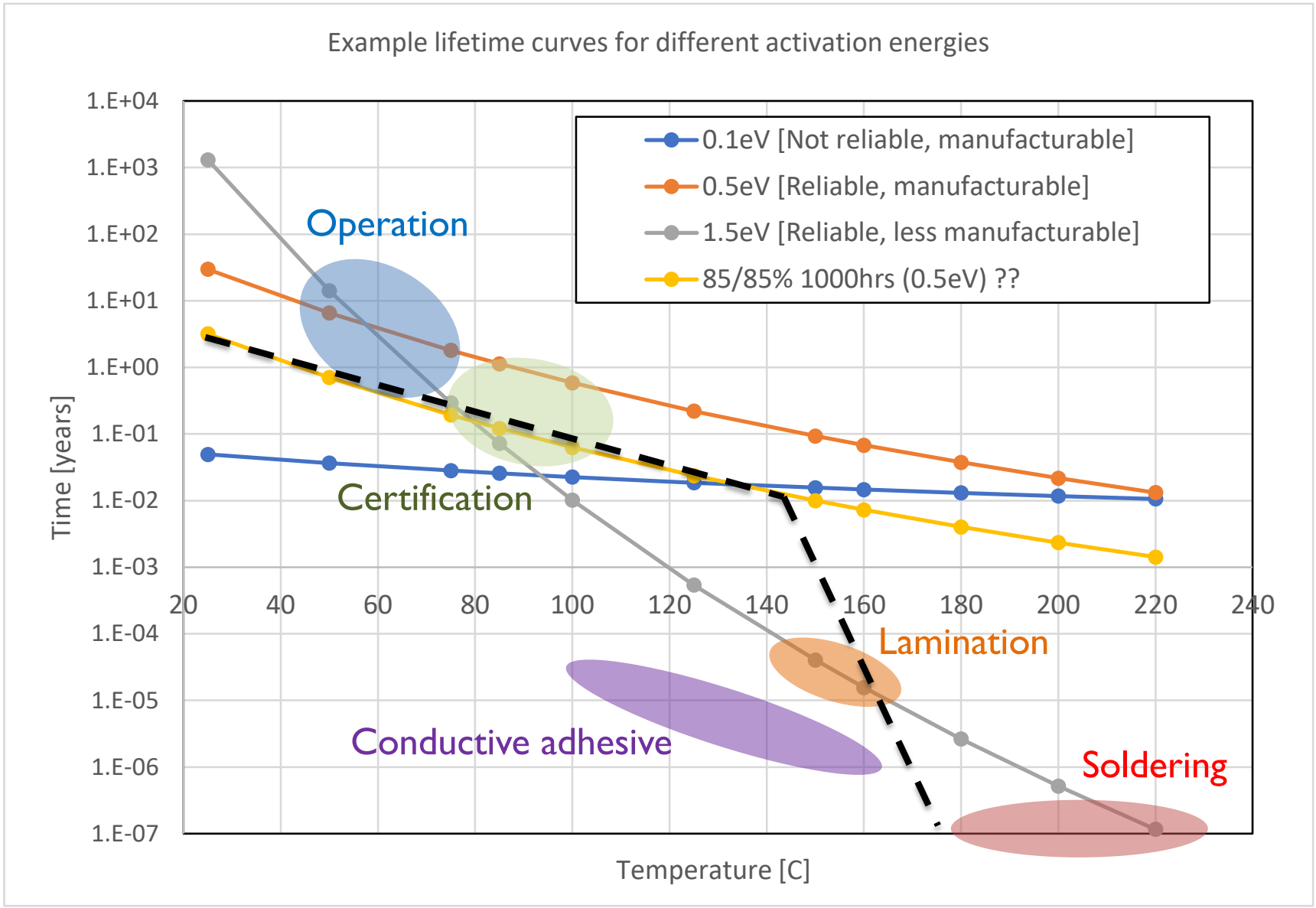
* Storage conditions may require humidity exposure for ~6mth period

Fabrication and testing conditions

Process step	Material type	Temperature	Duration
Interconnect	Soldering (lead free)	~220C	<5s
	Soldering (SnPb)	~190C	<5s
	Soldering (SnBi)	~160C	<5s
	ECA/CCT	25-160C	30mins – 5s
Lamination	Cross-linking POE	150-165C	30mins – 8mins
	Cross-linking EVA	130-155C	40mins – 8mins
	Thermoplastic TPO	100-130C	50mins – 10mins
	Silicones, low temp	25-100C	10hrs – 1hr
Reliability testing	HAST	120C/100% RH	>100hrs
	Damp heat	85C/85% RH*	1000-3000hrs
	Temp cycle	-70C to 120C	200-1000 cycles

* Hermetic modules tested at 85C/85%RH are locally at 85C/dry

Lifetime predictions for different activation energies



Moisture hardening (rigid modules)

Rigid	Level 1	Level 2	Level 3	Level 4	Level 5
Superstrate	Glass	Glass	Glass	Glass	Glass
Encapsulant	EVA	POE	POE	POE	POE
Edge-seal	None	None	None	Yes	Yes
Substrate	Backsheet	Backsheet	Glass	Metalized backsheet	Glass
Cell technology	c-Si (PERC, top-con)	c-Si (PERC, top-con) panels	c-Si (PERC, top-con panels, HJT)	Thin film, HJT	Thin film, HJT,

- Rigid modules are typically built with glass superstrates but 'lightweight-rigid' panels can be fabricated with composite substrates and thin glass or polymeric frontsheets.
- Composite materials are often hydroscopic and can be expected to hold high percentages of moisture
- In comparison to EVA, polyolefin materials have both lower water absorption, lower WTVR and higher volume resistivity.

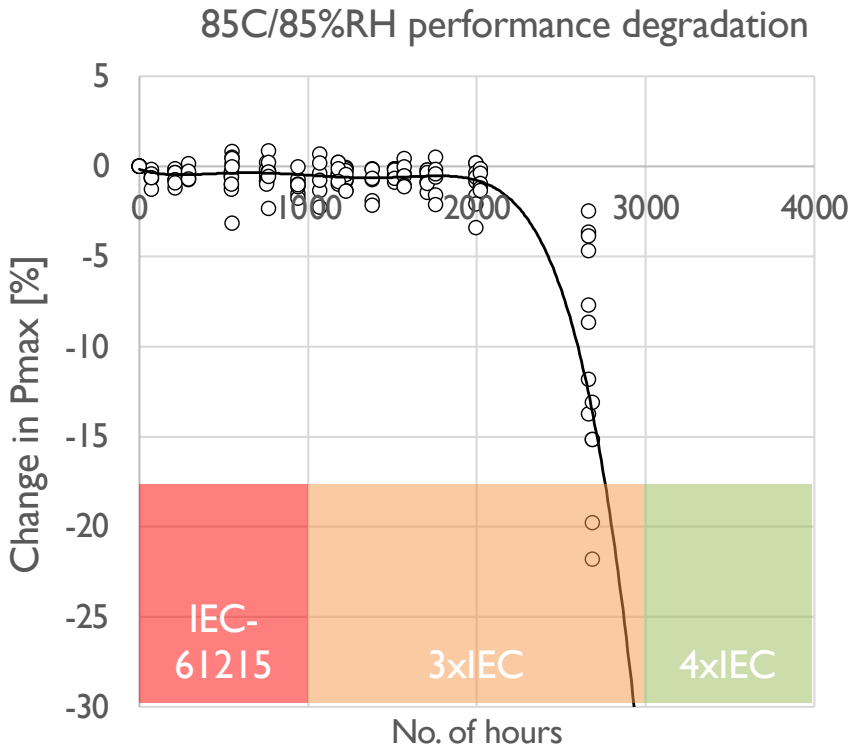
Moisture hardening (flexible modules)

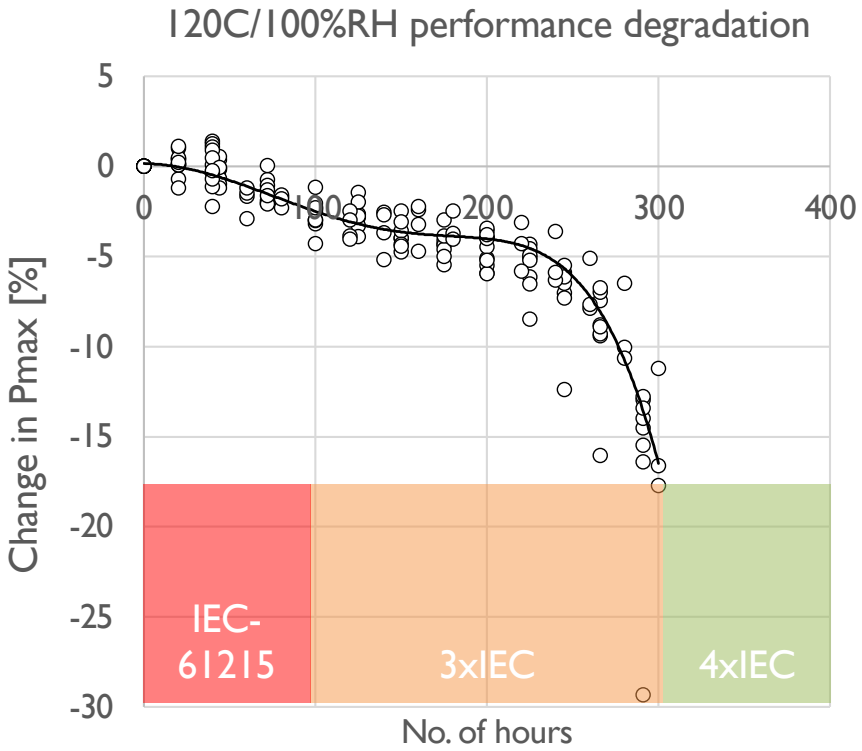
Rigid	Level 1	Level 2	Level 3	Level 4
Superstrate	PET	Fluoropolymer	Barrier film	Thin glass
Encapsulant	EVA	POE	POE	POE
Edge-seal	None	None	Butyl	Butyl/frit
Substrate	Backsheet	Backsheet	Metalized backsheet	Thin glass
Cell technology	c-Si (PERC, top-con)	c-Si (PERC, top-con) panels	Thin film, HJT	Thin film, HJT,

- Typical industry targets for high efficiency, high specific power applications are >200W/m2 and >>200W/kg.
- Specific power requirements can be limited by the weight of moisture hardened packaging materials.

Examples of moisture/temperature acceleration for c-Si panels

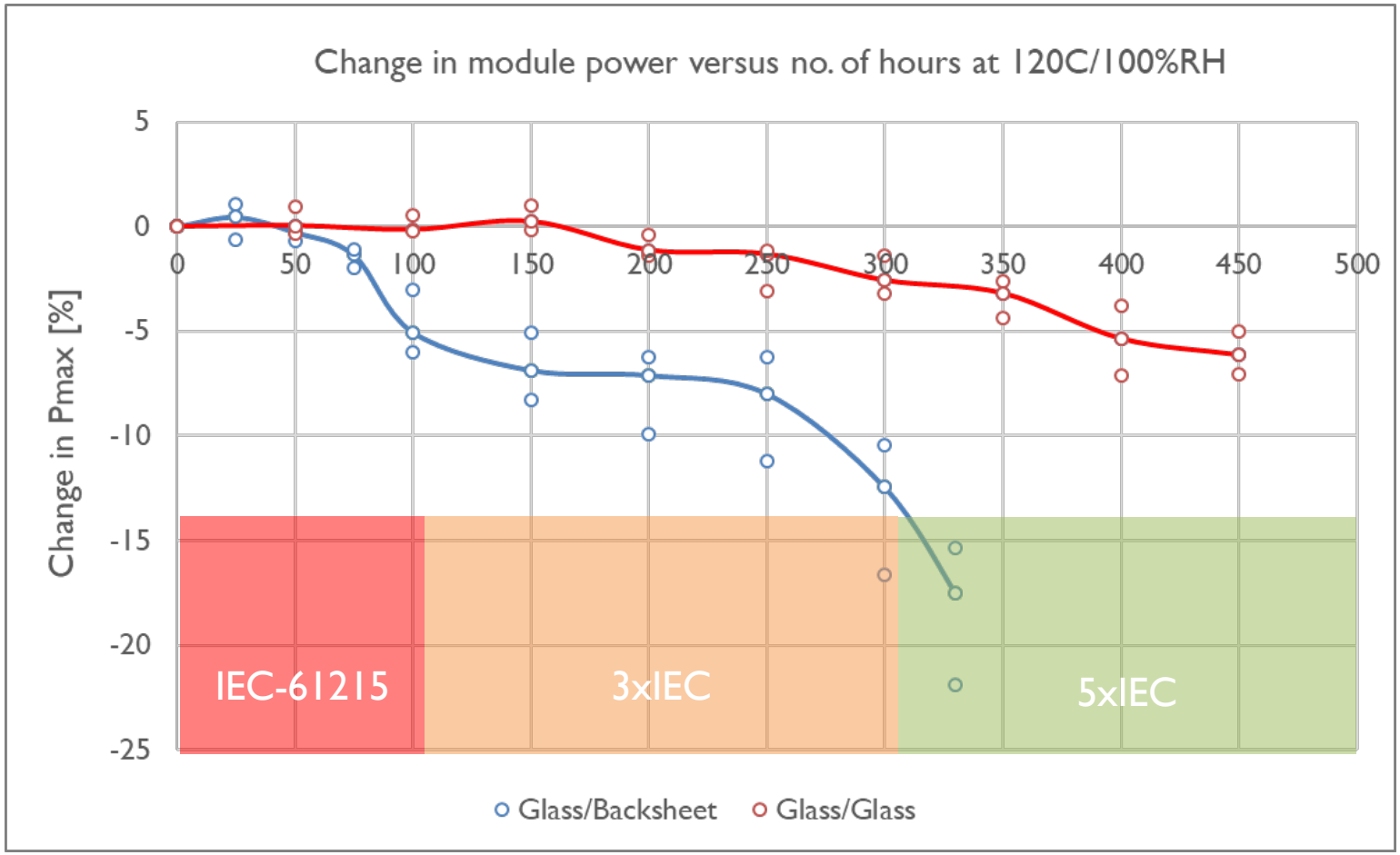
- 1000hrs of 85C/85% RH is considered sufficient to represent 25 years of life in most environments for traditional c-Si modules.
- High humidity (above water) or saturated environments (in water) may require extended tests or harsher protocols to generate data in a timely manner.





Improving moisture hardness

- Glass-glass modules are one example of a mainstream moisture hardened construction capable of improving lifetime in harsh moisture environments



Recommendations for early module development

Deliverable	Acceptable	Target
IV repeatability	<5	<2
ECA peel strength [N/mm]	>0.5	>1.0
ECA Rcontact [mohm.cm2]	<20	<10
Encapsulant peel strength [N/mm]	>0.5	>1.0
Edge seal peel strength [N/mm]	>0.5	>1.0
Pmax (ECA-Solder) [%]	<8	<5
CTM Perovskite	<5	<2
Pmax change @ 200hrs HAST (1" PERC cell)	<3	<2
Pmax change @ 200hrs HAST (6" PERC cell)	<3	<2
Pmax change @ 200hrs HAST (Perovskites)	<5	<2

- Establish testing/light soaking protocols to ensure repeatable IV measurements.
- Determine the temperature sensitivity of devices for packaging (temperature ladder)
- Based on temperature limits build low temperature / moisture hardened package with c-Si cells with known moisture sensitivity e.g. HJT.
- Depending upon material temperature limits HAST (120C/100%RH) and thermal shock (-40C to 85) can be used for 1-2 wk cycles of learning.
- Transfer interconnect and lamination processes to perovskite devices.