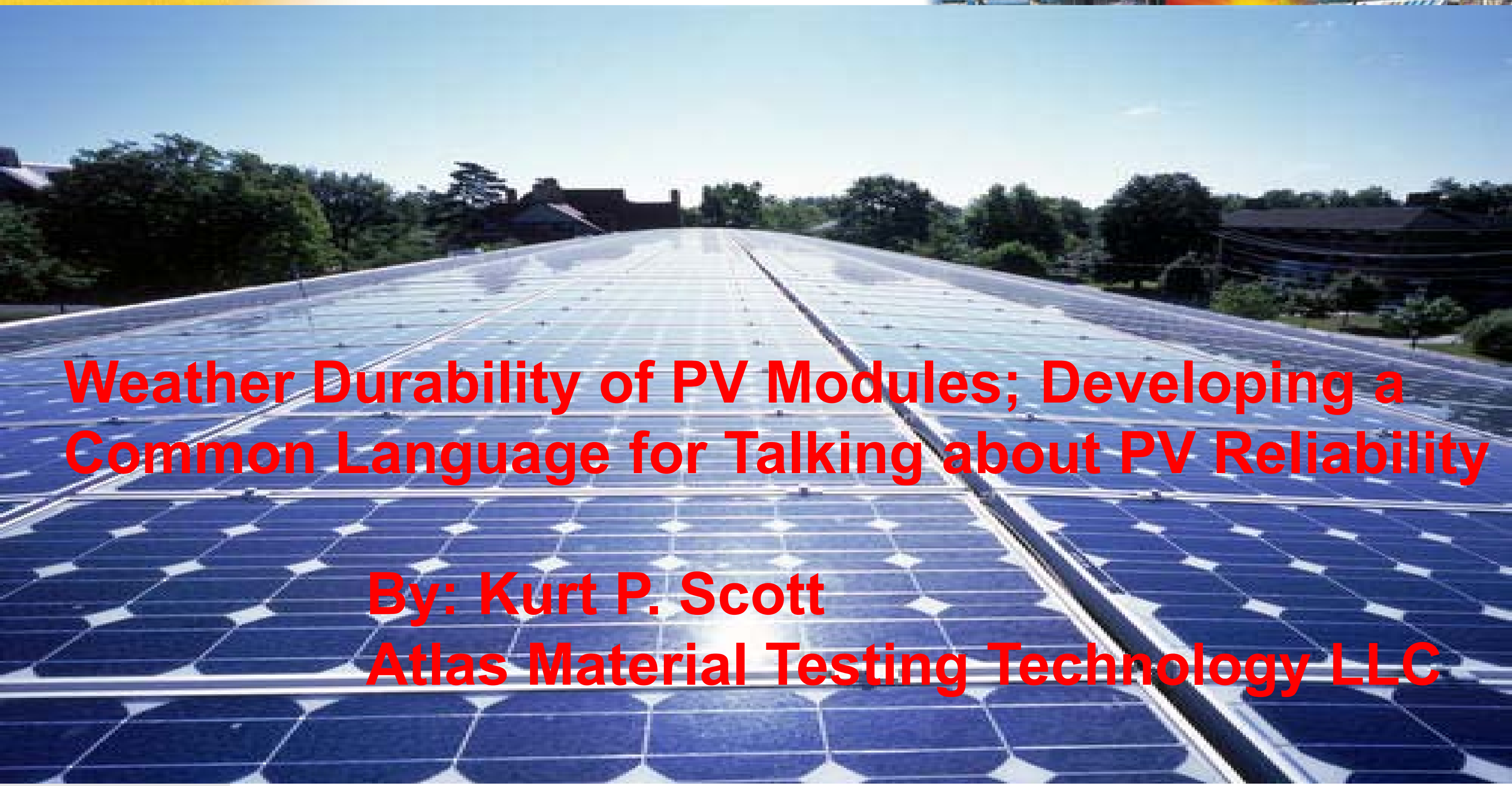
PV Durability and Reliability



Weather Durability of PV Modules; Developing a Common Language for Talking about PV Reliability

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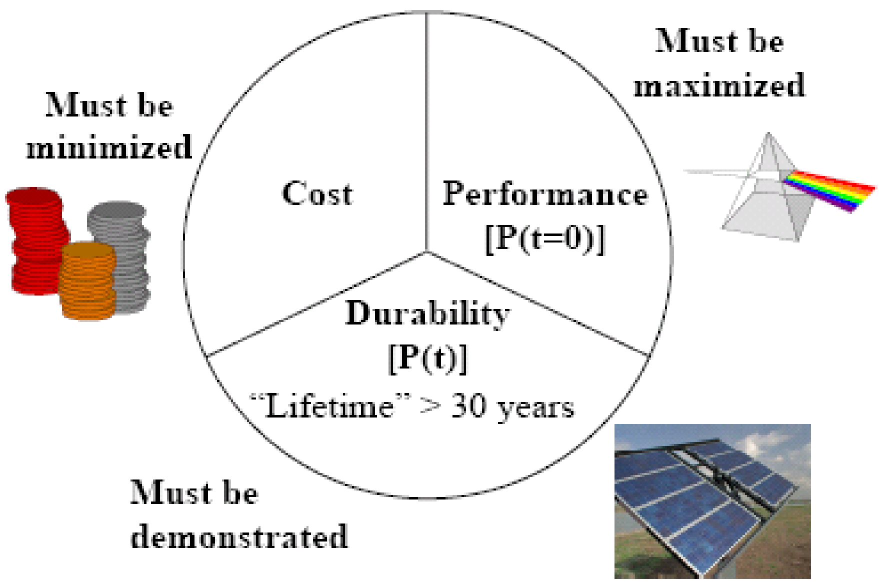
PV Today ……

Competing imperatives



<u>*Summary points:*</u>

- The major problem in solar energy technologies is **not** discovering how to collect the radiant flux, but how to collect it in a **cost competitive** way with conventional power generation.
- Service Lifetime Prediction (**SLP**) estimates of the photovoltaic devices **will determine** the life-cycle **costs**.
- The **cost-effective deployment** of any PV device is limited by the **durability** and life-cycle cost of the materials used.

(25) Accelerated Life Testing and Service Lifetime Prediction for PV Technologies in the Twenty-First Century. NREL, A.W. Czanderna and G.J. Jorgensen

Bankability - Durability Impact

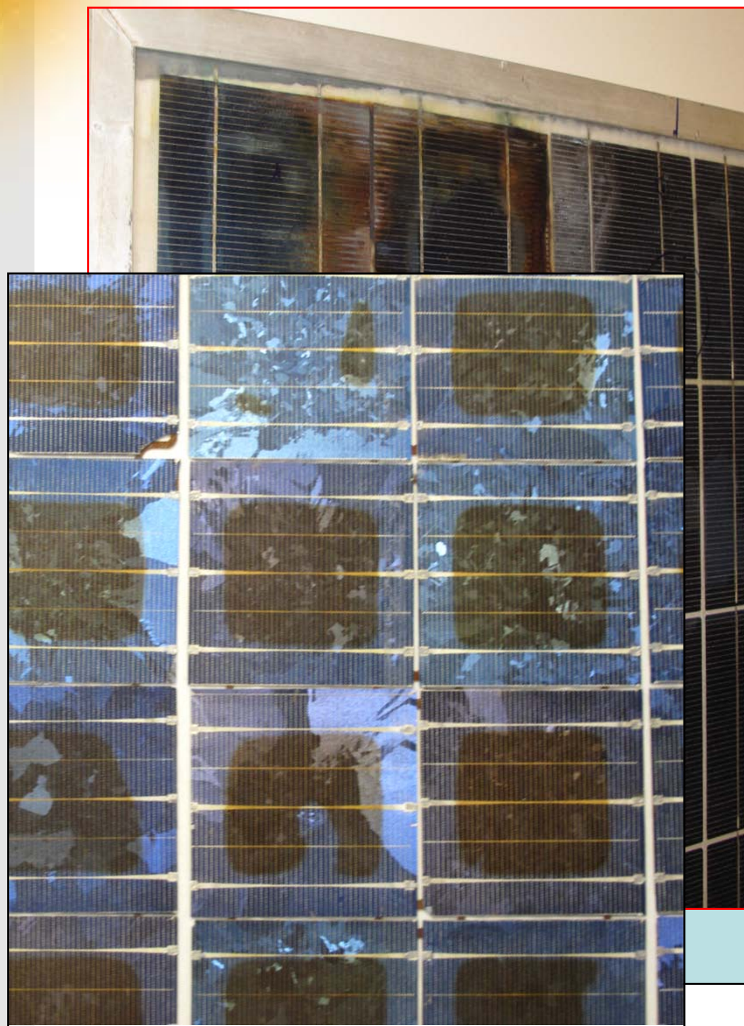
PV bankability - a function of durability

- Common calculation of PV costs = (upfront $ – incentives)
  - Durability often overlooked
  - Factoring in.5%/yr degradation may not be adequate – does not include catastrophic failure
- Internal rate of return (IRR) is sensitive to module degradation rate
- Because module degradation has a substantial impact on utility IRR – it should be of critical concern to investors.

Bankability- Reliability Impact

- PV bankability - a function of reliability
  - Cost of reliability significant to module suppliers
  - Module manufacturers need to set aside a portion of revenue to service warrantees
    - Based on expected failure rates - but in today's world – varies tremendously
    - In these early days of commercialism – manufacturers buying market, liberally replace sub-par modules
  - True warranty costs are not being tracked
  - Threatens profitability

Significance of Durability & Reliability



The PV “triumvirate”

- Safety
- Performance
- Reliability

Durability impacts all

Reliability

- **Reliability -** many definitions, but in a broad sense it is the measure of unanticipated interruptions during intended use of a product (or service)
- Reliability & Quality not synonymous
- Reliability is an engineering discipline that should be applied throughout all stages of development and maintenance of the product in its service life

http://www.wired.com/science/planetearth/multimedia/2005/11/69528?slide=3&slideView=3

Reliability

- **MIL-STD-721C and MIL-HDBK-338** have two definitions of for **reliability:**
- **The duration or probability of failure-free performance under stated conditions**
- **The probability that an item can perform its intended function for a specified interval under stated conditions**
- ***Notes:*** *For non-redundant items both definitions are equivalent*

when there is redundancy *the second definition is equivalent to definition of mission reliability*

Special case: *Reliability (the absence of failures which defines the probability of the failure-free interval) is often confused with availability (% up time). In redundant systems availability $\neq$ reliability*

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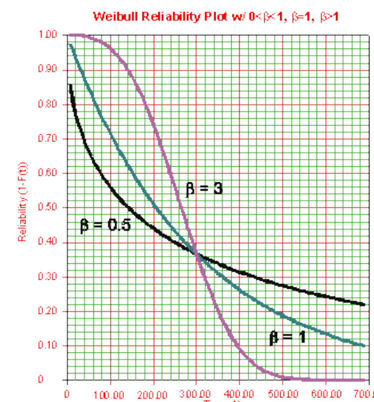
Reliability

- **Reliability Measurement**
  - Failure rates
  - Cumulative failures
  - Component lifetimes (time until failure or between failures)
  - Estimates of product lifetimes
- Techniques drawn mainly from probability statistics, and the theory of stochastic processes.
- Typically, production units are used and large sample populations are required for statistical purposes.



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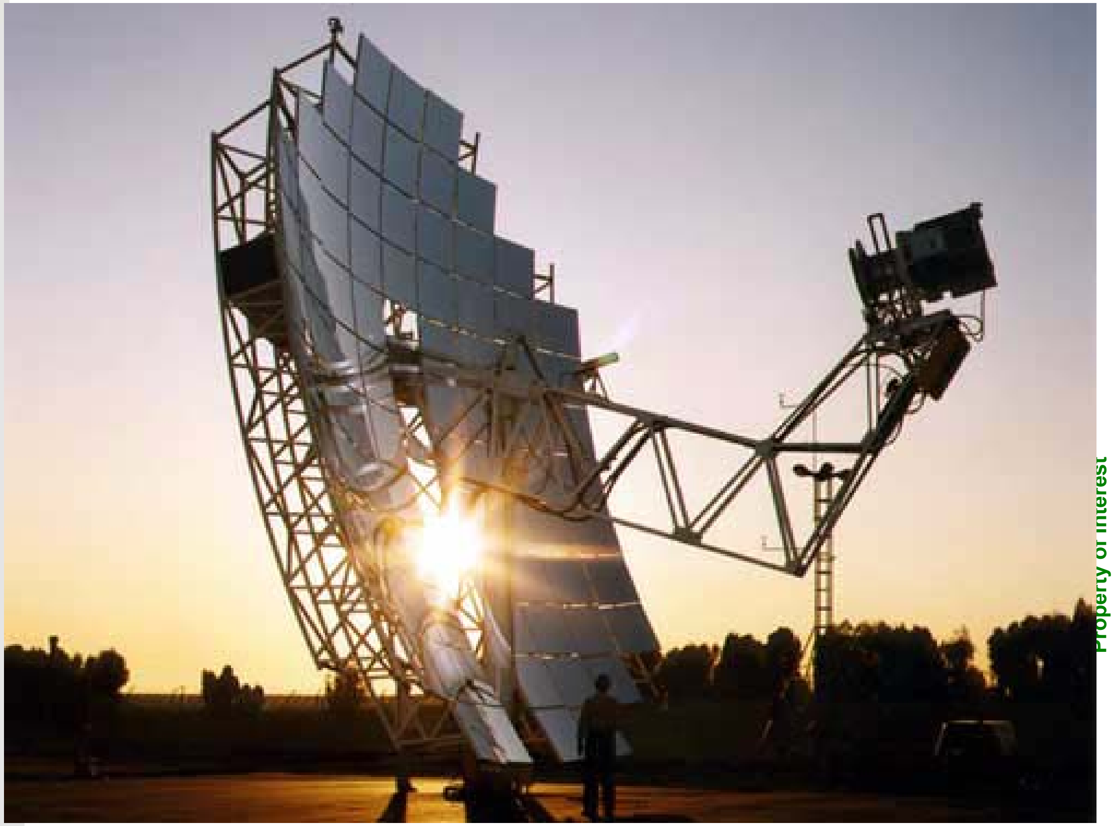
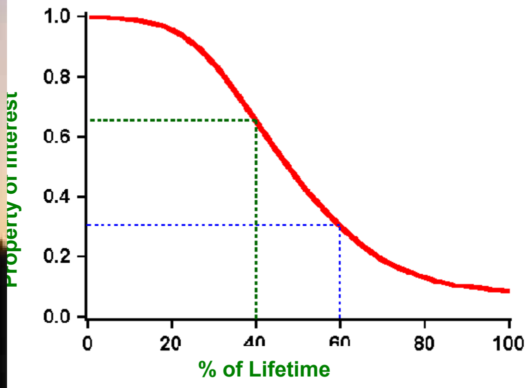
Durability

- **Durability -**
  Loss of requisite or desirable properties………





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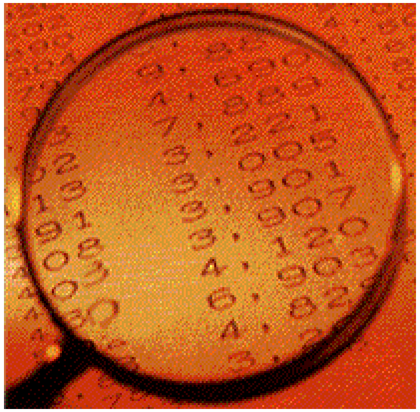
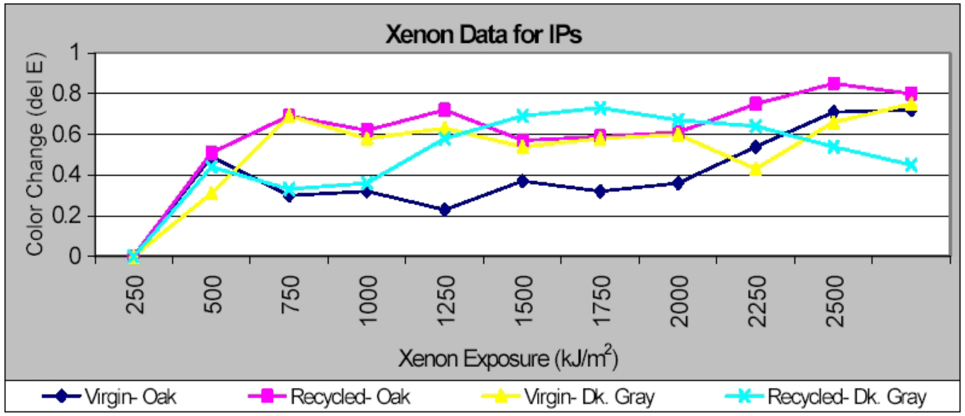
http://www.wired.com/science/planetearth/multimedia/2005/11/69528?slide=3&slideView=3

Durability

- **Durability Measurements**
  - include changes to - chemical, physical or appearance properties,
  - loss of performance
  - Rate of property change with time or stress,
  - Time to unacceptable change, etc.
  - (Note - *the PV industry tends to define these as reliability attributes, when in fact, they are durability issues that may, or may not, actually affect reliability*)





PV Durability

PV Module Durability = Primarily Weather-durability (weatherability)

ASTM G113 durability, *n*—in weathering, a measure of the retention of original condition and function of a material after exposure to a specified set of (weather) conditions.

Not: UV test, UV conditioning, Conditioning, or any of those other terms typically used in PV testing community

Environmental Durability

- **Environmental Durability** – (***Weatherability***, or the resistance to ***weather stresses) special discipline within the larger context of durability***
  - The specific ability of a material, component or product to resist degradation caused by stresses of the service environment(s).
- For PV, "environment" may include extra-terrestrial or terrestrial outdoor exposure

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Durability Tests - examples

- Temperature cycling
- Thermal shock testing
- Freeze/Thaw cycling
  Altitude testing
- Humidity testing
- Temperature/Humidity cycling
- Solar radiation testing
- Rain testing
- Immersion testing
- Icing/Freezing rain testing
- Fungus testing
- Salt fog testing
- Sand and Dust testing
- Vibration”

  - Many others – standard, or as appropriate for application

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Durability Test Categories

- **<u>Qualitative</u> Accelerated Life Tests -** used primarily to reveal probable failure modes - some examples include:
  - ALT – Accelerated Life Tests
  - HALT – Highly Accelerated Life Tests (product robustness)
  - ESS – Environmental Stress Screening
  - HASS – Highly Accelerated Stress Screening (infant mortality)
  - HAST – Highly Accelerated Stress Test
  - CALT – Calibrated Accelerated Life Tests (General Motors method

The exact definition and implementation of these tests may vary with specific industry practices

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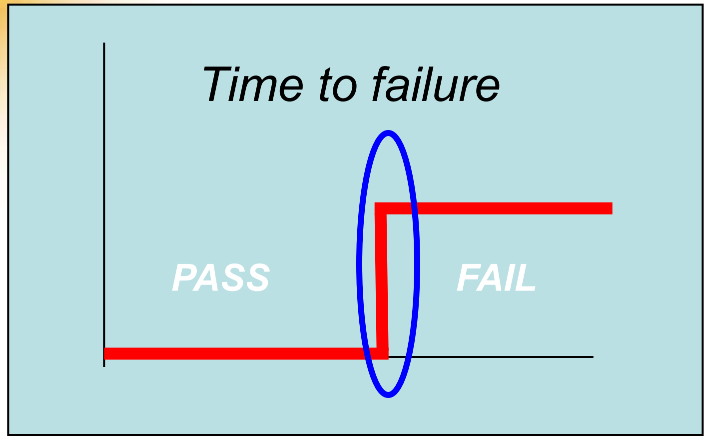
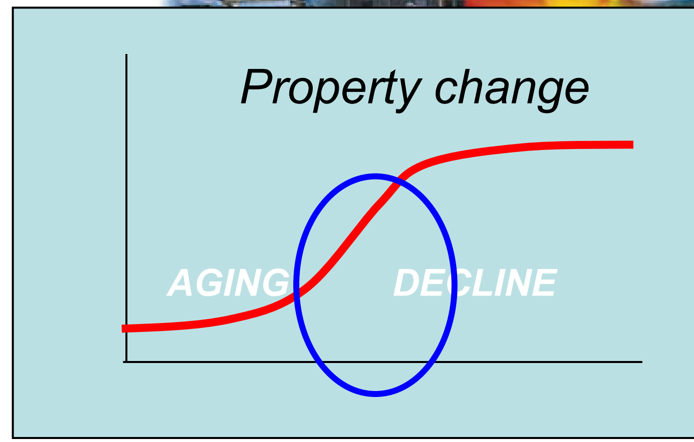
Reliability vs. Durability



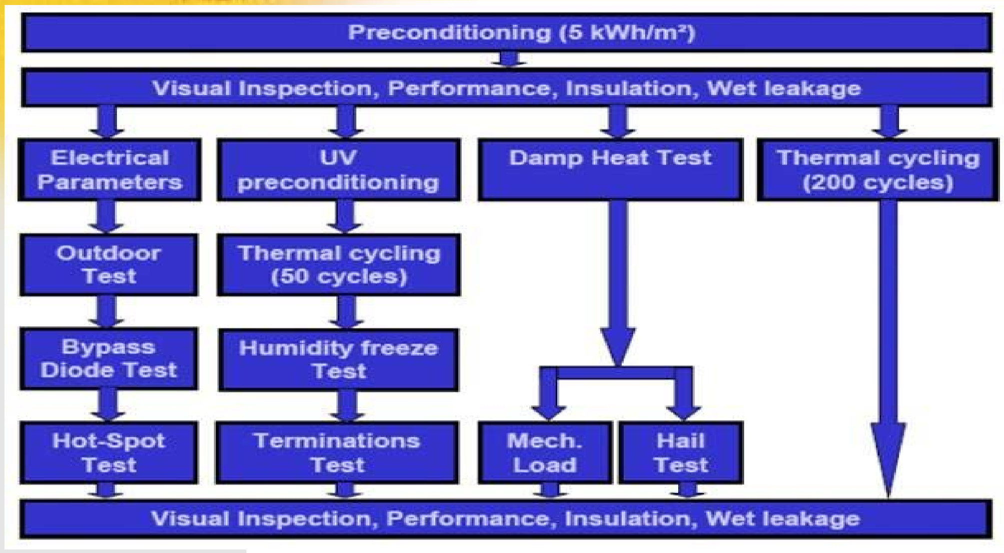


Reliability ***Durability***

- In very general terms, **reliability** analysis is concerned with measuring discrete, **absolute failures**

- **Durability** involves the **route to failures** (mechanisms), the property **rate of change** (kinetics), degree of **robustness**, etc. *These may not cause failure but result in declining performance and shortened service lifetimes.*

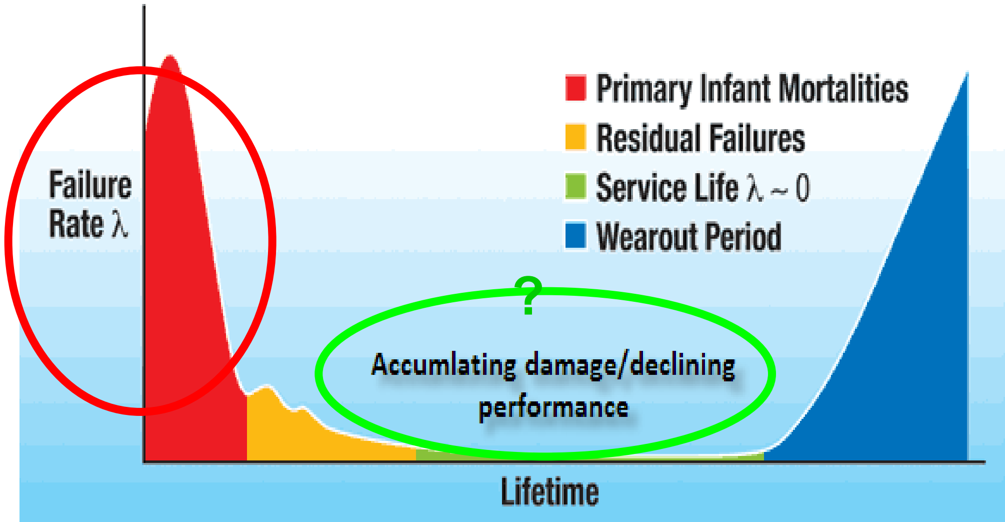
Reliability & Durability Testing



IEC design type qualification tests

IEC 61215 environmental tests

IEC 61646 environmental tests are similar



Qualification Test Objective

- To rapidly detect presence of failure or degradation modes -
  – “That may adversely affect ability of the tested item to serve its intended function in the intended environment”
- Most common use
  – “To verify durability of the final product before mass production is initiated” Serve valuable need in design, development and process control phase of product generation”
- “In the development testing phase,
  – required to provide rapid feedback of the relative strengths and suitability of design alternatives”
- “In process control applications
  – used to in indicate out of tolerance materials or processes”

Hoffman & Ross

Qualification Test Issues

- Therefore, “Qual” tests intended to:
  – To identify design and material flaws
  – Rank relative performance – materials, designs & processes
- But - difficult to equate qualification test results and field experience
- Not adequate to predict life-time of modules
- SLP tests –
  – More elaborate & extensive
  – Require expertise in testing and reliability analysis
  – Provide quantitative information

Solar ABCS

- Accelerated test standard proposal.
  - Objective - Recommend protocol for accelerated aging test
  - Will be offered to one of the standards writing bodies for adoption.
  - Three approaches anticipated
    - Accelerated Qualification – minimum requirement for module to be introduced into market
    - Comparative testing – compare performance of different designs – your own, or competition.
    - Accelerated lifetime testing – Goal to predict life time with high level of confidence
      - **requires more time – more expensive needs good understanding of failure modes and of models.**

IEC TC 82 Update

• New work item proposed for PV module back-sheet qualification and specification testing

- Based on work done by 15-company European consortium
- Premise\philosophy based on testing and qualification of individual materials, rather than complete cells and modules
-Perceived advantage of this approach – “Won’t need to do 18 months of RTI, but will still require re-test option”

- “Materials” group established
  - Big motivation - Complement\ Alternative to RTI

IEC Update Cont.

- Materials to be tested:-
  - **Backs-sheet, Encapsulant (transparent/opaque), Front-sheets**
  - Edge sealants, Junction box, adhesives, polymeric frames.
  - (Given the enormous effort that this would entail, only those in bold will be tackled in first round)

- Accelerated tests to be performed:-
  -UV (weather- durability & preconditioning), Damp-Heat, Thermal, Chemical, Electrical stress, Flammability, Mechanical Stress

- Properties to be used as pass\fail Criteria:-
  - Flammability – spread of flame, glow wire, ignition temp
  - Mechanical - Tensile, Impact, modulus
  - Electrical – Dielectric CTI, Partial discharge resistivity
  - Optical - transmission, reflection, color change
  - water vapor permeability.

ASTM E 44 Update – *November, 09*

- New std for durability and reliability of modules
  - Specifically, answering Solar ABCS
  - ASTM work item WK25362
- Approved scope -
- 1.1. This practice describes recommended procedures for conducting accelerated life testing of photovoltaic (PV) modules.
- 1.2. This practice applies to PV modules intended for residential and commercial and utility scale solar power generation.
- 1.3. This practice describes procedures for accelerating the failure mechanisms of PV modules caused by mechanical, electric, and environmental stresses.
- 1.4. The procedures for evaluating the effects of applied stresses on the performance of PV modules in order to predict their reliability under in-use conditions.

ASTM E 44 – Cont.

- New subcommittee E44.20 on glass for solar Applications - organized 09/29/09
  - Developed standards will address the characteristics that affect performance, durability and reliability
- Initial task - E 1596
  - Old, dormant PV module weathering standard
  - Updated by Atlas – balloted
  - Considered interim and something for other stds to reference until new standards complete
    - For example, ballot of the new Standard Practice for the Installation of Building Applied PV (WK 21327)

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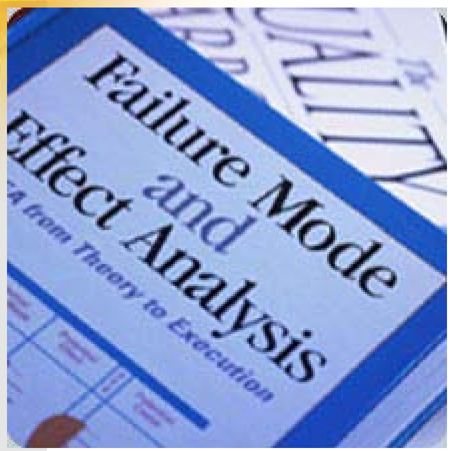
Testing for Durability & reliability

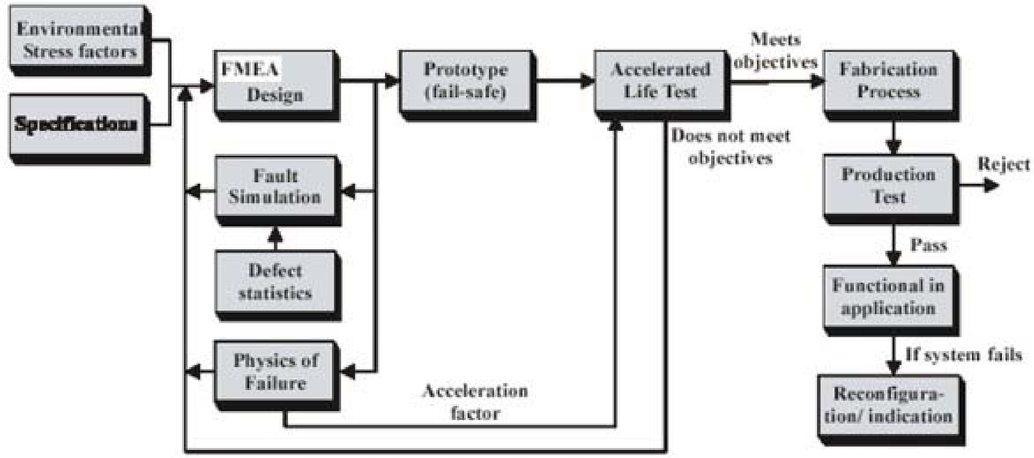
- Development of consensus standards
  - Long process
  - Inclusive of lowest common denominator
    - Compromised value?
- Good reliability testing requires a significant long-term investment
- Expertise is required for test design and proper interpretation of test results

Testing for Durability & Reliability

- Alternate methods
  - Utilize:
    - FMEA, Experience, Knowledge
    - Cumulative damage models
    - Results may never have better than "good estimates" (defensible)

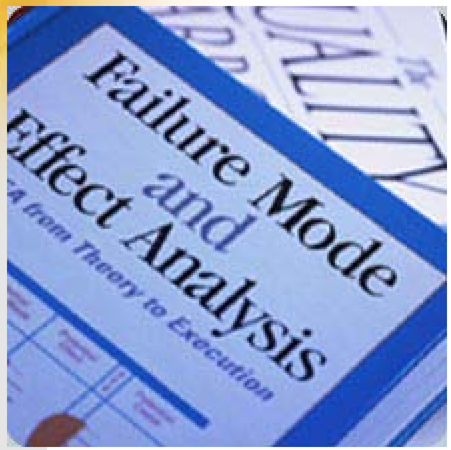
FMEA / FMECA

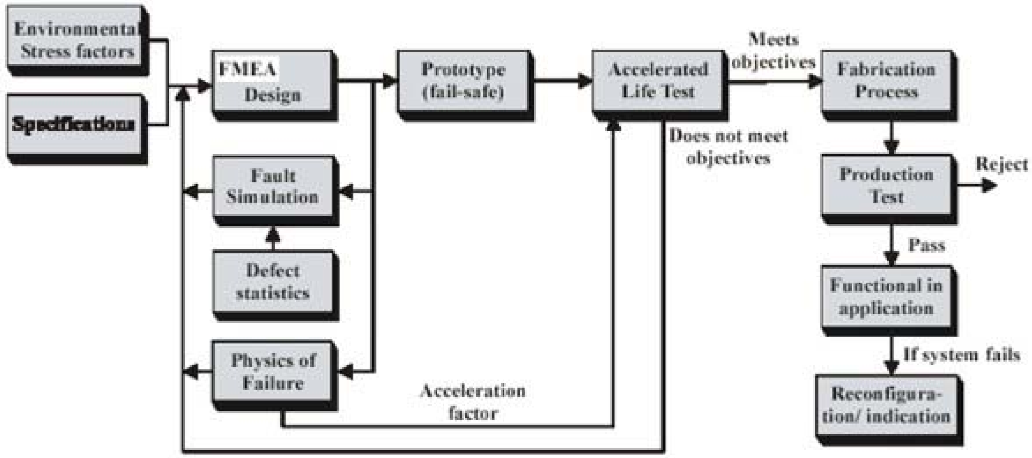




- The *d*FMEA is useful as a basis for establishing a bottom-up "materials" *m*FMEA which focuses on the role specific material chemistries play.
- Useful for planning <u>environmental durability</u> tests
- Determining the suitability of test methods for specific material chemistries
- interpreting the test results.

FMEA / FMECA





- The *d*FMEA can be a useful tool for deciding which durability test types and specific test conditions are appropriate.

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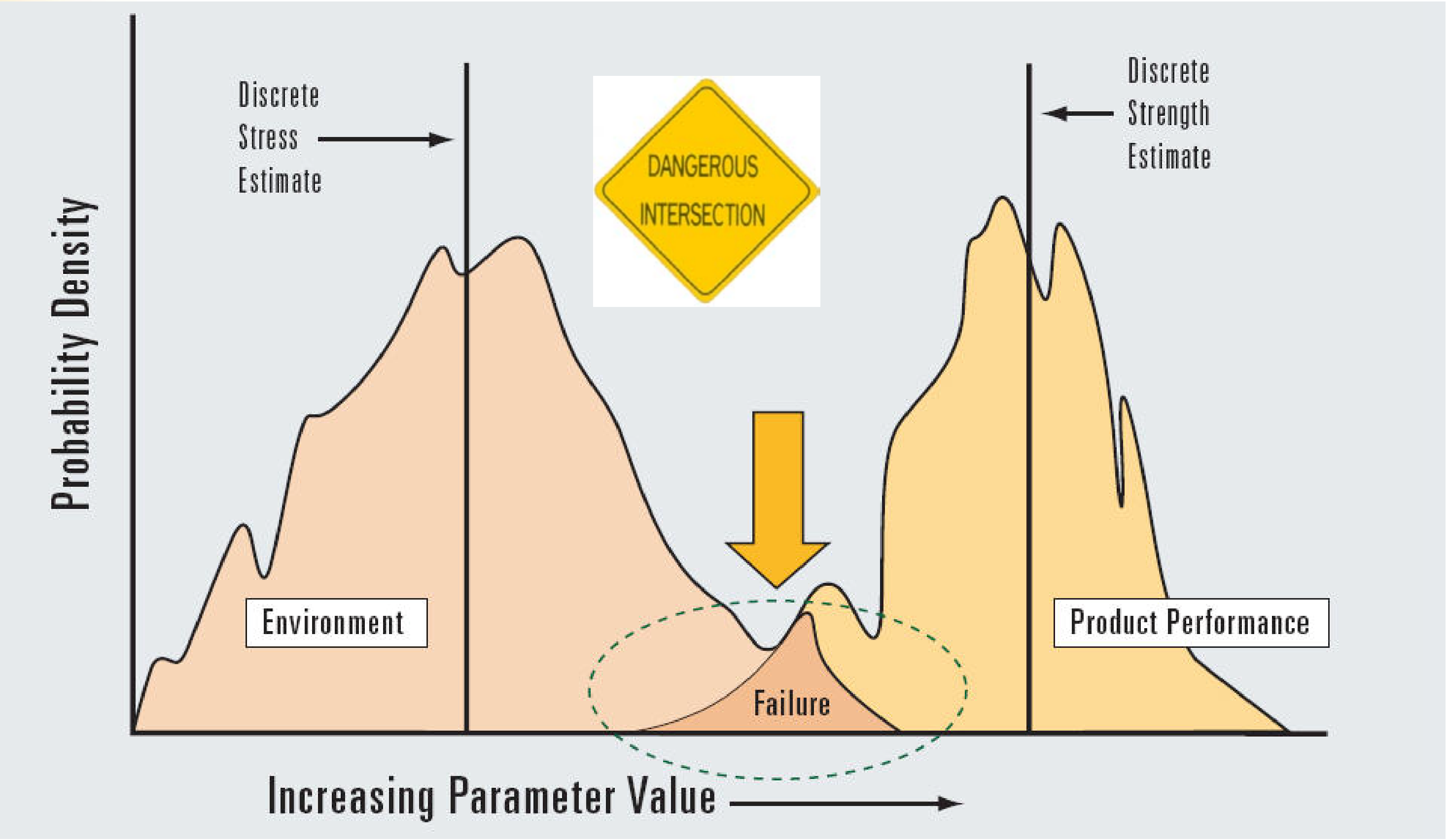
Design for Reliability/Durability



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Durability & Reliability – wrap up

- Especially as we become more involved in the current flurry of activity to develop PV standards….
- Mind your D's, R's & W's – let's make sure we can understand one another across technologies, disciplines & industries

Thank you!