



PV Module Reliability: Implications for the Latin American Market

September 13, 2017

GLOBAL REACH – LOCAL COMPETENCE



150+

years

350

offices

100+

countries

14,000

employees

SERVICES FOR SOLAR PROJECTS AND COMPONENTS THROUGHOUT THE PROJECT LIFECYCLE



| FEASIBILITY

- Feasibility studies
- Utility grid integration
- Environmental permitting
- Component technology reviews
- Component qualification testing

| ENGINEERING & DEVELOPMENT

- Due diligence/Independent Engineering
- Owner's Engineering
- Energy assessment
- Pre-construction engineering
- Interconnection support

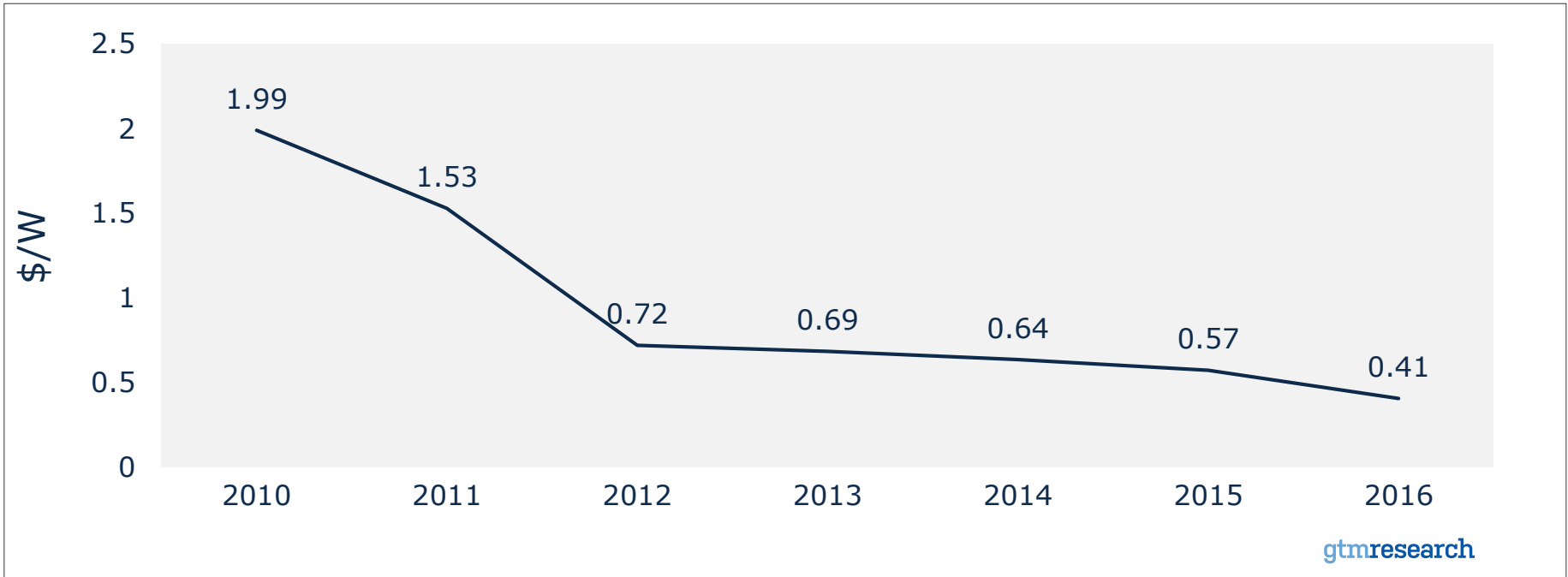
| CONSTRUCTION & COMMISSIONING

- Due diligence/Independent Engineering
- Owner's Engineering
- Construction oversight
- System testing and inspection
- Project certification and grid code compliance
- Module batch testing

| OPERATIONS

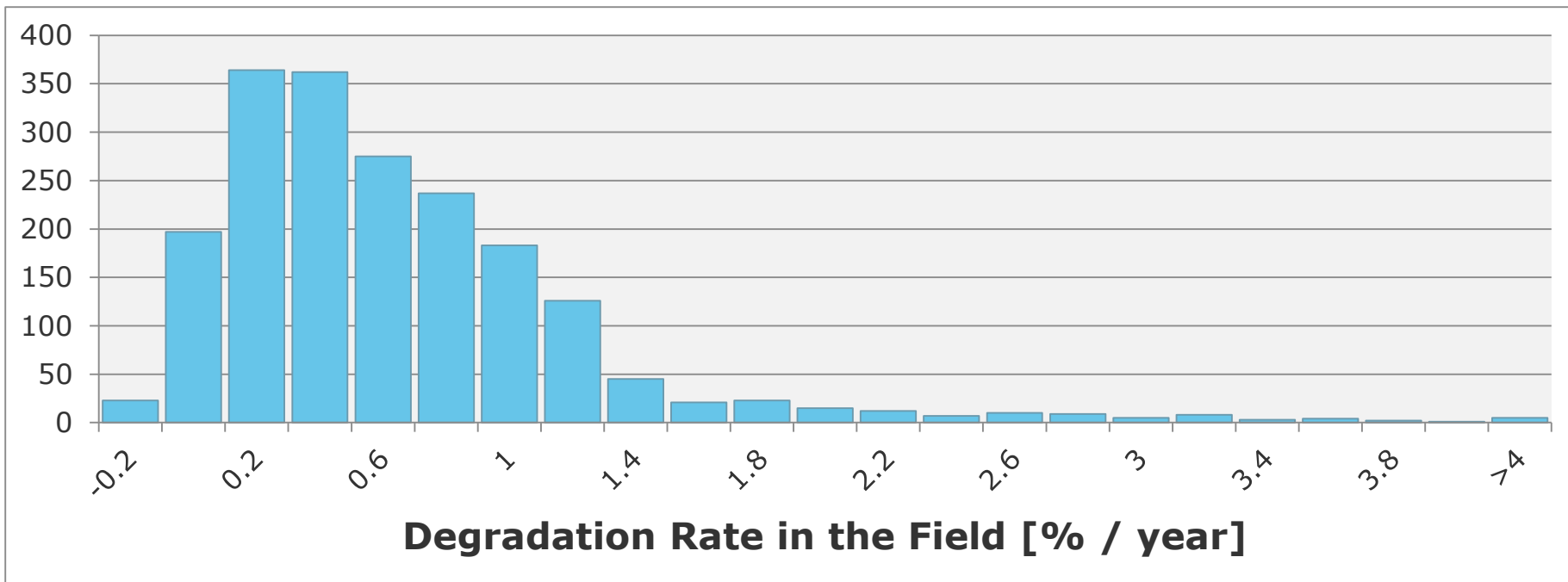
- Performance validation
- Resource and energy forecasting
- Existing asset consulting, inspections and decommissioning
- Refinancing and mergers and acquisitions advisory services
- Forensic investigations
- Monitoring, control and asset management

GLOBAL BLENDED MODULE PRICE



- ~80% drop in module price since 2010
- Very dynamic and severe pressure on manufacturers to reduce their costs
 - Can impact raw material quality and many other factors

NREL FIELD DEGRADATION STUDY "HIGH QUALITY" DATASET



Mean degradation rate

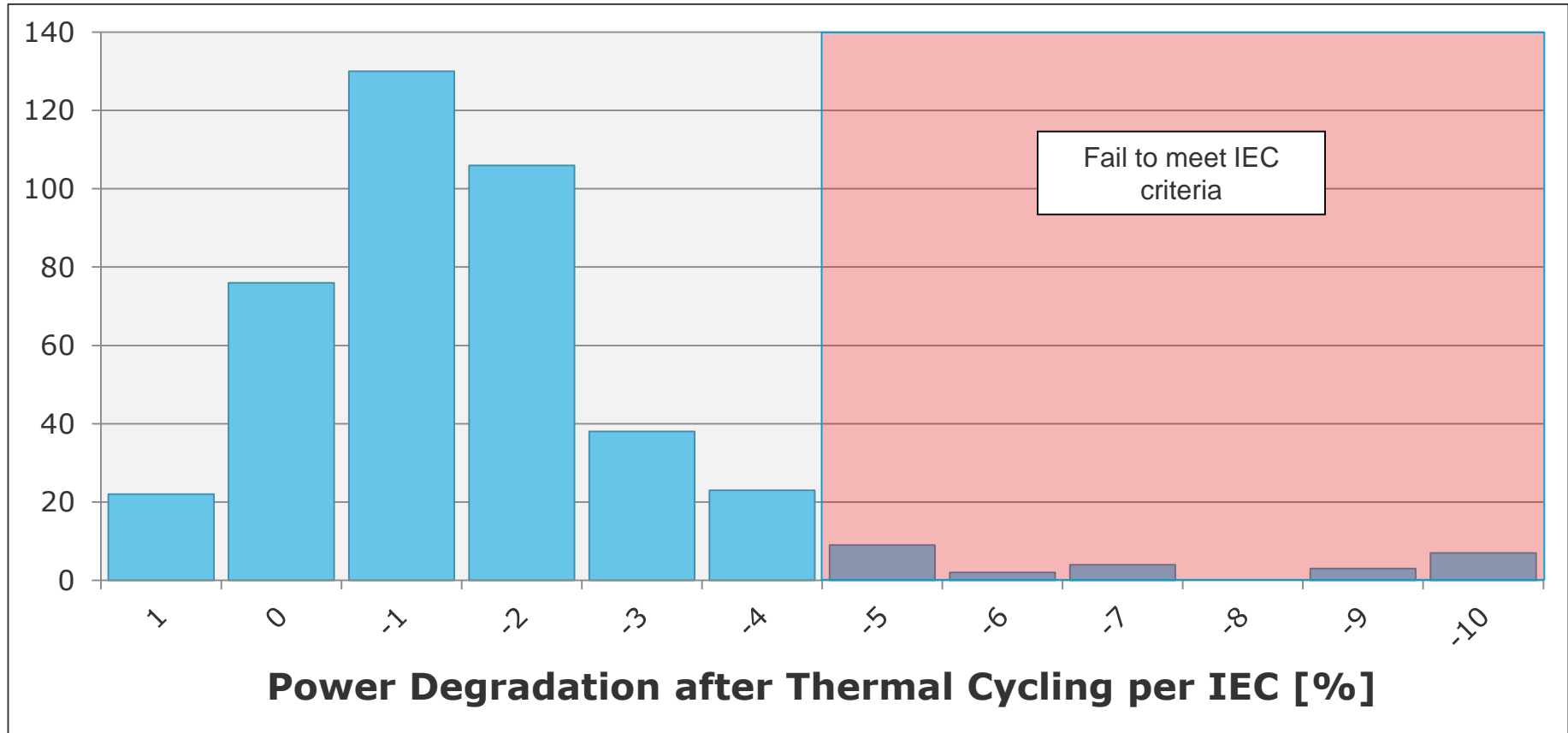
0.5 – 0.6 % / year

**P90
degradation rate**

1.2 % / year

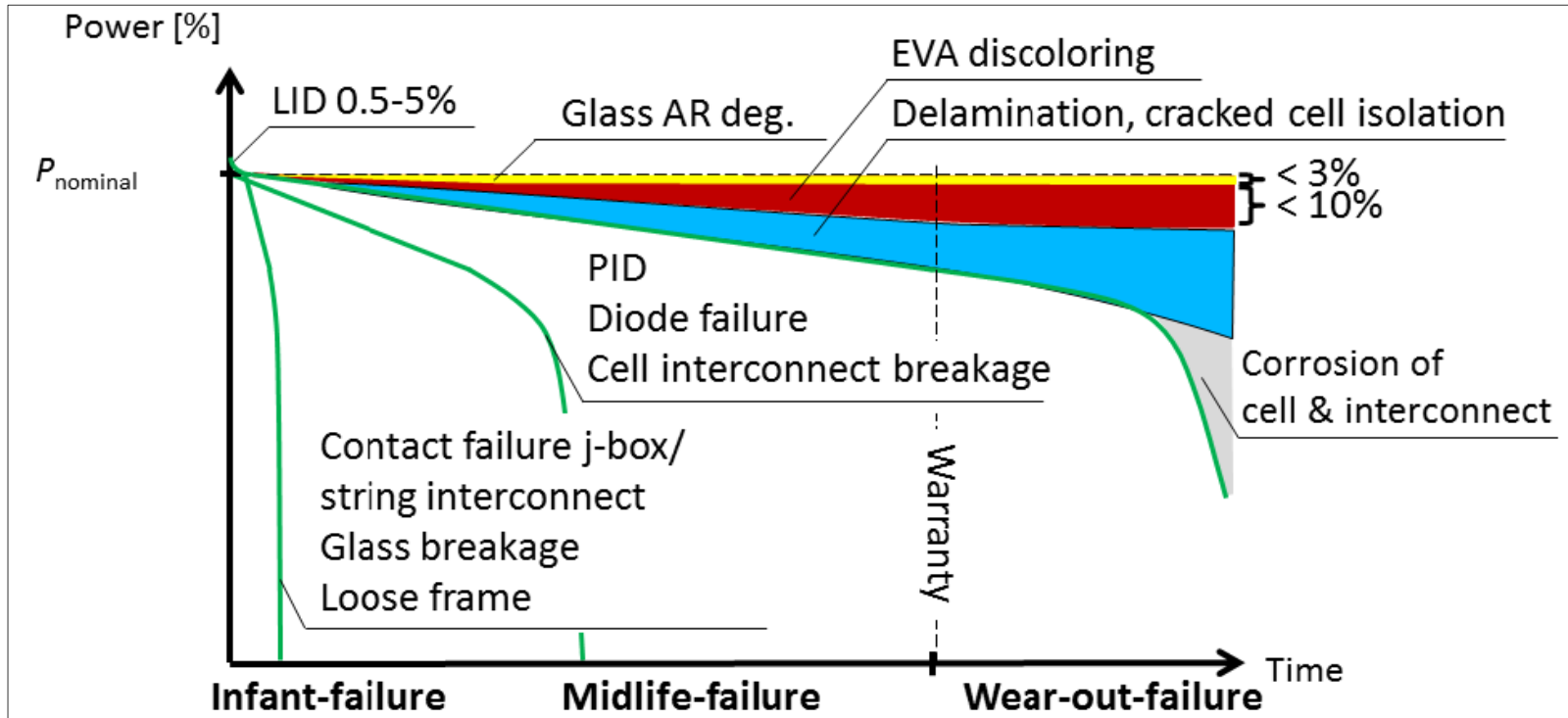
"Compendium of Photovoltaic Degradation Rates", D.C. Jordan, et al, NREL, 2015

THERMAL CYCLING (200 CYCLES) RESULTS FROM DNV GL LABS



- 6% of commercially available modules don't meet IEC certification criteria

PV MODULE DEGRADATION MECHANISMS



- Various aging mechanisms cause power degradation – we can test for these
- *Review of Failures of Photovoltaic Modules*, IEA PVPS 2014

CRITICAL FACTORS THAT IMPACT EQUIPMENT RELIABILITY

- PV Modules are manufactured:
 - with various Bill of Materials (BOMs) such as cells, encapsulants, backsheets, glass, etc. – materials are critical
 - in various factories, contracting is common – production process is critical
- Understanding the BOM and Factory of production is critical to qualifying equipment.
 - We recommend stating approved materials and factory location in Module Supply Agreements
- Every module tested in the DNV GL Product Qualification Program has 3rd party oversight and verification of BOM and factory – all combinations are tested

SOLAR TESTING SERVICES

1. Product Qualification Program (PQP):

PV Modules	PV Inverters	Energy Storage
<ul style="list-style-type: none">■ Testing for BOM■ Extended Reliability Testing■ Performance Testing<ul style="list-style-type: none">— PAN Files— IAM coefficients— LID— NOCT	<ul style="list-style-type: none">■ Reliability Testing■ Envelope Characterization■ Transient Response■ Low Light Performance■ Efficiency■ Arc / ground fault■ Micro, string, and utility scale■ AFCI nuisance trip	<ul style="list-style-type: none">■ Round Trip Efficiency■ Self-Discharge■ Response Time & Ramp Rate■ Overvoltage / undervoltage Protection■ SOC Validation■ Full System Cycle Testing■ Environmental Testing■ Cell Level Testing

2. Statistical Batch Testing:

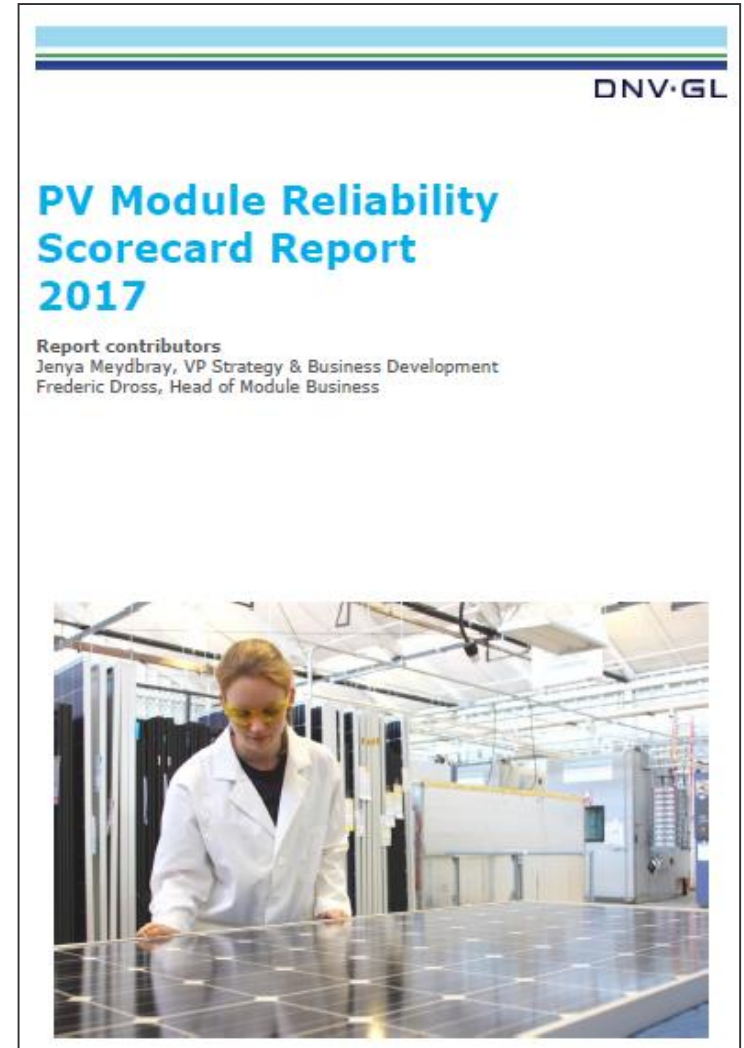
- At the project by project level to screen for defects

3. Field Testing:

- Verification that power plant operation matches expectations

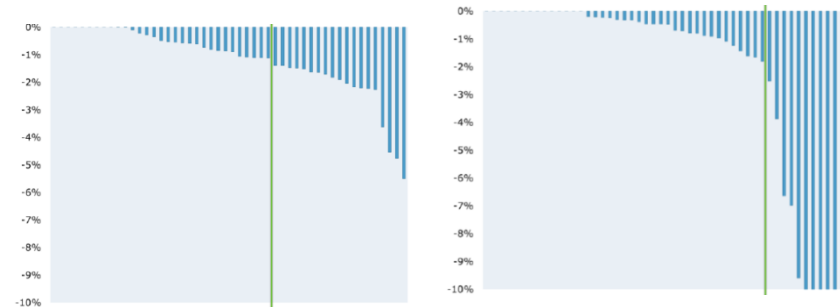
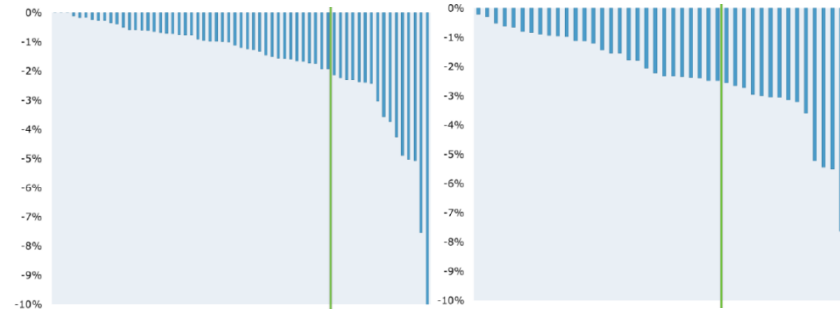
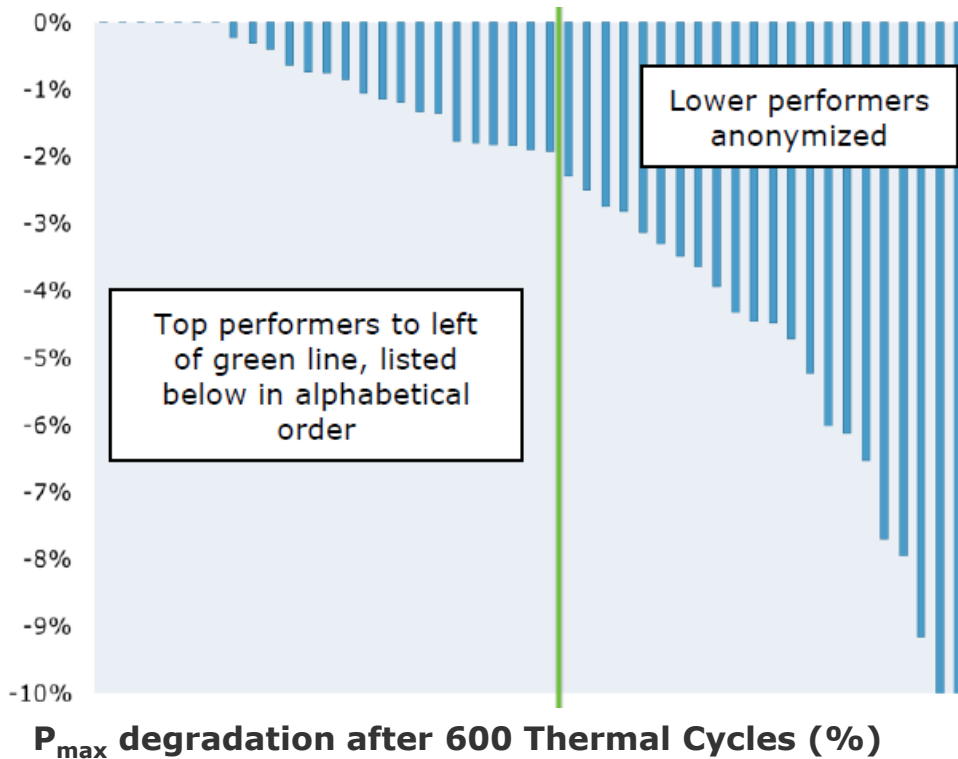
PV MODULE RELIABILITY SCORECARD 2017

- Using data from the PQP we released the PV Module Reliability Scorecard Report
- High level summary of results
- Good performers are named alphabetically, poor performers are anonymous
- Free Download
- Detailed PQP reports are available to Downstream Partners – also for free!



SCORECARD TESTING RESULTS - 2017

- Percentage of **degradation of power** (P_{max}) after environmental chamber testing
- Each bar is a PV module model/type (defined by BOM and Factory)



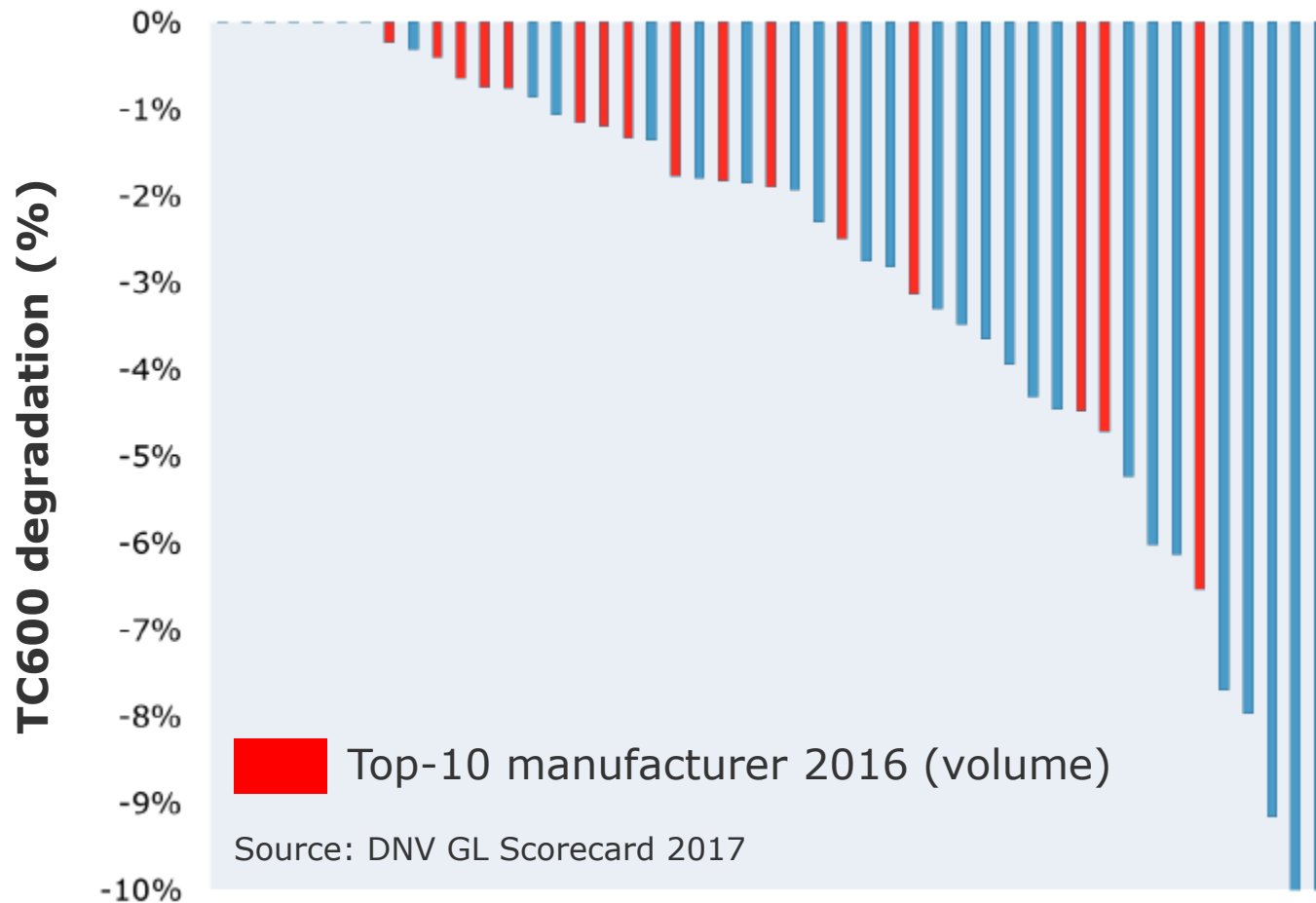
Only the top performers are listed by name

LISTED TOP PERFORMERS IN THE 2017 RELIABILITY SCORECARD

In alphabetical order:

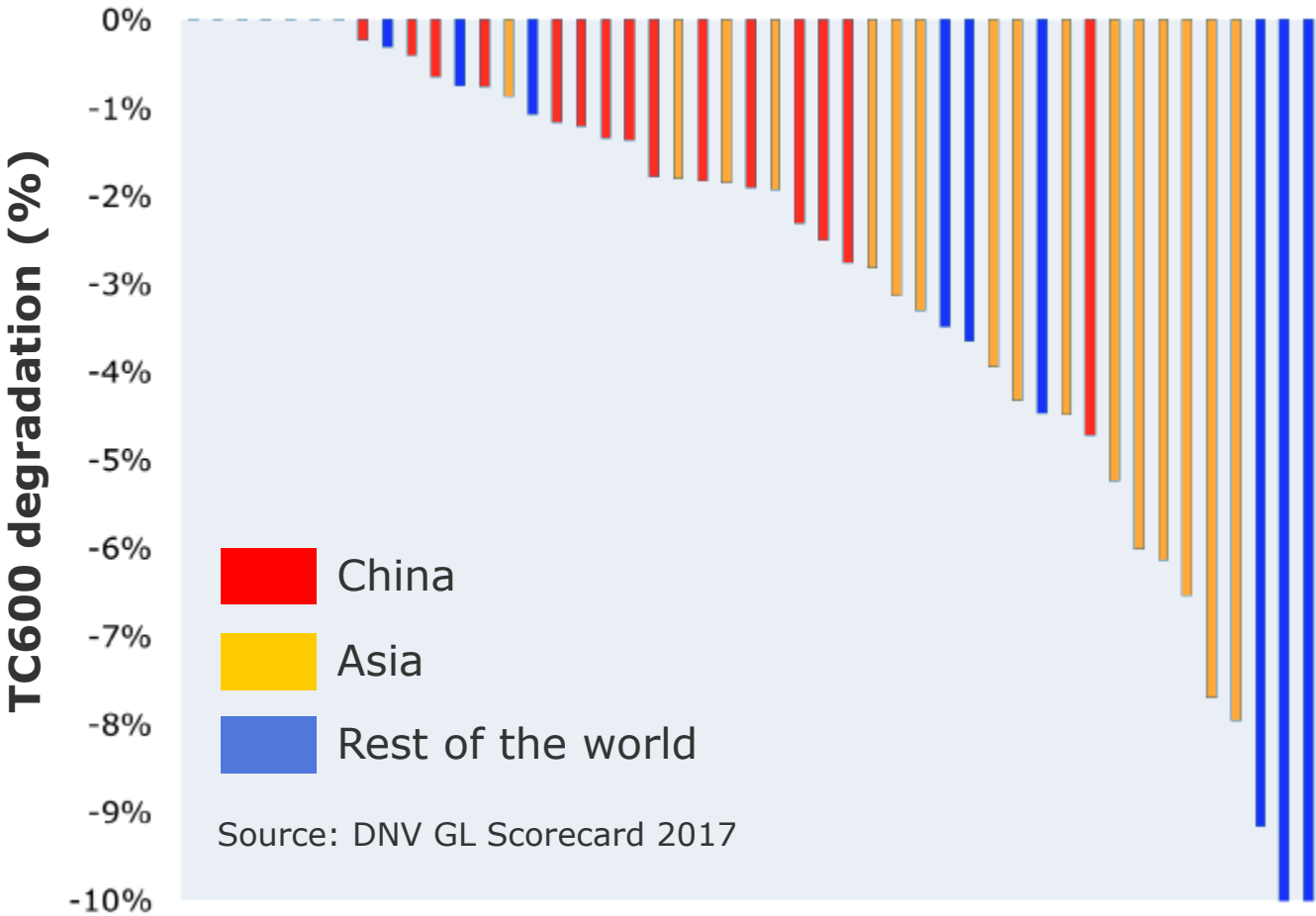
- **Astronergy**
- **BYD**
- **Flextronics**
- **GCL**
- **Hanwha Q CELLS**
- **Hyundai**
- **Jinko Solar**
- **Kyocera**
- **LONGi**
- **NSP**
- **REC**
- **S-ENERGY**
- **Seraphim**
- **Silfab**
- **Solaria**
- **SolarWorld**
- **SunPower**
- **SunSpark**
- **Talesun**
- **Trina Solar**
- **Vikram**
- **Yingli**

KEY FINDING 1: SHIPMENT VOLUME IS NOT A GOOD PROXY

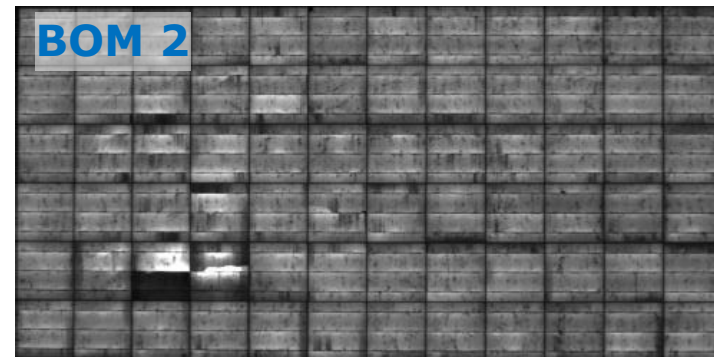
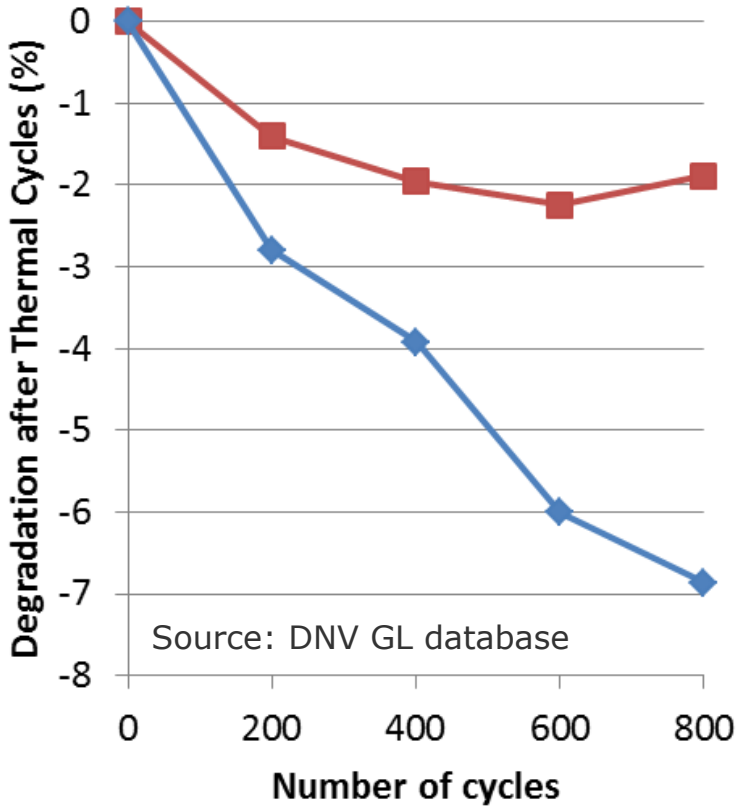


Big and small manufacturers show good and bad results

KEY FINDING 2: FACTORY LOCATION IS NOT A GOOD PROXY FOR QUALITY



KEY FINDING 3: BILL OF MATERIALS (BOM) MATTER

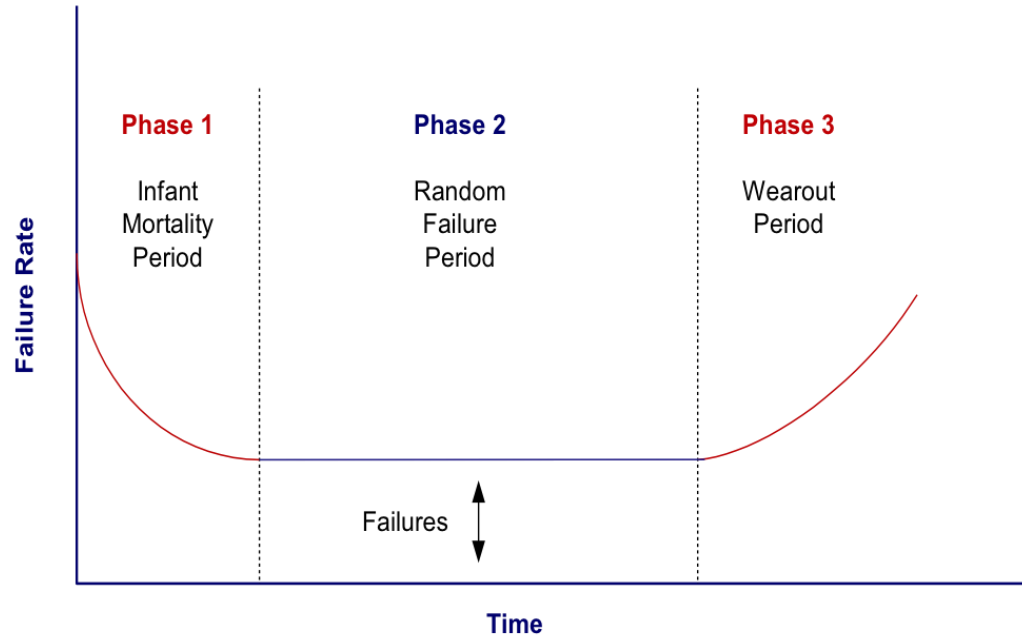


Same exact module; different BOM

LatAm modules may have different BOM than US – you need to check!

BATHTUB CURVE

- Higher probability of failure for first years and at end of life
- Testing can help screen both



Infant Mortality

Caused by manufacturing or materials Defects
Can use **Statistical Batch Testing** to screen

Wear-Out

Caused by reaching design limits
Can use **PQP** to screen
Long duration testing

PROCUREMENT BEST PRACTICE – SCREENING THE BATHTUB

Before Production

Product Qualification Program (PQP)

- Extended reliability testing reports
- Performance evaluation (PAN files, etc.)
- Factory witness

During Production

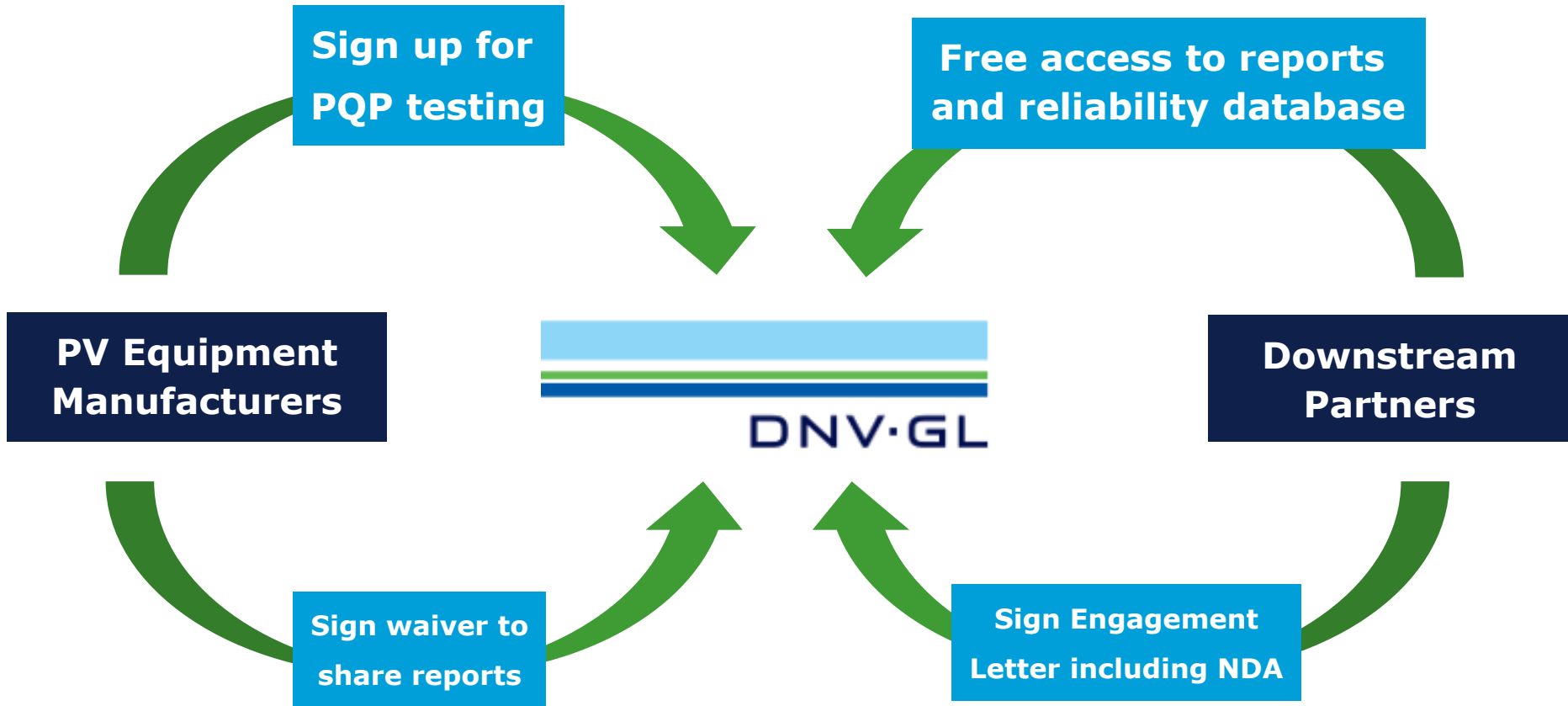
Statistical Batch Testing

- Test on actual modules from the project
- Factory production oversight

- Latin American buyers and investors can learn from US experience to avoid quality issues
- Leverage the PQP to evaluate new module vendors rather than assuming large vendors or certain regions are all producing high quality modules

PQP LARGELY ADOPTED AS BEST PRACTICE TODAY

- **Several hundred reports** available to DNV GL Downstream Partners
- **World's largest reliability database** of commercial PV products



Thank you for your attention!



Sign up for the Product Qualification Program today!

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SAFER, SMARTER, GREENER