Solar PV Indoor and Outdoor Testing

CSIR Energy Centre Solar PV and EAC
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Outline

1. CSIR facilities – indoor and outdoor
2. Results from outdoor testing
3. Results from indoor testing
4. Quality versus Reliability
5. Reliability Testing
6. Summary

Types of Research and Testing Services

1. Outdoor PV modules and systems
   – Long-term performance monitoring, model validation, power quality analysis, yield studies, failure analysis, loss characterization, etc.

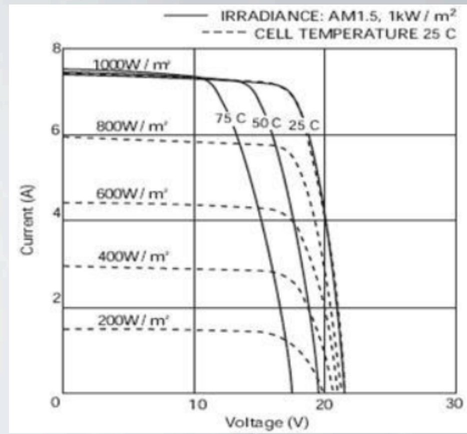
2. Indoor quality for PV modules
   – PV module power measurements, energy rating, temperature coefficients, multi-irradiance measurements, electro-luminescence imaging, high voltage safety testing, etc.

3. Indoor reliability for PV modules
   – Accelerated stress testing, thermal cycling, humidity freeze, damp heat, potential induced degradation, and mechanical load

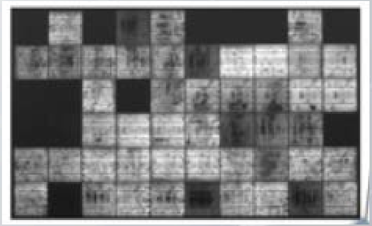
Testing Facilities – Indoor and Outdoor

Sun simulator with temperature chamber

IV Curves



Thermal Cycles
Humidity Freeze
Damp Heat



Potential Induced Degradation

Mechanical Load

Outdoor Testing

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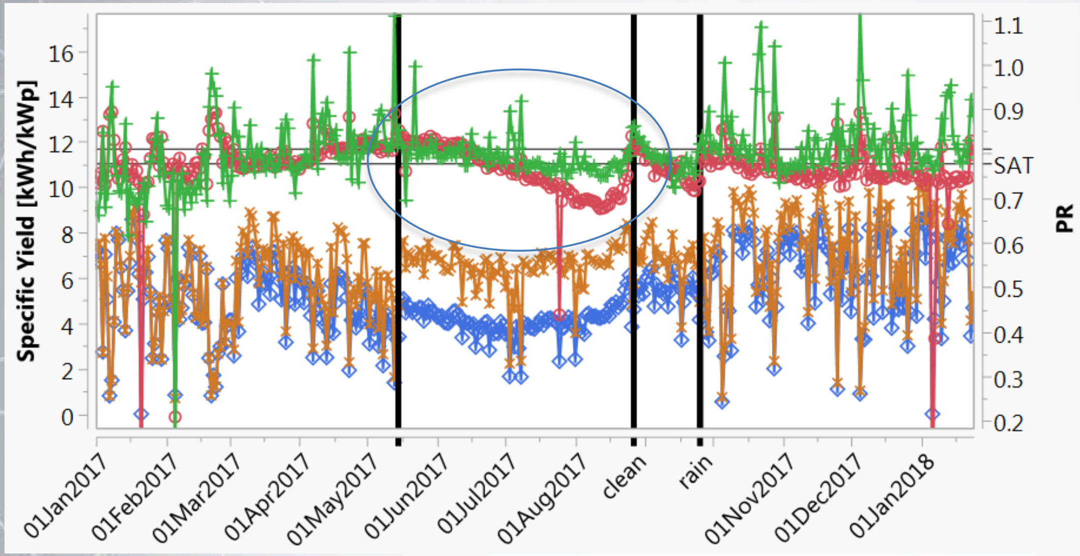
Soiling losses: Single Axis versus Dual Axis



14 May through 02 Sept 2017

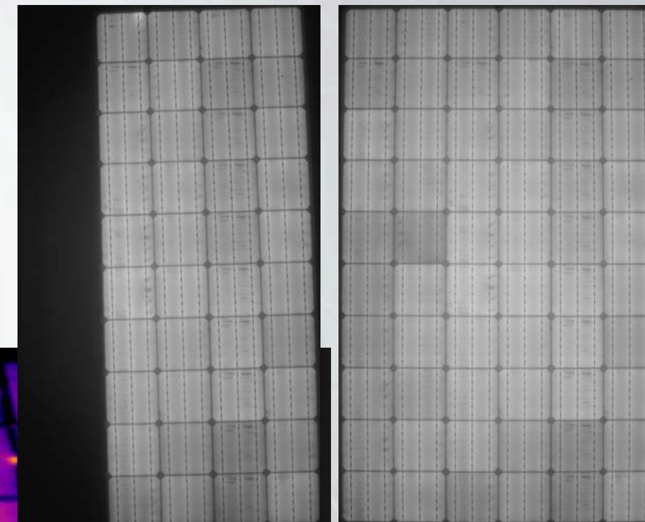
System	Soiling Loss [%]	Soiling Rate [%/week]	PR
SAT	20	1.5	0.77
DAT	5	0.5	0.80

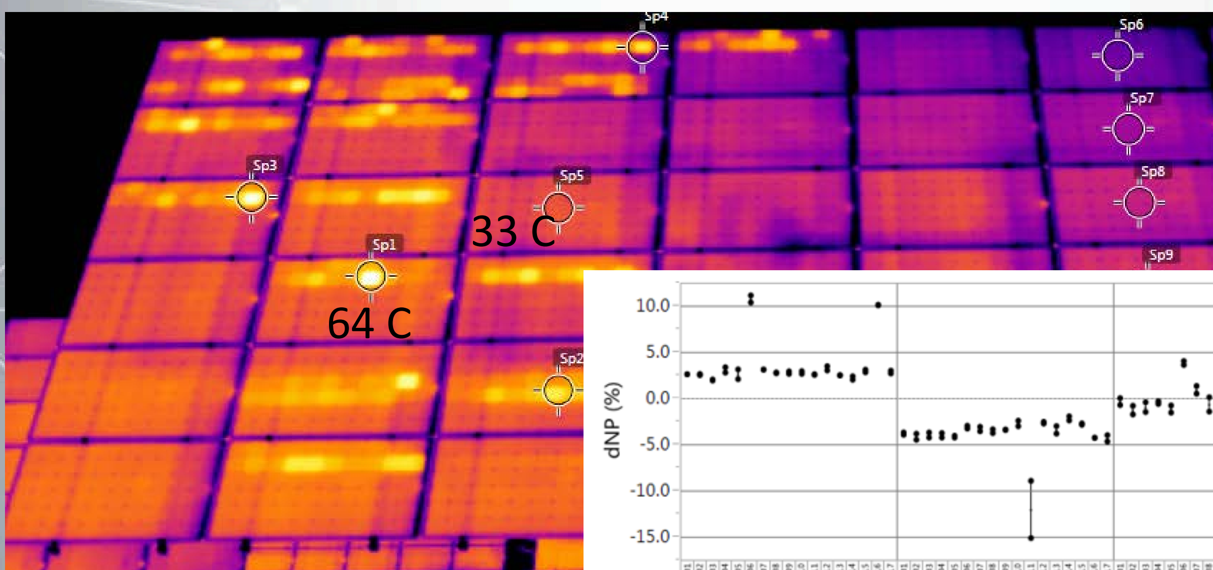
- In 2017, the soiling loss was 4x greater on the single axis tracker during the 3 winter months without rainfall
- We speculate that this is due to the height of the dual axis tracker and the orientation of the dual axis tracker in the dry, winter months
- The specific yield of the dual axis tracker was 50% higher during the winter months compared to the single axis tracker (4.1 vs. 6.5 kWh/kWp)

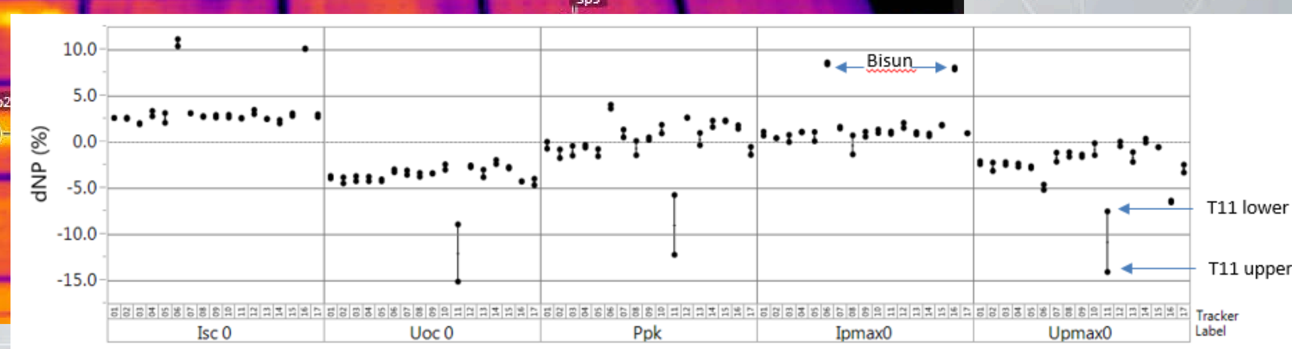
Hotspot testing: Failed Bypass Diodes

- Module substrings with hotspots – August 2017
  - 11 on upper string, 5 on lower string
- IV curves correlate voltage loss to number of failed substrings
- Determined bypass diode failed in short-circuit on a sample of two modules
- We suspect damage due to lightning

Diode in place   Diode removed

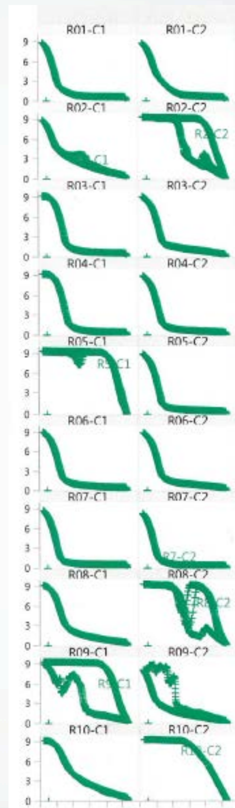


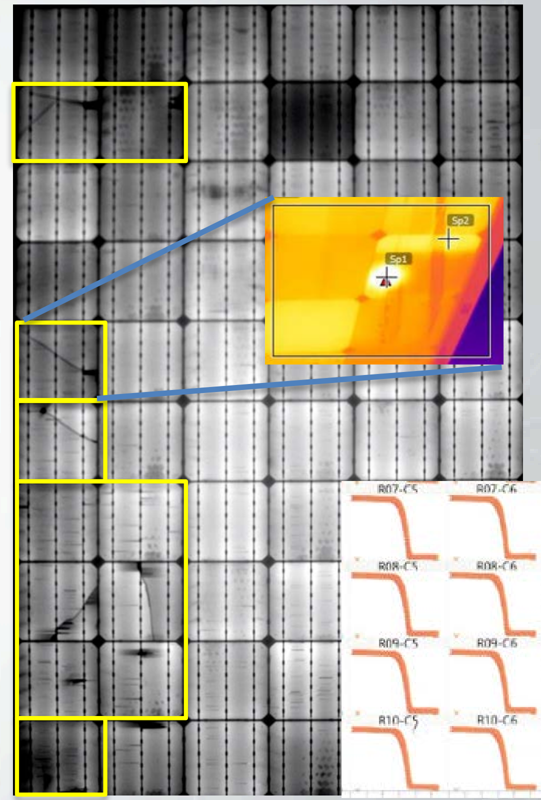




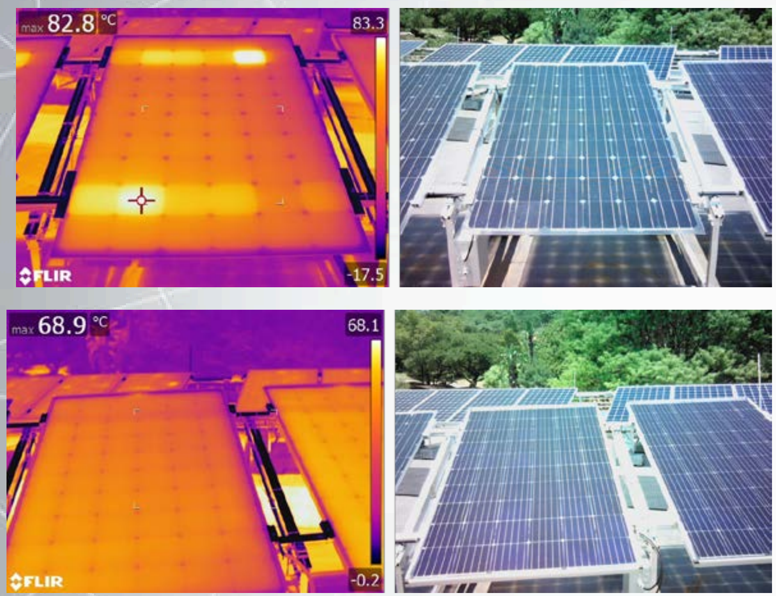
Hotspot testing: Failed Bypass Diode

1. Shaded IV curves from Tracker 11 module removed July ‘18
2. Cracks on R02-C1, R05-C1, R06-C1, R08-C1, R08-C2
3. No crackes observed the in substrings at the center and the right side
4. Areas marked yellow have burnt marks on the backsheet
5. 160 C backsheet temp when C1R5 was covered 75%
6. Bypass diode solder bond failed resulting in open circuit

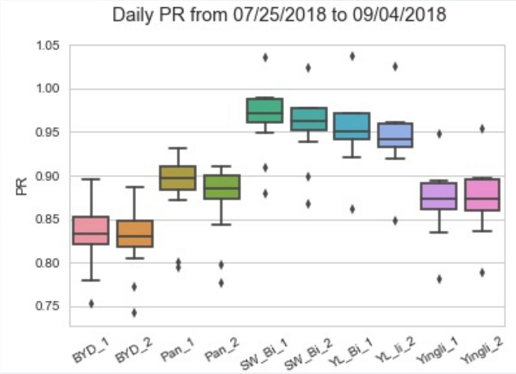




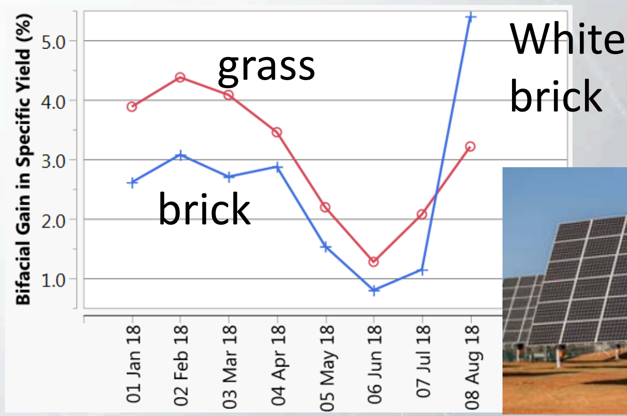
Bifacial Modules: Performance Ratios



1. Frameless bifacial module showed hotspots in front of mounting rails
2. Framed bifacials did not show hotspots
3. These hotspots vanished later in the day
4. We speculate that spacing between rail and backside and the albedo is causing non-uniform irradiance on the back side



1. DC PR for bifacials: .94 to .97
2. DC PR for monofacials: .83 to .90



1. Bifacial gains on a dual axis tracker
2. White paint on bricks increased the gain

Indoor: Quality Testing

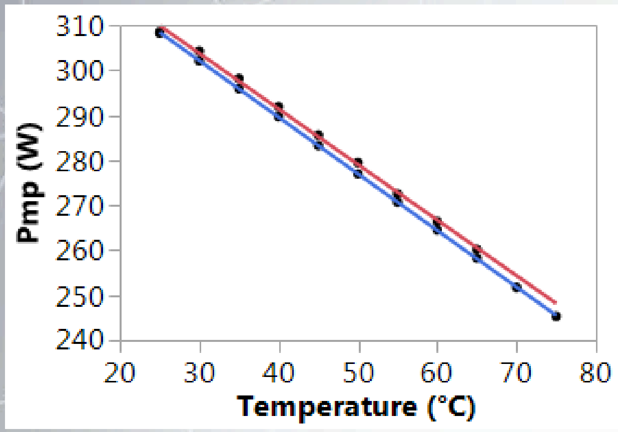


Fig 1. Temperature Coefficients

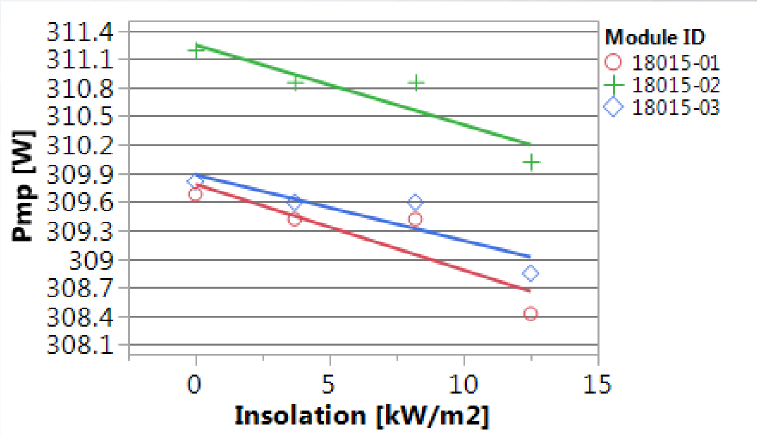


Fig 2. Light induced degradation (LID)

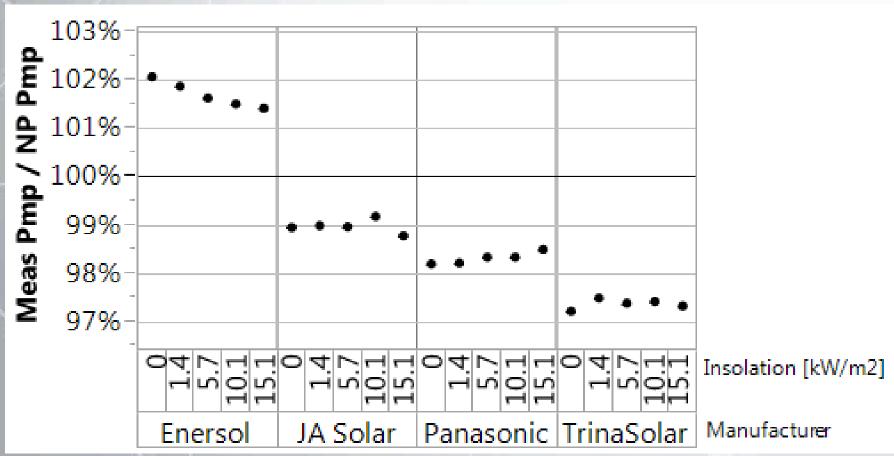


Fig 3. Pmp delta to nameplate

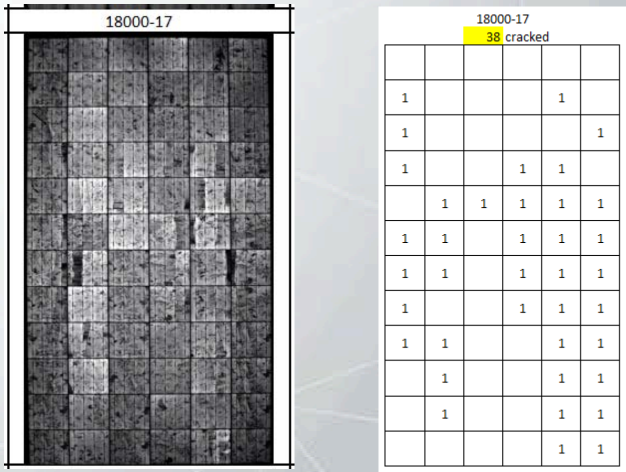


Fig 4. EL and Crack Map

Indoor: C450 Extended Reliability Program

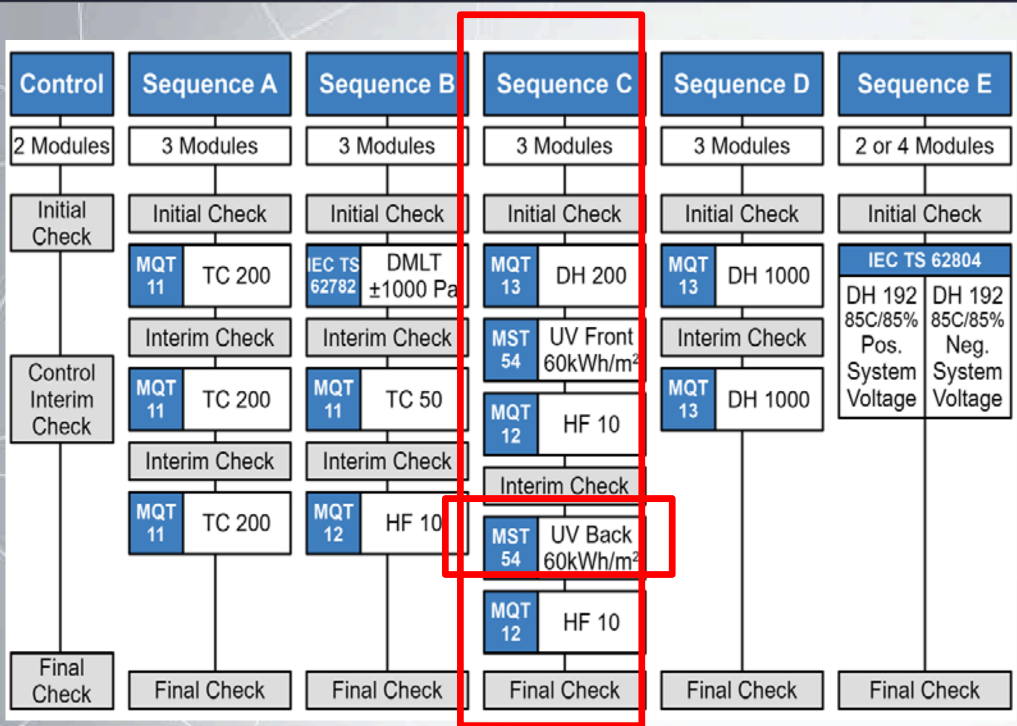


Figure 5. EXP C450 test protocol

Source: C450 PV module testing protocol for quality assurance programs, 2018

1. C450 is an international standard protocol for PV module reliability testing
2. C450 is based on IEC standards
3. C450 development committee included representatives from the commercial, research, and testing segments of the PV industry
4. C450 is comparative in nature, providing science based data on the relative performance of PV modules in the market place
5. Results are used to manage PV module supplier quality
6. Module manufacturer is motivated to supply the best modules, not the worst of the lot

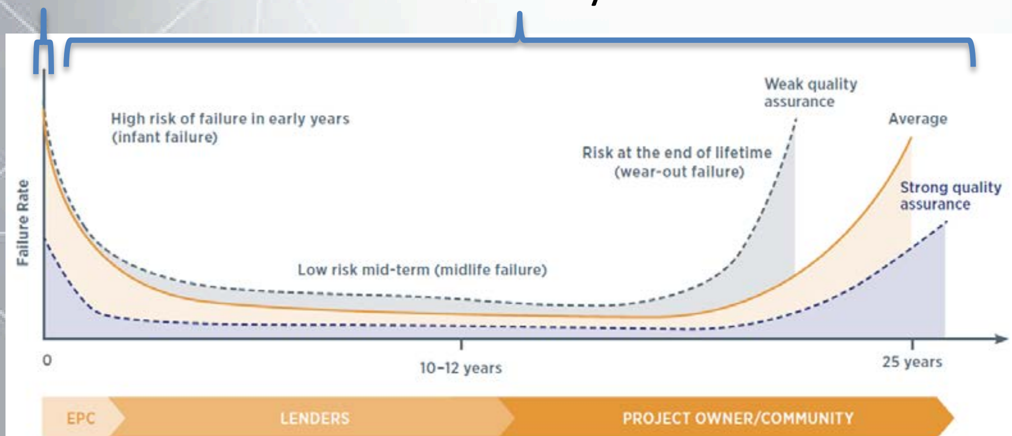
Cost of Quality versus Reliability

Description	Quality	Reliability
Project size [MW]	1	10
Average module power [W]	300	300
Number of modules in the project [N]	3 333	33 333
Number of modules in the RANDOM sample [n]	100	20
Sampling rate n/N [%]	3.0	0.06
Cost of modules in the project [R]	3 200 000	32 000 000
Price for IV, EL, Wet Leakage, and Dry Hipot [R]	460 000	included
Price for C450 reliability test service [R]		1 000 000
Quality testing as percentage of module cost [%]	14.4	3.1
Duration of testing [weeks]	2	16

Note: indicitive pricing only

Quality

Reliability



1. Quality assurance testing is focused on validating nameplate performance out of the box
2. Reliability is quality over time / stress
3. Reliability is focused on reducing risk of failure over the lifetime of the project
4. Reliability testing entails longer test periods on few modules
5. Reliability testing makes sense on larger projects when the risks justify the costs
6. IRENA reports claims a 2-3% gain in plant performance when quality assurance testing is announced
7. Estimates based on indicative pricing

Source: IRENA 2017 BOOSTING SOLAR PV MARKETS: THE ROLE OF QUALITY INFRASTRUCTURE

Indoor: Quality Testing Cost/Benefit

Table 1.2. Cost/benefit analyses of implementing specific quality infrastructure services

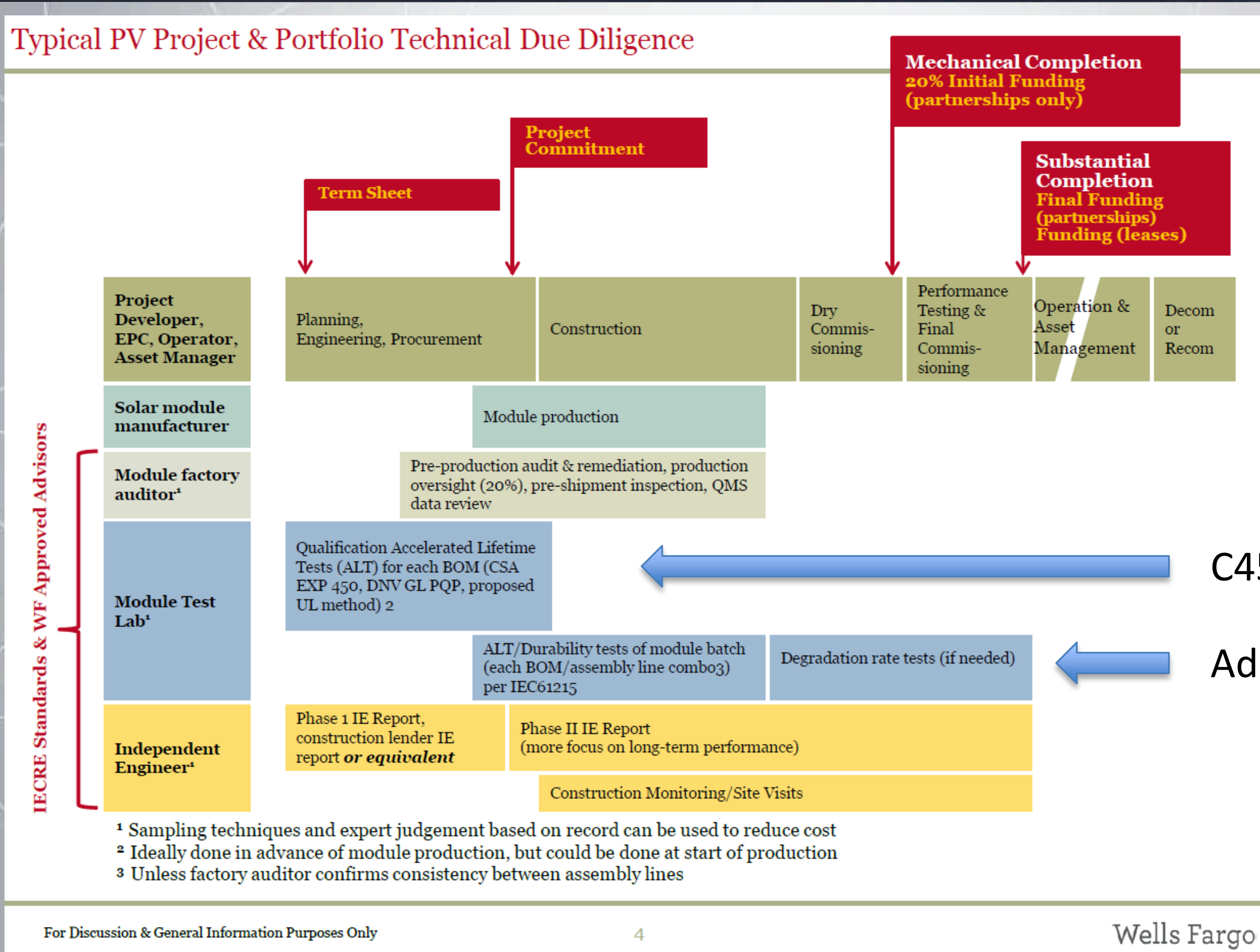
Quality infrastructure service	Cost	Benefit
Development: Solar resource and yield uncertainty		
Energy Production Assessment (EPA) based on measured irradiance data	Measuring local irradiance for at least one year	Reduction of uncertainty in EPA from 8% to 6% leads to an increase in P90 values by 3%. Rewarded through improved loan conditions.
Preconstruction: Prevention of low plant yields		
Batch acceptance testing for wholesale and utility projects	The cost of a batch acceptance test (Typically USD 50 000–55 350 for a 20 megawatt (MW) plant)	A reduction of the degradation rate from 0.75% a year to 0.4–0.6% a year in a project's financial model (Resulting in USD 450 000–1 000 000 of increased revenue over 25 years for a 20 MW plant)
Construction: Performance testing		
Includes independent testing in engineering, procurement and construction contracts on photovoltaic systems performance	The cost of batch testing for a 20 MW plant is USD 276.75–553.50/MW	Photovoltaic module manufacturers deliver modules exceeding contracted performance by 2–3% when batch testing is announced. (Earning an additional EUR 4 000–6 000/MW a year increased generation for a 20 MW plant) (USD 4 428–6 642/MW/year)
Operation and maintenance		
Potential induced degradation (PID) reduction. Inspections to detect, classify and mitigate PID effects	Cost of inspection and corrective actions (for a 6 MW plant in Western Europe: EUR 2 500–4 000/MW) (USD 2 767.5–4 428/MW)	Tackling PID reduces underperformance of 3–5%; however, recovery is not immediate (for the 6 MW plant, EUR 6 000–10 000/MW/year) (USD 6 642–11 070 MW/year)

SAT cost (R/kWh):
0.82 @ 0.75% / yr
0.80 @ 0.50% / yr

The difference equates to R 20 million for a 20 MW plant over 25 years

Source: IRENA 2017 BOOSTING SOLAR PV MARKETS: THE ROLE OF QUALITY INFRASTRUCTURE

Indoor: Reliability Testing by Wells Fargo



C450 for each BOM *

Additional batch tests *

Source: The Value of Durable Materials in Maximizing Your Investment in Solar Energy, * added by CSIR

Summary

1. The CSIR is developing state of the art research and testing facility to support the South African solar PV industry
2. Soiling losses on the CSIR single axis tracker reached 20% after three months of no rain during the winter season of 2017
3. Quality and reliability testing should be included in large PV plant planning and construction, depending on the size
4. Quality and reliability testing can reap real cost savings and improved LCOE over the lifetime of a plant
5. Reliability matters!

Thank you

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