School of Photovoltaic and Renewable Energy Engineering

Control of Manufacturing Variations in Emitter Resistivity to Increase PERC Solar cell performance

Rhett Evans

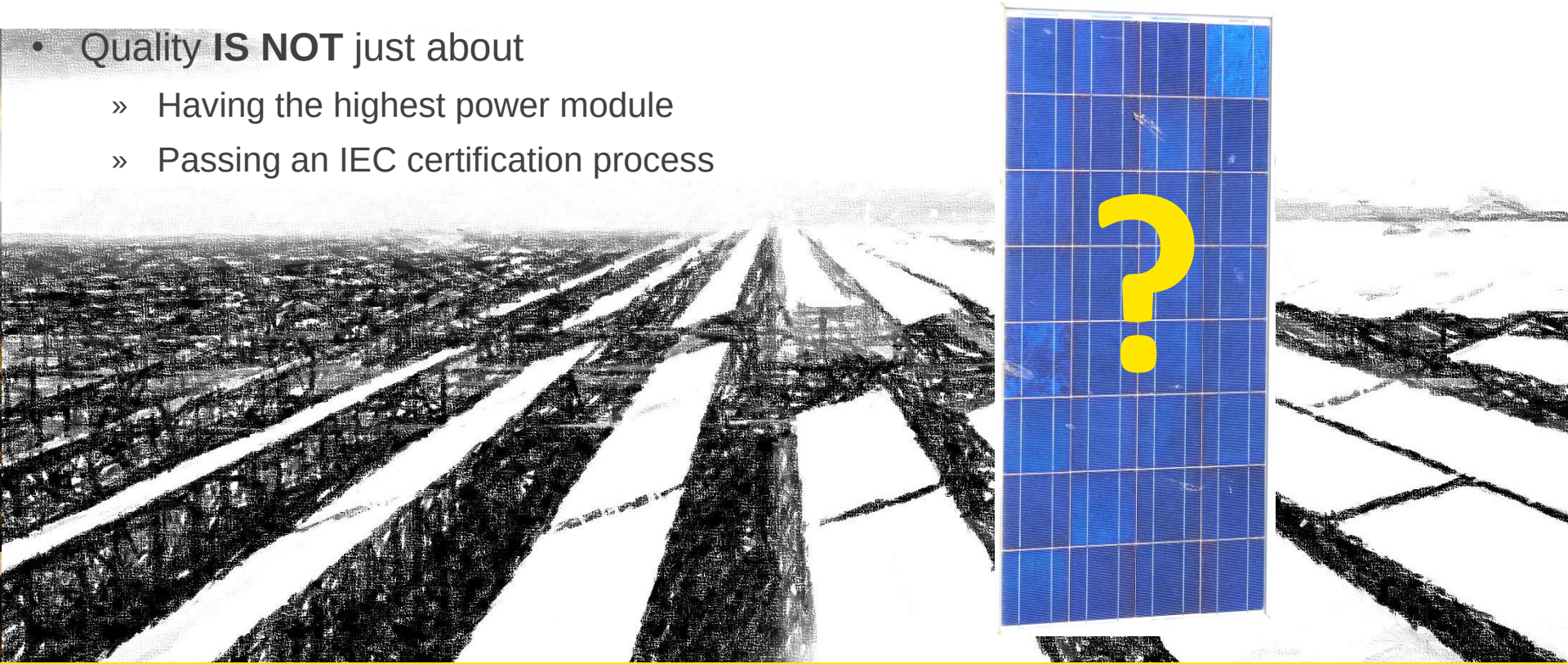
rhett.evans@unsw.edu.au

Overview

1. The quality mission
2. Quantifying quality using “Process State”
3. Case Study: Controlling emitter resistivity to increase PERC performance.
4. Conclusions and future outlook

The quality mission

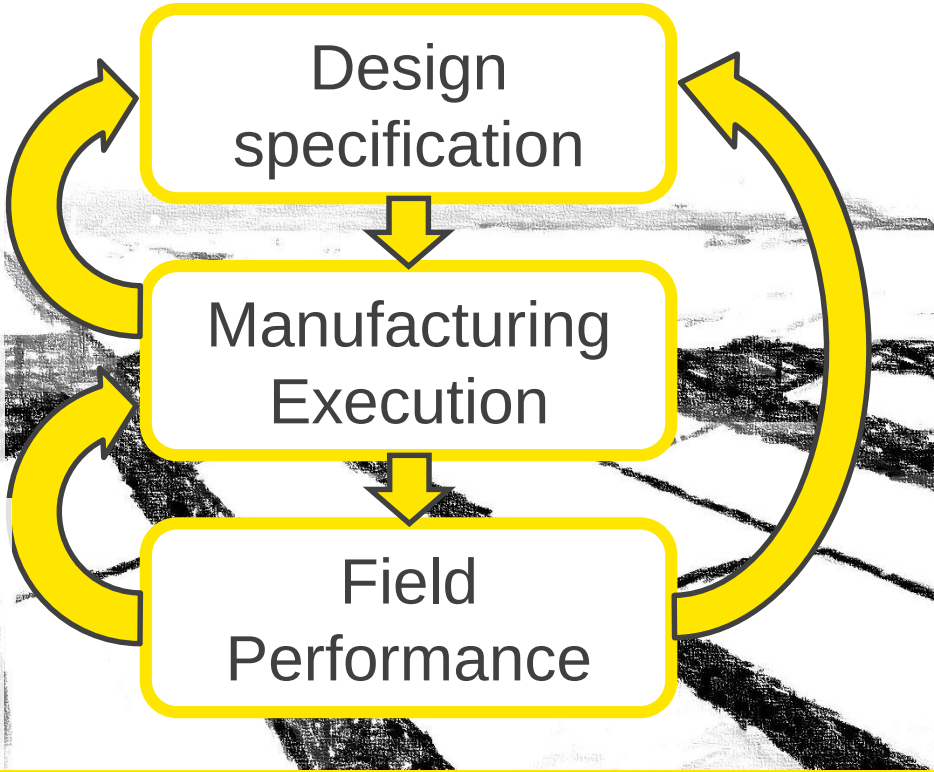
- Quality **IS NOT** just about
  - » Having the highest power module
  - » Passing an IEC certification process



The quality mission

- Quality **IS NOT** just about
  - » Having the highest power module
  - » Passing an IEC certification process
- Quality **IS** about
  - » Having a design specification
  - » Consistently executing it

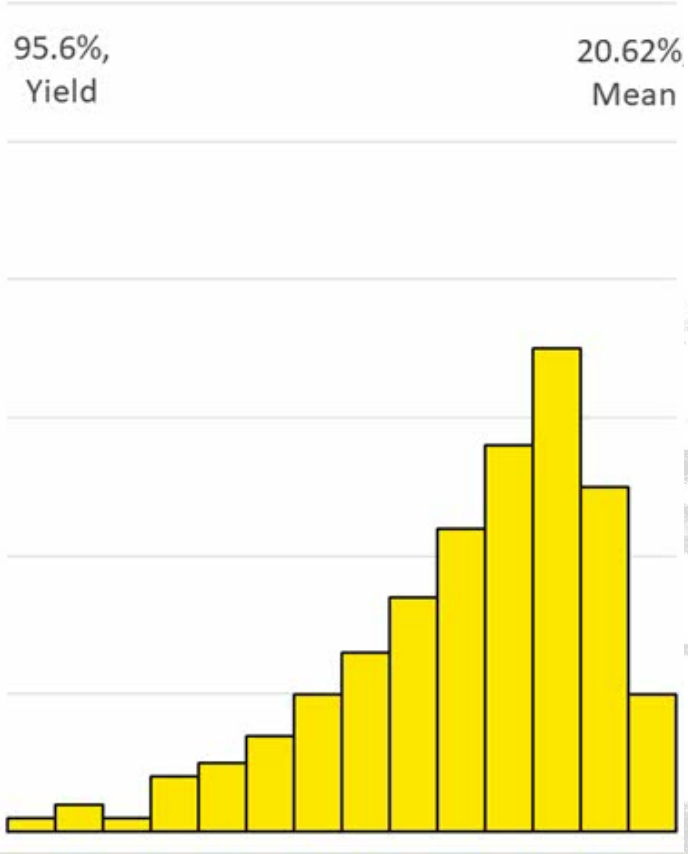
  “making the same thing every time”
  - » Continuous improvement and feedback from field performance
- Identified as a **priority area** for Chinese manufacturing in “Made in China 2025” strategy



The quality mission

- Higher quality gives you
  - » Tighter bin distribution and product range
  - » Lower yield loss / manufacturing outliers / warranty liabilities
  - » The ability to optimize your process towards higher performance
  - » Product differentiation as the market matures

We need a way to measure and talk about quality



1. The quality mission

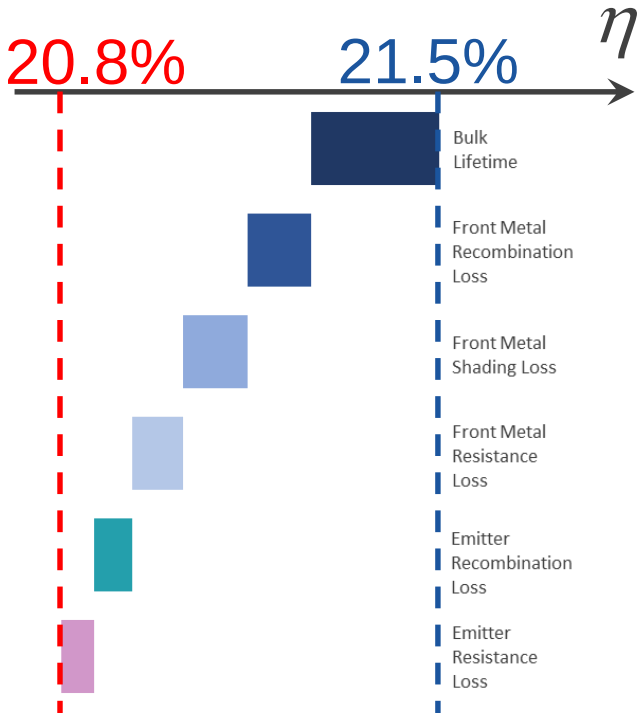
2. **Quantifying quality using “Process State”**

3. Case Study: Controlling emitter resistivity to increase PERC performance.

4. Conclusions and future outlook

Quantifying quality using “Process State”

- “Process State” is a generic manufacturing term to describe the operating condition of a process step.
- In PV manufacturing, we have defined the process states as a set of loss metrics associated with the manufacturing steps.
    1. Start with a design efficiency
    2. Calculate a set of losses for every cell describing how it is below designed efficiency
    3. Monitor and track these losses over time
- The process states are calculated in real time using a statistical model that fits to the relationships in end-of-line data



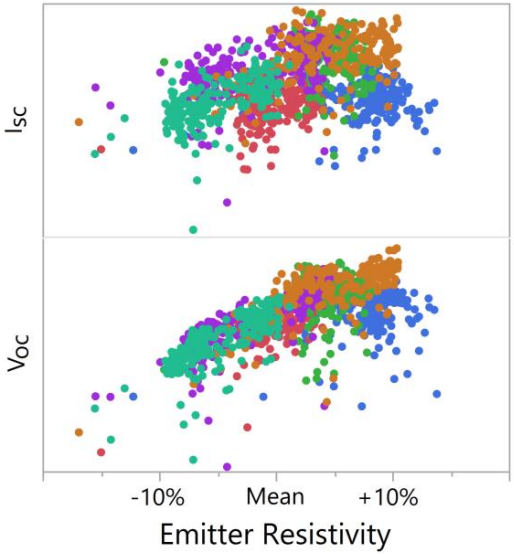
Quantifying quality using “Process State”

- The process state approach addresses three main observed inadequacies with how process control is commonly executed in PV manufacturing

1. The “When do I act” problem
   - » Process state is a form of multivariate control that shows in detail when a line is acting in an unusual, anomalous or non-standard state.
2. The “Why should I act” problem
   - » The choice of variables to monitor and the way limits are set often undermine the enforcement of control charts. Process state metrics describe the impact on final product and can help build confidence in process control.
3. The “How should I act” problem
   - » Process states break losses down into components and make root cause action easier to organise and manage.

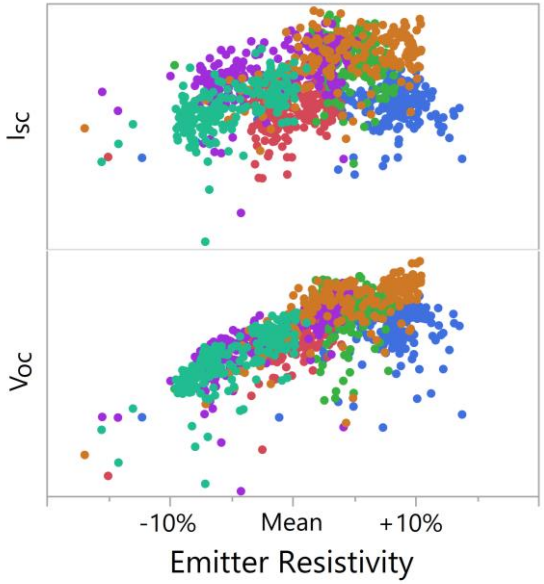
1. The quality mission
2. Quantifying quality using “Process State”
3. **Case Study: Controlling emitter resistivity to increase PERC performance.**
4. Conclusions and future outlook

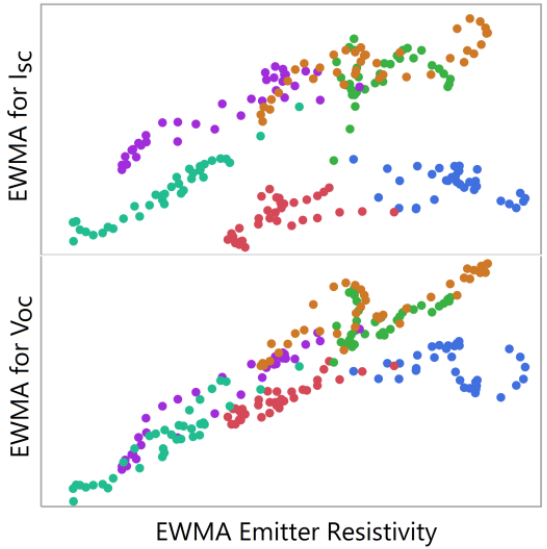
Control of Emitter Resistivity

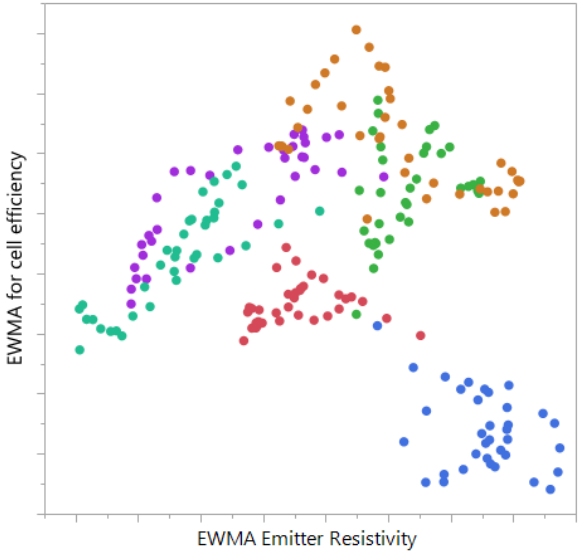


- The case study was a tracked trial of 1200 cells with
  - » Start-of-line wafer resistivity
  - » Mid-line emitter resistivity
  - » End-of-line IV tester data
- There are trade-offs in the Isc, Voc and FF, and a local maxima for efficiency
- Study was done over many weeks with small groups of cells processed 1 to 2 weeks apart.
  - » A detailed analysis shows the process differences and trade-offs changing across each group.
  - » This is interesting to analyse with process state metrics

Control of Emitter Resistivity

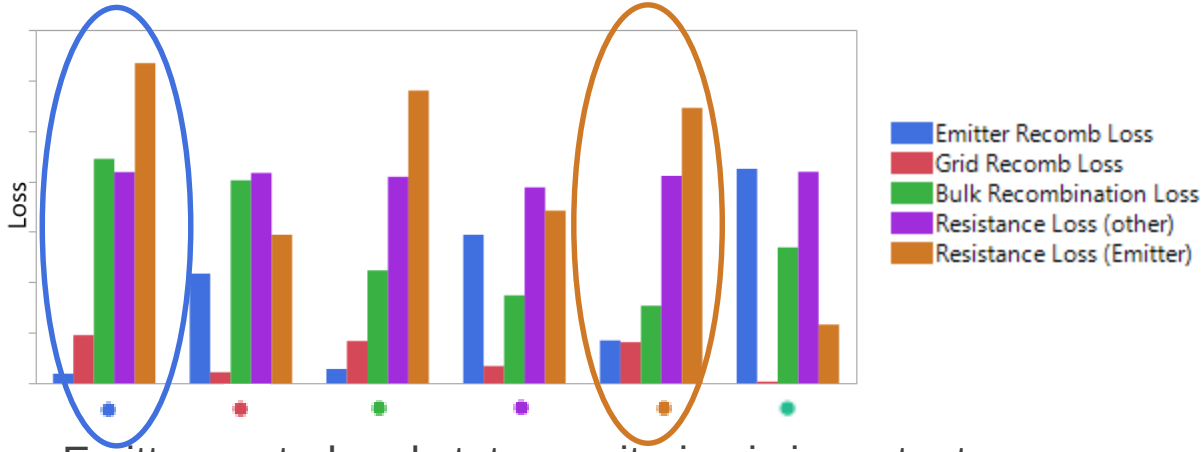


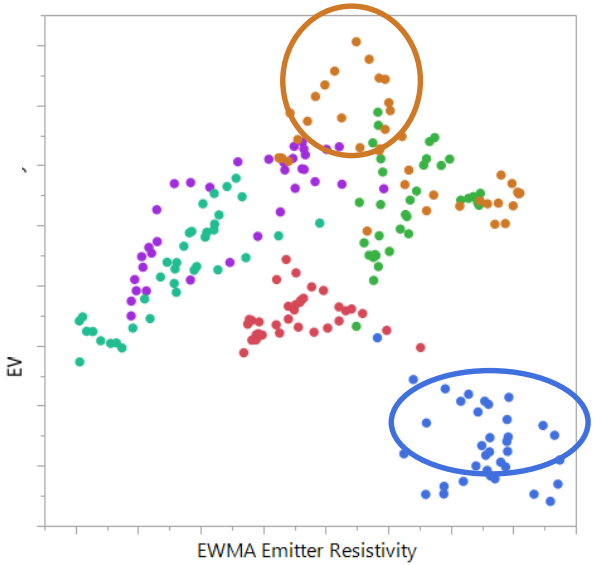




Control of Emitter Resistivity

- Process state data for the six different groups show the process is operating in a different state across the experiment.





- Emitter control and state monitoring is important on an ONGOING BASIS to keep the line operating in an optimal condition.

1. The quality mission
2. Quantifying quality using “Process State”
3. Case Study: Controlling emitter resistivity to increase PERC performance.
4. **Conclusions and future outlook**

Future of PV Manufacturing

- Better, automated analytical approaches will be essential to continue to scale manufacturing, and maintain quality from shift to shift, line to line and factory to factory.
- Process state metrics are a quantifiable way to measure and monitor quality on a production line in real time.
  - » These will lead to quantifiable measures of quality that manufacturers will be able to differentiate on it.
- PERC manufacturing is a case study of the trade-offs involved with cell manufacturing
  - » Monitoring the process states enables the processes to be held closer to the optimal performance and tuned on an ongoing basis as required.

Thank you
for your kind attention

Please ask a question or contact me for further information

rhett.evans@unsw.edu.au