# Connecting the Dots

Collaborating from factory to field to reduce long-term module quality risk for specific project locations

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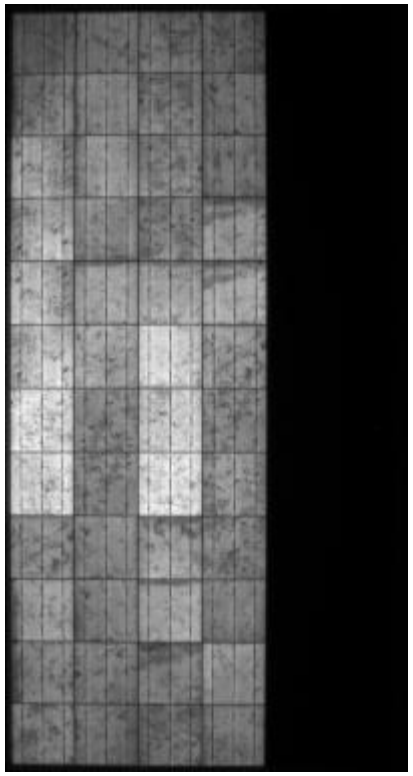
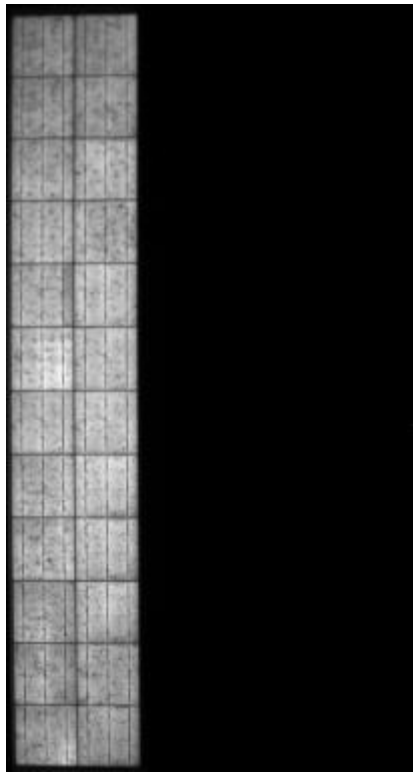
# Example 1: Diode Failures

Observed warping / deformation of junction box lid due to excessive heat from Diodes – Post TC400



Observed diode failure at TC400



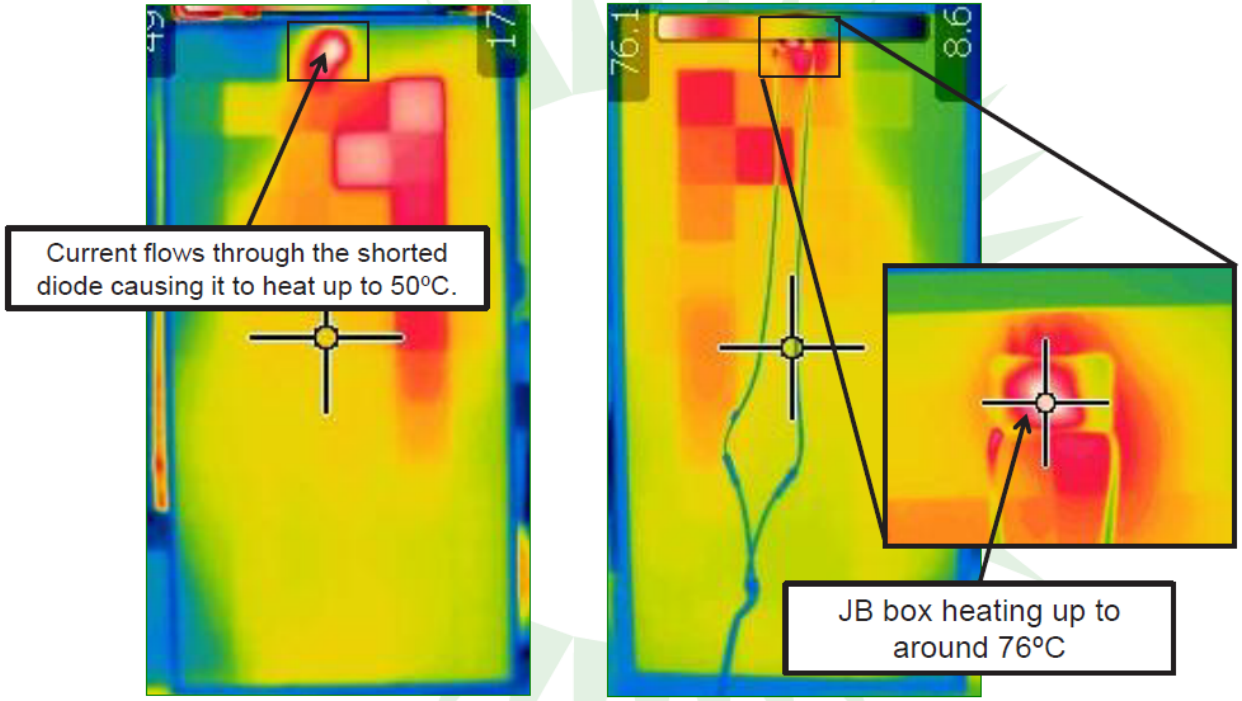
Observed 2-diodes failure at TC600

## Example 1: Diode Failures

### Situation

- Utility scale, location confidential, ~$50 million, 20 year investment.
- ~50k modules installed.
- Diodes failed in a small subset of population during extended lab tests.
- Root cause analysis by module manufacturer: poor diode quality and lack of electric testing in factory (visual only). Supported by factory inspector (SolarBuyer) and test lab (RETC).

**Image taken while exposed to the sun and under load.**




**Front View** **Back View**

## Example 1: Diode Failures

### Project Acquisition Solution

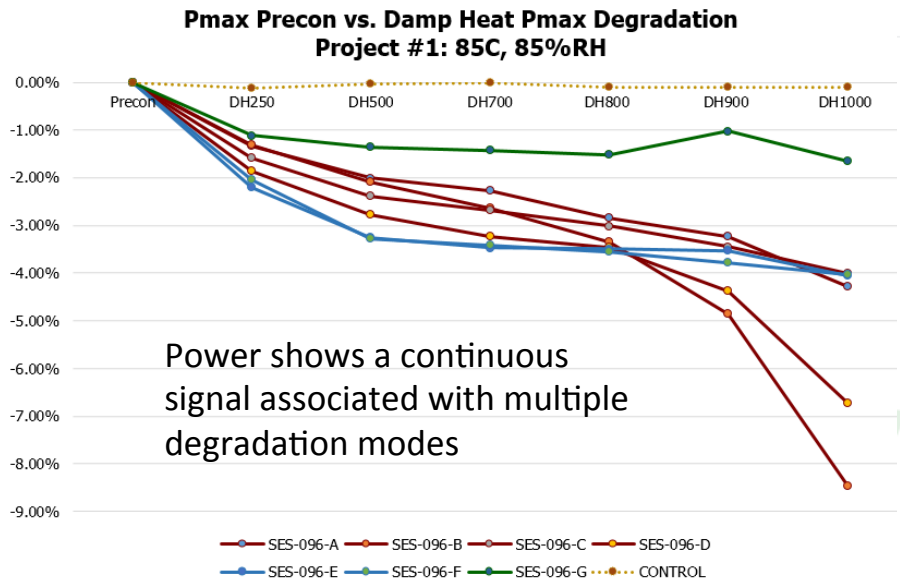
- None: *this level of testing was not a condition precedent to funding.*

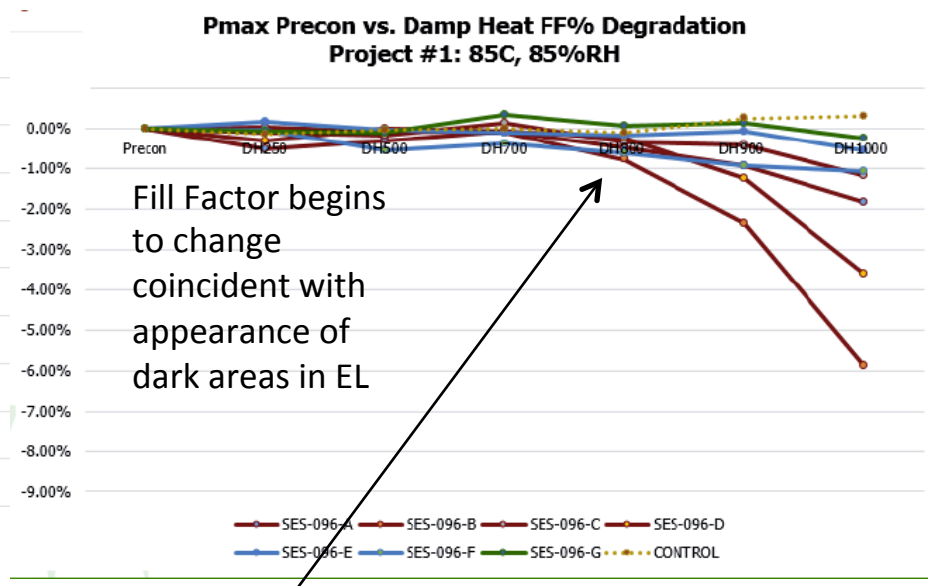
### Project Operations Solution

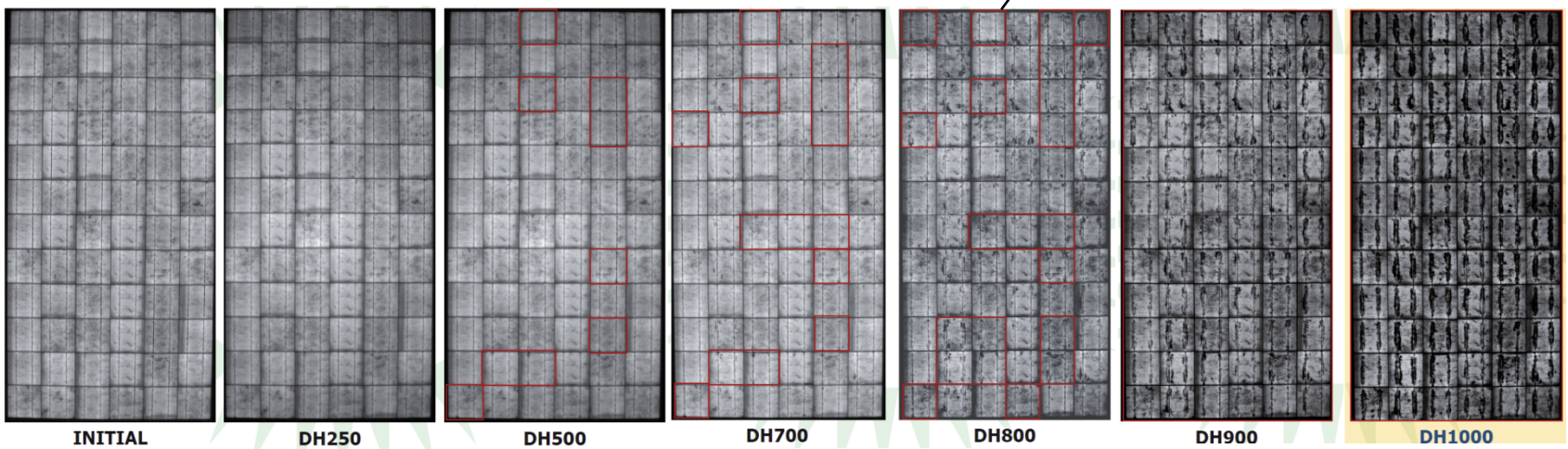
- Assembled a team: test lab (RETC), factory inspector (SolarBuyer), module manufacturer, project operator.
- Safety risk determined to be low by test lab (RETC).
- Field monitoring protocol recommended and demonstrated at test lab (RETC).
  - IR scanning or portion of arrays and conditional string-level Voc testing if minimum heat delta observed.
- Module warranty amended to call out issue.
- O&M agreement modified to include field monitoring protocol.
- *Module-level* testing not specified, however, so after one year operator has done areal IR imaging – effectiveness TBD.

# Example 2: Abnormal PV Cell Corrosion

**Module IEC Test Observation:** EL Darkening Correlating with Fill Factor Loss



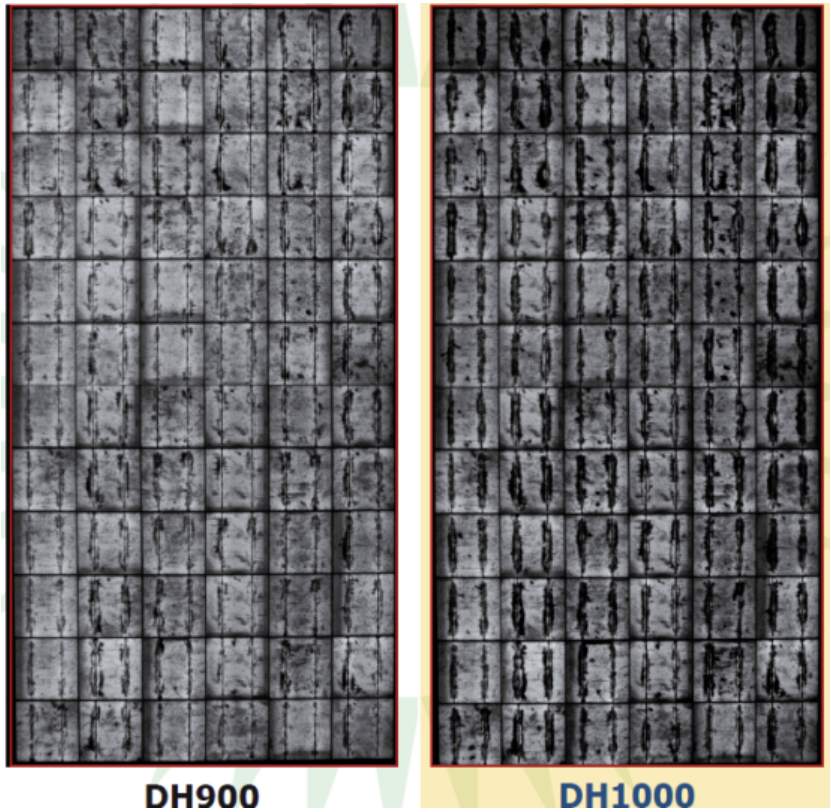



## Example 2: Abnormal PV Cell Corrosion

### Situation

- 20+ MWdc, Central Valley CA, ~$100 million, 20 year investment.
- ~90k modules installed.
- Samples failed IEC tests slightly (corrosion).
- Root cause analysis by module manufacturer: inconclusive after significant effort.
- ~6 months before PPA liquidated damages and ITC claim expiration (3 months after COD).



## Example 2: Abnormal PV Cell Corrosion

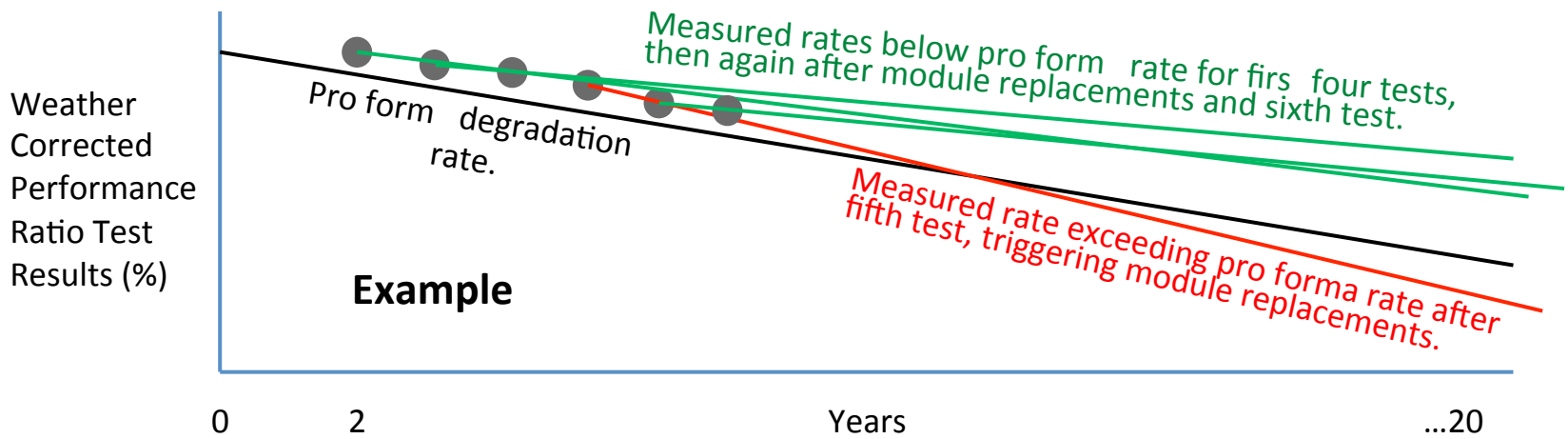
### Project Acquisition Solution

- Assembled team: lab (RETC), science advisor (NREL), factory inspector (SolarBuyer), independent engineer (Leidos), project developer, module manufacturer.
- Test plan created.
- Suspect module population identified.
- Matrix of multi-factor chamber tests performed.
- Corrosion mechanism modeled.
- Effected area estimated using image analysis.
- Location-specific, corrosion degradation rate estimated using TMY (Whitfield paper).
- Corrosion degradation rate added to baseline degradation (Jordan study).
- New degradation rate used for production estimate.
- New financial pro forma and new purchase price found (slightly less).
- Project acquired.

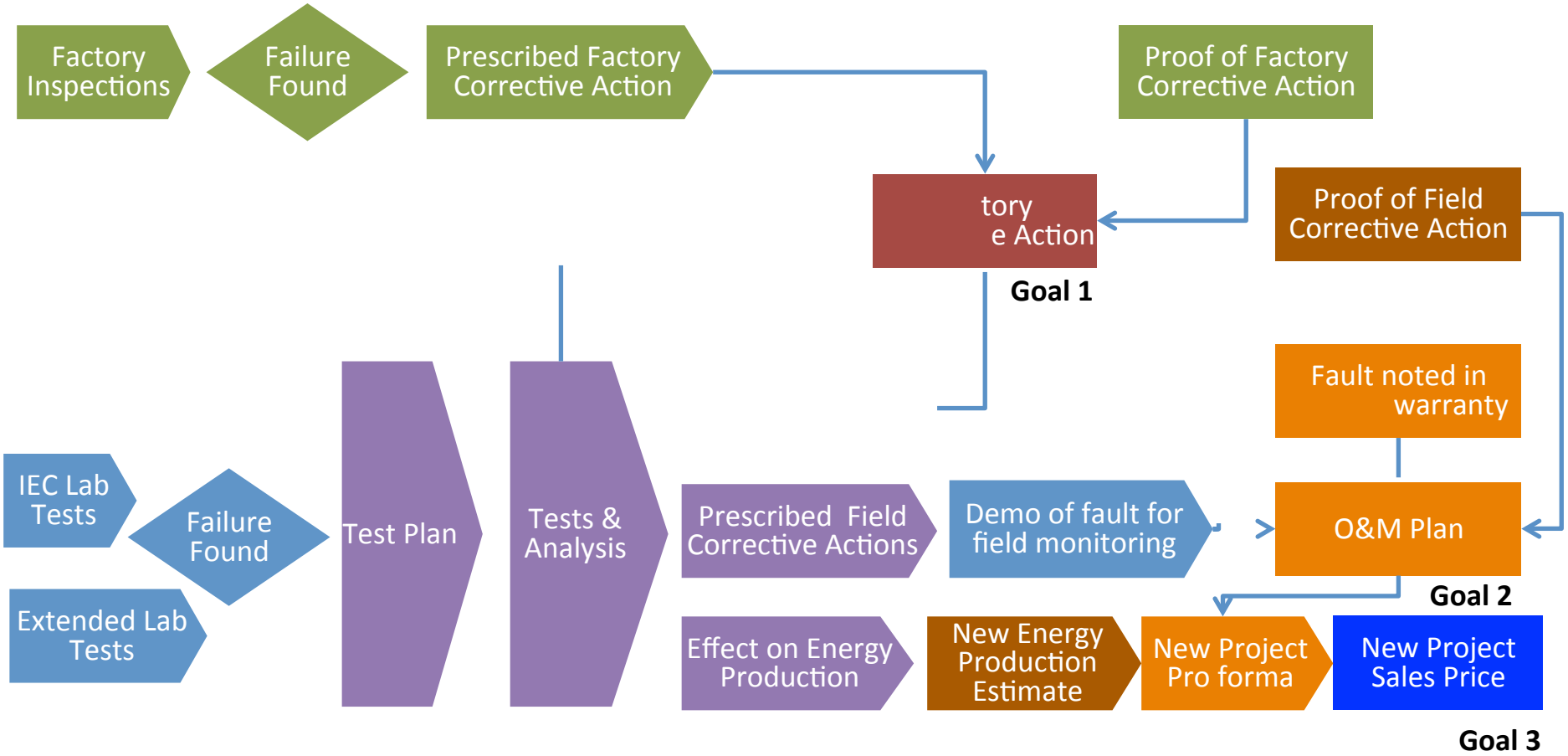
## Example 2: Abnormal PV Cell Corrosion

### Project Operations Solution

- Module warranty amended to call out issue (not good enough).
- O&M agreement amended to perform advanced monitoring and system-level testing.
- Small test array built at project location with suspect modules.
- String-level IV curve monitoring done through combiner boxes. Assessed yearly.
- System-wide performance ratio test done yearly after two years.
- If degradation rate is thought to be higher than the pro forma rate **by an independent engineer** using both string and system test results, surplus revenue will be "trapped".
- Modules will be replaced using trapped revenue until degradation rate is brought down to pro forma rate again.



# (Ad Hoc) Coordinated Module Quality Assurance Process




## Keys to Success: Expertise, Collaboration & Data Sharing

| Factory Inspector | Test Lab | Project Developer / Operator | Module Vendor | Independent Engineer | Bank | Team* |
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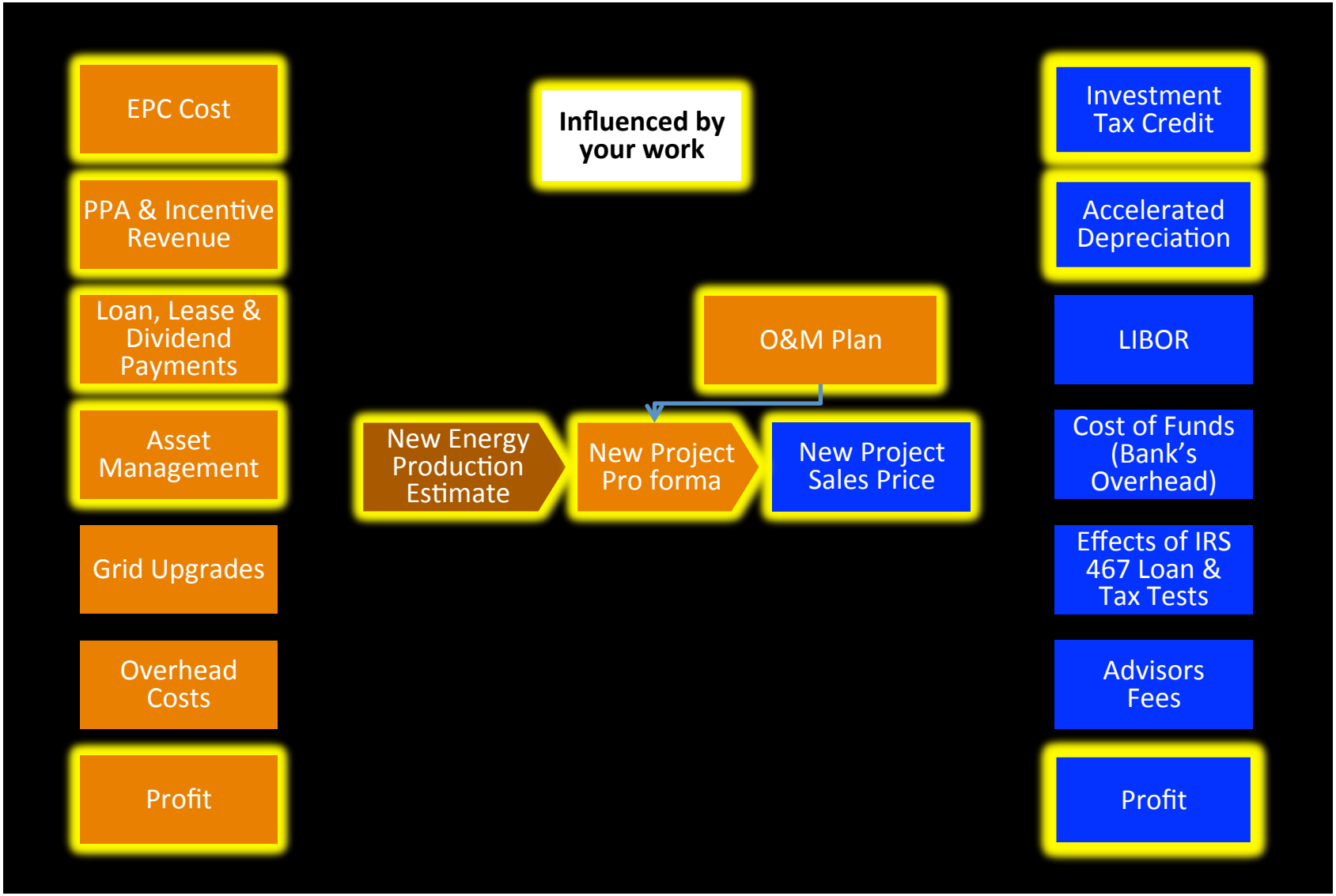
* Sometimes includes science advisor

# Tax Equity Project Finance: Inside the Black Box



# Thank you from Wells Fargo!

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