Performance Matrices per IEC 61853 Standards:
Their Importance for the Energy Estimation Models

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Presented at the 2013 Sandia PV Performance Modeling Workshop
Santa Clara, CA. May 1-2, 2013
Published by Sandia National Laboratories with the Permission of the Author.

Outline

- **Number of Power Rating Conditions: An Evolution**

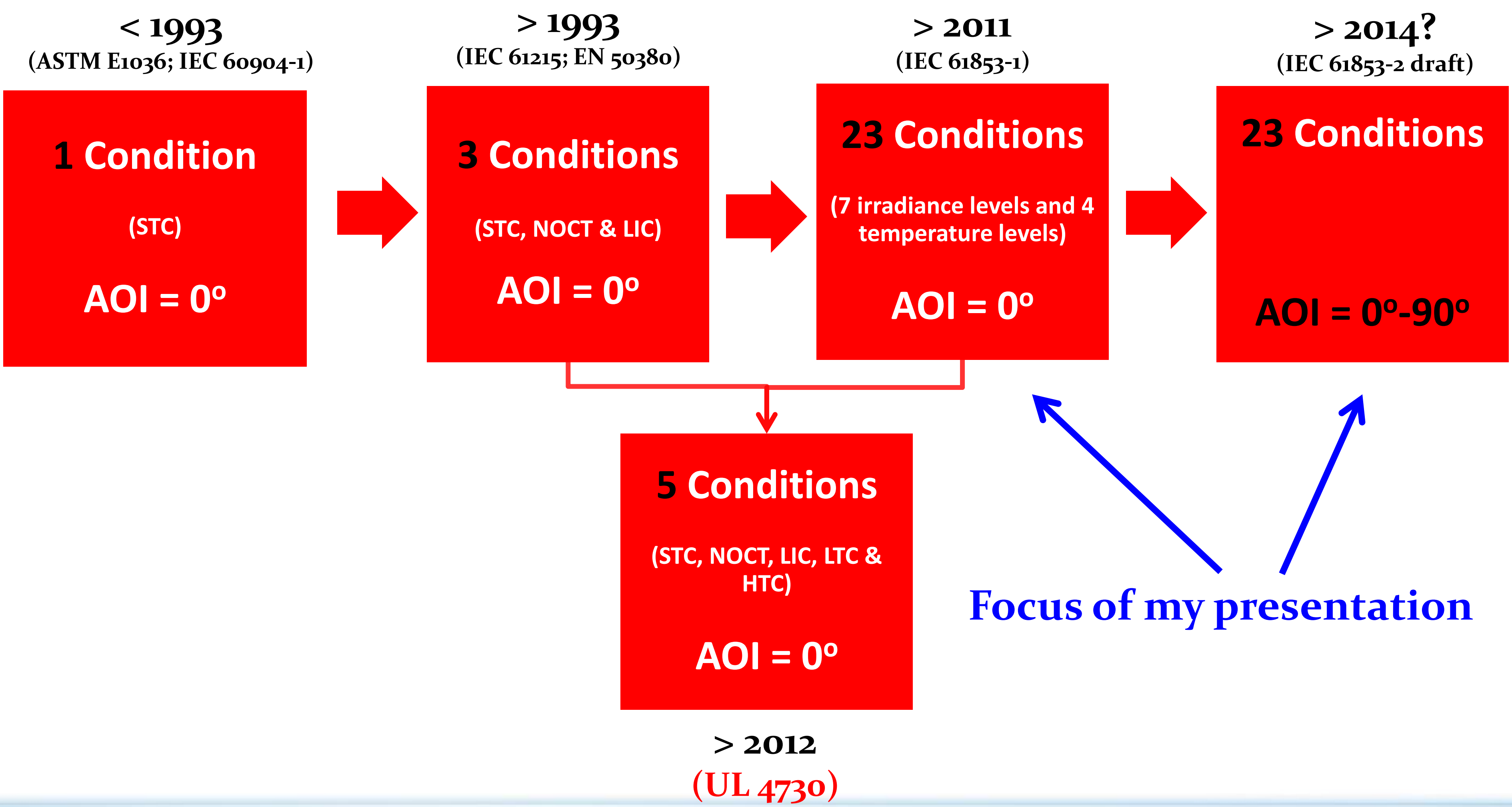
- **IEC 61853-1**
  - ***Temperature-Irradiance Matrices Generation***
    - ***Using IEC 60891 setup and models***
    - ***Using Sandia setup and model***
  - ***Importance to Energy Estimation Models***

- **IEC 61853-2 *(draft)***
  - ***Angle of Incidence***
    - ***Background***
    - ***Setup and Models***
  - ***Importance to Energy Estimation Models***

- **Conclusions**

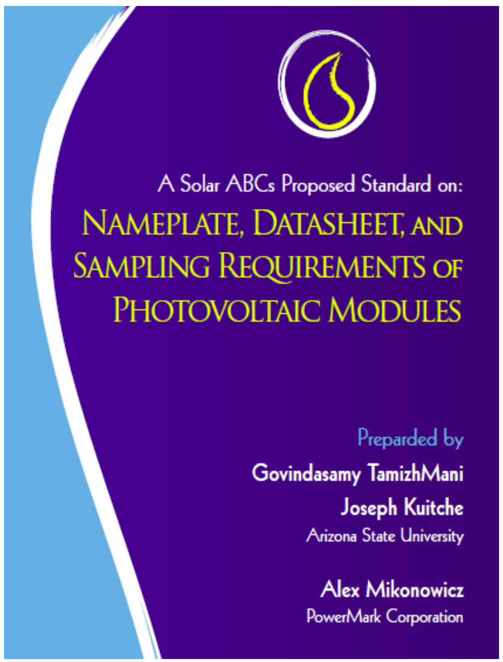
Number of Power Rating Conditions: An Evolution

Number of Power Rating Conditions: An Evolution



UL 4730: 5 Test Conditions

UL 4730 standard is based on the following Solar ABCs report



www.solarABCs.org

Abbreviation	Description	Irradiance (W/m^2)	Module Temperature (°C)	Ambient Temperature (°C)	Wind Speed (m/s)	Spectrum
HTC	High temperature conditions	1000	75	---	---	AM 1.5
STC	Standard test conditions	1000	25	---	---	AM 1.5
NOCT	Nominal operating cell temperature conditions	800	---	20	1	AM 1.5
LTC	Low temperature conditions	500	15	---	---	AM 1.5
LIC	Low irradiance conditions	200	25	---	---	AM 1.5

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IEC 61853-1: 23 Test Conditions

IEC 61730-1 standard is validated in the following Solar ABCs report

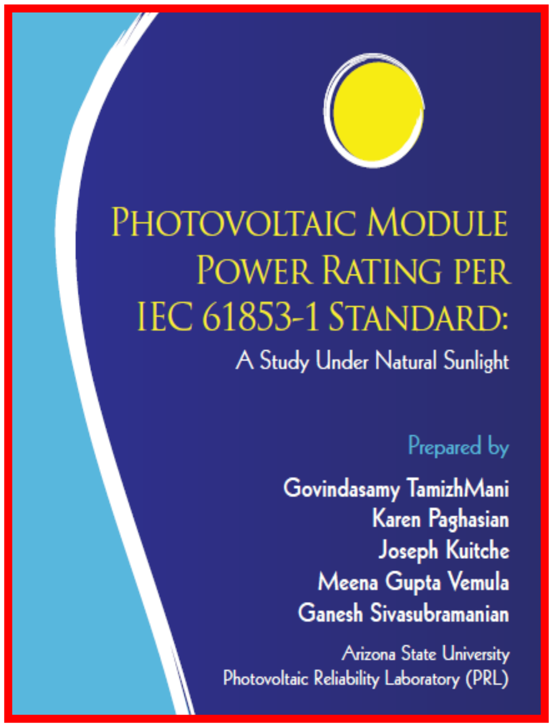

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TABLE 1

I_{sc}, P_{max}, V_{oc}, and V_{max} at 23 Sets of Irradiance and Temperature Conditions

Irradiance (W/m^2)	Module Temperature (°C)			
	15	25	50	75
1100	NA	1	2	3
1000	4	5	6	7
800	8	9	10	11
600	12	13	14	15
400	16	17	18	NA
200	19	20	21	NA
100	22	23	NA	NA

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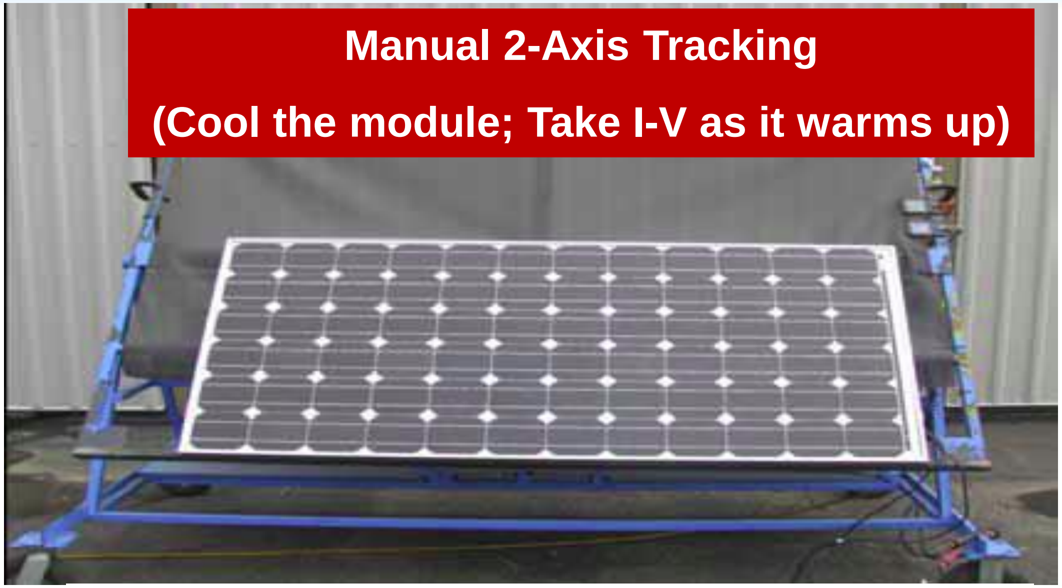
IEC 61853-1

Temperature-Irradiance Matrices Generation:
Using IEC 60891 test setup



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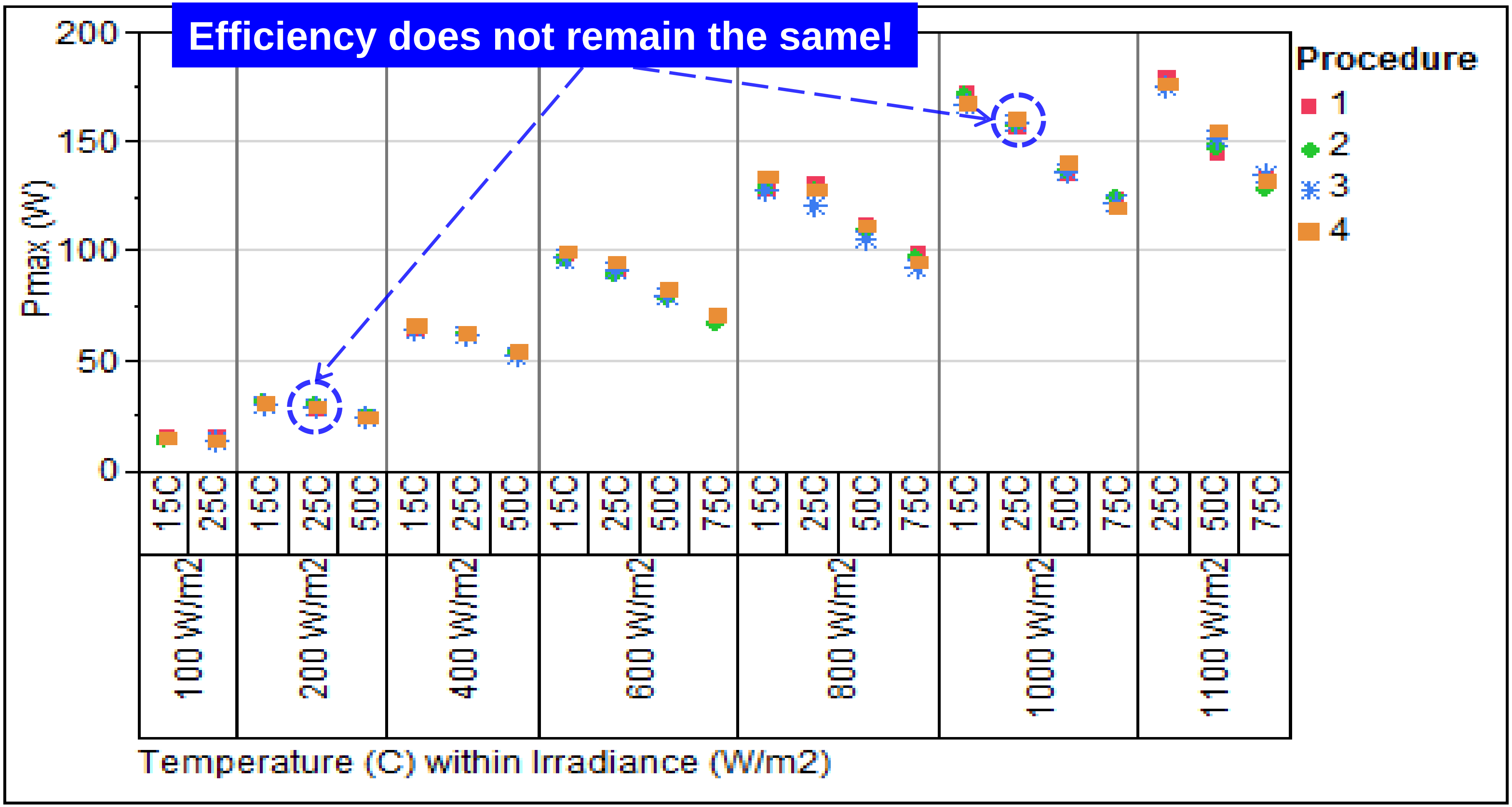
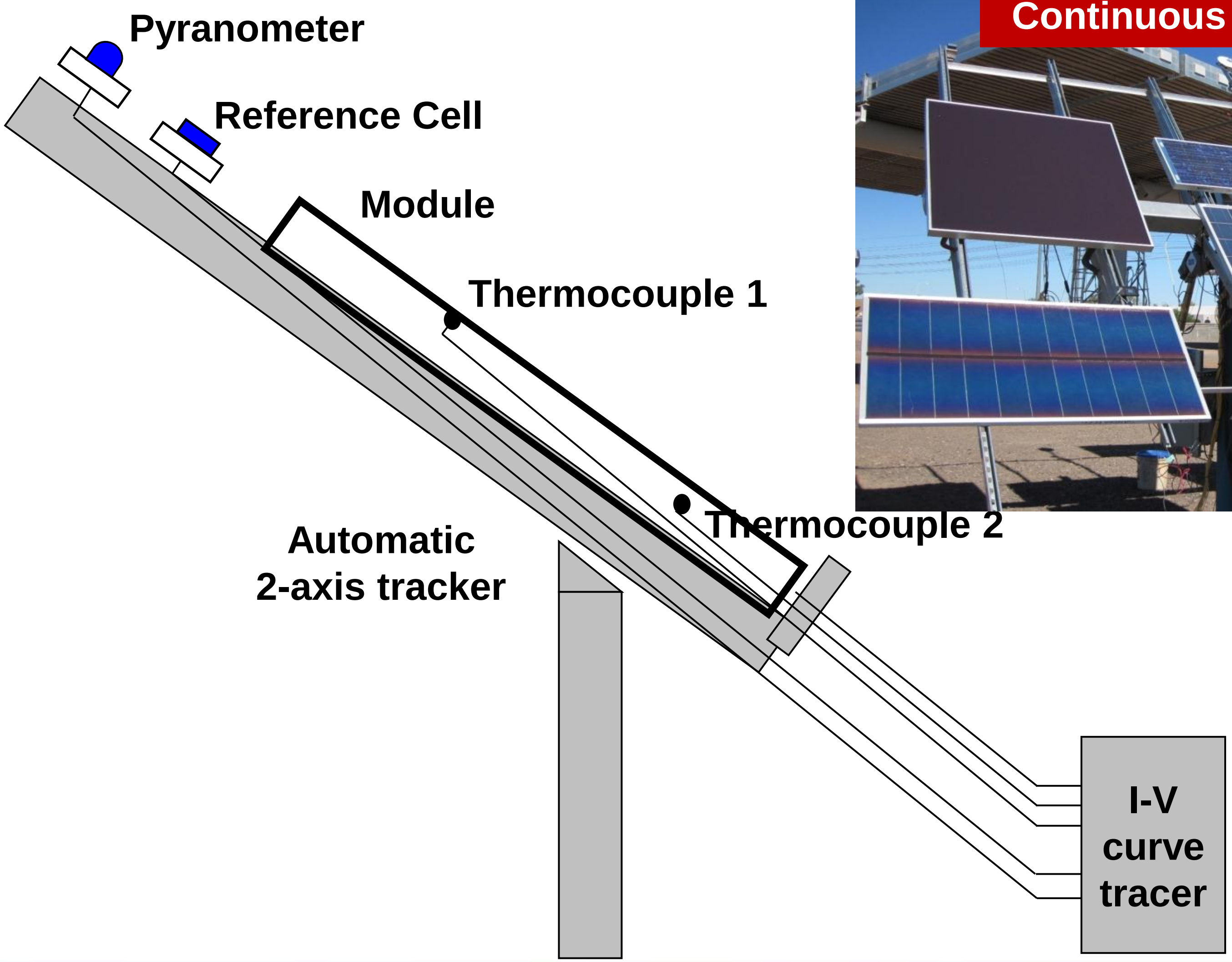
Temperature-Irradiance Matrices Generation:
Using IEC 60891 models and results (example)



1, 2 & 3 = IEC 60891 procedures; 4 = NREL procedure

Temperature-Irradiance Matrices Generation:
Using Sandia setup



Continuous Daylong Tracking

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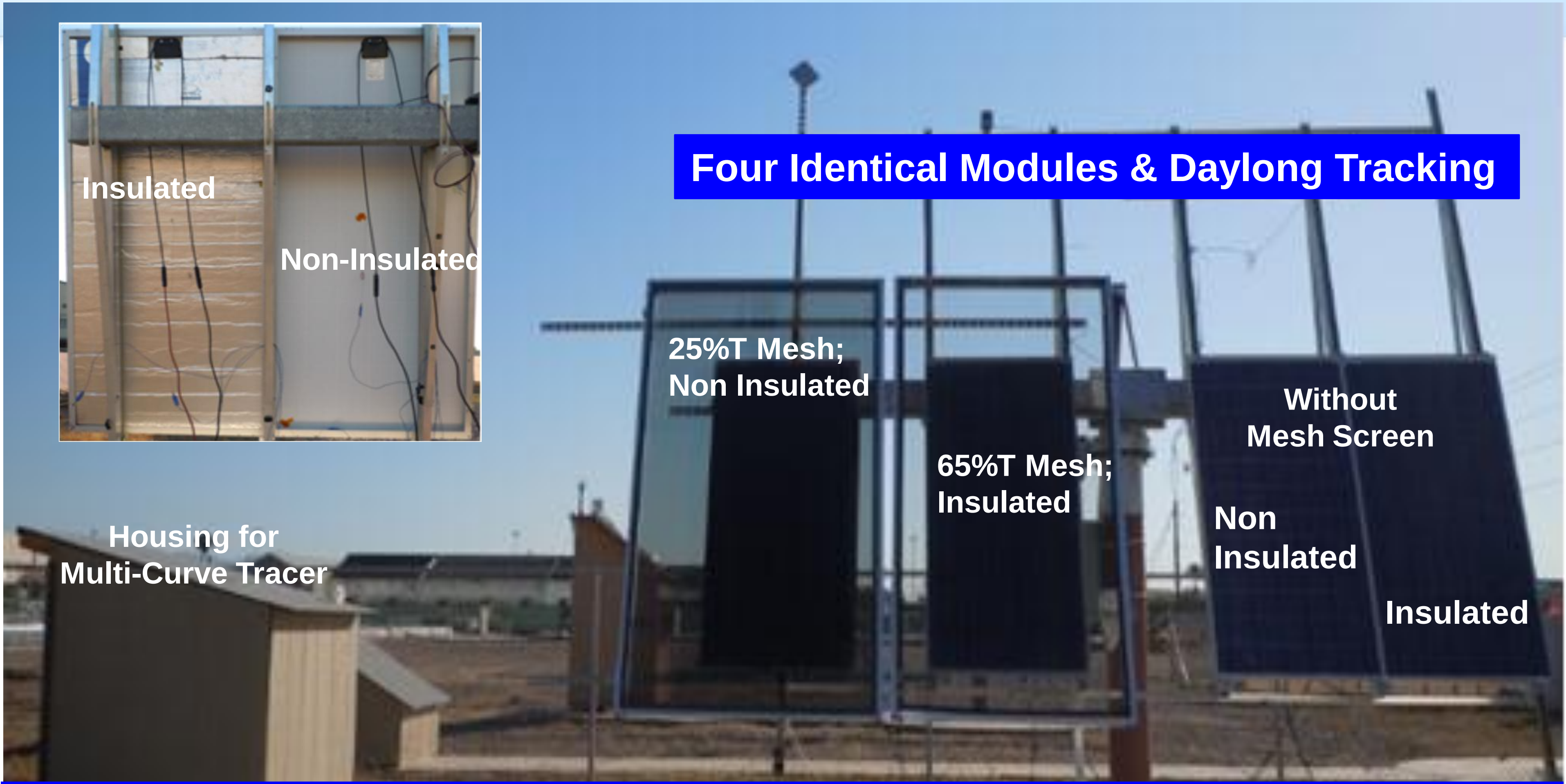
Temperature-Irradiance Matrices Generation:
Using Sandia model and results (example)

Efficiency does not remain the same!

Egni	Module Temperature			
W/m^2	15^{o}C	25^{o}C	50^{o}C	75^{o}C
1200	272.2	260.9	233	205.7
1100	249.3	238.9	213.3	188.2
1000	226.3	216.9	193.6	170.7
800	180.4	172.8	154.1	135.7
600	134.5	128.8	114.7	100.9
400	88.8	85.0	75.4	66.2
300	66.1	63.1	55.9	48.9
200	43.4	41.5	36.6	31.9
100	21.1	20.1	17.5	15.2

Temperature-Irradiance Matrices Generation:

A New Test Setup: A Hybrid IEC-Sandia Approach



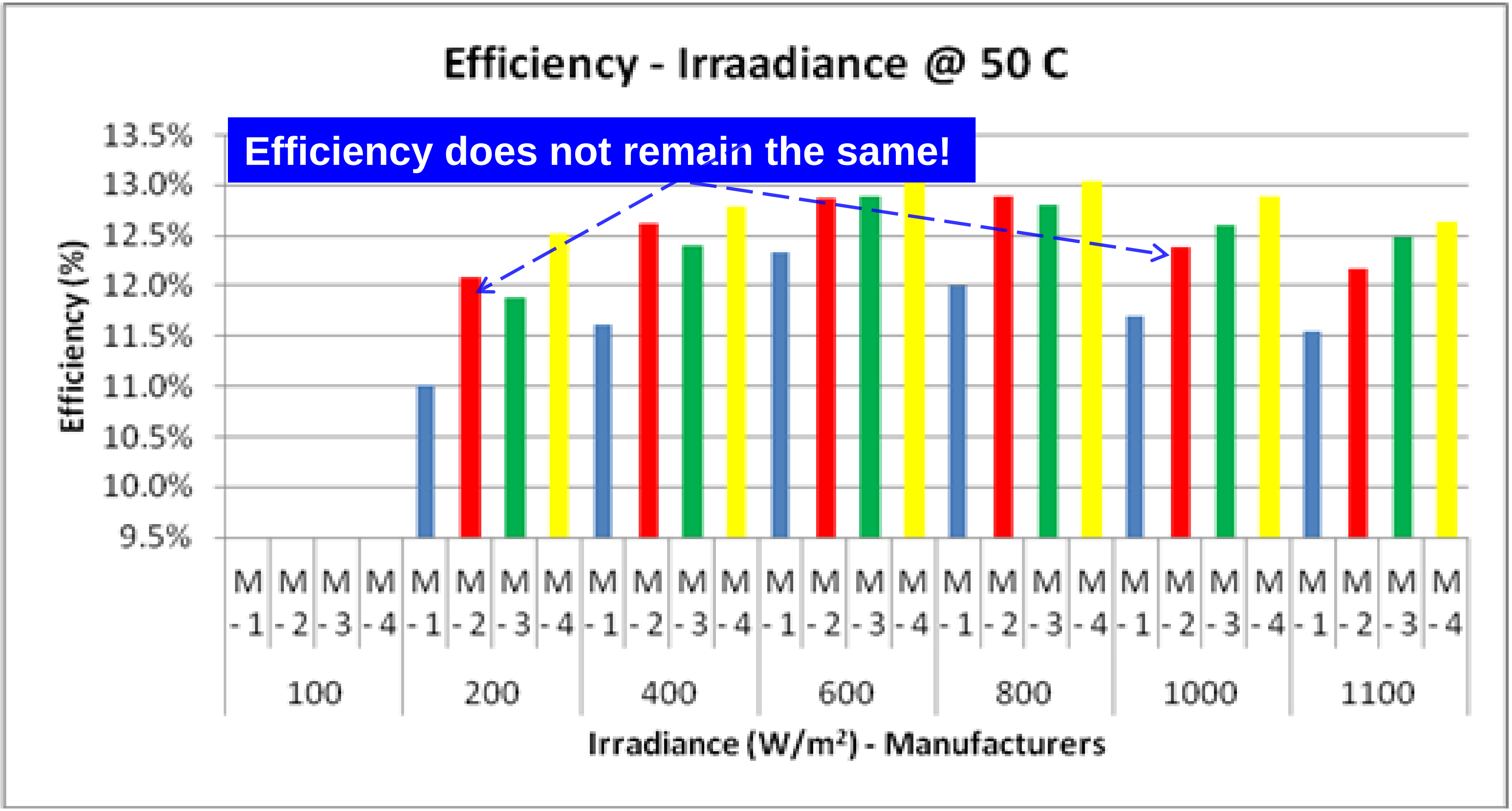
Merits:

- **Additional data at low irradiances and high temperatures as compared to Sandia approach**
- **Reduced data collection time and labor as compared to IEC approach**

Challenges:

- **Low temperature data during summer months of Arizona!**

Temperature-Irradiance Matrices Generation:
Using hybrid approach and IEC 60891 model



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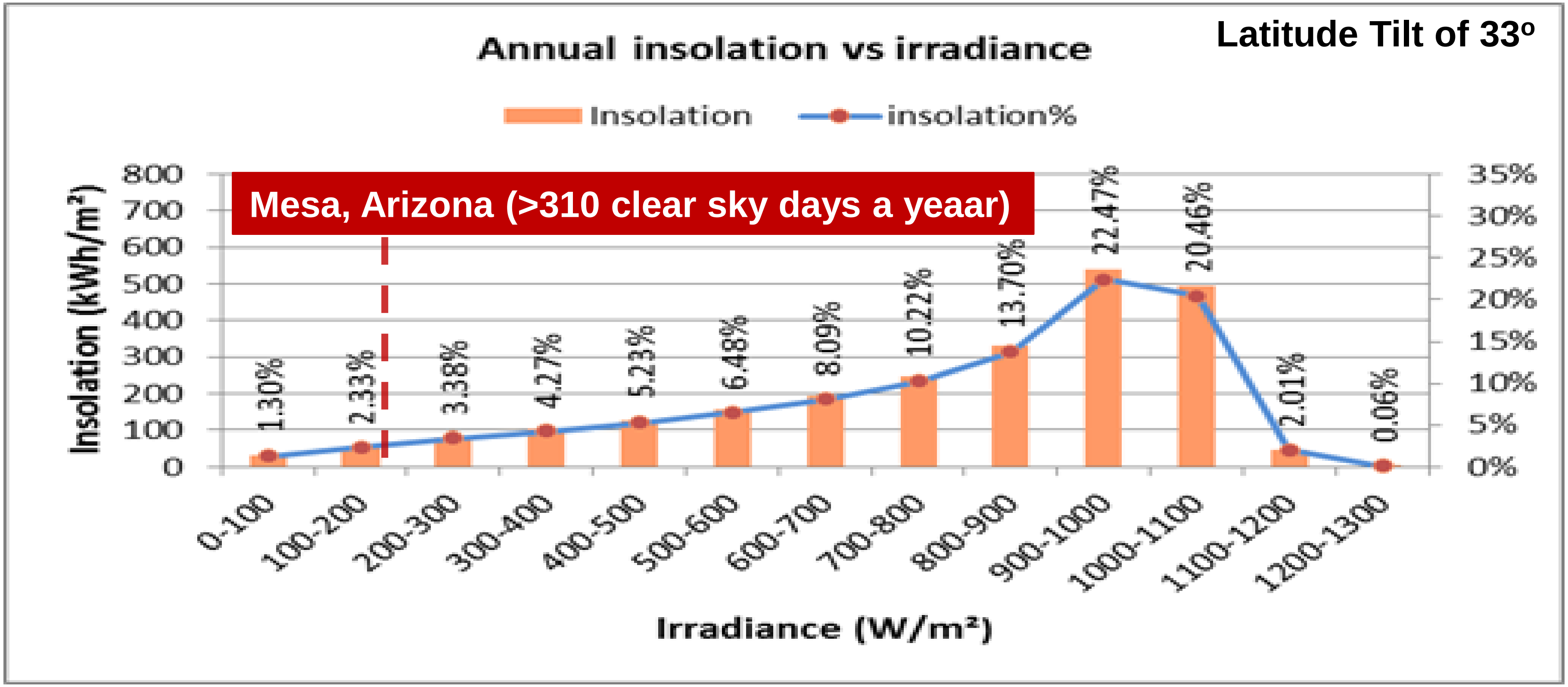
Efficiency Changes as Irradiance Changes:
Importance to energy estimation models

Even in sunny/desert climatic conditions about 4% of energy is generated at irradiances lower than 200 W/m²!

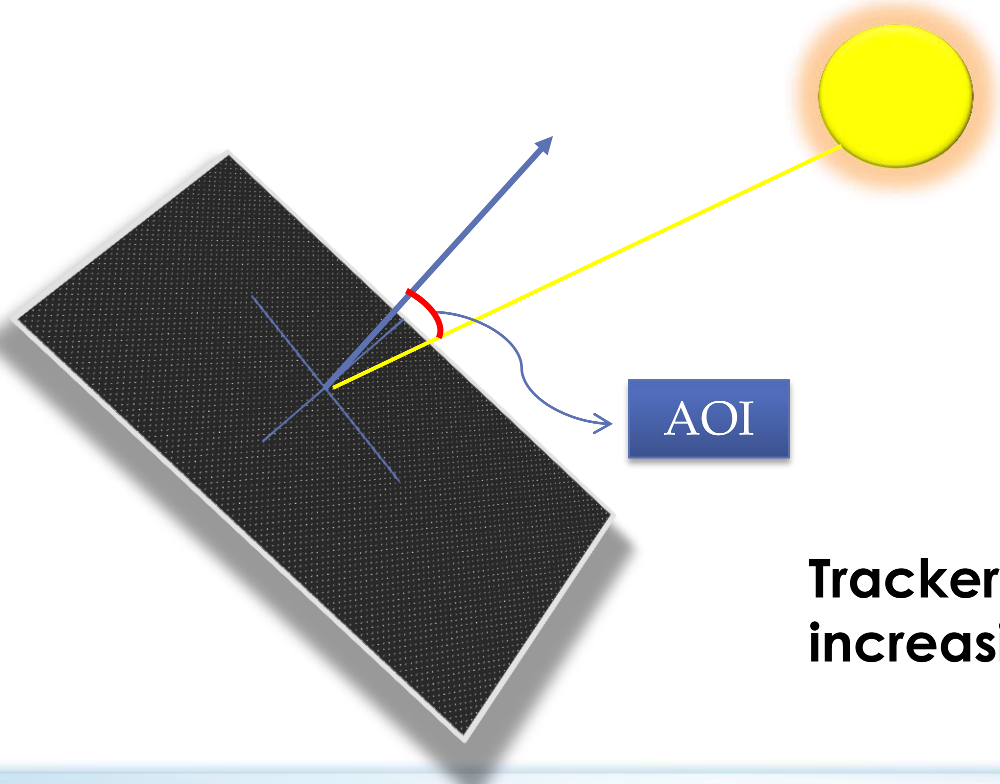


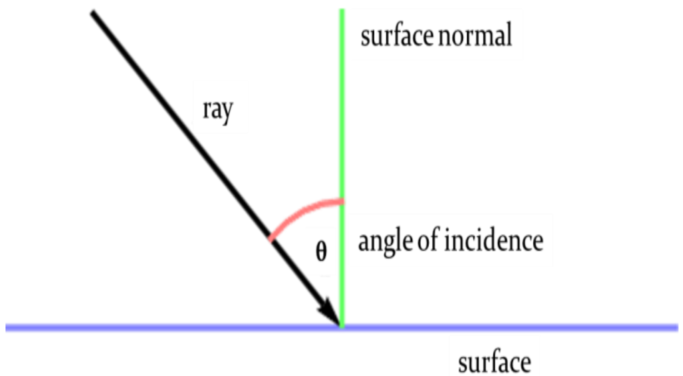
Energy estimation models should consider accounting for the efficiency changes due to irradiance changes. This can be accounted by using the IEC 61853-1 matrices.

IEC 61853-2 *(draft)*

What is Angle of Incidence

AOI = θ = Angle between incident beam of light and surface normal of the PV module

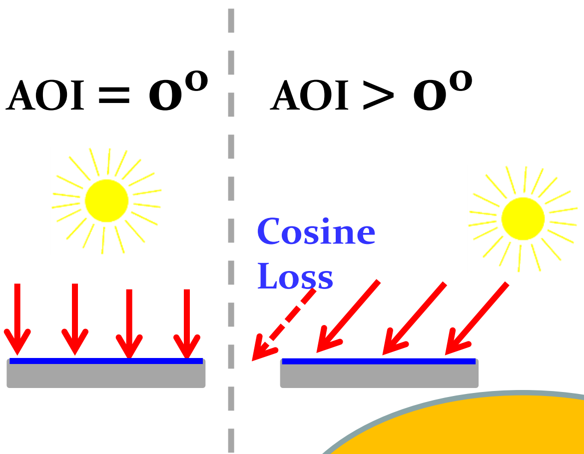


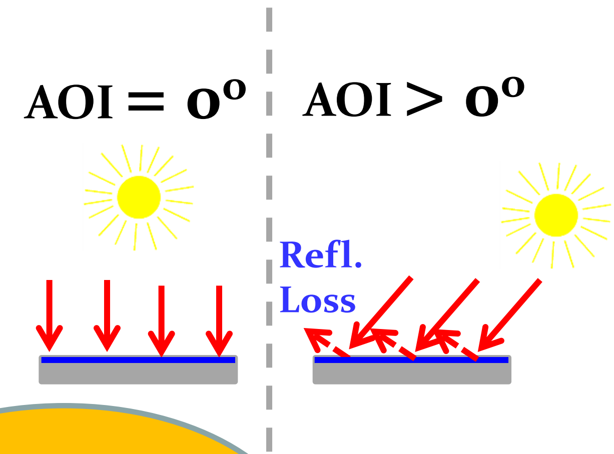


Trackers can help minimizing AOI thus increasing energy production

Effect of Angle of Incidence : Cosine Loss & Reflection Loss

AOI Influence on PV Module Current





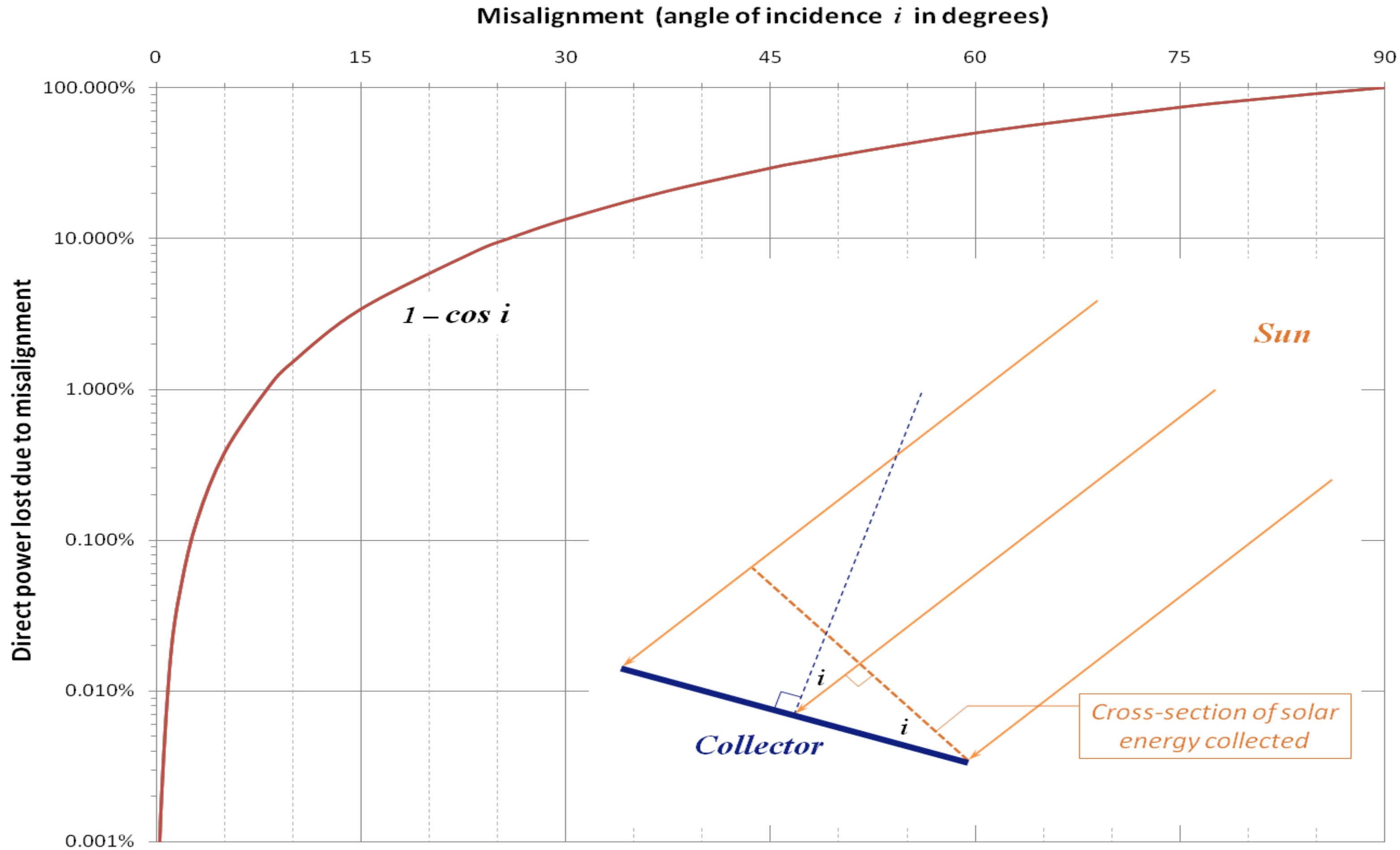
Geometrical Loss

Depends on plane orientation with respect to sunlight
[loss proportional to cosine(AOI)]

Reflection Loss

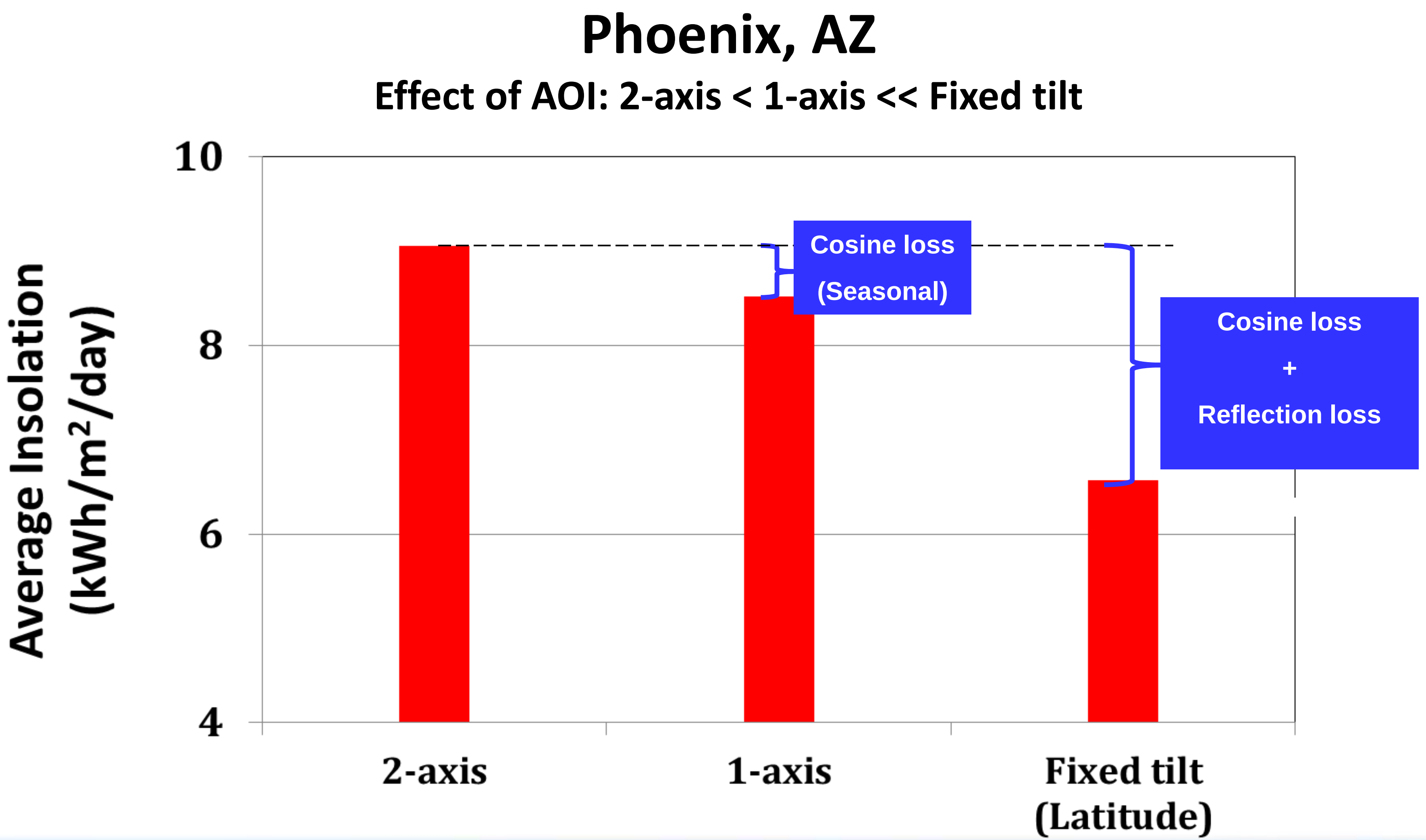
Depends on surface characteristics
[Loss depends on air/surface interface]

Effect of Angle of Incidence: Cosine Loss Only



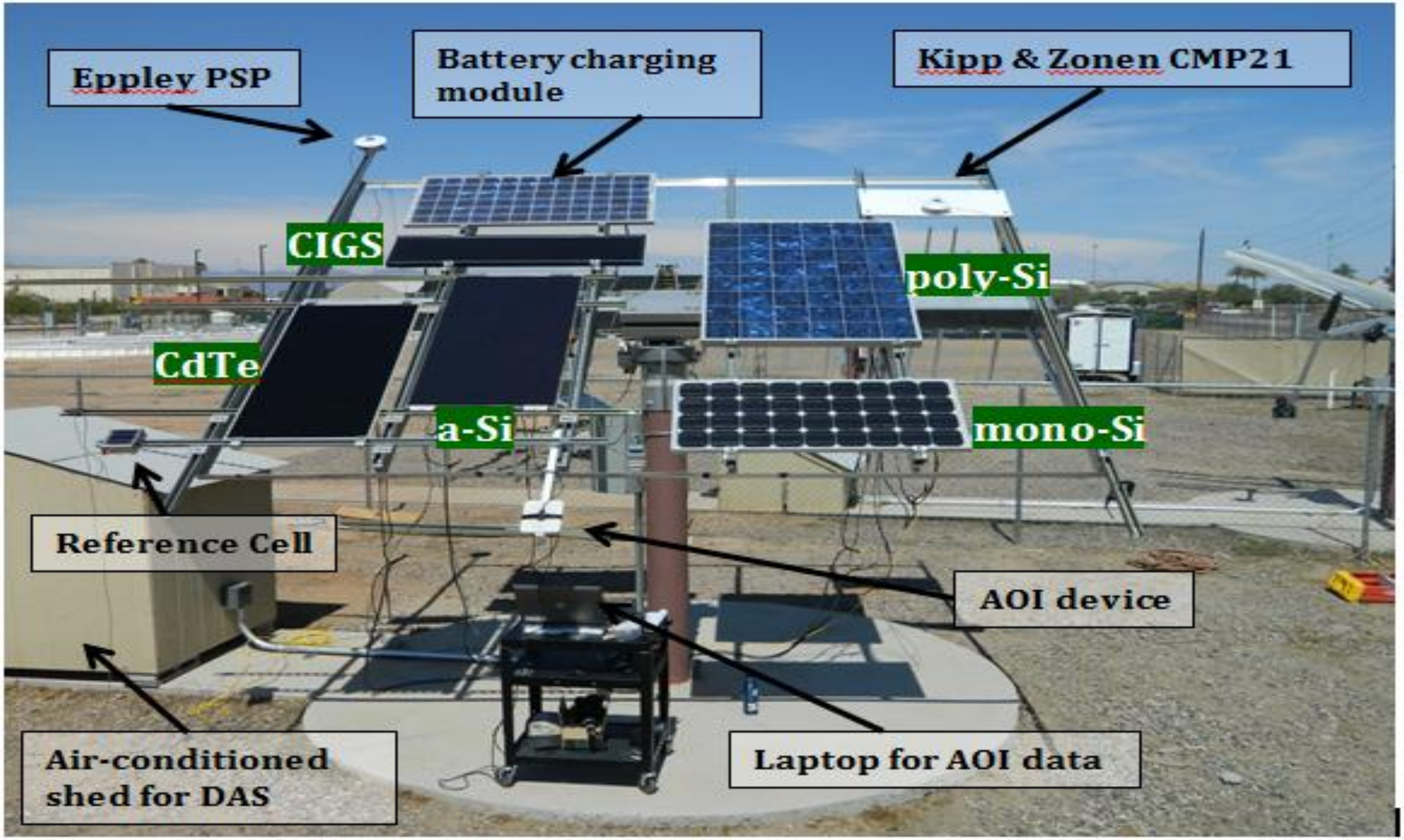
Source: Wikipedia

Effect of Angle of Incidence : Cosine Loss & Reflection Loss



AOI Test Setup

Five Module Technologies *(Superstrate: Glass; Interface: air/glass)*



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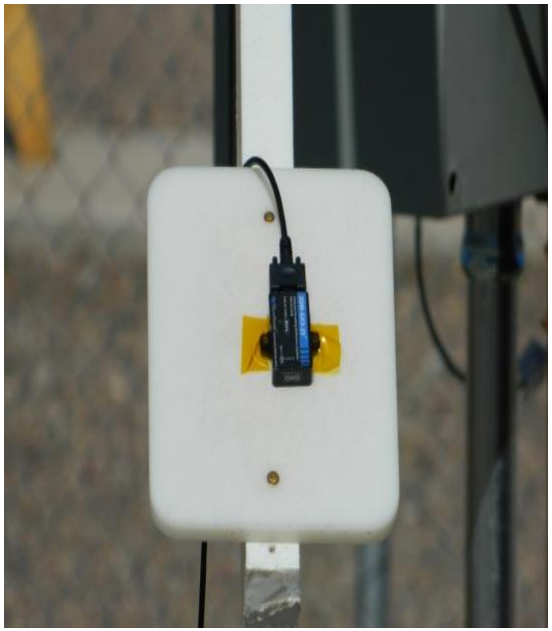
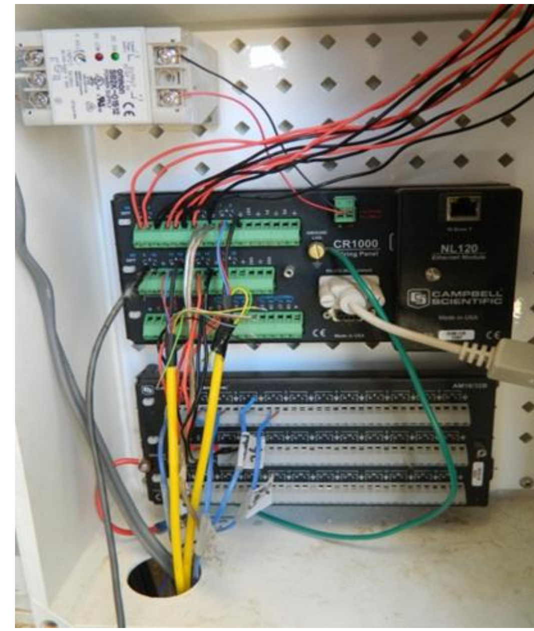
Test Setup

AOI Measuring Device and DAS



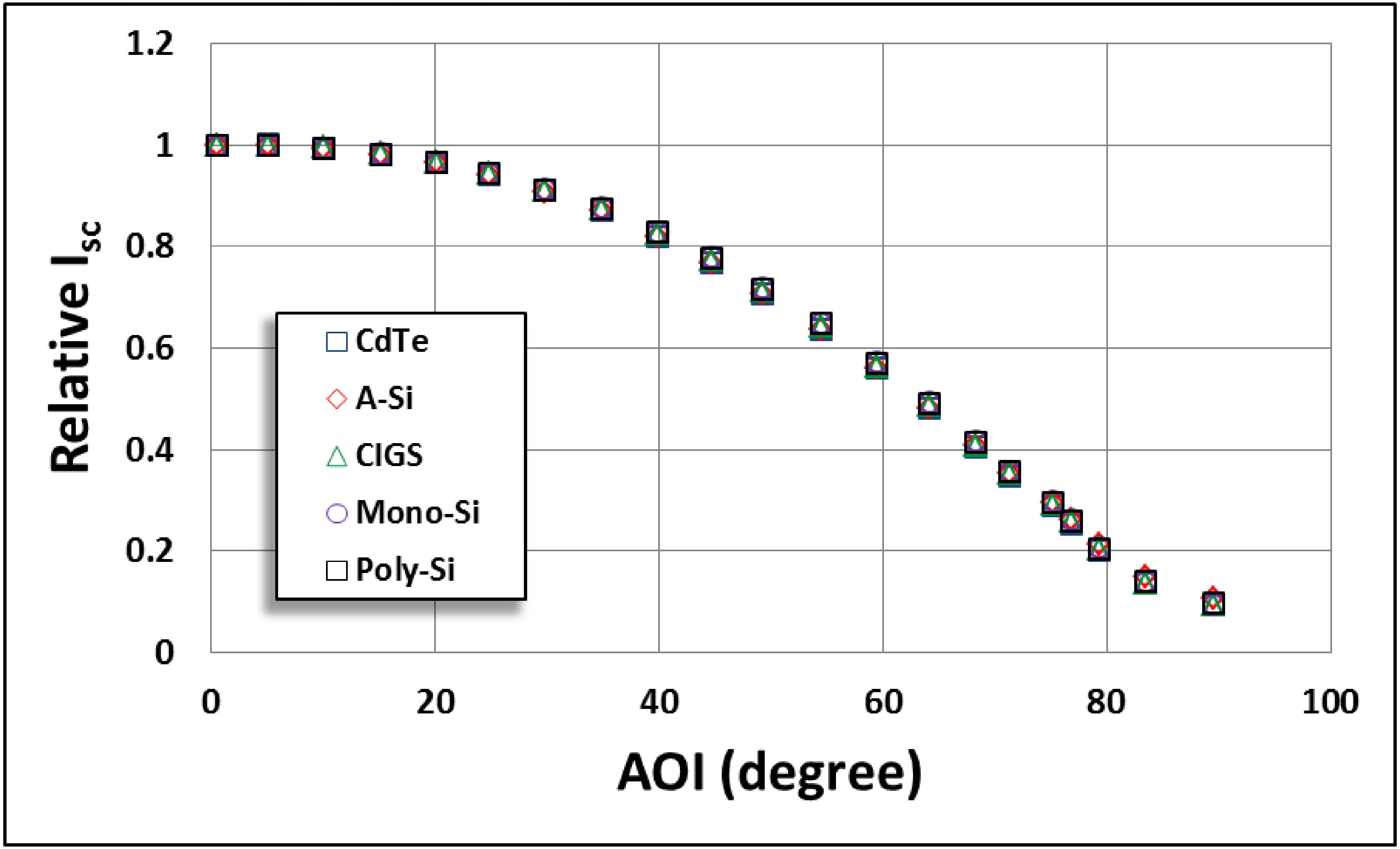
AOI Device

DC Current Transducers



CR 1000 DAS with a Multiplexer

Relative I_{sc} with Diffuse Component and Cosine Effects



IEC 61853-2 Model: Removing Diffuse Component and Cosine Effect

The diffused component visible to the module is:

$$G_{diff} = G_{tpoa} - G_{dni}\,[\cos(\theta)] \qquad (1)$$

Where:

"G_{tpoa}" total irradiance measured by pyranometer

"G_{dni}" direct component measured by the pyrheliometer.

"θ" angle of Incidence.

$$I_{sc}(\theta) = I_{sc\_measured}(\theta)\,(1 - G_{diff} / G_{tpoa}) \qquad (2)$$

The relative angular light transmission (or relative angular optical response) into the module is given by:

$$\tau(\theta) = I_{sc}(\theta)/(\cos(\theta)\, I_{sc}(0)) \qquad (3)$$

Sandia Model: Removing Diffuse Component and Cosine Effect

$$I_{scro} = I_{sc}*(E_o/E_{poa})/(1+\alpha_{Isc}(T_c-25))$$

$$f_2(AOI) = [E_o* (I_{sc}/(1+\alpha_{Isc}(T_c-25)))/I_{scro} -(E_{poa}-E_{dni}*cos(AOI))]/(E_{dni}*cos(AOI))$$

Where:

E_{dni} = Direct normal solar irradiance (W/m^2)

E_{poa} = Global solar irradiance on the plane-of-array (module) (W/m^2)

E_o = Reference global solar irradiance, typically 1000 W/m^2

AOI = Angle between solar beam and module normal vector (deg)

T_c = Measured module temperature (^oC)

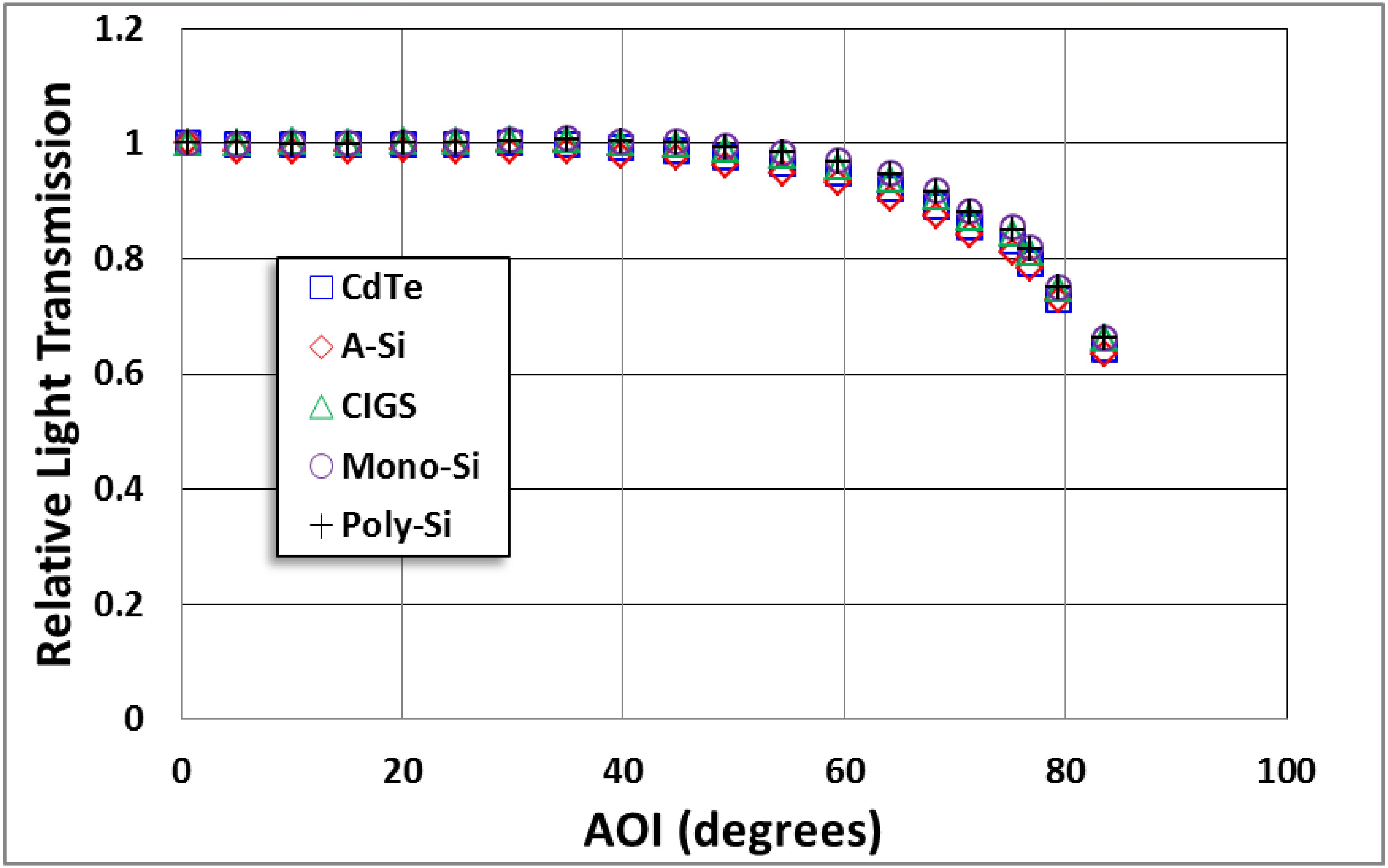
α_{Isc} = Short-circuit current temperature coefficient ($1/^oC$)

I_{scr0} = Module short circuit current at STC conditions at 0^o of AOI (A)

I_{sc} = Measured short circuit current (A)

Relative I_{sc} without Diffused Component and Cosine Effects

IEC Model



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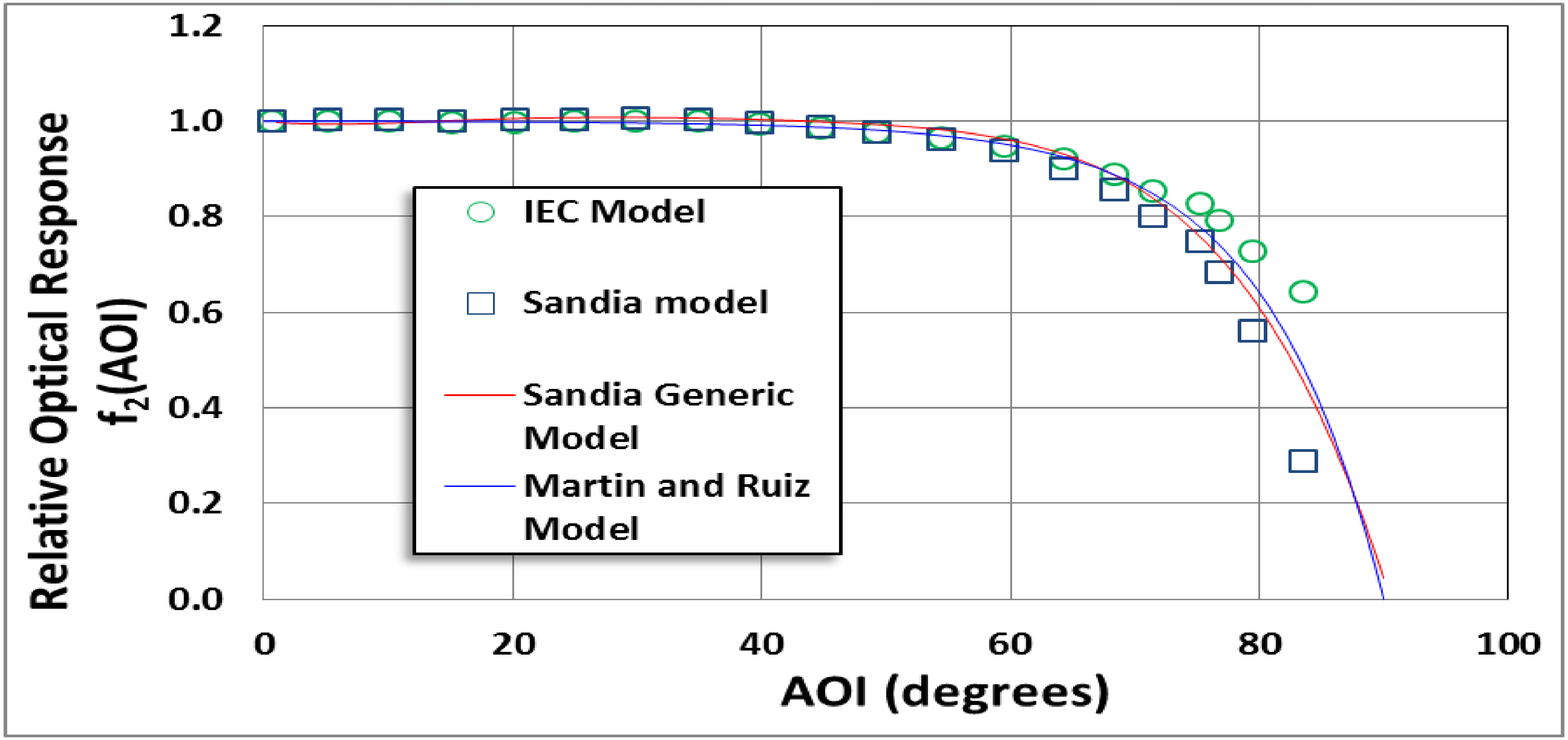
AOI Curve Changes as Air/Superstrate Interface Changes: *Importance to energy estimation models*



All models have an excellent match with each other, confirming that the relative optical response of all the glass superstrate modules is almost exclusively dictated by the air/glass interface. However, this curve may not be assumed for other air/superstrate interfaces (for example, polymeric superstrates or AR coated glasses)!

Conclusions

Energy production/estimation models should consider accounting for:

- **Efficiency change due to irradiance change**
  - **this cannot be accounted if a single efficiency is assumed at all irradiance levels**
  - **this can be accounted by using IEC 61853-1 matrices**

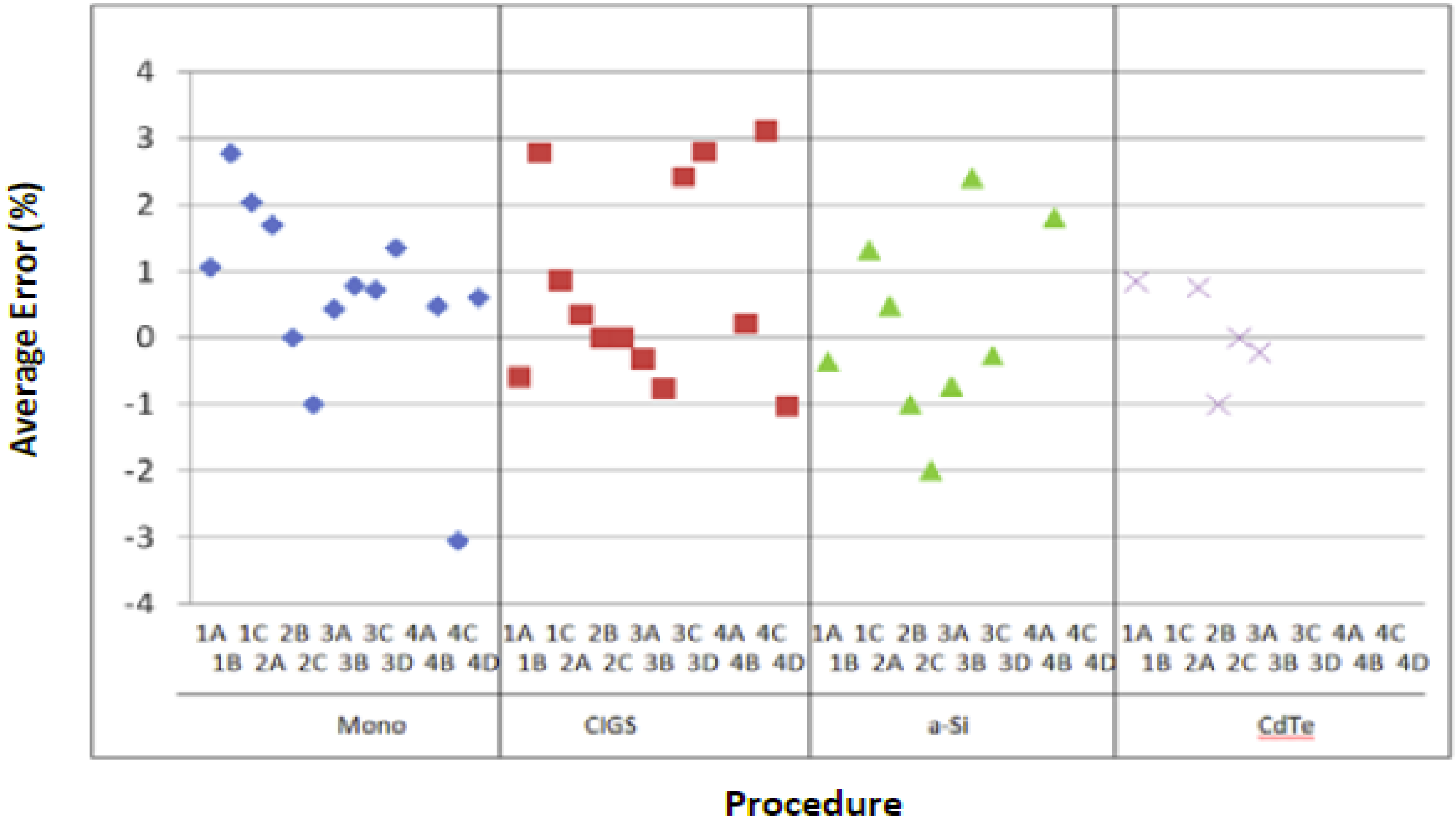
- **Reflection change due to air/glass interface change**
  - **this may not be accounted if air/glass interface is assumed for all module technologies**
  - **this can be accounted by using IEC 61853-2 (draft) or Sandia model**

Thank You!

Additional Info Slides

IEC 61853-2: AOI Model Validation

A: Within 1% of target irradiance; B: 400-1000 W/m^2; C: 100-400 W/m^2 *(very sensitive range)*; D: 600-1000 W/m^2



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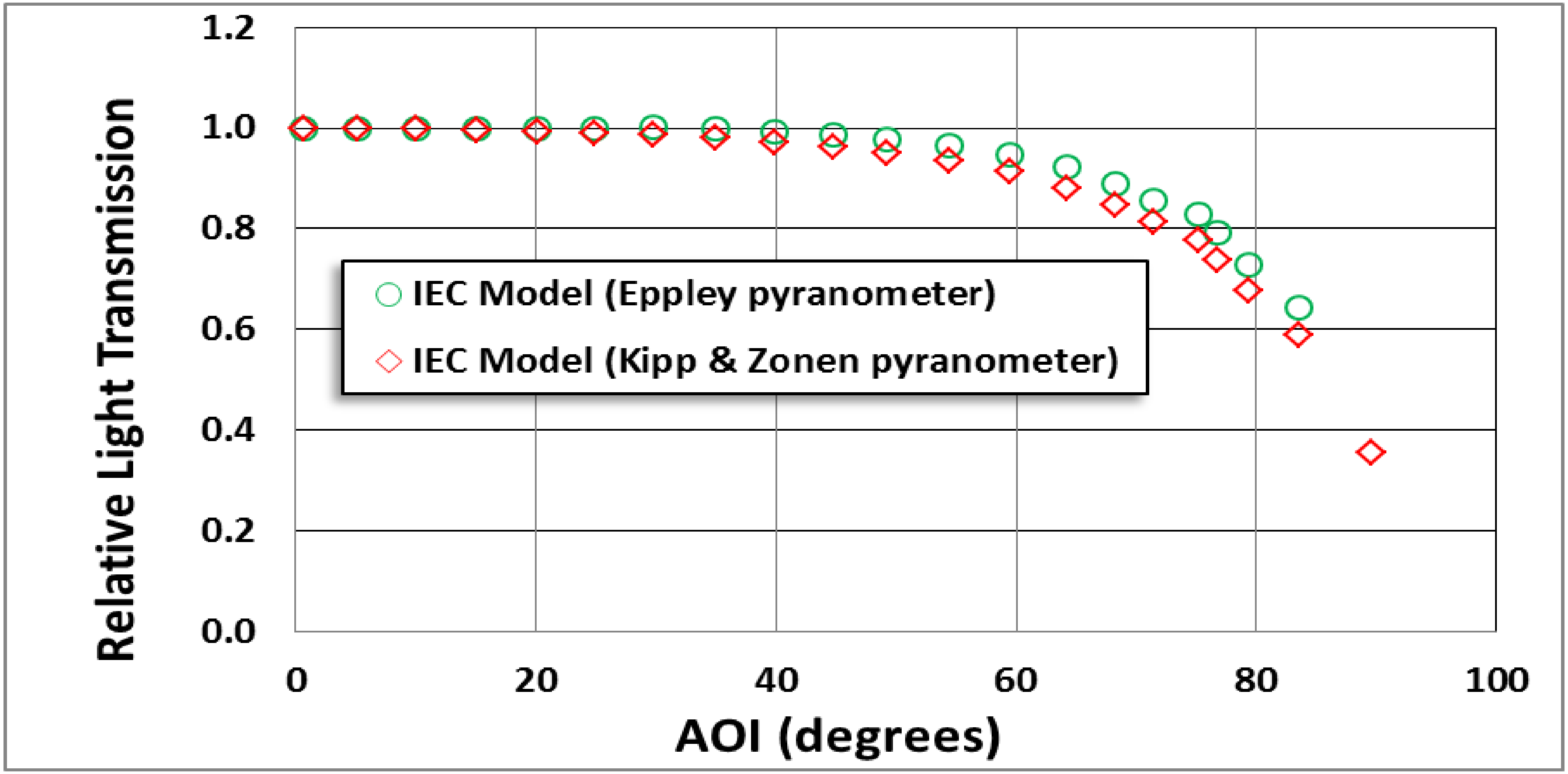
Comparison Between Eppley and Kipp & Zonen Pyranometers

Calibration factors of the pyranometers above 60º is sensitive to AOI



Modeled data using IEC or Sandia model can be slightly influenced at higher AOI values (>60º) by the sensitivity of pyranometer calibration factors

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