ten K SOLAR

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CTO / Founder
tenKsolar

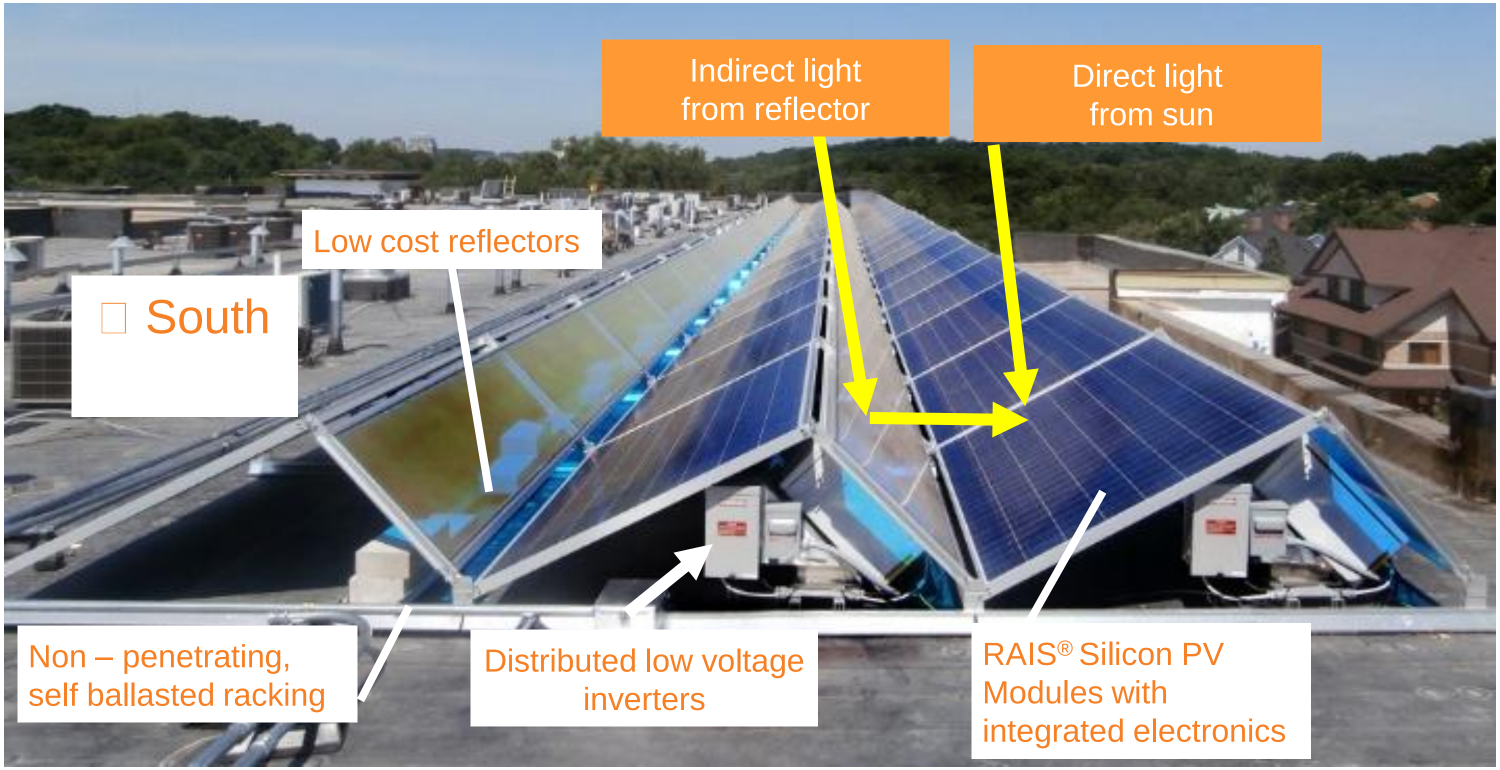
# Modeling Shading / Reflection in NREL SAM

# tenK Corporate Overview

Photo Courtesy Full Spectrum Solar

- Privately held, in 6th year of operation
- Corporate HQ  in Minneapolis, Minnesota
- Manufacturing sites in Shanghai, China and Minneapolis
- Strong intellectual property position 80+ patent filings
- Installations in 18 US States, Canada, Europe and Asia

# Overview of the tenK System




**Integrated electronics + reflection =**

**superior energy production**

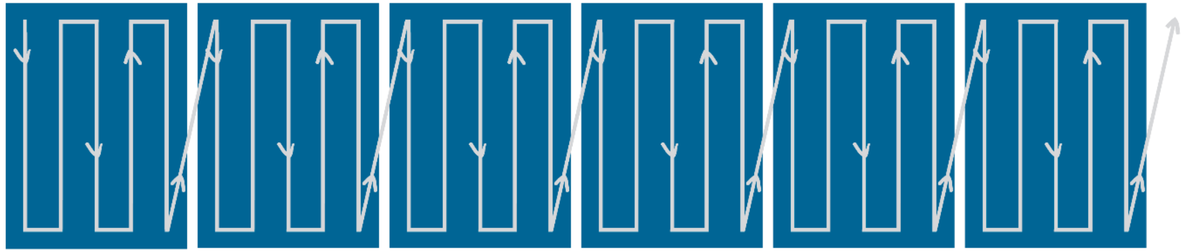
**& Non-standard modeling!**



Photo Courtesy Full Spectrum Sola

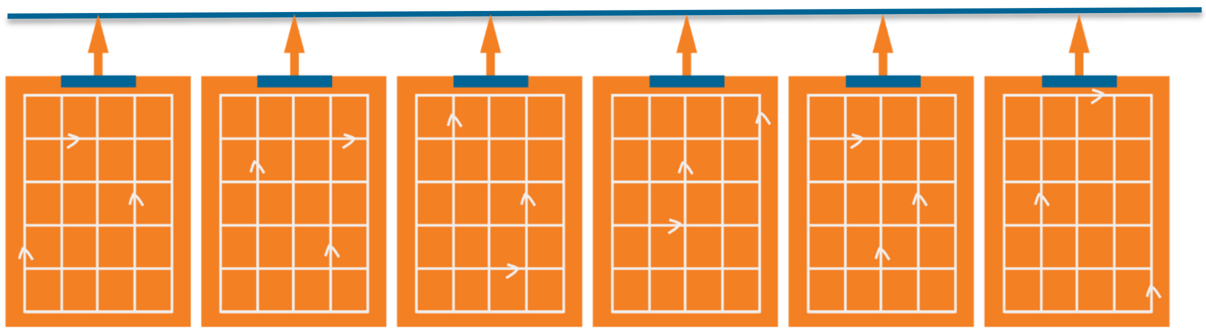
# Limitations of Serial Connections

Only one path for energy to flow, any disruption (soil, shade, damage) affects entire system



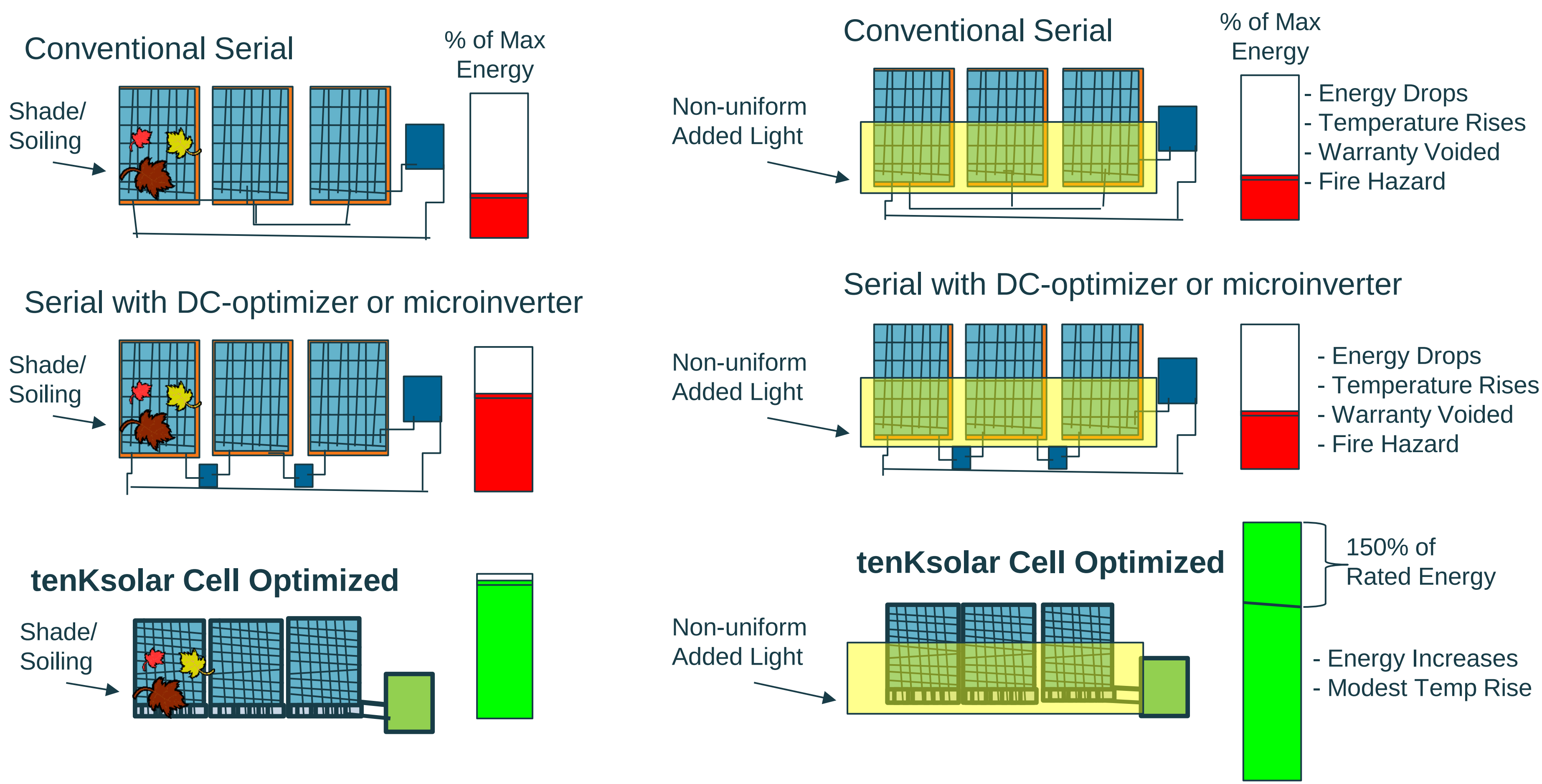
# Serial Plus Parallel Removes Constraint

tenK is a true integrated system, multiple
paths for energy to flow from each individual cell to the grid – allows for non-uniform light.



# tenK Optimized Design Makes More Energy

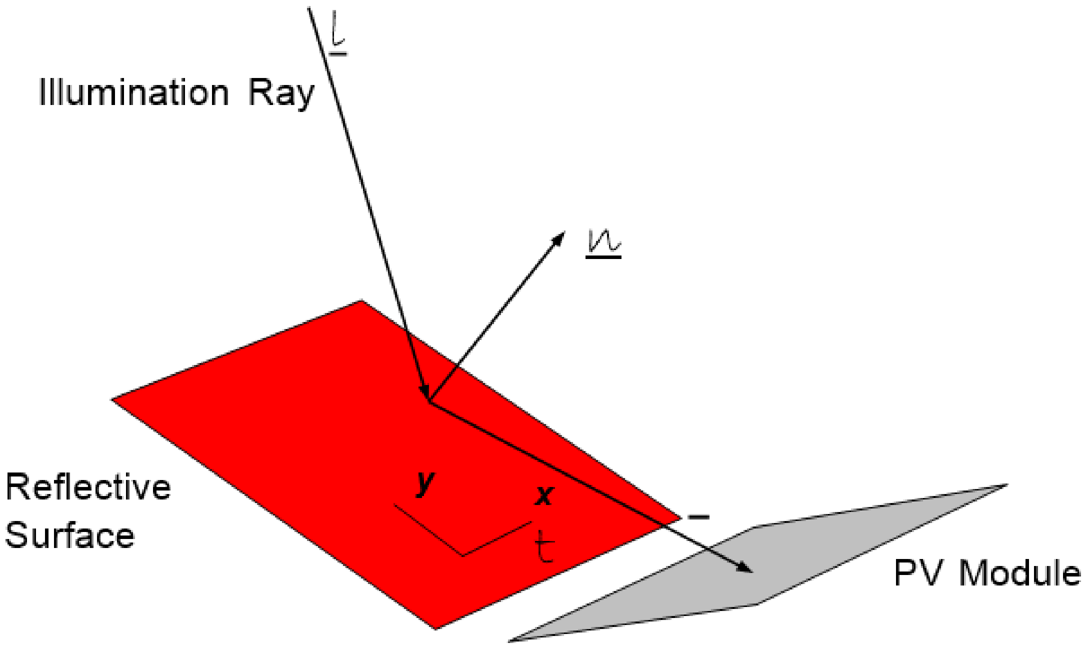
*Reflector Contribution + Shade Tolerance = Maximum Energy Yield*



# *Reflection Modeling*

# Determining the Reflection Gain Values

The geometry used for the calculation of the direct beam reflection gain values.




Reflection gain is the integral sum of all rays that strike the PV module and reflector surface for all table values in SAM Azimuth by Altitude Table.

Fresnel Losses on the surface of the PV module must also be accounted for

Computational Details can be found at http://bit.ly/12R6IY4

# Reflection Example

June 21 @ Solar Noon

Minneapolis (45 degrees N Latitude)

Sun is at a high altitude (64 degrees) and at 180 azimuth (due south)

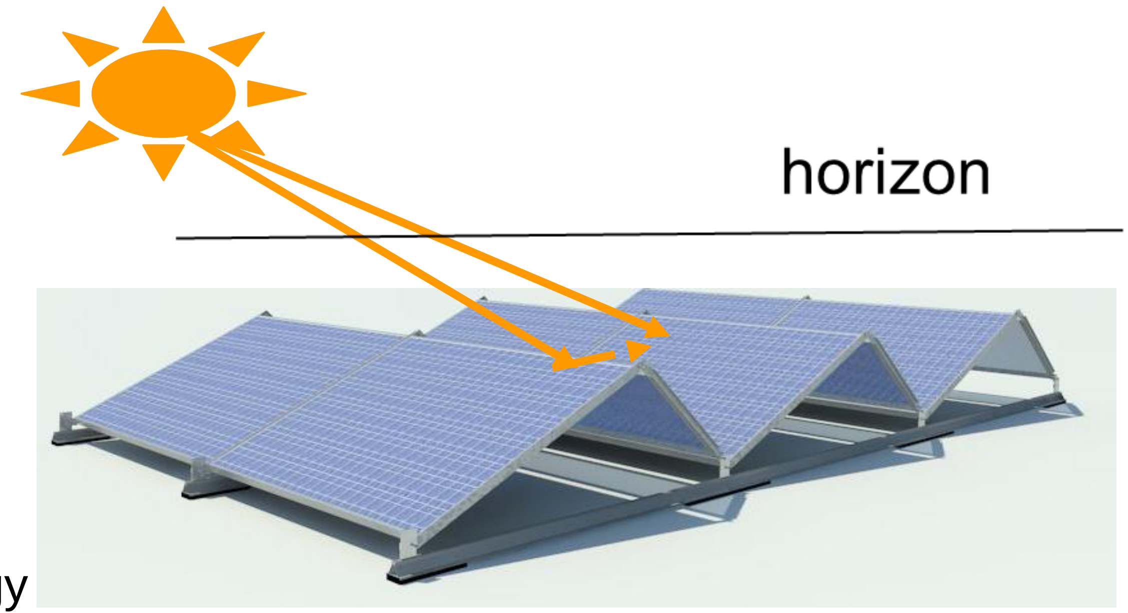
Two components of solar energy

1. Direct
2. Reflected

Components are additive

Reflector Gain Value 1.13

SAM integrates average power value for each hour of the year.




Reflector Gain Table

| 0 | 140 | 160 | 180 | 200 | 220 |
|---|---|---|---|---|---|
| 90 | 1.30485 | 1.30485 | 1.30485 | 1.30485 | 1.30485 |
| 80 | 1.24737 | 1.23532 | 1.23121 | 1.23532 | 1.24737 |
| 70 | 1.19353 | 1.1719 | 1.16465 | 1.1719 | 1.19353 |
| 60 | 1.13984 | 1.10896 | 1.09741 | 1.10896 | 1.13984 |
| 50 | 1.07652 | 1.03347 | 1.01953 | 1.03347 | 1.07652 |
| 40 | 1.00005 | 0.993148 | 0.97401 | 0.993148 | 1.00005 |
| 30 | 0.940245 | 0.873971 | 0.85342 | 0.873971 | 0.940245 |
| 20 | 0.79224 | 0.73316 | 0.715391 | 0.73316 | 0.79224 |
| 10 | 0.591335 | 0.541597 | 0.527292 | 0.541597 | 0.591335 |
| 2 | 0.317993 | 0.300932 | 0.2963 | 0.300932 | 0.317993 |

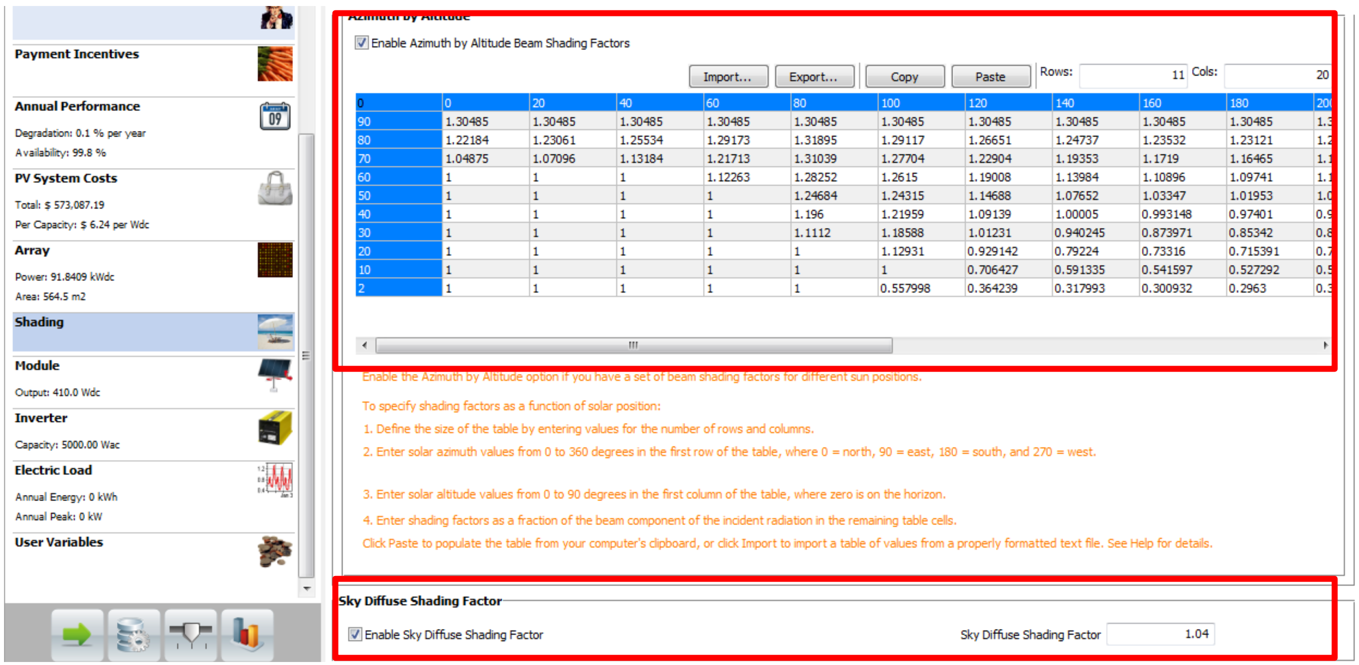
# SAM input page: Shading

Shading input page is another input page.

Modeling a tenKsolar RAIS XT array with reflectors requires input to two sections

1. Azimuth by Altitude Reflection Shading Factors.
2. Sky Diffuse Shading Factors.

Both of these features are disabled for SAM Case for front row modules




| 0 | 0 | 20 | 40 | 60 | 80 | 100 | 120 | 140 | 160 | 180 |
|---|---|---|---|---|---|---|---|---|---|---|
| 90 | 1.30485 | 1.30485 | 1.30485 | 1.30485 | 1.30485 | 1.30485 | 1.30485 | 1.30485 | 1.30485 | 1.30485 |
| 80 | 1.22184 | 1.23061 | 1.25534 | 1.29173 | 1.31895 | 1.29117 | 1.26651 | 1.24737 | 1.23532 | 1.23121 |
| 70 | 1.04875 | 1.07096 | 1.13184 | 1.21713 | 1.31039 | 1.27704 | 1.22904 | 1.19353 | 1.1719 | 1.16465 |
| 60 | 1 | 1 | 1 | 1.12263 | 1.28252 | 1.2615 | 1.19008 | 1.13984 | 1.10896 | 1.09741 |
| 50 | 1 | 1 | 1 | 1 | 1.24684 | 1.24315 | 1.14688 | 1.07652 | 1.03347 | 1.01953 |
| 40 | 1 | 1 | 1 | 1 | 1.196 | 1.21959 | 1.09139 | 1.00005 | 0.993148 | 0.97401 |
| 30 | 1 | 1 | 1 | 1 | 1.1112 | 1.18588 | 1.01231 | 0.940245 | 0.873971 | 0.85342 |
| 20 | 1 | 1 | 1 | 1 | 1 | 1.12931 | 0.929142 | 0.79224 | 0.73316 | 0.715391 |
| 10 | 1 | 1 | 1 | 1 | 1 | 1 | 0.706427 | 0.591335 | 0.541597 | 0.527292 |
| 2 | 1 | 1 | 1 | 1 | 1 | 0.557998 | 0.364239 | 0.317993 | 0.300932 | 0.2963 |

# *Model Validation*

# NREL - Golden, CO:
# tenKsolar Test Site Summary

| | |
|---|---|
| **Size** | 1.8 kW |
| ***Location*** | *National Renewable Energy Laboratory, Golden, CO* |
| ***Configuration*** | *45° Tilt (-32° Reflector)*<br>*180° Azimuth*<br>*180W Modules*<br>*Ground Mount* |
| ***Installed*** | *February 2012* |

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# *NREL Insolation Data Collection*

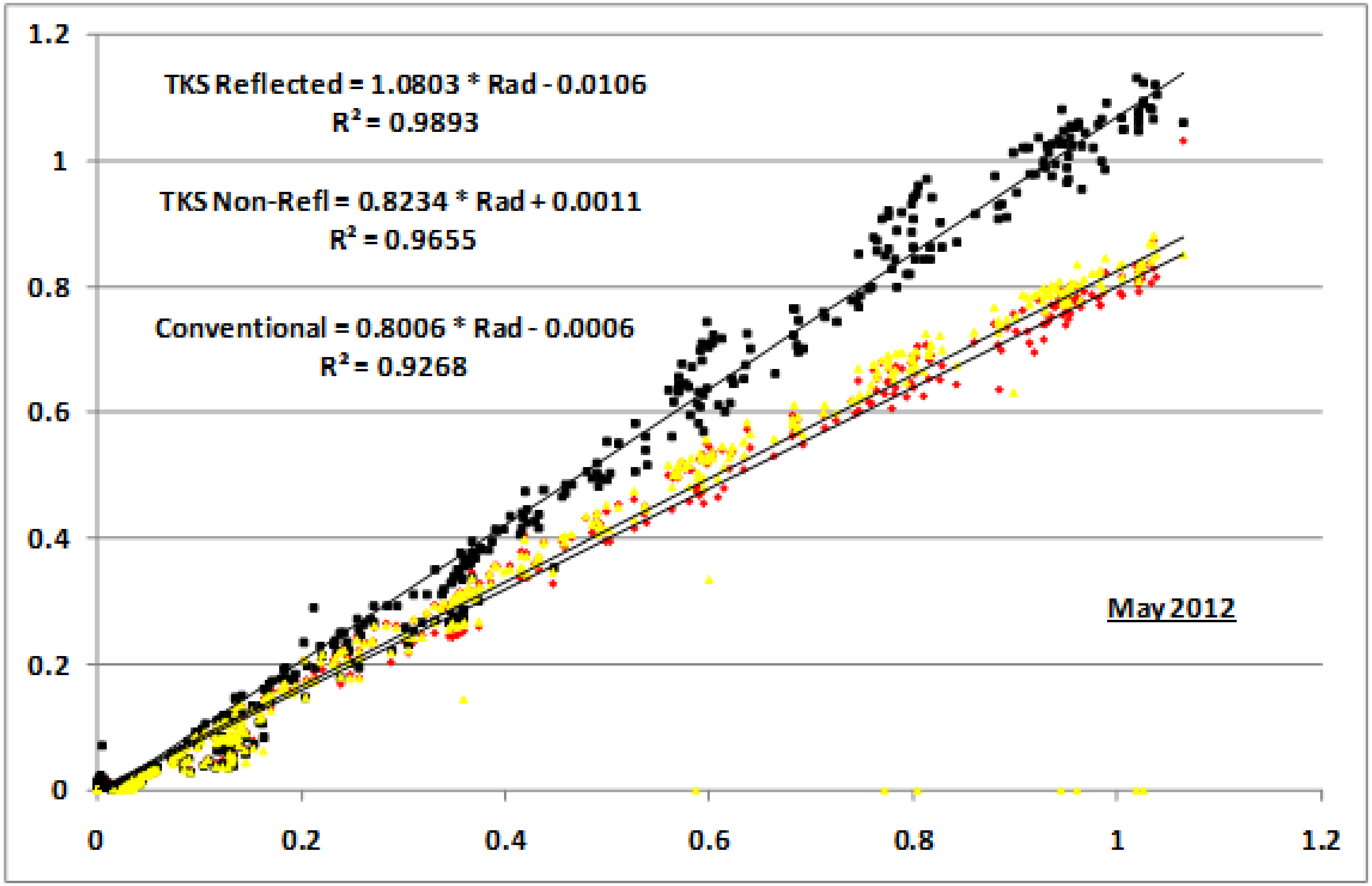
**Solar Resource Data is collected at NREL by Solar Resource Measurement System**

**Conversion to hourly TMY3 format completed by averaging the minute by minute data for the hour in accordance with TMY3 definitions.**

**Data is tabulated by minute for the following variables by the corresponding instruments.**

| Irradiance Component | Instrumentation |
|---|---|
| ***Plane of Array*** | ***45 degree fixed tilt Kipp&Zonen CMP-22.*** |
| **Plane of Array** | 45 degree fixed tilt Licor silicon photodiode |
| ***Global Horizontal*** | ***horizontal CMP-22*** |
| **Diffuse Horizontal** | horizontal CMP-22 with the DH shaded by a tracking ball. |
| ***Direct Normal*** | ***a CHP-1 pyrheliometer is on a 2-axis tracking system.*** |

# May 2012 Energy Yield vs 45 POA

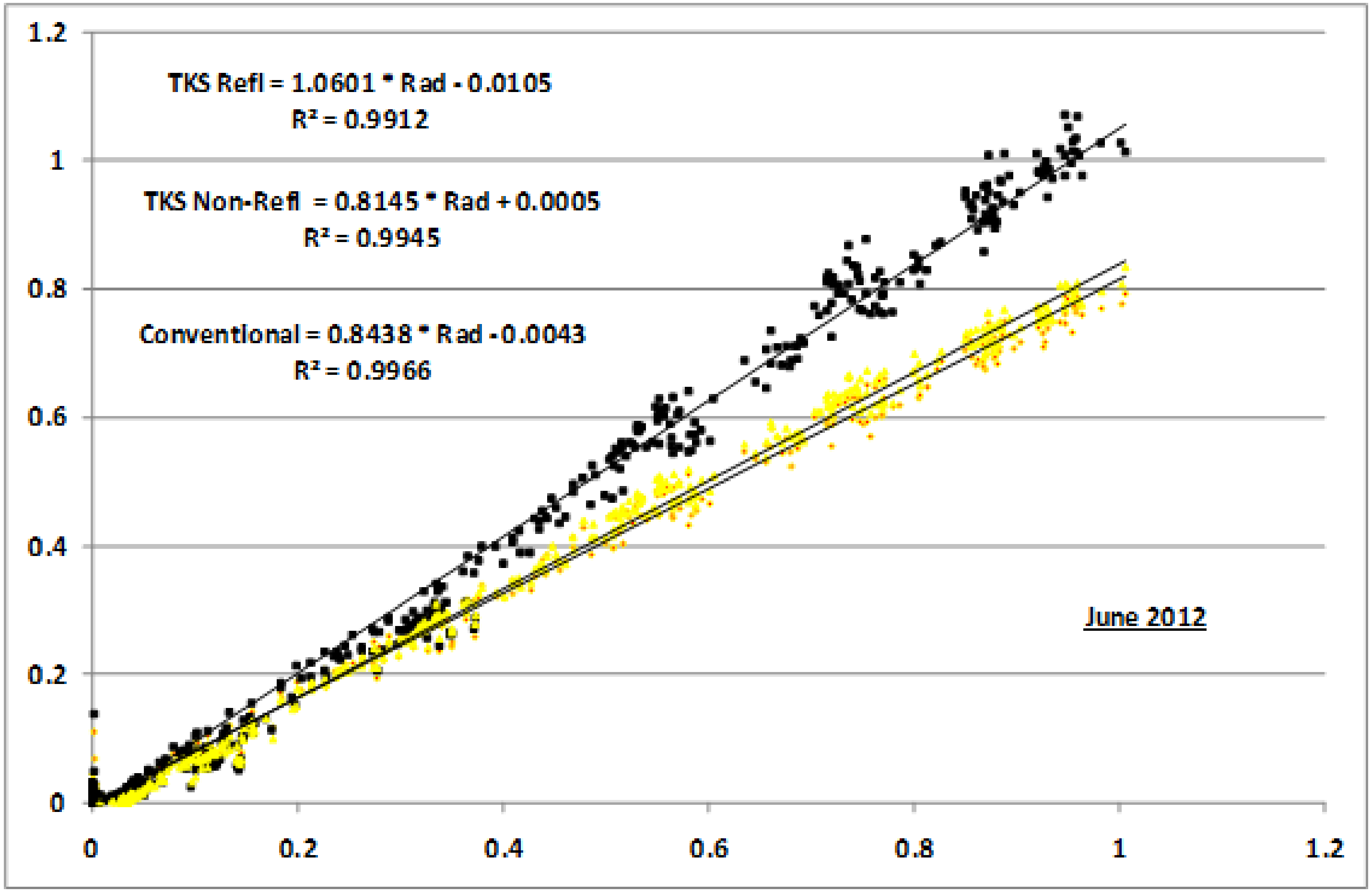



Energy yield (kWh AC / kWh DC)

45 Deg POA (kWh / m2)

# June 2012 Energy Yield vs 45 POA

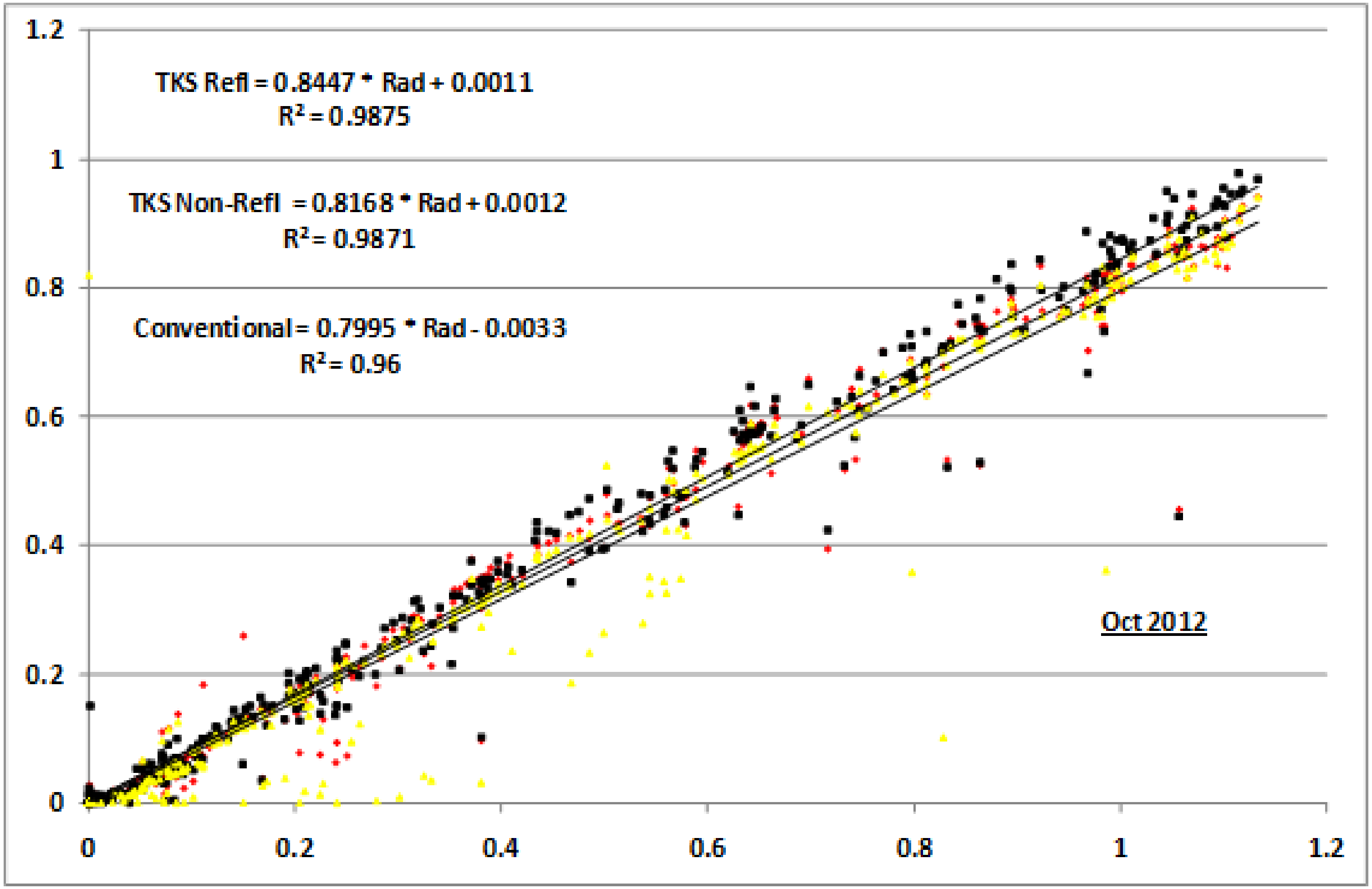
Energy yield (kWh AC / kWh DC




45 Deg POA (kWh / m2)

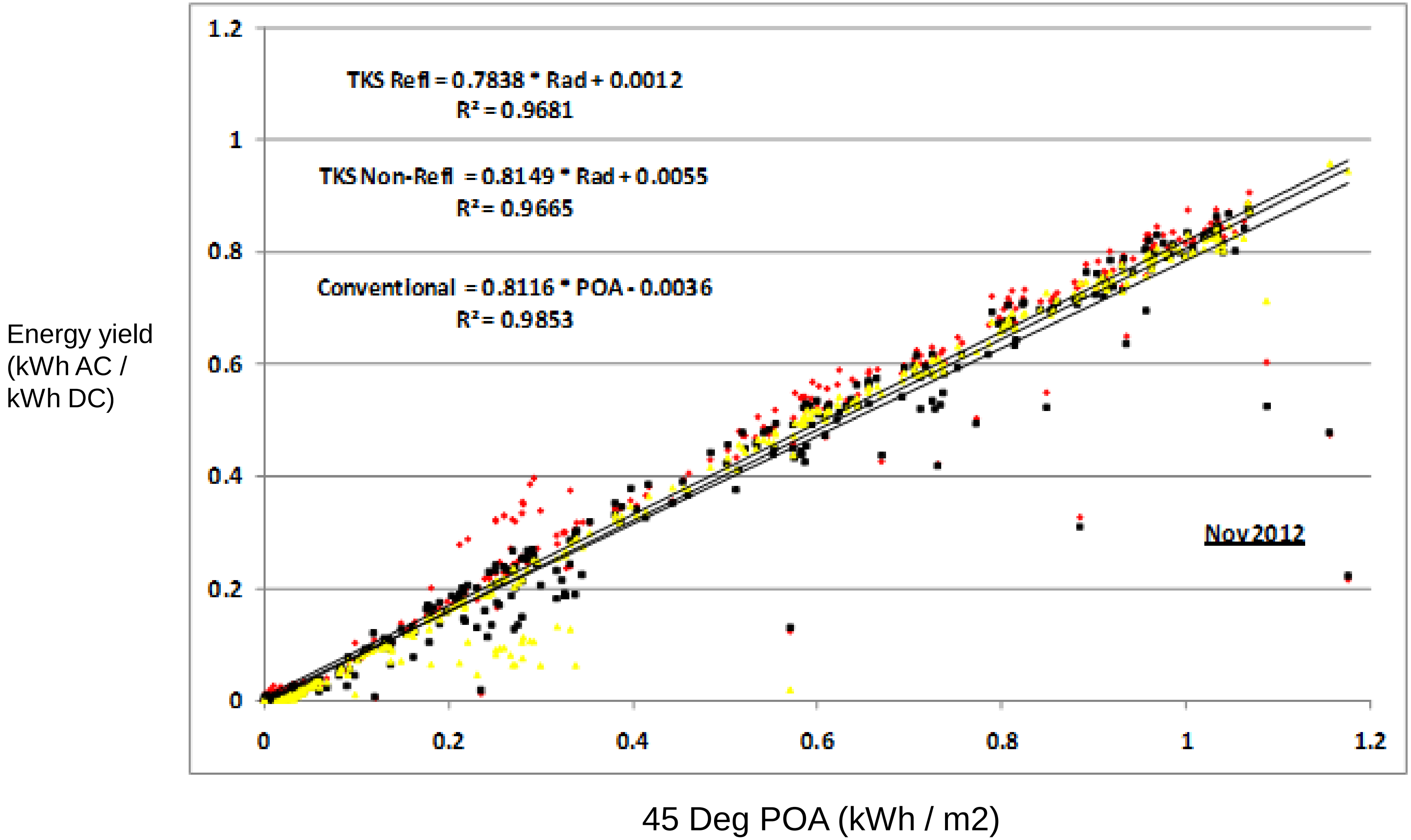
# Oct 2012 Energy Yield vs 45 POA

Energy yield (kWh AC / kWh DC)




45 Deg POA (kWh / m2)

# Nov 2012 Energy Yield vs 45 POA

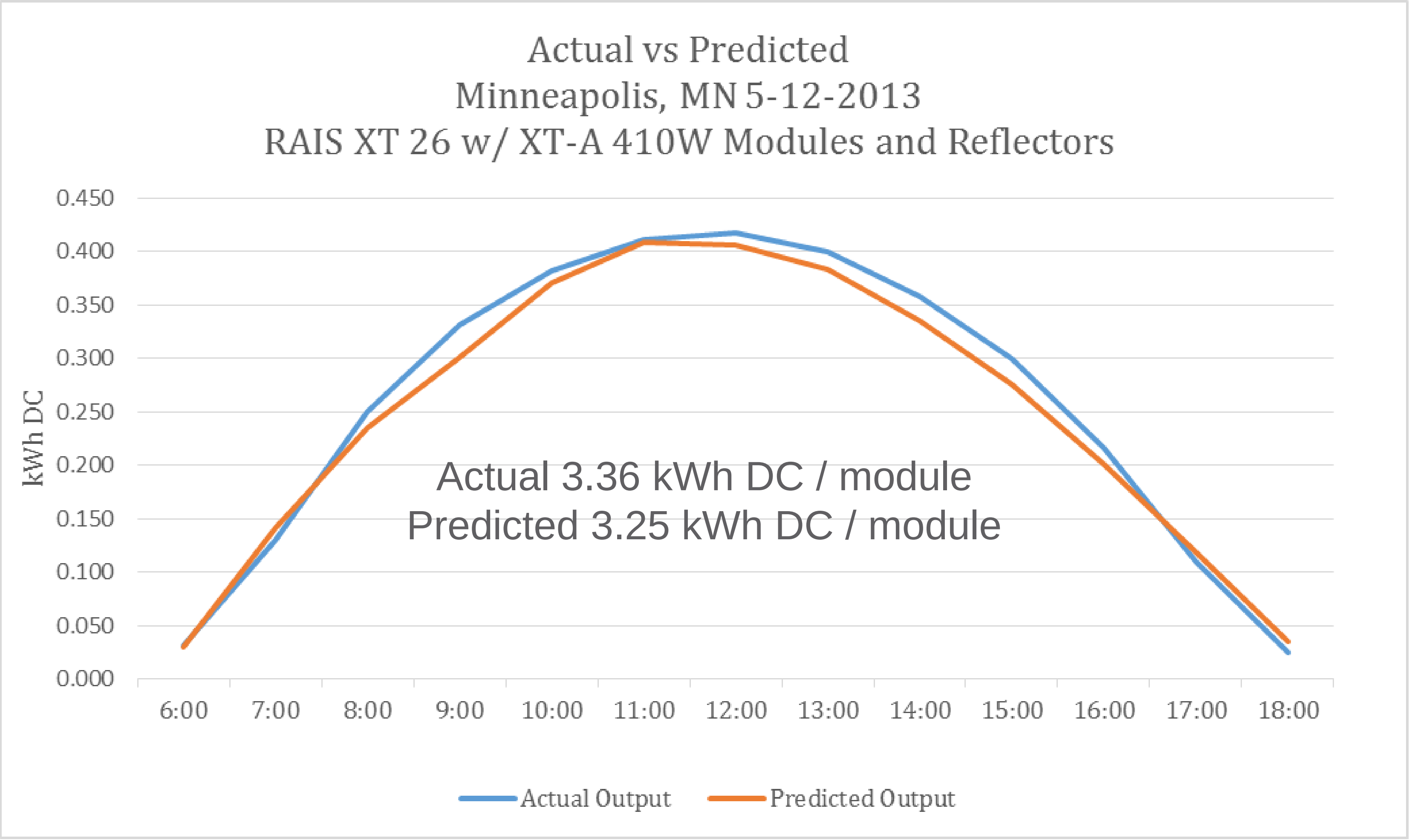


# RAIS® XT – tenK's most recent product release

- **RAIS® XT** (410W)
- Powerful: 96 cell equivalent
- Application flexibility:
  – XT 26° - Higher Density for Maximum Rooftop Production
  – XT 28° - Optimized for Additional Energy Production per Watt.

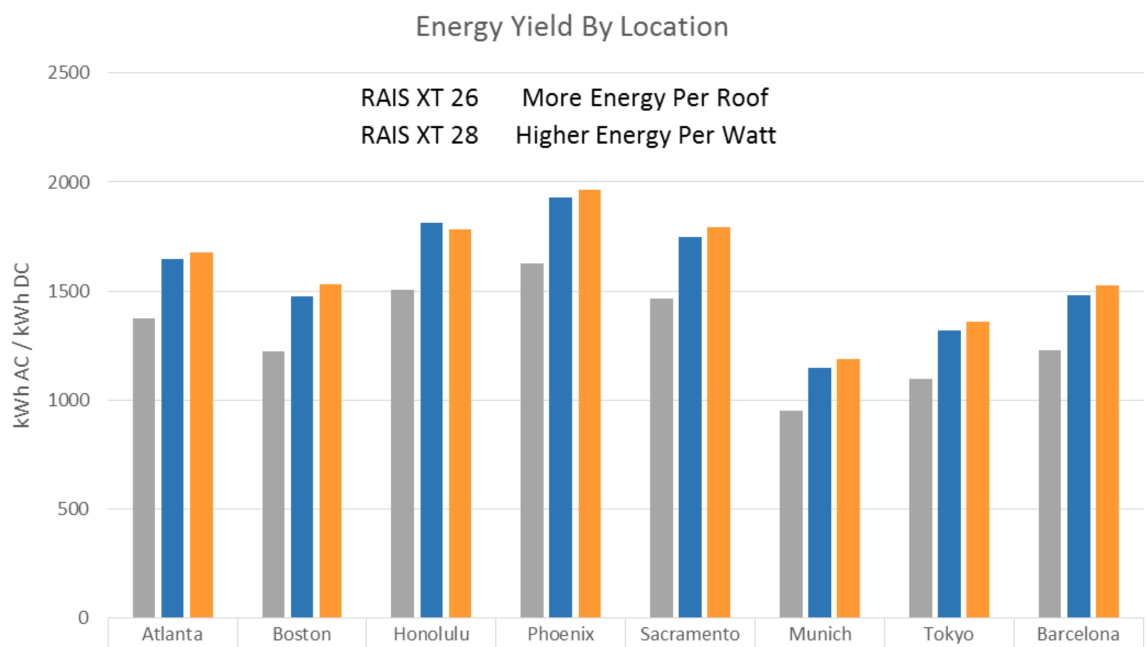
**More Energy, More Reliable**

# RAIS® XT 26 Energy Output




Modeled with NREL SAM, tenK's Energy Prediciton Model using Solar Data Warehouse Irradiance Data

# ***RAIS XT*** *Modeled Energy Yield*




| | Atlanta | Boston | Honolulu | Phoenix | Sacramento | Munich | Tokyo | Barcelona |
|---|---|---|---|---|---|---|---|---|
| c-Si 10° | 1377 | 1225 | 1508 | 1628 | 1467 | 950 | 1097 | 1229 |
| XT 26° | 1646 | 1475 | 1813 | 1931 | 1750 | 1149 | 1318 | 1479 |
| XT 28° | 1677 | 1532 | 1781 | 1967 | 1792 | 1191 | 1359 | 1528 |

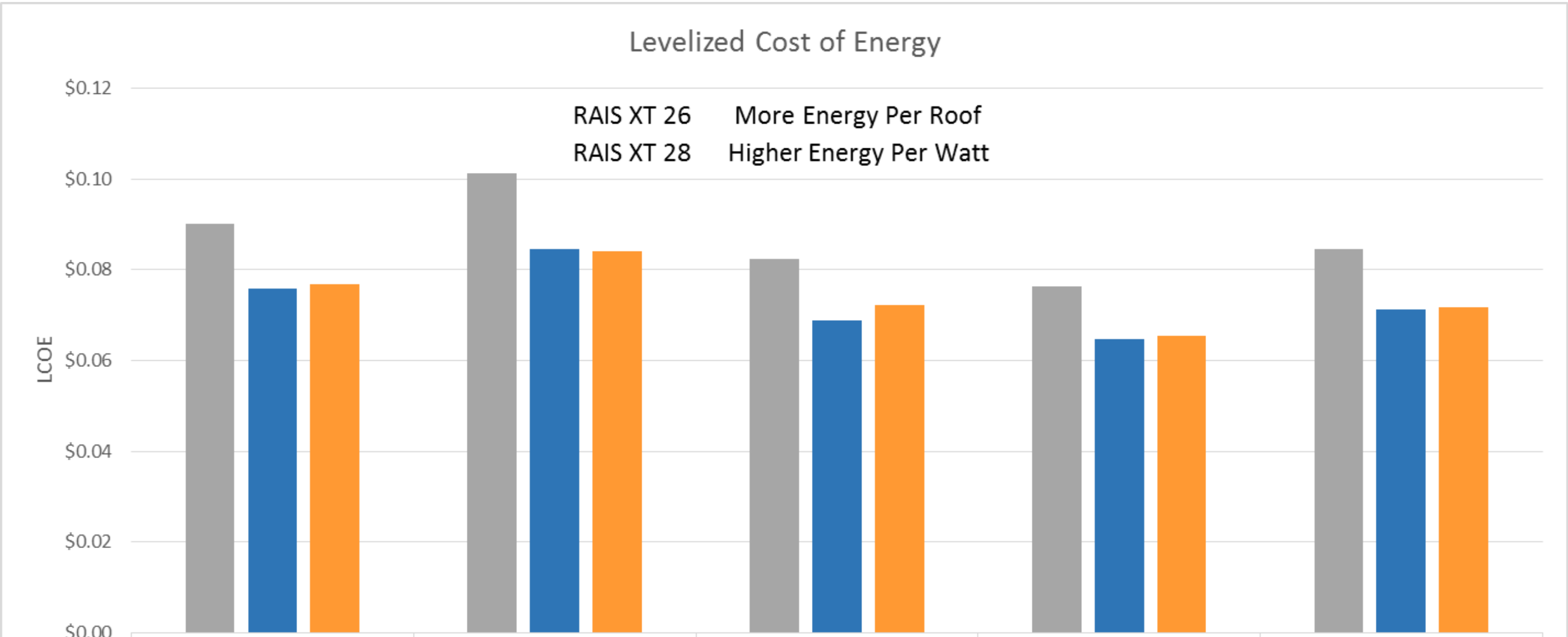
c-Si 10° XT 26° XT 28°

| XT 26° | vs 10° |
|---|---|
| Atlanta | +20% |
| Boston | +20% |
| Honolulu | +20% |
| Phoenix | +19% |
| Sacramento | +19% |
| Munich | +21% |
| Tokyo | +20% |
| Barcelona | +20% |

| XT 28° | vs 10° |
|---|---|
| Atlanta | +22% |
| Boston | +25% |
| Honolulu | +18% |
| Phoenix | +21% |
| Sacramento | +22% |
| Munich | +25% |
| Tokyo | +24% |
| Barcelona | +24% |

Annual Energy Yield using identical weather files in NREL Solar Advisor Module (SAM), both arrays facing due south, assumes no impact due to interrow self shading on conventional

# Lower Cost of Energy




| | Atlanta | Boston | Honolulu | Phoenix | Sacramento |
|---|---|---|---|---|---|
| c-Si 10° | 0.0902 | 0.1013 | 0.0823 | 0.0762 | 0.0846 |
| XT 26 | 0.0758 | 0.0845 | 0.0688 | 0.0646 | 0.0713 |
| XT 28 | 0.0767 | 0.0840 | 0.0723 | 0.0654 | 0.0718 |

c-Si 10° XT 26 XT 28

Assumes US 30% ITC Depreciation

| | RAIS XT 26 | RAIS XT 28 | Conventional |
|---|---|---|---|
| PV Kit Cost | $1.38 | $1.40 | 1.16 |
| Installed Cost | $2.68 | $2.74 | $2.50 |

- Complete Instructions on how to model a tenKsolar array using SAM can be found at http://bit.ly/13s10uH