What are you trying to accomplish?

**kWh Production (Yield)**
- Annual Max, Time of Day and Month of Year.
- It is specific to the array latitude & longitude.

**Demand Reduction**
- Array azimuth (direction) affects daily peak.
- Design can maximize this benefit (time of day reductions).

**Reliability**
- Product selection, bankability & long term performance.
- Operations, Maintenance, Warranties & long term ownership
Technology Selection

- What is being used in large scale solar today?
- There are numerous niche technologies in modules, racking & inverters.
- Is a specific cost savings worth the associated risk.
- Historic performance and predictability are important.
- Other speakers will cover Bankability of the manufacturers.
### Racking

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
</table>
| **Fixed Tilt driven pier** | - Classic large scale installation.  
                             - Steel piles driven into the earth.  
                             - Low installation cost, requires soils study. |
| **Tracker**               | - Single or Dual axis: Increased generation  
                             - Increased array footprint, maintenance, & cost.  
                             - As module prices decrease, they make less sense. |
| **Ballasted ground mount** | - Land fills or poor subsurface conditions  
                             - Concrete or rock ballast |
Fixed Tilt Driven Pier Ground Mount
Single Axis Tracker
Dual Axis Tracker
Racking production comparison

<table>
<thead>
<tr>
<th>100 kW (PV Watts software)</th>
<th>kWh (PV Watts)</th>
<th>% (rough comparison using PV watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 Degree Fixed Tilt</td>
<td>141,900 kWh</td>
<td>100%</td>
</tr>
<tr>
<td>Single Axis Tracker</td>
<td>176,400 kWh</td>
<td>124%</td>
</tr>
<tr>
<td>Dual Axis Tracker</td>
<td>190,700 kWh</td>
<td>134%</td>
</tr>
</tbody>
</table>

- Parasitic loads (motor consumption if utilized)
- Increased maintenance.
- Increased installation costs.
- Larger land area for trackers to reduce shading.
- Decreasing module costs work against tracking benefits.
Effect of Array Direction on Peak Output

Peak Production Shifting

- South
- East
- West

HOUR OF DAY

KW PRODUCTION

0 100 200 300 400 500 600 700 800 900

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
## PV Modules (Panels)

<table>
<thead>
<tr>
<th>Module</th>
<th>Characteristics</th>
</tr>
</thead>
</table>
| Monocrystalline | • Highest $/watt but most efficient (~20%)  
                          • Proven track record (since the 70’s)                     |
| Polycrystalline | • Slightly less efficient than Mono due to lower silicon purity  
                          • Most commonly used module                                  |
| Thin Film     | • Lowest $/watt – currently lowest efficiency but could surpass crystalline (~15%)  
                          • Newer technology with a more complex structure             |
Thin Film – frameless
<table>
<thead>
<tr>
<th>Modules – what affects production</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Module Performance</strong></td>
</tr>
<tr>
<td>• Temperature – the colder the better</td>
</tr>
<tr>
<td>• Irradiance – brightness of the sun</td>
</tr>
<tr>
<td><strong>System Losses</strong></td>
</tr>
<tr>
<td>• AC &amp; DC line losses</td>
</tr>
<tr>
<td>• Mismatch, Soiling, Snow Cover &amp; Shading</td>
</tr>
<tr>
<td><strong>Angle of incidence (angle between module and sun)</strong></td>
</tr>
<tr>
<td>• Sun path varies throughout day &amp; year</td>
</tr>
<tr>
<td>• Modules perpendicular to the sun produce the most energy</td>
</tr>
</tbody>
</table>
Modules – selection considerations

Warranty
- Warranty on most modules are the same.
- 10 year physical defects.
- 20-25 year performance (80% of output).

Availability
- Can they meet your construction schedule?
- Design may vary slightly since module wattages change.

History
- What is the manufacturers track record?
- Will they be around to honor a warranty?
Inverters – converting DC to AC

**String**
- 24-50 kW range
- ~22 inverters in 1MW

**Central**
- 100kW to 1MW
- 1-4 inverters in 1MW

**Micro**
- 1 per module
- Not typically used in large scale solar
Inverters – Central
Inverters – String
## Inverter Design Considerations

<table>
<thead>
<tr>
<th>Repair &amp; Replacement ease.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead times on new units or parts.</td>
</tr>
<tr>
<td>Extended warranties – 10 to 12 standard, up to 25 available</td>
</tr>
<tr>
<td>All manufacturers have had their issues, but how do they resolve it?</td>
</tr>
<tr>
<td>DC to DC converters (SolarEdge &amp; module integrated)</td>
</tr>
</tbody>
</table>
# System Performance

<table>
<thead>
<tr>
<th>Using Software to model expected performance.</th>
<th>PV Syst – utility standard for modeling.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAN files</td>
<td>Built by physicists in Geneva, Switzerland.</td>
</tr>
<tr>
<td>These contain the data the software utilizes</td>
<td>Screening process to validate performance (modules &amp; inverters) data.</td>
</tr>
<tr>
<td>Need to be 3rd party verified.</td>
<td></td>
</tr>
<tr>
<td>Black &amp; Veatch does much of this work.</td>
<td></td>
</tr>
<tr>
<td>Other Software for modeling</td>
<td>System Advisor Model (free, from NREL)</td>
</tr>
<tr>
<td></td>
<td>HelioScope</td>
</tr>
</tbody>
</table>
### System Performance - Variables

<table>
<thead>
<tr>
<th>Section</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>There are a lot of moving parts in the software packages</td>
<td>- There are industry accepted values.</td>
</tr>
</tbody>
</table>
| Independent verification of PV plant production is important | - Can be self performed or hired out depending on your experience.  
- I typically model in 2 software packages to compare data. |
| Weather data | - not all data sets are complete  
- I recommend comparing nearby cities  
- Micro-climates: what local or regional effects should be considered |
Snow Shedding

- Steeper module tilt will shed snow more quickly.
- Summer production is approximately 2.5 x winter production.
- Higher module tilt requires larger row spacing which means more land to avoid row to row shading.
Dirty modules produce less power.

There is not a common consensus on if they should be cleaned and how often.

Dry dusty climates tend to have a cleaning regiment

Iowa receives enough rainfall, my opinion is to evaluate the array annually.
Electrical Losses

• Conductor losses are designed at maximum inverter output per the National Electric Code.
• Actual losses have been found do be significantly less.
• This is primarily due to the limited amount of time an inverter runs at maximum output.
Inverter Clipping Losses

• Oversizing or DC to AC ratio refer to the kW of Modules to the kW of Inverters

• This is a common design practice, the right amount depends on project specific economics.

• It can be as high as 150% in some cases, a safe ratio that works for most projects is 125%.

• The higher the ratio, the lower your $/watt of inverters, but revenue is lost as well due to increased clipping.

• The highest ROI will always have some clipping.
Performance Monitoring

- Inverter level to module level options
- 3rd party systems or inverter integrated
- Automatic fault notification
- Self monitoring or professional services
- Cloud based reporting
- Some services model expected vs. actual performance
Questions?

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