System design for utility-scale solar PV and Battery Energy Storage Systems

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Presented to IEEE

Bill Novak, P.E., MSE, MBA
Tropenas Company
President and Chief Engineer
(615) 538-8519
bill.novak@tropenas.com

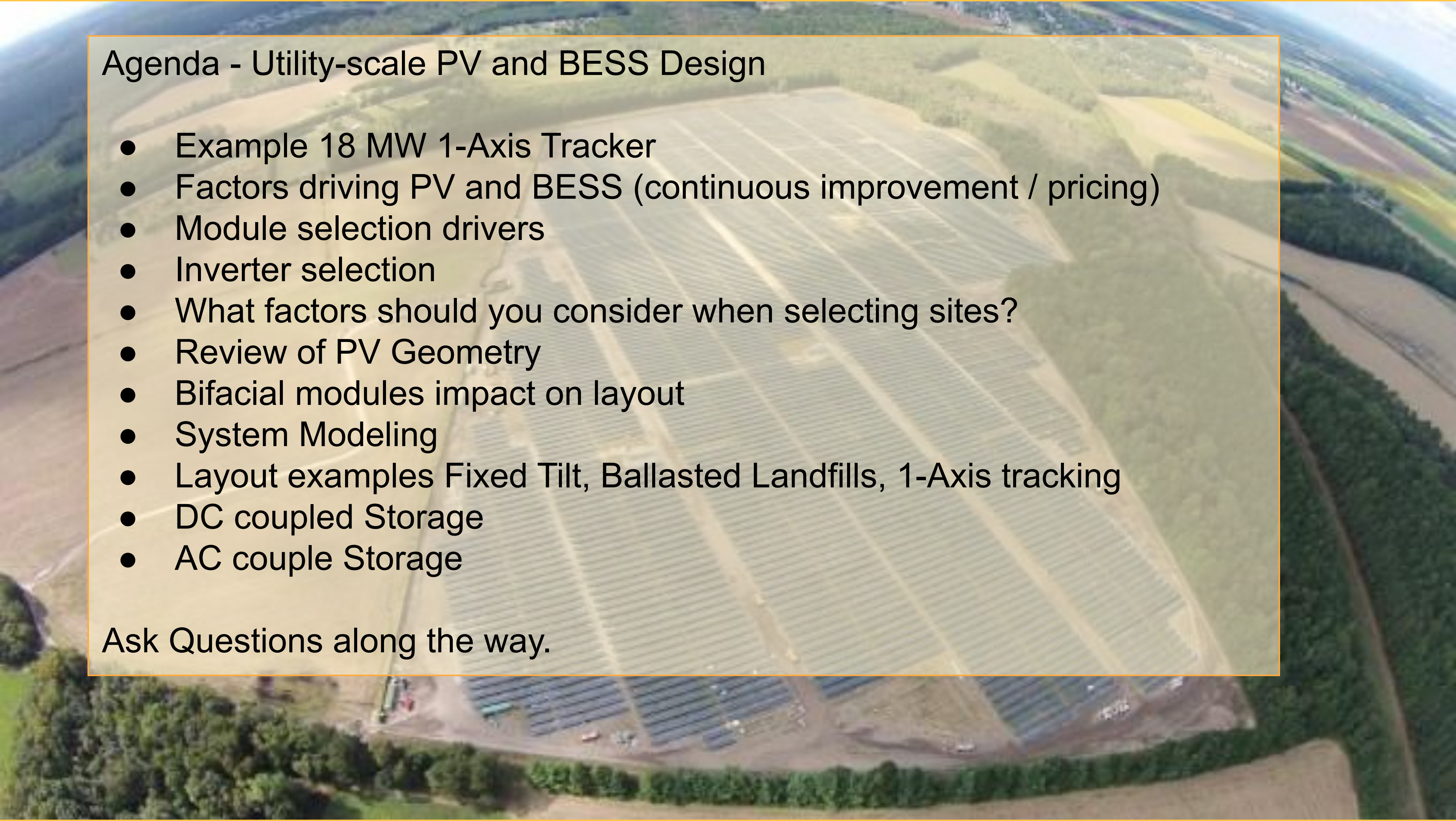
Tropenas Company (independent engineering firm) with expertise in

- Engineering for utility-scale renewable energy and storage facilities,
- Continuous improvement of affordable, robust, resilient systems,
- Solar PV, energy storage systems, substations, etc.

Typical renewable energy projects:

- Interconnection application drawings and support,
- IFC Electrical, mechanical and civil permit drawings,
- Component and system value engineering,
- Advice on feasibility, procurement, project implementation and oversight.

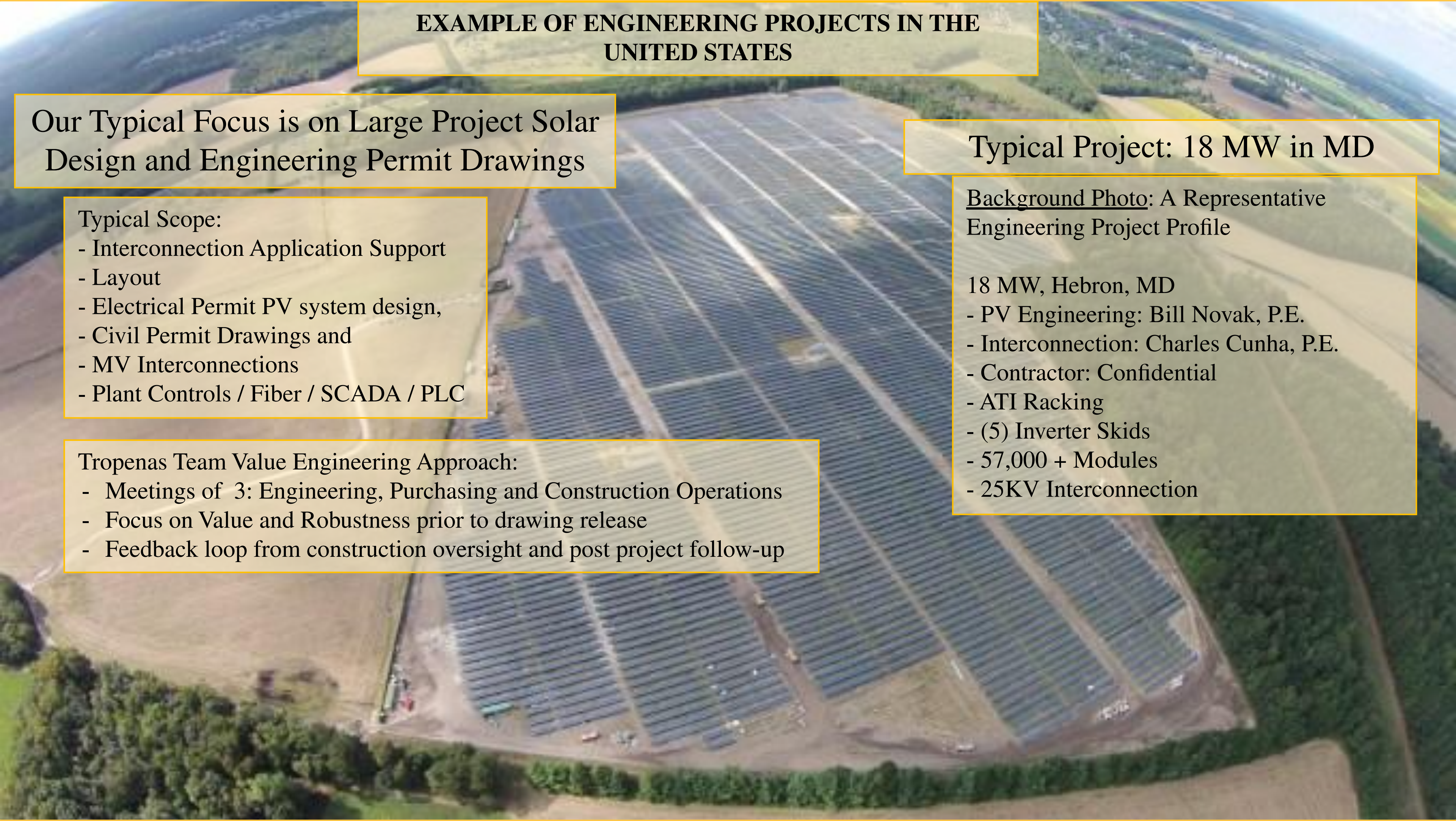
- Professional Engineering Licenses in 28 states:
  - Bill Novak, P.E., MSE, MBA, 22 states, PV & BESS Chief Engineer
  - Charles W. Cunha, P.E.: CA, HI, NV, OR, WA, US Virgin Islands, Substation design
  - Jon Novak: Director of Civil



Agenda - Utility-scale PV and BESS Design

- Example 18 MW 1-Axis Tracker
- Factors driving PV and BESS (continuous improvement / pricing)
- Module selection drivers
- Inverter selection
- What factors should you consider when selecting sites?
- Review of PV Geometry
- Bifacial modules impact on layout
- System Modeling
- Layout examples Fixed Tilt, Ballasted Landfills, 1-Axis tracking
- DC coupled Storage
- AC couple Storage

Ask Questions along the way.



EXAMPLE OF ENGINEERING PROJECTS IN THE UNITED STATES

Our Typical Focus is on Large Project Solar Design and Engineering Permit Drawings

Typical Scope:
- Interconnection Application Support
- Layout
- Electrical Permit PV system design,
- Civil Permit Drawings and
- MV Interconnections
- Plant Controls / Fiber / SCADA / PLC

Tropenas Team Value Engineering Approach:
- Meetings of 3: Engineering, Purchasing and Construction Operations
- Focus on Value and Robustness prior to drawing release
- Feedback loop from construction oversight and post project follow-up

Typical Project: 18 MW in MD

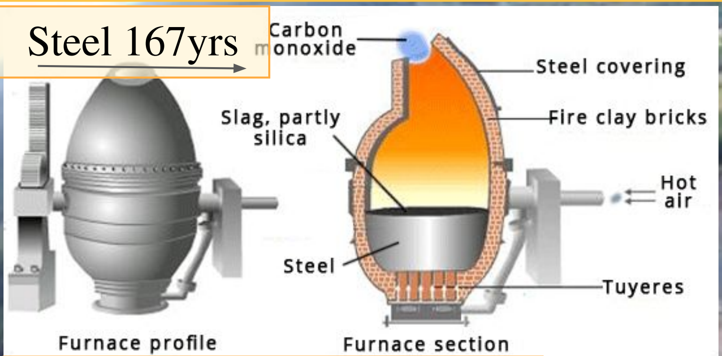
Background Photo: A Representative Engineering Project Profile

18 MW, Hebron, MD
- PV Engineering: Bill Novak, P.E.
- Interconnection: Charles Cunha, P.E.
- Contractor: Confidential
- ATI Racking
- (5) Inverter Skids
- 57,000 + Modules
- 25KV Interconnection

System design for utility-scale solar PV and Battery Energy Storage Systems

Continuous Improvement
Comparison of Steel and Solar

Steel 167yrs



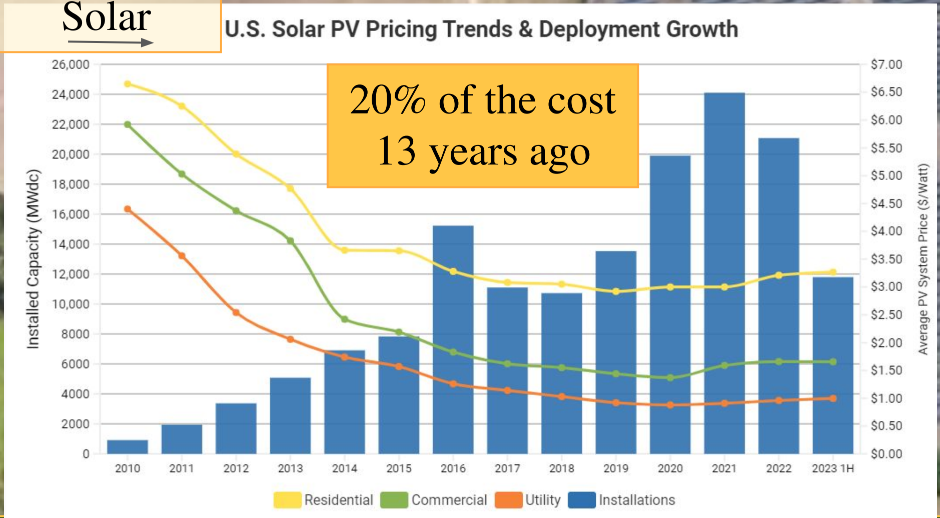
Bessemer Process 1856
$100/ton to $50/ton 1875
$ 18/ton 1890s

20% of the cost over ~15 years

Tropenas Process (1894): Air blown across the surface of the molten metal from tuyères on the side of the vessel rather than the bottom.

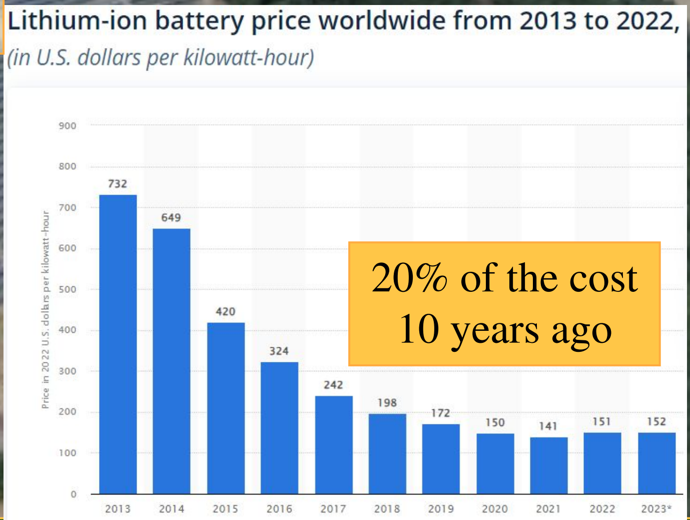
Oxygen converter process
2021 $1742/ton to
2023 $760/ton

Solar



20% of the cost 13 years ago

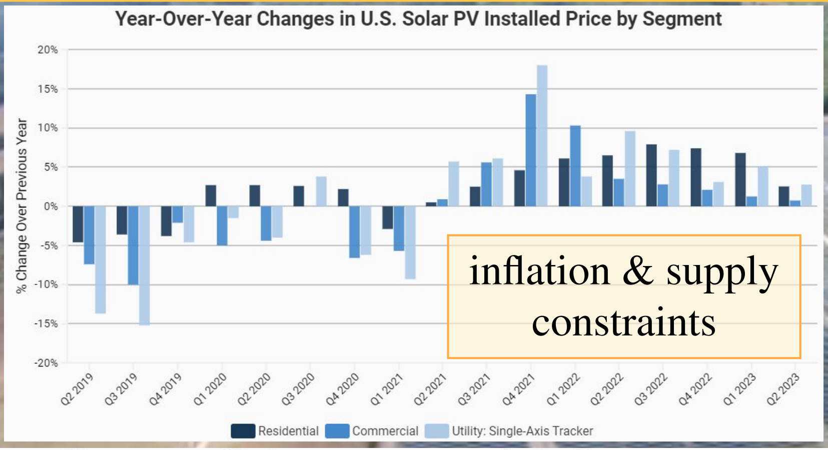
BESS



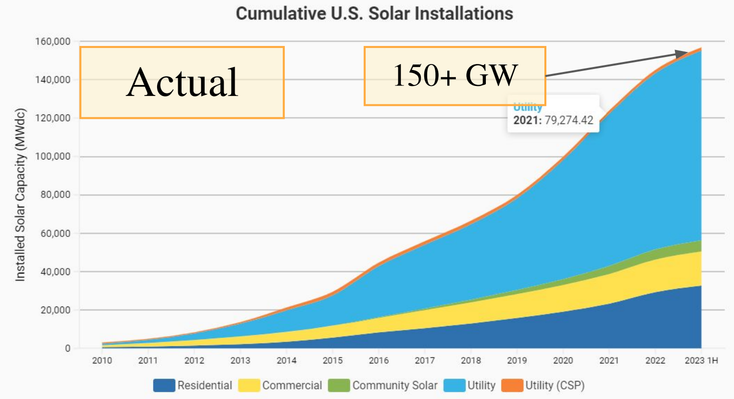
20% of the cost 10 years ago

Bill Novak, P.E., MSE, MBA
(615) 538-8519 bill.novak@tropenas.com
Licensed Professional Engineer, S.P.: AL, AR, FL, GA, KS, KY, LA, MA, MD, ME, MI, MN, MS, NM, NY, NC, OH, SC, TN, TX, UT, VA
Tropenas Company Licensed Engineering Firm: MA, TN, TX

Inflationary pressures on solar & Utility PV installations

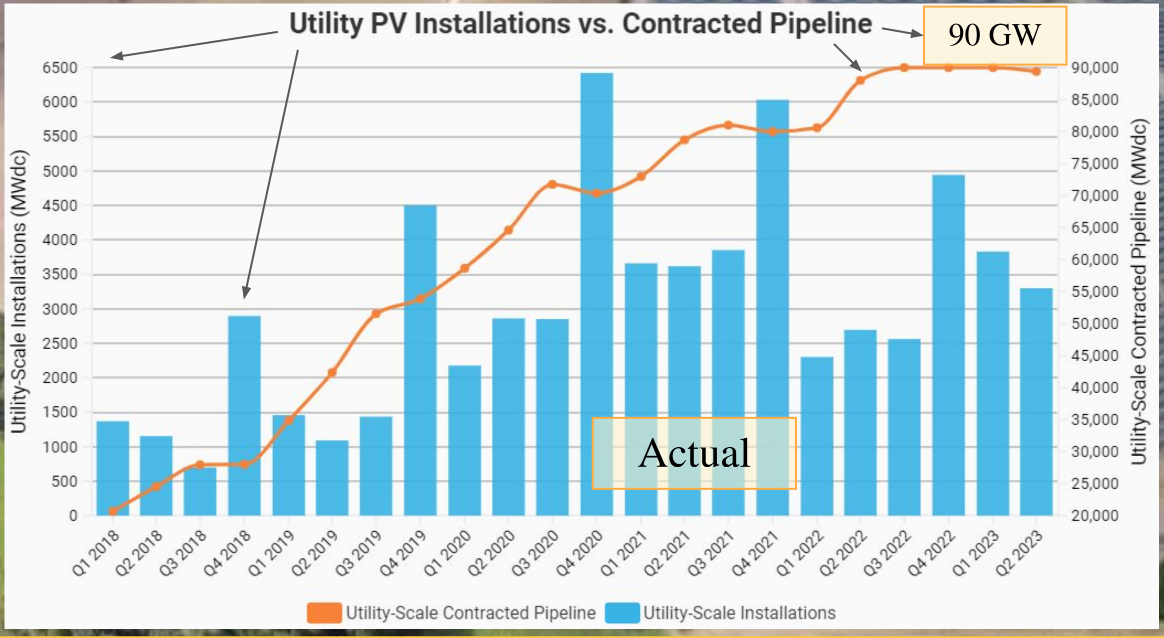


inflation & supply constraints



Actual

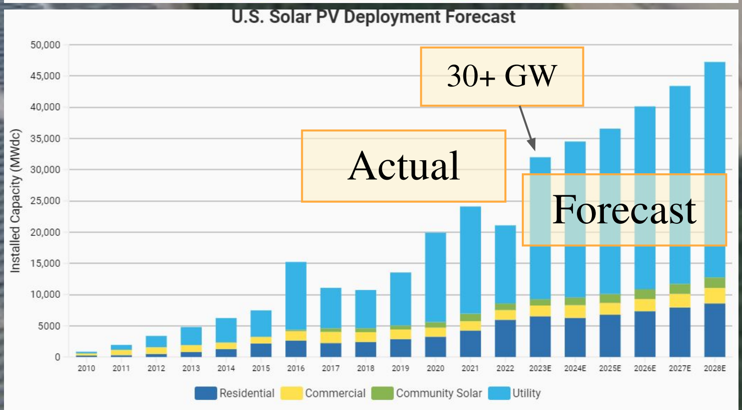
150+ GW



Utility PV Installations vs. Contracted Pipeline

90 GW

Actual



30+ GW

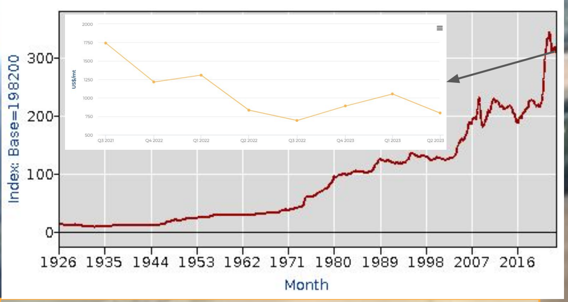
Actual

Forecast

System design for utility-scale solar PV and Battery Energy Storage Systems

RENEWABLE ENERGY
ENGINEERING

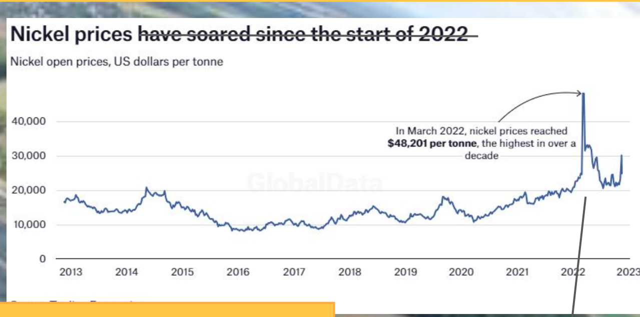
Value Engineering &
Price of related commodities



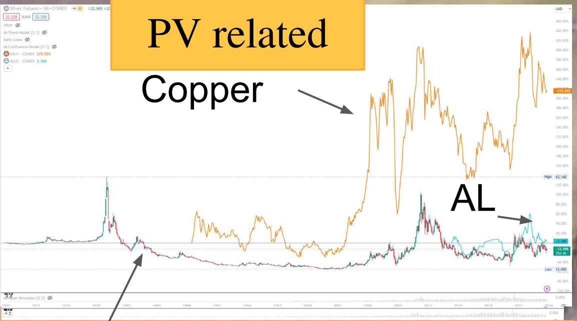
PPI of Steel 1926 to present

BESS related

Lithium 5/21 to present
$77 peak, $16 low, $22 current



PV related



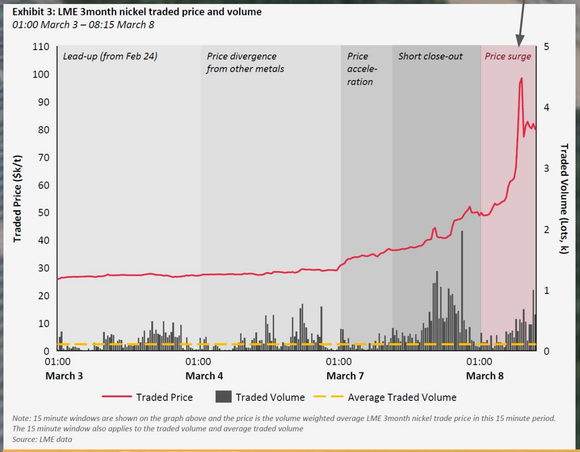
Silver 1970 to present
$63 peak, $12 low, $23 current

Copper 1988 to present
$5.3 peak, $1 low, $3.7 current

Aluminum 2014 to present
$3930 peak, $1706 low, $2246

Cobalt 12/20 to present
$32 peak, $12 low, $16 current

Exhibit 3: LME 3month nickel traded price and volume
01:00 March 3 – 08:15 March 8



Note: 15 minute windows are shown on the graph above and the price is the volume weighted average LME 3month nickel trade price in this 15 minute period. The 15 minute window also applies to the traded volume and average traded volume
Source: LME data

Nickel 3/4 -3/8/2022
$101 peak, $27 low, $18 current

Bill Novak, P.E., MSE, MBA (615) 538-8519 bill.novak@tropenas.com
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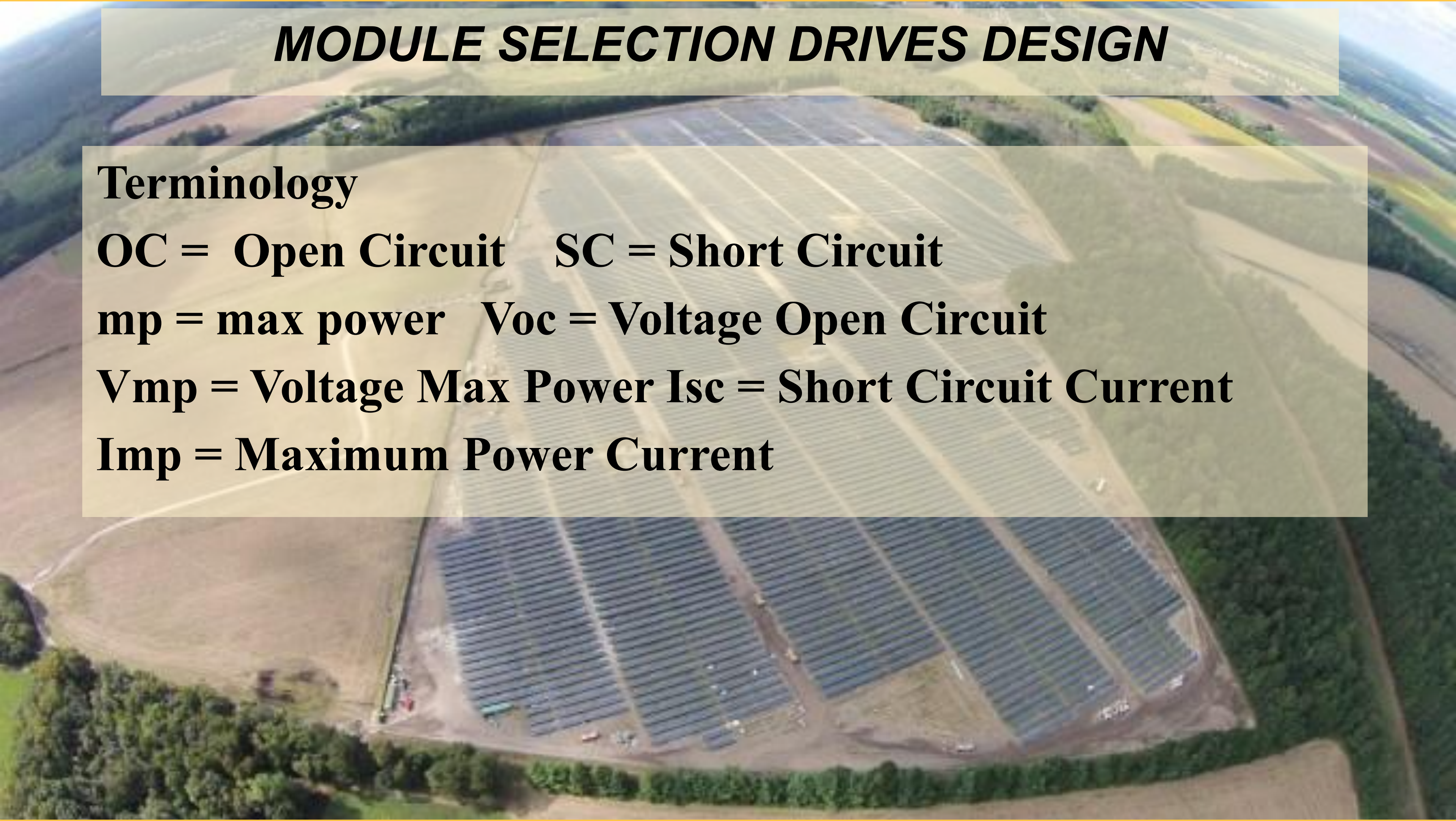
MODULE SELECTION DRIVES DESIGN



Terminology

OC = Open Circuit SC = Short Circuit

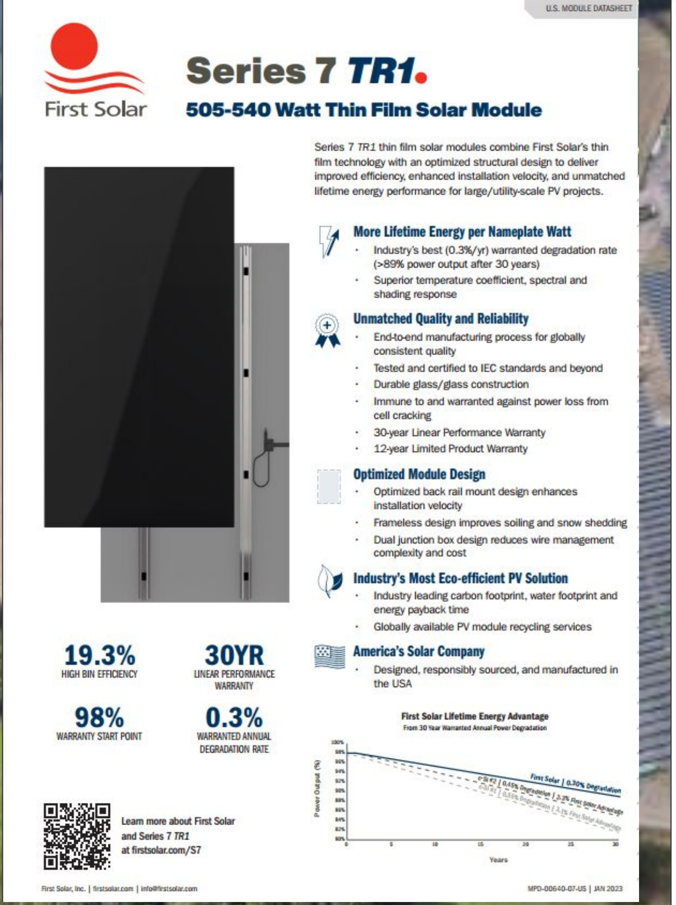
mp = max power Voc = Voltage Open Circuit

Vmp = Voltage Max Power Isc = Short Circuit Current

Imp = Maximum Power Current

PV Module - Thin Film Example

MODULE SELECTION DRIVES DESIGN



U.S. MODULE DATASHEET

First Solar

Series 7 *TR1*.

505-540 Watt Thin Film Solar Module

Series 7 *TR1* thin film solar modules combine First Solar's thin film technology with an optimized structural design to deliver improved efficiency, enhanced installation velocity, and unmatched lifetime energy performance for large/utility-scale PV projects.

More Lifetime Energy per Nameplate Watt

- Industry's best (0.3%/yr) warranted degradation rate (>89% power output after 30 years)
- Superior temperature coefficient, spectral and shading response

Unmatched Quality and Reliability

- End-to-end manufacturing process for globally consistent quality
- Tested and certified to IEC standards and beyond
- Durable glass/glass construction
- Immune to and warranted against power loss from cell cracking
- 30-year Linear Performance Warranty
- 12-year Limited Product Warranty

Optimized Module Design

- Optimized back rail mount design enhances installation velocity
- Frameless design improves soiling and snow shedding
- Dual junction box design reduces wire management complexity and cost

Industry's Most Eco-efficient PV Solution

- Industry leading carbon footprint, water footprint and energy payback time
- Globally available PV module recycling services

America's Solar Company

- Designed, responsibly sourced, and manufactured in the USA

19.3% HIGH BIN EFFICIENCY

30YR LINEAR PERFORMANCE WARRANTY

98% WARRANTY START POINT

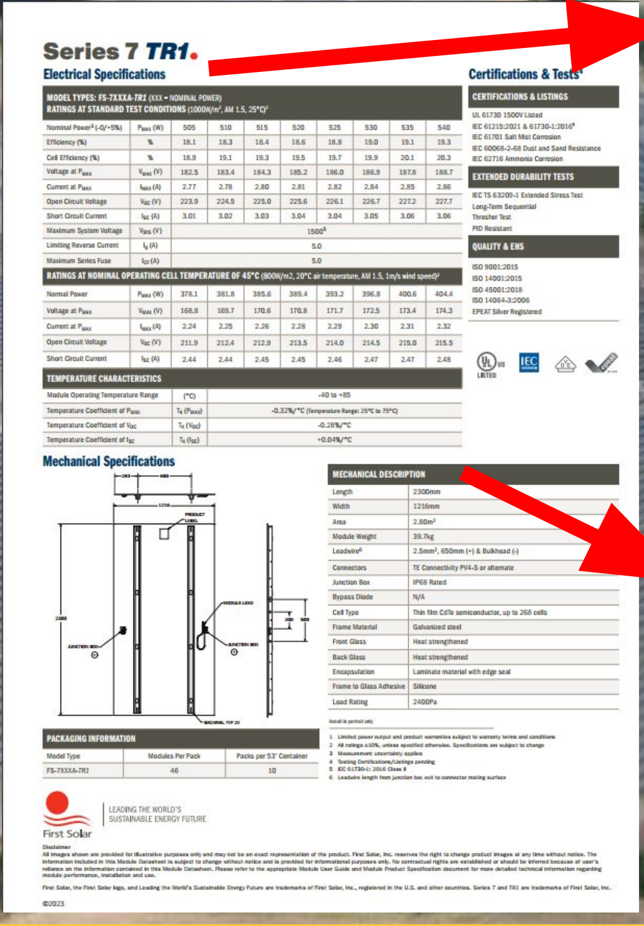
0.3% WARRANTED ANNUAL DEGRADATION RATE

First Solar Lifetime Energy Advantage
From 30 Year Warranted Annual Power Degradation

Learn more about First Solar and Series 7 *TR1* at firstsolar.com/S7

First Solar, Inc. | firstsolar.com | info@firstsolar.com

MPD-00640-07-US | JAN 2023



Series 7 *TR1*.

Electrical Specifications

MODEL TYPES: FS-7XXXA-*TR1* (XXX = NOMINAL POWER) RATINGS AT STANDARD TEST CONDITIONS (1000W/m², AM 1.5, 25°C)²									
Nominal Power³ (-0/+5%)	P_{MAX} (W)	505	510	515	520	525	530	535	540
Efficiency (%)	%	18.1	18.3	18.4	18.6	18.8	19.0	19.1	19.3
Cell Efficiency (%)	%	18.9	19.1	19.3	19.5	19.7	19.9	20.1	20.3
Voltage at P_{MAX}	V_{MAX} (V)	182.5	183.4	184.3	185.2	186.0	186.9	187.8	188.7
Current at P_{MAX}	I_{MAX} (A)	2.77	2.78	2.80	2.81	2.82	2.84	2.85	2.86
Open Circuit Voltage	V_{OC} (V)	223.9	224.5	225.0	225.6	226.1	226.7	227.2	227.7
Short Circuit Current	I_{SC} (A)	3.01	3.02	3.03	3.04	3.04	3.05	3.06	3.06
Maximum System Voltage	V_{SYS} (V)	1500⁵							
Limiting Reverse Current	I_R (A)	5.0							
Maximum Series Fuse	I_{CF} (A)	5.0							
RATINGS AT NOMINAL OPERATING CELL TEMPERATURE OF 45°C (800W/m2, 20°C air temperature, AM 1.5, 1m/s wind speed)²									
Normal Power	P_{MAX} (W)	378.1	381.8	385.6	389.4	393.2	396.8	400.6	404.4
Voltage at P_{MAX}	V_{MAX} (V)	168.8	169.7	170.6	170.8	171.7	172.5	173.4	174.3
Current at P_{MAX}	I_{MAX} (A)	2.24	2.25	2.26	2.28	2.29	2.30	2.31	2.32
Open Circuit Voltage	V_{OC} (V)	211.9	212.4	212.9	213.5	214.0	214.5	215.0	215.5
Short Circuit Current	I_{SC} (A)	2.44	2.44	2.45	2.45	2.46	2.47	2.47	2.48

TEMPERATURE CHARACTERISTICS		
Module Operating Temperature Range	(°C)	-40 to +85
Temperature Coefficient of P_{MAX}	T_K (P_{MAX})	-0.32%/°C (Temperature Range: 25°C to 75°C)
Temperature Coefficient of V_{OC}	T_K (V_{OC})	-0.28%/°C
Temperature Coefficient of I_{SC}	T_K (I_{SC})	+0.04%/°C

Certifications & Tests⁴

CERTIFICATIONS & LISTINGS

UL 61730 1500V Listed
IEC 61215:2021 & 61730-1:2016⁸
IEC 61701 Salt Mist Corrosion
IEC 60068-2-68 Dust and Sand Resistance
IEC 62716 Ammonia Corrosion

EXTENDED DURABILITY TESTS

IEC TS 63209-1 Extended Stress Test
Long-Term Sequential
Thresher Test
PID Resistant

QUALITY & EHS

ISO 9001:2015
ISO 14001:2015
ISO 45001:2018
ISO 14064-3:2006
EPEAT Silver Registered

Mechanical Specifications

MECHANICAL DESCRIPTION	
Length	2300mm
Width	1216mm
Area	2.80m²
Module Weight	39.7kg
Leadwire⁶	2.5mm², 650mm (+) & Bulkhead (-)
Connectors	TE Connectivity PV4-S or alternate
Junction Box	IP68 Rated
Bypass Diode	N/A
Cell Type	Thin film CdTe semiconductor, up to 268 cells
Frame Material	Galvanized steel
Front Glass	Heat strengthened
Back Glass	Heat strengthened
Encapsulation	Laminate material with edge seal
Frame to Glass Adhesive	Silicone
Load Rating	2400Pa

Install in portrait only

PACKAGING INFORMATION		
Model Type	Modules Per Pack	Packs per 53' Container
FS-7XXXA-*TR1*	46	10

1 Limited power output and product warranties subject to warranty terms and conditions
2 All ratings ±10%, unless specified otherwise. Specifications are subject to change
3 Measurement uncertainty applies
4 Testing Certifications/Listings pending
5 IEC 61730-1: 2016 Class II
6 Leadwire length from junction box exit to connector mating surface

First Solar | LEADING THE WORLD'S SUSTAINABLE ENERGY FUTURE

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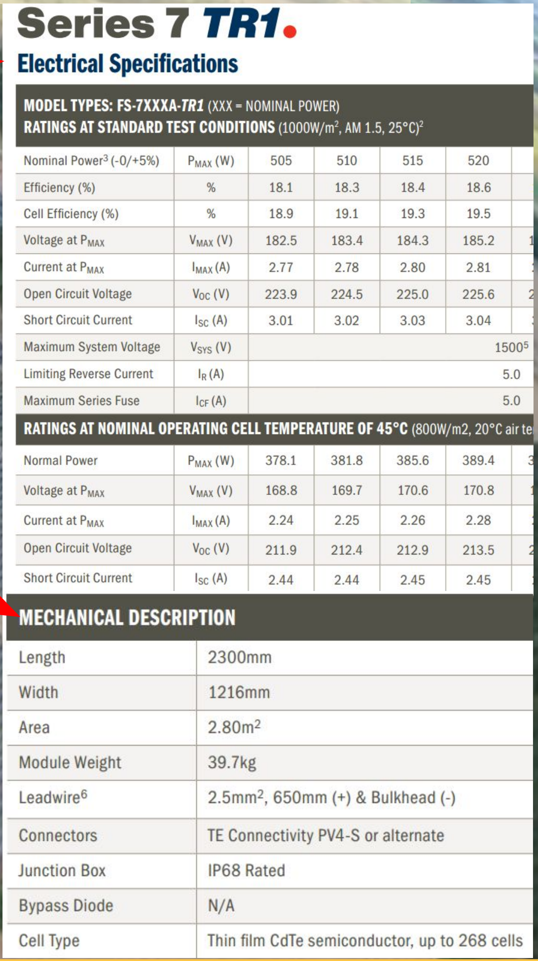

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Cell Efficiency (%)	%	18.9	19.1	19.3	19.5
Voltage at P_{MAX}	V_{MAX} (V)	182.5	183.4	184.3	185.2
Current at P_{MAX}	I_{MAX} (A)	2.77	2.78	2.80	2.81
Open Circuit Voltage	V_{OC} (V)	223.9	224.5	225.0	225.6
Short Circuit Current	I_{SC} (A)	3.01	3.02	3.03	3.04
Maximum System Voltage	V_{SYS} (V)				1500⁵
Limiting Reverse Current	I_R (A)				5.0
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RATINGS AT NOMINAL OPERATING CELL TEMPERATURE OF 45°C (800W/m2, 20°C air te					
Normal Power	P_{MAX} (W)	378.1	381.8	385.6	389.4
Voltage at P_{MAX}	V_{MAX} (V)	168.8	169.7	170.6	170.8
Current at P_{MAX}	I_{MAX} (A)	2.24	2.25	2.26	2.28
Open Circuit Voltage	V_{OC} (V)	211.9	212.4	212.9	213.5
Short Circuit Current	I_{SC} (A)	2.44	2.44	2.45	2.45

MECHANICAL DESCRIPTION	
Length	2300mm
Width	1216mm
Area	2.80m²
Module Weight	39.7kg
Leadwire⁶	2.5mm², 650mm (+) & Bulkhead (-)
Connectors	TE Connectivity PV4-S or alternate
Junction Box	IP68 Rated
Bypass Diode	N/A
Cell Type	Thin film CdTe semiconductor, up to 268 cells

PV Module - Mono / Poly Example

MODULE SELECTION DRIVES DESIGN

NEW

CanadianSolar

TOPBiHiKu7

N-type Bifacial TOPCon Technology

675 W ~ 705 W

CS7N-675|680|685|690|695|705TB-AG

MORE POWER

- Module power up to 705 W
Module efficiency up to 22.7 %
- Up to 85% Power Bifaciality, more power from the back side
- Excellent anti-LeTID & anti-PID performance. Low power degradation, high energy yield
- Lower temperature coefficient (Pmax): -0.29%/°C, increases energy yield in hot climate
- Lower LCOE & system cost

MORE RELIABLE

- Minimizes micro-crack impacts
- Heavy snow load up to 5400 Pa, wind load up to 2400 Pa*

12 Years Enhanced Product Warranty on Materials and Workmanship*

30 Years Linear Power Performance Warranty*

1st year power degradation no more than 1%
Subsequent annual power degradation no more than 0.4%

*According to the applicable Canadian Solar Limited Warranty Statement.

MANAGEMENT SYSTEM CERTIFICATES*

ISO 9001: 2015 / Quality management system
ISO 14001: 2015 / Standards for environmental management system
ISO 45001: 2018 / International standards for occupational health & safety
IEC 62941: 2019 / Photovoltaic module manufacturing quality system

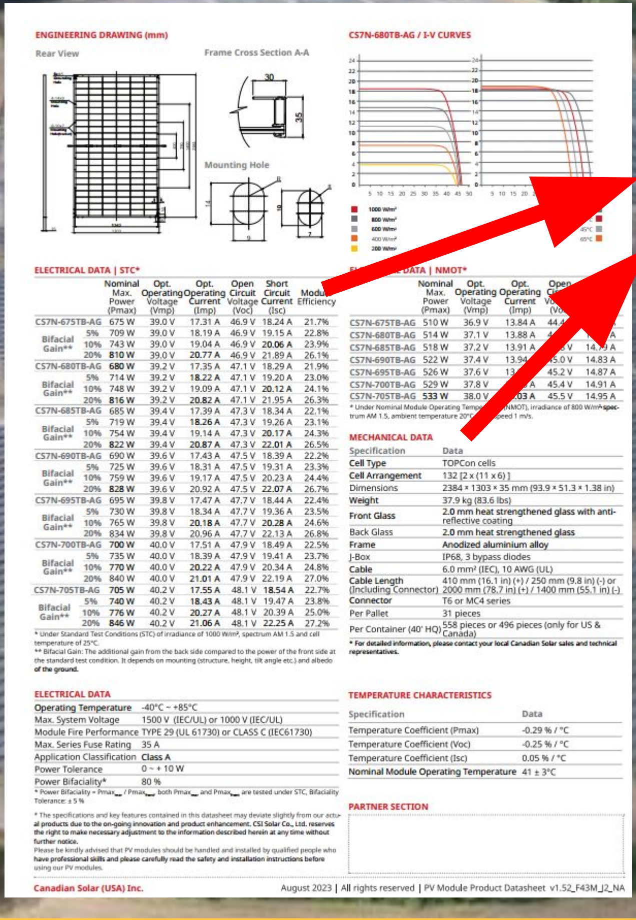
PRODUCT CERTIFICATES*

IEC 61215 / IEC 61730 / CE / INMETRO / MCS / UKCA / CGC
CEC listed (US California) / FSEC (US Florida)
UL 61730 / IEC 61701 / IEC 62716 / IEC 60068-2-68
Take-e-way

* The specific certificates applicable to different module types and markets will vary, and therefore not all of the certifications listed herein will simultaneously apply to the products you order or use. Please contact your local Canadian Solar sales representative to confirm the specific certificates available for your Product and applicable in the regions in which the products will be used.

CSI Solar Co., Ltd. is committed to providing high quality solar photovoltaic modules, solar energy and battery storage solutions to customers. The company was recognized as the No. 1 module supplier for quality and performance/price ratio in the IHS Module Customer Insight Survey. Over the past 22 years, it has successfully delivered around 100 GW of premium-quality solar modules across the world.

* For detailed information, please refer to the Installation Manual.



ENGINEERING DRAWING (mm)

CS7N-680TB-AG / I-V CURVES

ELECTRICAL DATA | STC*

		Nominal Max. Power (Pmax)	Opt. Operating Voltage (Vmp)	Opt. Operating Current (Imp)	Open Circuit Voltage (Voc)	Short Circuit Current (Isc)	Module Efficiency
CS7N-675TB-AG		675 W	39.0 V	17.31 A	46.9 V	18.24 A	21.7%
Bifacial Gain**	5%	709 W	39.0 V	18.19 A	46.9 V	19.15 A	22.8%
	10%	743 W	39.0 V	19.04 A	46.9 V	20.06 A	23.9%
	20%	810 W	39.0 V	20.77 A	46.9 V	21.89 A	26.1%
CS7N-680TB-AG		680 W	39.2 V	17.35 A	47.1 V	18.29 A	21.9%
Bifacial Gain**	5%	714 W	39.2 V	18.22 A	47.1 V	19.20 A	23.0%
	10%	748 W	39.2 V	19.09 A	47.1 V	20.12 A	24.1%
	20%	816 W	39.2 V	20.82 A	47.1 V	21.95 A	26.3%
CS7N-685TB-AG		685 W	39.4 V	17.39 A	47.3 V	18.34 A	22.1%
Bifacial Gain**	5%	719 W	39.4 V	18.26 A	47.3 V	19.26 A	23.1%
	10%	754 W	39.4 V	19.14 A	47.3 V	20.17 A	24.3%
	20%	822 W	39.4 V	20.87 A	47.3 V	22.01 A	26.5%
CS7N-690TB-AG		690 W	39.6 V	17.43 A	47.5 V	18.39 A	22.2%
Bifacial Gain**	5%	725 W	39.6 V	18.31 A	47.5 V	19.31 A	23.3%
	10%	759 W	39.6 V	19.17 A	47.5 V	20.23 A	24.4%
	20%	828 W	39.6 V	20.92 A	47.5 V	22.07 A	26.7%
CS7N-695TB-AG		695 W	39.8 V	17.47 A	47.7 V	18.44 A	22.4%
Bifacial Gain**	5%	730 W	39.8 V	18.34 A	47.7 V	19.36 A	23.5%
	10%	765 W	39.8 V	20.18 A	47.7 V	20.28 A	24.6%
	20%	834 W	39.8 V	20.96 A	47.7 V	22.13 A	26.8%
CS7N-700TB-AG		700 W	40.0 V	17.51 A	47.9 V	18.49 A	22.5%
Bifacial Gain**	5%	735 W	40.0 V	18.39 A	47.9 V	19.41 A	23.7%
	10%	770 W	40.0 V	20.22 A	47.9 V	20.34 A	24.8%
	20%	840 W	40.0 V	21.01 A	47.9 V	22.19 A	27.0%
CS7N-705TB-AG		705 W	40.2 V	17.55 A	48.1 V	18.54 A	22.7%
Bifacial Gain**	5%	740 W	40.2 V	18.43 A	48.1 V	19.47 A	23.8%
	10%	776 W	40.2 V	20.27 A	48.1 V	20.39 A	25.0%
	20%	846 W	40.2 V	21.06 A	48.1 V	22.25 A	27.2%

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m², spectrum AM 1.5 and cell temperature of 25°C.
** Bifacial Gain: The additional gain from the back side compared to the power of the front side at the standard test condition. It depends on mounting (structure, height, tilt angle etc.) and albedo of the ground.

[illegible] DATA | NMOT*

	Nominal Max. Power (Pmax)	Opt. Operating Voltage (Vmp)	Opt. Operating Current (Imp)	Open Circuit Voltage (Voc)	[illegible]
CS7N-675TB-AG	510 W	36.9 V	13.84 A	[illegible]	[illegible]
CS7N-680TB-AG	514 W	37.1 V	13.88 A	[illegible]	[illegible]
CS7N-685TB-AG	518 W	37.2 V	13.91 A	[illegible]	[illegible]
CS7N-690TB-AG	522 W	37.4 V	13.94 [illegible]	45.0 V	14.83 A
CS7N-695TB-AG	526 W	37.6 V	[illegible]	45.2 V	14.87 A
CS7N-700TB-AG	529 W	37.8 V	[illegible]	45.4 V	14.91 A
CS7N-705TB-AG	533 W	38.0 V	[illegible]	45.5 V	14.95 A

* Under Nominal Module Operating Tempe[illegible] (NMOT), irradiance of 800 W/m², spectrum AM 1.5, ambient temperature 20°C, [illegible] speed 1 m/s.

MECHANICAL DATA

Specification	Data
Cell Type	TOPCon cells
Cell Arrangement	132 [2 x (11 x 6)]
Dimensions	2384 × 1303 × 35 mm (93.9 × 51.3 × 1.38 in)
Weight	37.9 kg (83.6 lbs)
Front Glass	2.0 mm heat strengthened glass with anti-reflective coating
Back Glass	2.0 mm heat strengthened glass
Frame	Anodized aluminium alloy
J-Box	IP68, 3 bypass diodes
Cable	6.0 mm² (IEC), 10 AWG (UL)
Cable Length (Including Connector)	410 mm (16.1 in) (+) / 250 mm (9.8 in) (-) or 2000 mm (78.7 in) (+) / 1400 mm (55.1 in) (-)
Connector	T6 or MC4 series
Per Pallet	31 pieces
Per Container (40' HQ)	558 pieces or 496 pieces (only for US & Canada)

* For detailed information, please contact your local Canadian Solar sales and technical representatives.

ELECTRICAL DATA

Operating Temperature	-40°C ~ +85°C
Max. System Voltage	1500 V (IEC/UL) or 1000 V (IEC/UL)
Module Fire Performance	TYPE 29 (UL 61730) or CLASS C (IEC61730)
Max. Series Fuse Rating	35 A
Application Classification	Class A
Power Tolerance	0 ~ + 10 W
Power Bifaciality*	80 %

* Power Bifaciality = $Pmax_{rear}$ / $Pmax_{front}$, both $Pmax_{rear}$ and $Pmax_{front}$ are tested under STC, Bifaciality Tolerance: ± 5 %

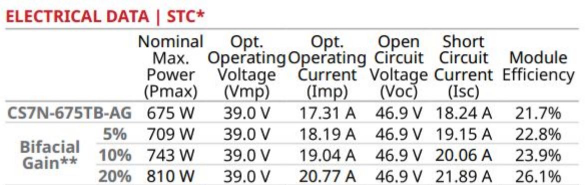
TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.29 % / °C
Temperature Coefficient (Voc)	-0.25 % / °C
Temperature Coefficient (Isc)	0.05 % / °C
Nominal Module Operating Temperature	41 ± 3°C

* The specifications and key features contained in this datasheet may deviate slightly from our actual products due to the on-going innovation and product enhancement. CSI Solar Co., Ltd. reserves the right to make necessary adjustment to the information described herein at any time without further notice.
Please be kindly advised that PV modules should be handled and installed by qualified people who have professional skills and please carefully read the safety and installation instructions before using our PV modules.

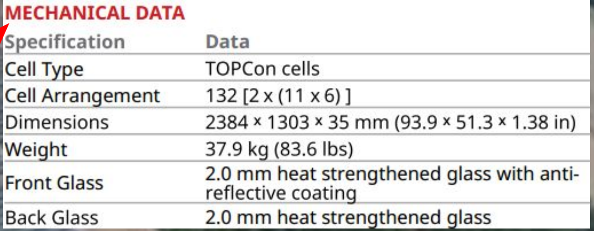
PARTNER SECTION

Canadian Solar (USA) Inc. August 2023 | All rights reserved | PV Module Product Datasheet v1.52_F43M_J2_NA



ELECTRICAL DATA | STC*

		Nominal Max. Power (Pmax)	Opt. Operating Voltage (Vmp)	Opt. Operating Current (Imp)	Open Circuit Voltage (Voc)	Short Circuit Current (Isc)	Module Efficiency
CS7N-675TB-AG		675 W	39.0 V	17.31 A	46.9 V	18.24 A	21.7%
Bifacial Gain**	5%	709 W	39.0 V	18.19 A	46.9 V	19.15 A	22.8%
	10%	743 W	39.0 V	19.04 A	46.9 V	20.06 A	23.9%
	20%	810 W	39.0 V	20.77 A	46.9 V	21.89 A	26.1%



MECHANICAL DATA

Specification	Data
Cell Type	TOPCon cells
Cell Arrangement	132 [2 x (11 x 6)]
Dimensions	2384 × 1303 × 35 mm (93.9 × 51.3 × 1.38 in)
Weight	37.9 kg (83.6 lbs)
Front Glass	2.0 mm heat strengthened glass with anti-reflective coating
Back Glass	2.0 mm heat strengthened glass

Comparison: Thin Film / Poly

Area: 2.8 / 3.1 = 90%
Power: 510 / 675 = 76%
Net Power / Area: 84%
Weight: 105%
Other: Shading & Temperature, Bifacial boost, degradation, etc.

MODULE SELECTION DRIVES DESIGN

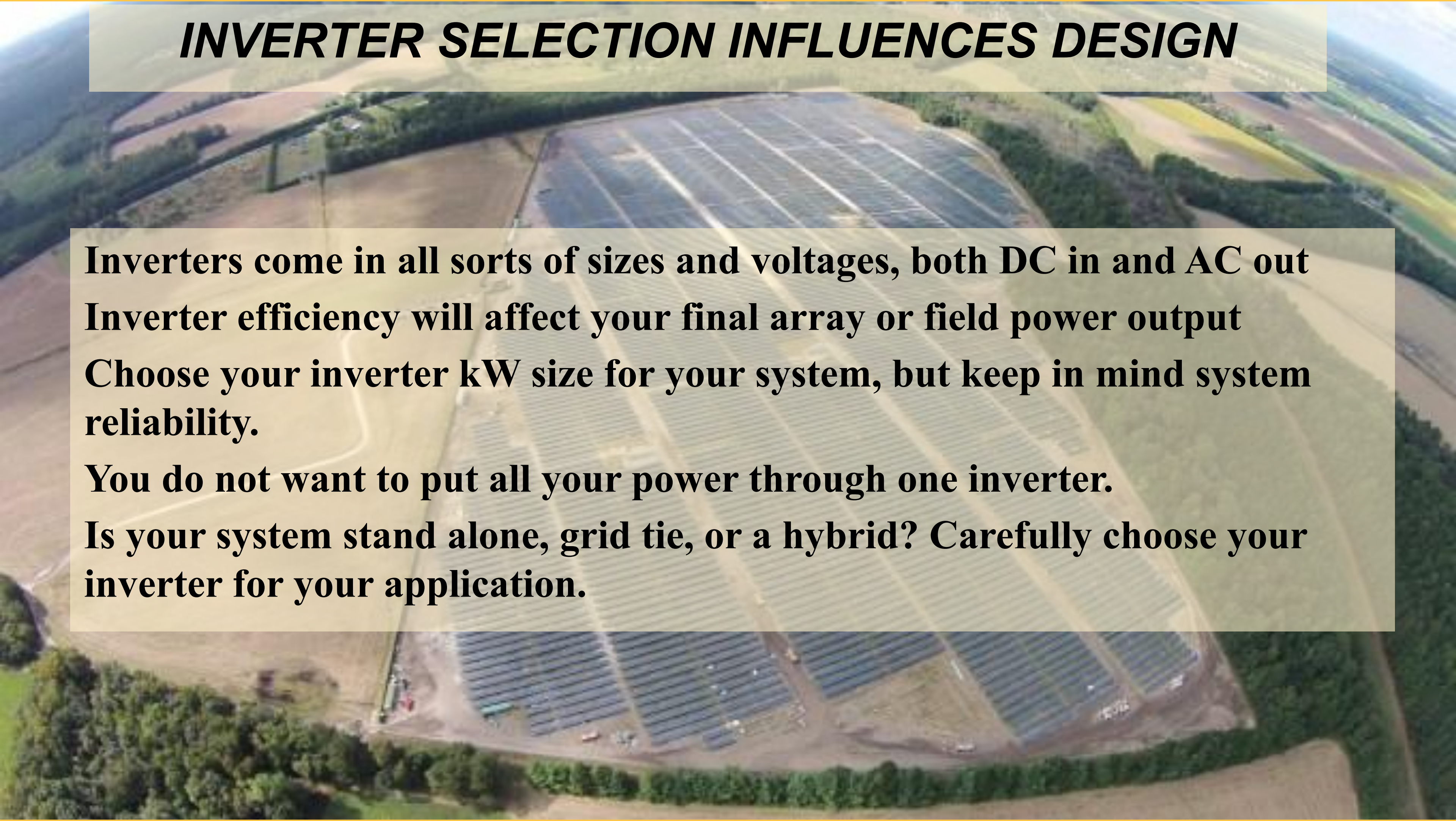
Orientation of the PV modules

For a fixed tilt system, face it towards true south and at the same angle of your latitude. This gives maximum year long power output.

For those smaller sites, you can increase the angle by another 15 degrees for winter and decrease by 15 degrees for summer.

Or, use trackers. Most utility-scale projects use single axis trackers.

INVERTER SELECTION INFLUENCES DESIGN



Inverters come in all sorts of sizes and voltages, both DC in and AC out

Inverter efficiency will affect your final array or field power output

Choose your inverter kW size for your system, but keep in mind system reliability.

You do not want to put all your power through one inverter.

Is your system stand alone, grid tie, or a hybrid? Carefully choose your inverter for your application.

INVERTER SELECTION INFLUENCES DESIGN

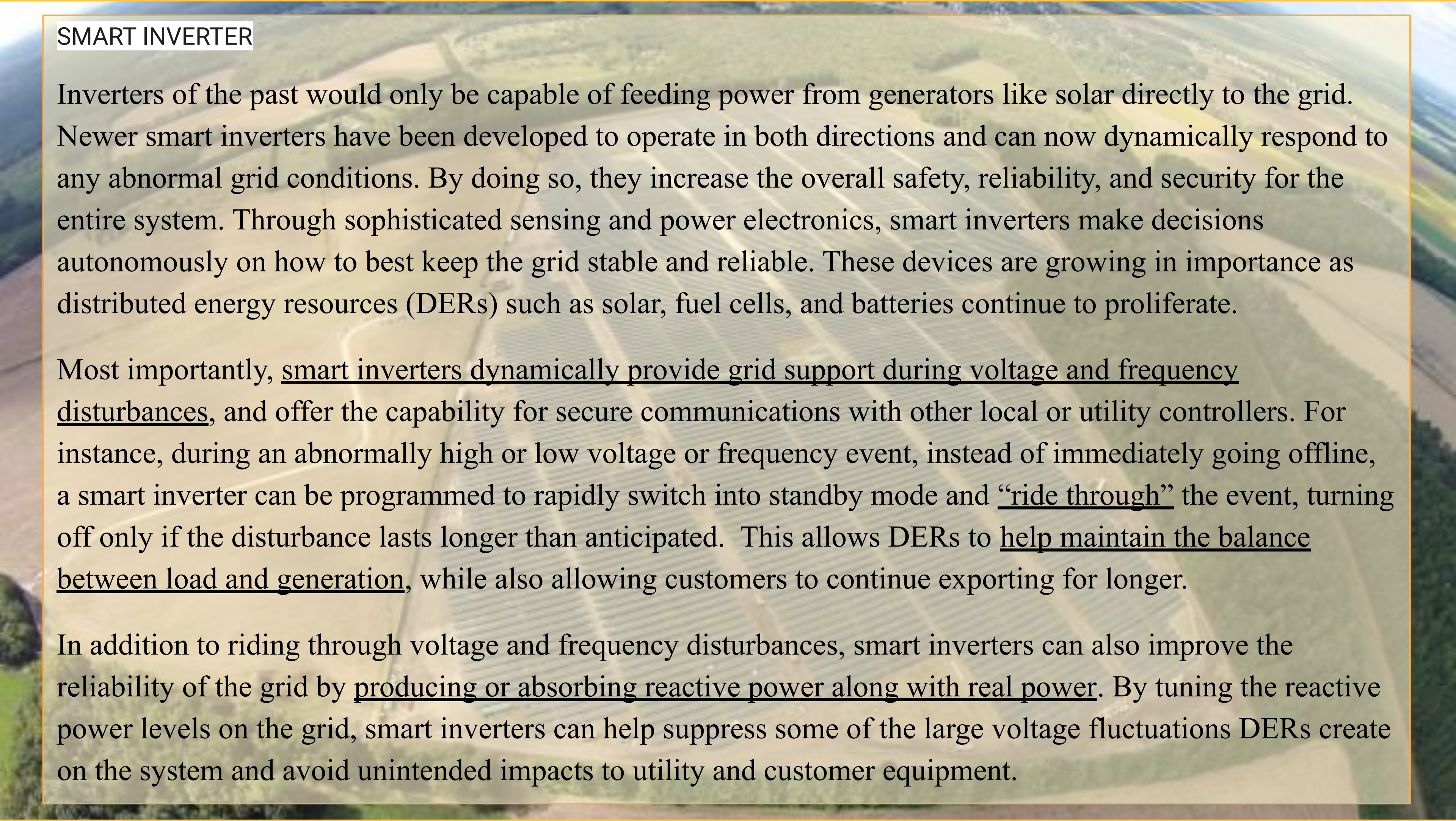
When there is enough voltage produced by the array, the inverter turns itself on and the voltage output will synchronize with the utility voltage, within the inverter limits, and as the input DC voltage increases, the output voltage stays the same, but the power output increases. The turn-on voltage is user programmable within a predetermined amount. UL 1741 type inverters have all the utility interface protection built in.

INVERTER SELECTION INFLUENCES DESIGN

The inverters have a min and max voltage input, a max current input, a peak efficiency, and an ambient temperature range.

Don’t forget to shade these if you want to put them in the desert. Also, don’t run them hard in the high-heat areas. Inverters have an altitude rating, mount these in the mountains and then you derate them like HV breakers.

Evolution of Smart Inverters



SMART INVERTER

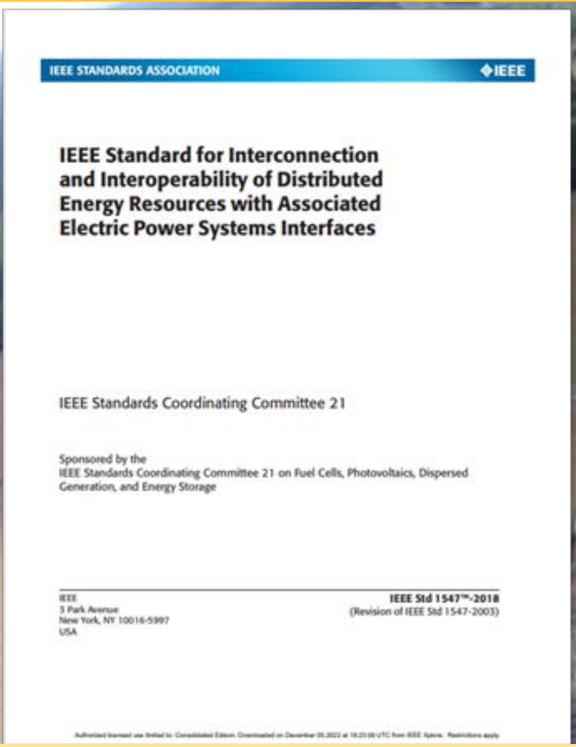
Inverters of the past would only be capable of feeding power from generators like solar directly to the grid. Newer smart inverters have been developed to operate in both directions and can now dynamically respond to any abnormal grid conditions. By doing so, they increase the overall safety, reliability, and security for the entire system. Through sophisticated sensing and power electronics, smart inverters make decisions autonomously on how to best keep the grid stable and reliable. These devices are growing in importance as distributed energy resources (DERs) such as solar, fuel cells, and batteries continue to proliferate.

Most importantly, smart inverters dynamically provide grid support during voltage and frequency disturbances, and offer the capability for secure communications with other local or utility controllers. For instance, during an abnormally high or low voltage or frequency event, instead of immediately going offline, a smart inverter can be programmed to rapidly switch into standby mode and "ride through" the event, turning off only if the disturbance lasts longer than anticipated. This allows DERs to help maintain the balance between load and generation, while also allowing customers to continue exporting for longer.

In addition to riding through voltage and frequency disturbances, smart inverters can also improve the reliability of the grid by producing or absorbing reactive power along with real power. By tuning the reactive power levels on the grid, smart inverters can help suppress some of the large voltage fluctuations DERs create on the system and avoid unintended impacts to utility and customer equipment.

System design for utility-scale solar PV and Battery Energy Storage Systems

Standards



IEEE STANDARDS ASSOCIATION ◆IEEE

IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

IEEE Standards Coordinating Committee 21

Sponsored by the
IEEE Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

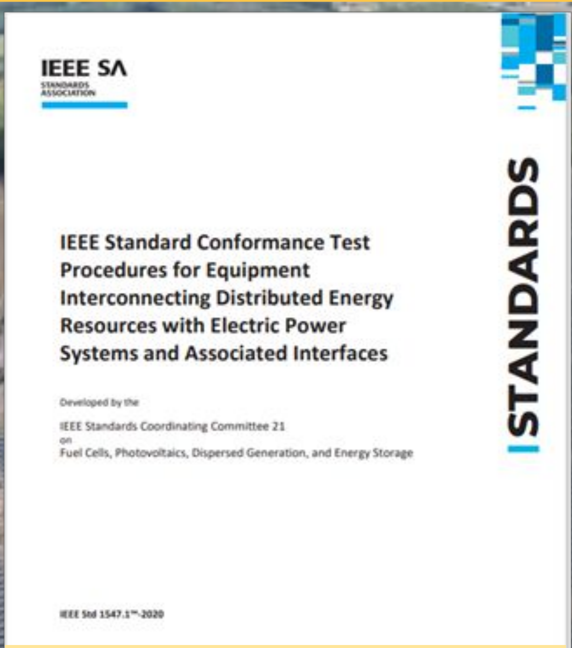
IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 1547™-2018
(Revision of IEEE Std 1547-2003)

IEEE 1547-2018

Interconnection Requirements

- System requirements for voltage and frequency
- System protection & grounding
- Operation of DERs as an island



IEEE SA
STANDARDS ASSOCIATION

IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces

Developed by the

IEEE Standards Coordinating Committee 21
on
Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

IEEE Std 1547.1™-2020

STANDARDS

IEEE 1547.1-2020

System Testing Requirements

- System testing for voltage and frequency responses
- Device surge current testing
- Harmonics testing
- Islanding testing

UL

UL 1741

STANDARD FOR SAFETY

Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources

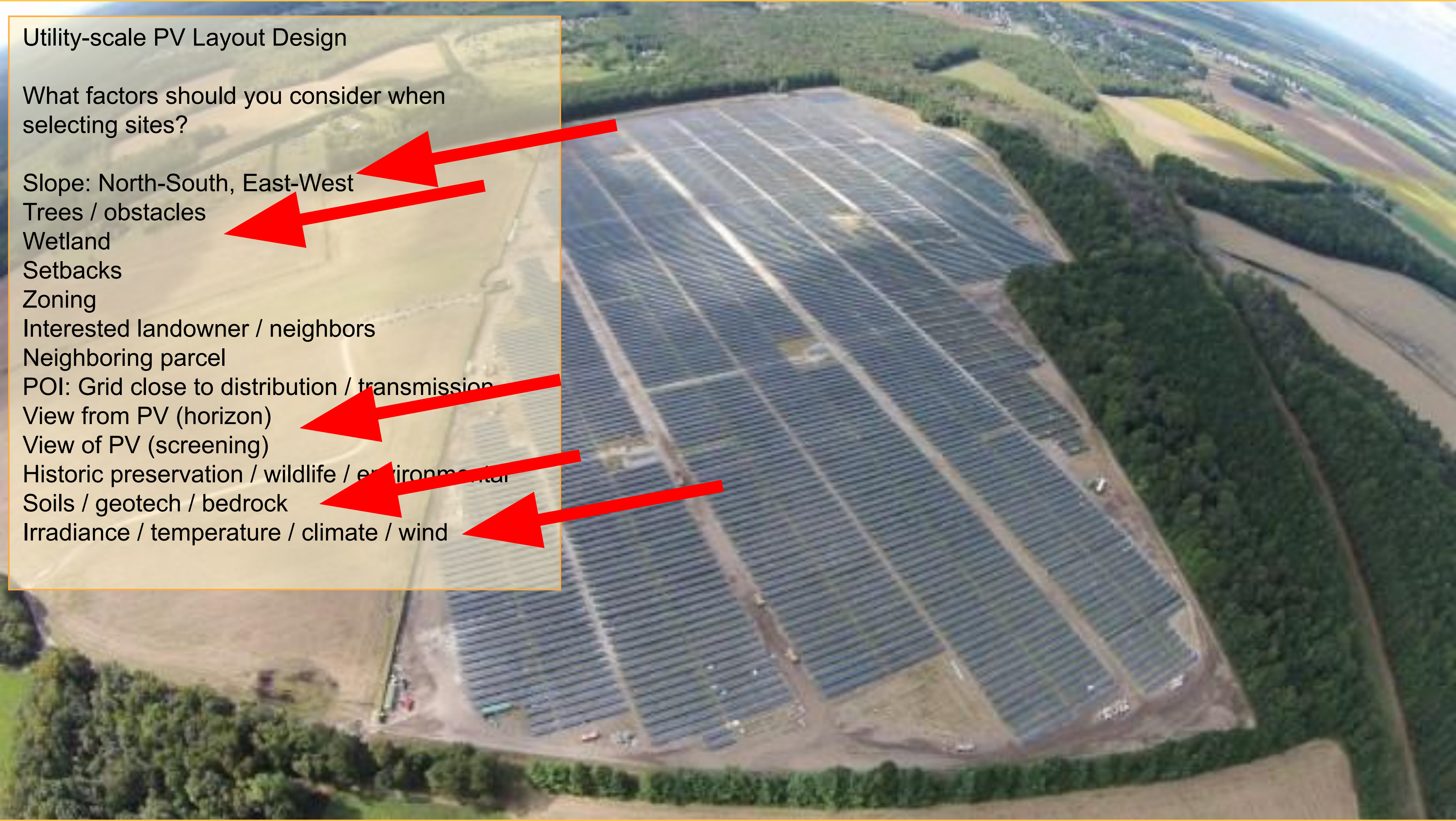
UL1741 and A, B Supplements

Equipment Standard

- Provides the basis for UL listing of an inverter
- UL 1741SB inverters uses 1547.1 testing
- Covers inverter construction, ratings, markings, and protection

The latest UL 1741 Supplement B (SB), added in 2021, conforms to the testing requirements set forth in the 2020 revision to 1547.1. With the release of UL 1741 SB, manufacturers can now produce UL1741 SB listed inverters. By doing so, this ensures devices have been tested according to the latest IEEE standards, and can safely provide the required grid-support functionality.

Site factors



Utility-scale PV Layout Design

What factors should you consider when selecting sites?

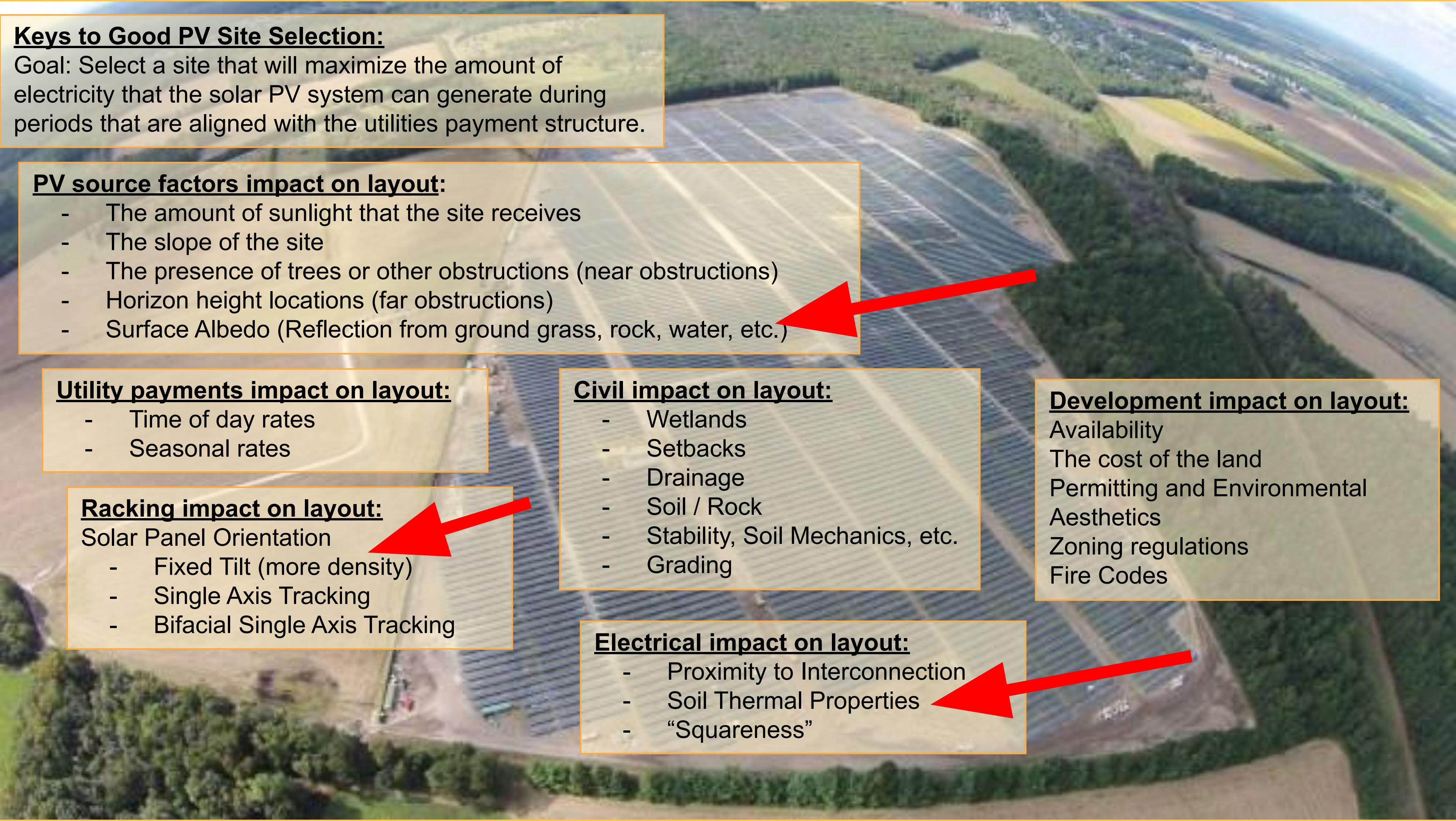
Slope: North-South, East-West
Trees / obstacles
Wetland
Setbacks
Zoning
Interested landowner / neighbors
Neighboring parcel
POI: Grid close to distribution / transmission
View from PV (horizon)
View of PV (screening)
Historic preservation / wildlife / environmental
Soils / geotech / bedrock
Irradiance / temperature / climate / wind

TROPENAS COMPANY ESTABLISHED 1920

System design for utility-scale solar PV and Battery Energy Storage Systems

RENEWABLE ENERGY ENGINEERING

Site factors



Keys to Good PV Site Selection:
Goal: Select a site that will maximize the amount of electricity that the solar PV system can generate during periods that are aligned with the utilities payment structure.

PV source factors impact on layout:
- The amount of sunlight that the site receives
- The slope of the site
- The presence of trees or other obstructions (near obstructions)
- Horizon height locations (far obstructions)
- Surface Albedo (Reflection from ground grass, rock, water, etc.)

Utility payments impact on layout:
- Time of day rates
- Seasonal rates

Racking impact on layout:
Solar Panel Orientation
- Fixed Tilt (more density)
- Single Axis Tracking
- Bifacial Single Axis Tracking

Civil impact on layout:
- Wetlands
- Setbacks
- Drainage
- Soil / Rock
- Stability, Soil Mechanics, etc.
- Grading

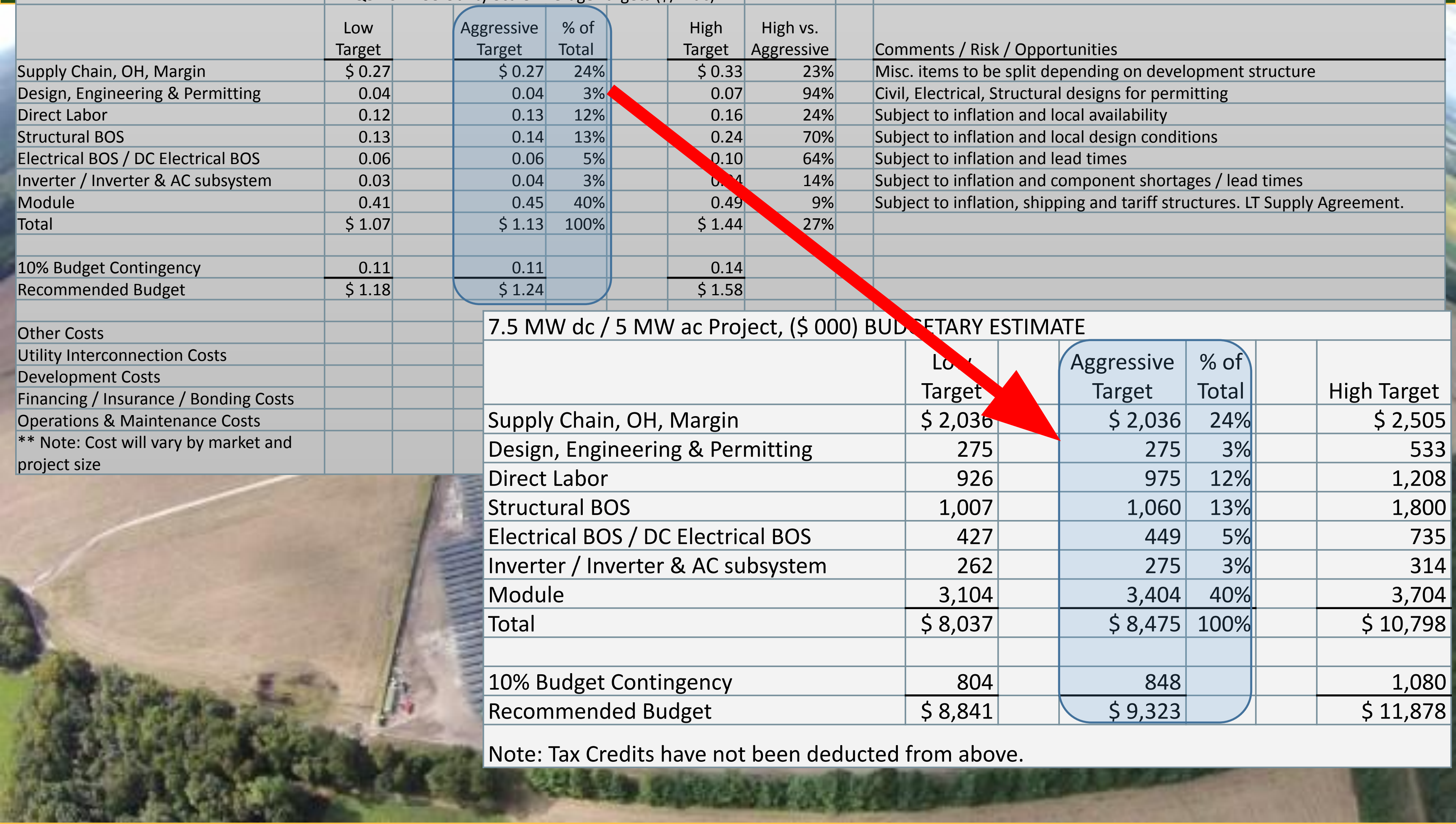
Development impact on layout:
Availability
The cost of the land
Permitting and Environmental
Aesthetics
Zoning regulations
Fire Codes

Electrical impact on layout:
- Proximity to Interconnection
- Soil Thermal Properties
- “Squareness”

Bill Novak, P.E., MSE, MBA
(615) 538-8519 bill.novak@tropenas.com
Licensed Professional Engineer, S.P.: AL, AR, FL, GA, KS, KY, LA, MA, MD, ME, MI, MN, MS, NM, NY, NC, OH, SC, TN, TX, UT, VA
Tropenas Company Licensed Engineering Firm: MA, TN, TX

System design for utility-scale solar PV and Battery Energy Storage Systems

Site Selection and Layouts can have significant impact on overall cost:



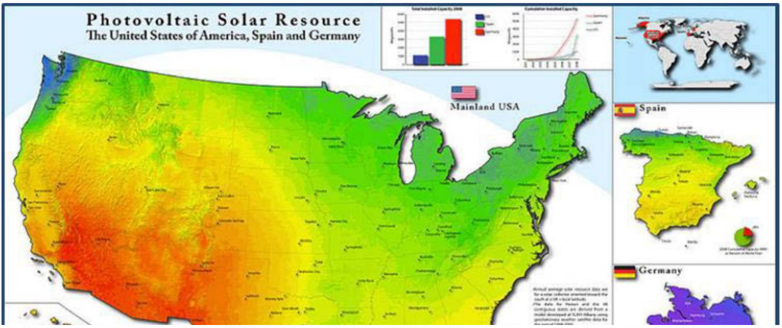
	Q3 2021 US Utility Scale Average Targets ($/Wdc)								
	Low Target		Aggressive Target	% of Total		High Target	High vs. Aggressive		Comments / Risk / Opportunities
Supply Chain, OH, Margin	$ 0.27		$ 0.27	24%		$ 0.33	23%		Misc. items to be split depending on development structure
Design, Engineering & Permitting	0.04		0.04	3%		0.07	94%		Civil, Electrical, Structural designs for permitting
Direct Labor	0.12		0.13	12%		0.16	24%		Subject to inflation and local availability
Structural BOS	0.13		0.14	13%		0.24	70%		Subject to inflation and local design conditions
Electrical BOS / DC Electrical BOS	0.06		0.06	5%		0.10	64%		Subject to inflation and lead times
Inverter / Inverter & AC subsystem	0.03		0.04	3%		0.04	14%		Subject to inflation and component shortages / lead times
Module	0.41		0.45	40%		0.49	9%		Subject to inflation, shipping and tariff structures. LT Supply Agreement.
Total	$ 1.07		$ 1.13	100%		$ 1.44	27%		
10% Budget Contingency	0.11		0.11			0.14			
Recommended Budget	$ 1.18		$ 1.24			$ 1.58			
Other Costs									
Utility Interconnection Costs									
Development Costs									
Financing / Insurance / Bonding Costs									
Operations & Maintenance Costs									
** Note: Cost will vary by market and project size									

7.5 MW dc / 5 MW ac Project, ($ 000) BUDGETARY ESTIMATE

	Low Target		Aggressive Target	% of Total		High Target
Supply Chain, OH, Margin	$ 2,036		$ 2,036	24%		$ 2,505
Design, Engineering & Permitting	275		275	3%		533
Direct Labor	926		975	12%		1,208
Structural BOS	1,007		1,060	13%		1,800
Electrical BOS / DC Electrical BOS	427		449	5%		735
Inverter / Inverter & AC subsystem	262		275	3%		314
Module	3,104		3,404	40%		3,704
Total	$ 8,037		$ 8,475	100%		$ 10,798
10% Budget Contingency	804		848			1,080
Recommended Budget	$ 8,841		$ 9,323			$ 11,878

Note: Tax Credits have not been deducted from above.

Review of PV Irradiance and Geometry



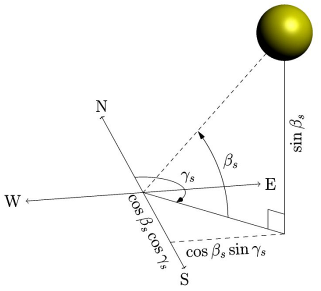
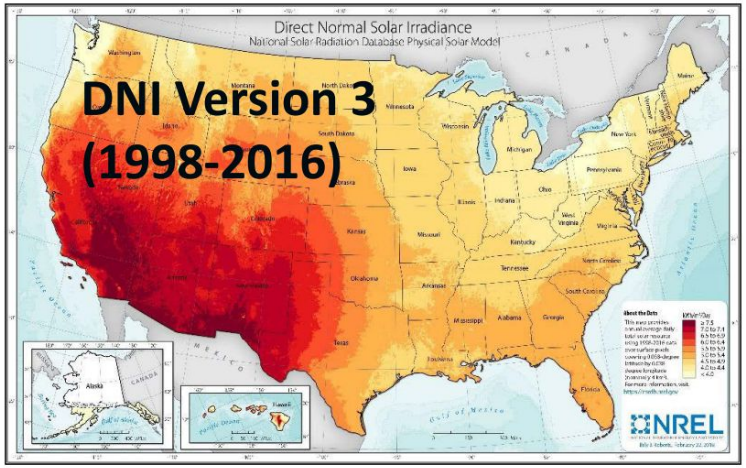
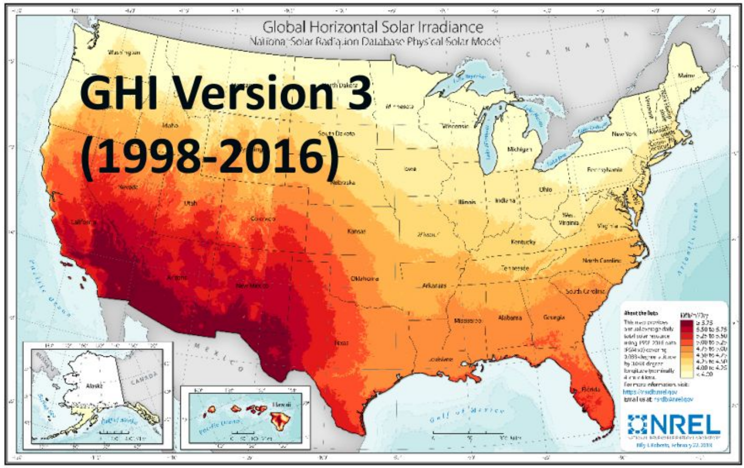


Figure 2: Solar position angles and the corresponding Cartesian coordinates. The global Cartesian coordinates are found by treating the solar position angles as spherical coordinates. In this case, the corresponding Cartesian x and y coordinates are positive and negative, respectively (sun in eastern and southern sky).





Review of PV Geometry

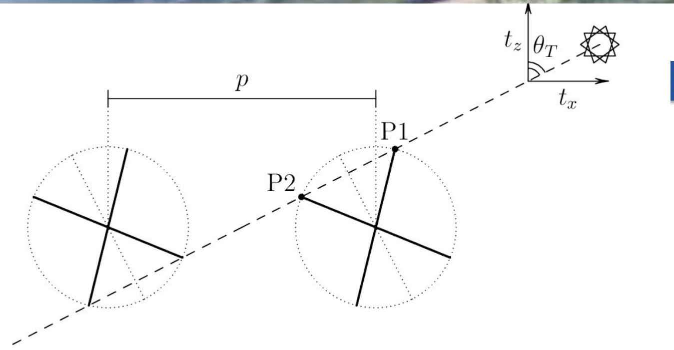
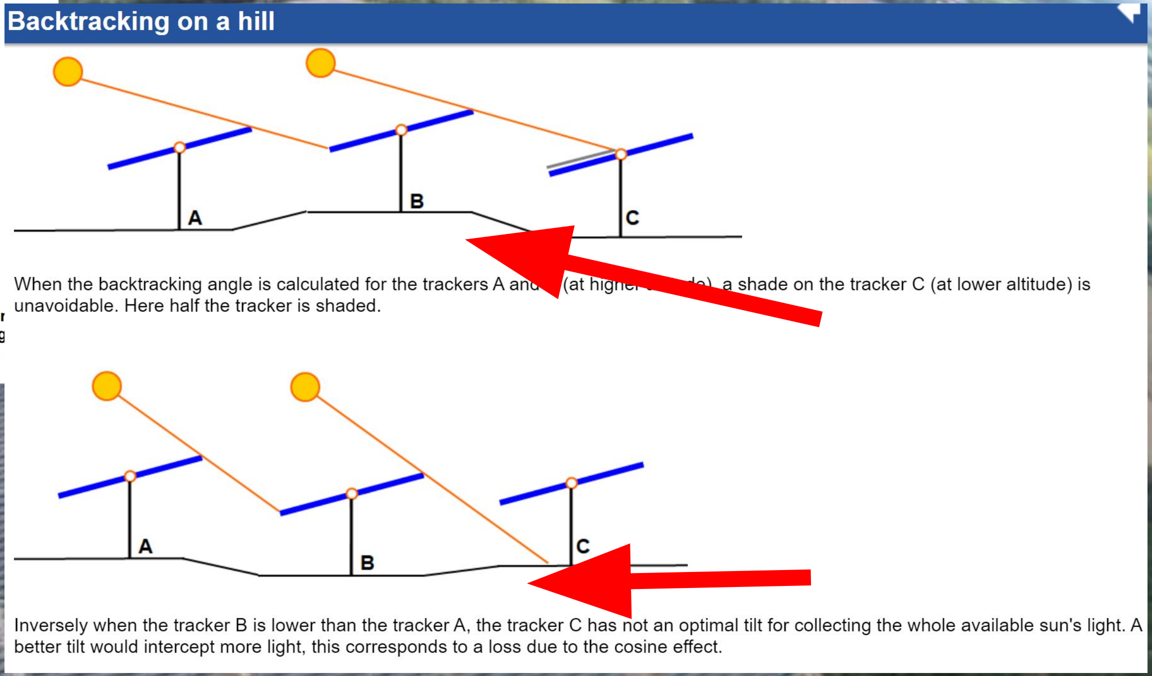


Figure 7. Cross-section of two adjacent tracker rows. The tracker axes point into the page and ar not visible in this 2D diagram. The two optimal positions P1 and P2 eliminate row to row shading P1 and P2 expose the same cross section to beam irradiance and are symmetrical around the true-tracking position, shown as a dotted line perpendicular to the solar vector.

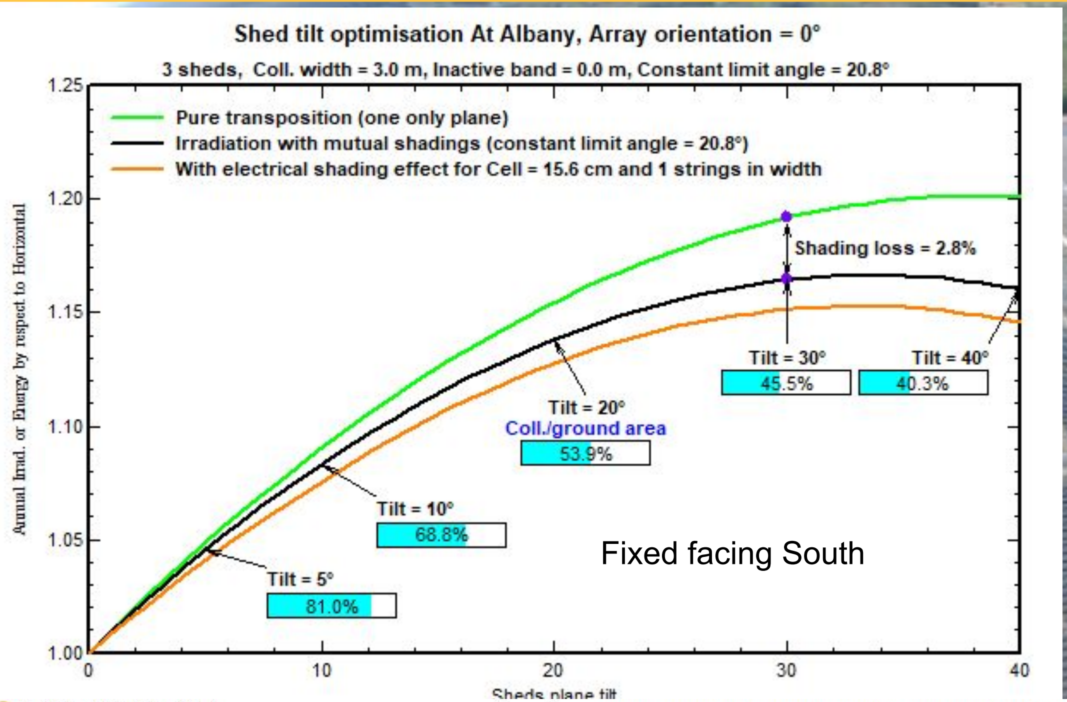


Backtracking on a hill

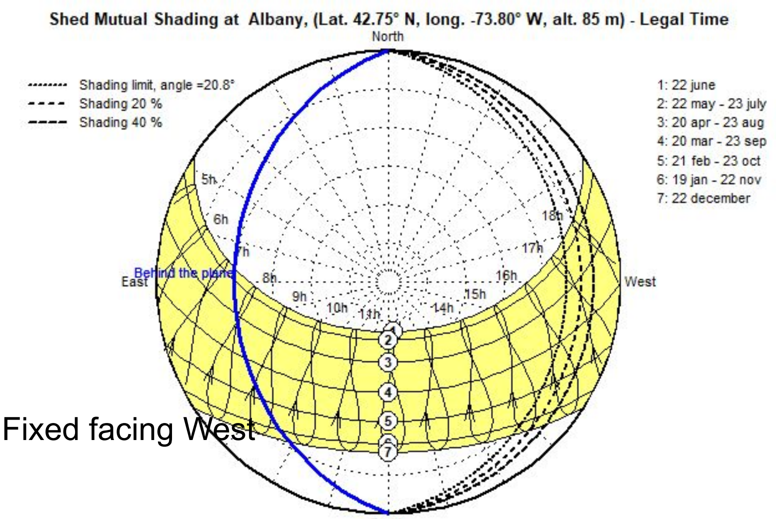
When the backtracking angle is calculated for the trackers A and [illegible] (at higher [illegible]), a shade on the tracker C (at lower altitude) is unavoidable. Here half the tracker is shaded.

Inversely when the tracker B is lower than the tracker A, the tracker C has not an optimal tilt for collecting the whole available sun's light. A better tilt would intercept more light, this corresponds to a loss due to the cosine effect.

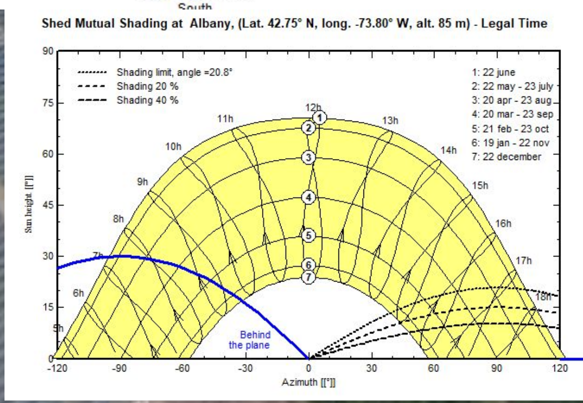
Simulation of PV Geometry

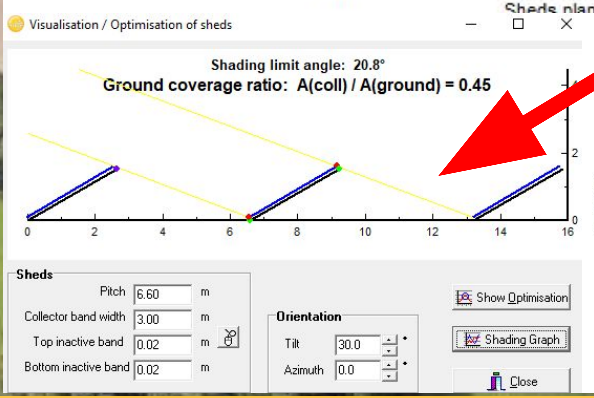


Fixed facing South



Fixed facing West





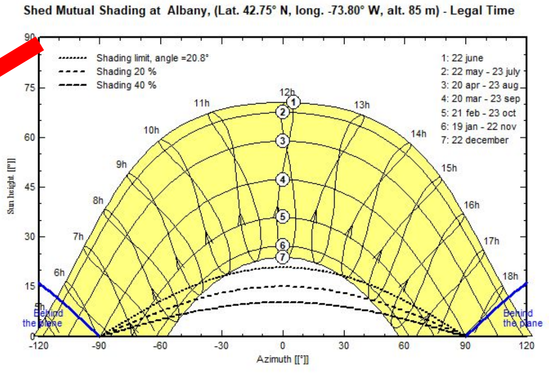
Shading limit angle: 20.8°
Ground coverage ratio: A(coll) / A(ground) = 0.45

Sheds

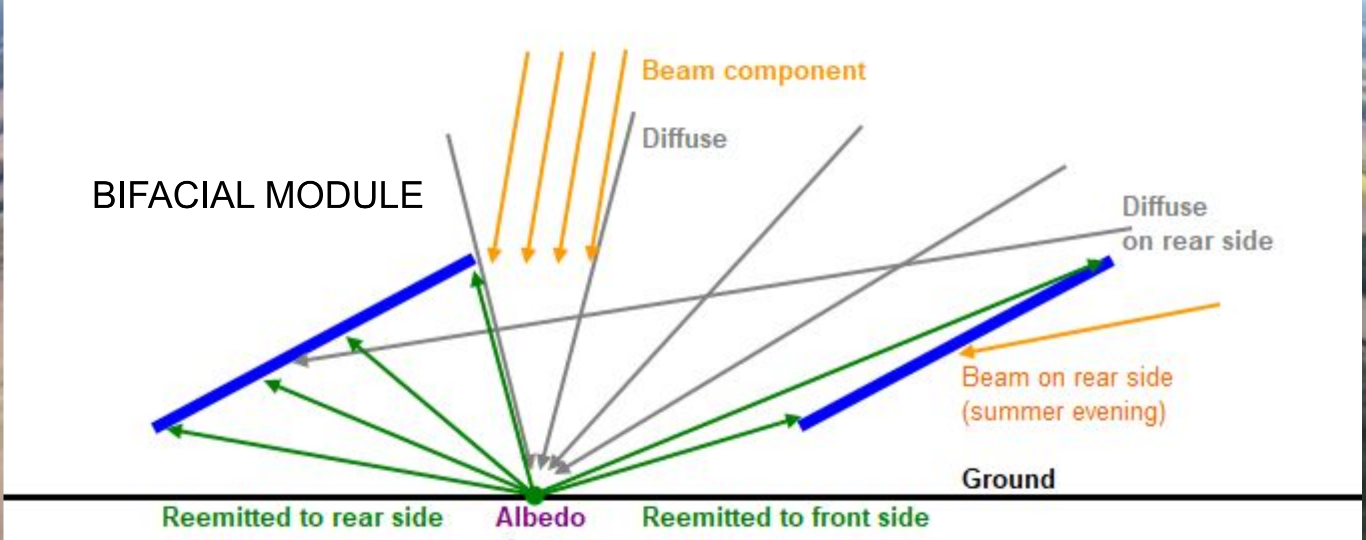
Pitch 6.60 m
Collector band width 3.00 m
Top inactive band 0.02 m
Bottom inactive band 0.02 m

Orientation

Tilt 30.0
Azimuth 0.0

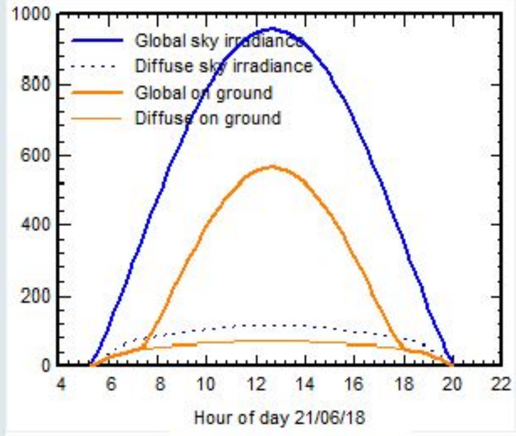


Simulation of bifacial modules

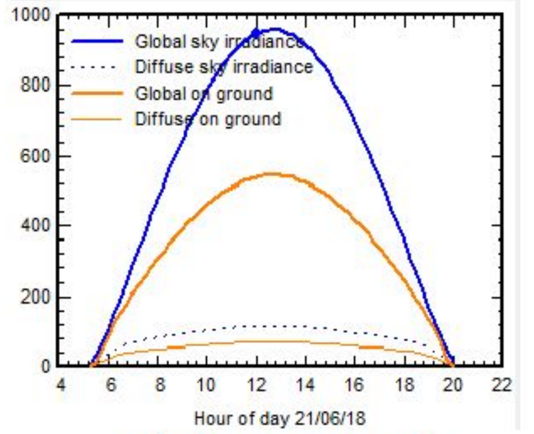


A Tracking Strategy tends to optimize the trapping of the sun's rays; therefore there is less beam irradiance reaching the ground.

In June, the beam fraction on ground is 44% with tracking, and 60% with sheds systems.

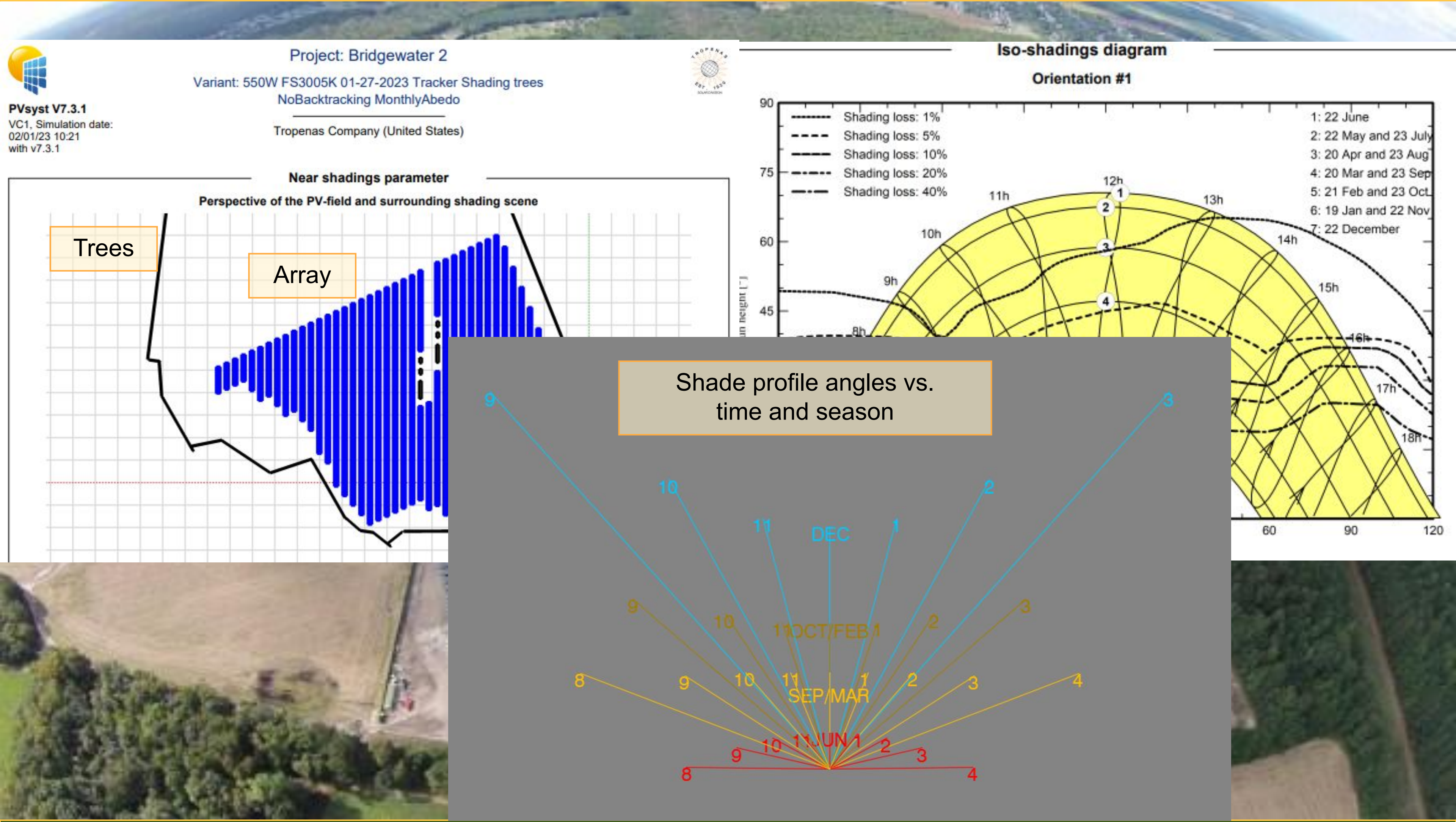


Tracking system



Shed system 25° south

Simulation of PV - Shading angles



PVsyst V7.3.1
VC1, Simulation date:
02/01/23 10:21
with v7.3.1

Project: Bridgewater 2

Variant: 550W FS3005K 01-27-2023 Tracker Shading trees NoBacktracking MonthlyAbedo

Tropenas Company (United States)

Near shadings parameter

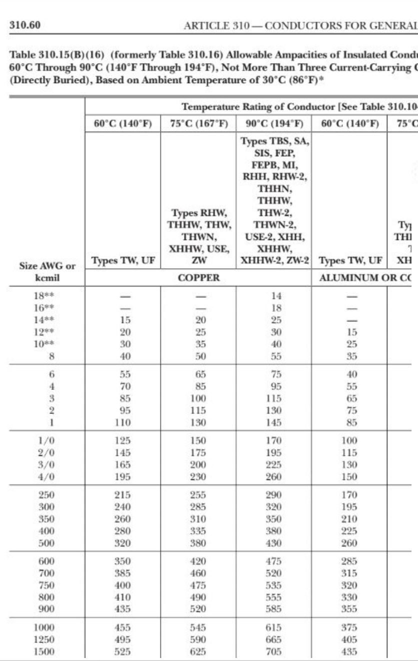
Perspective of the PV-field and surrounding shading scene

PV design - Conductors

Electrical impact on layout:
- Proximity to Interconnection
- Soil Thermal Properties
- “Squareness”

NEC code vs. simulations

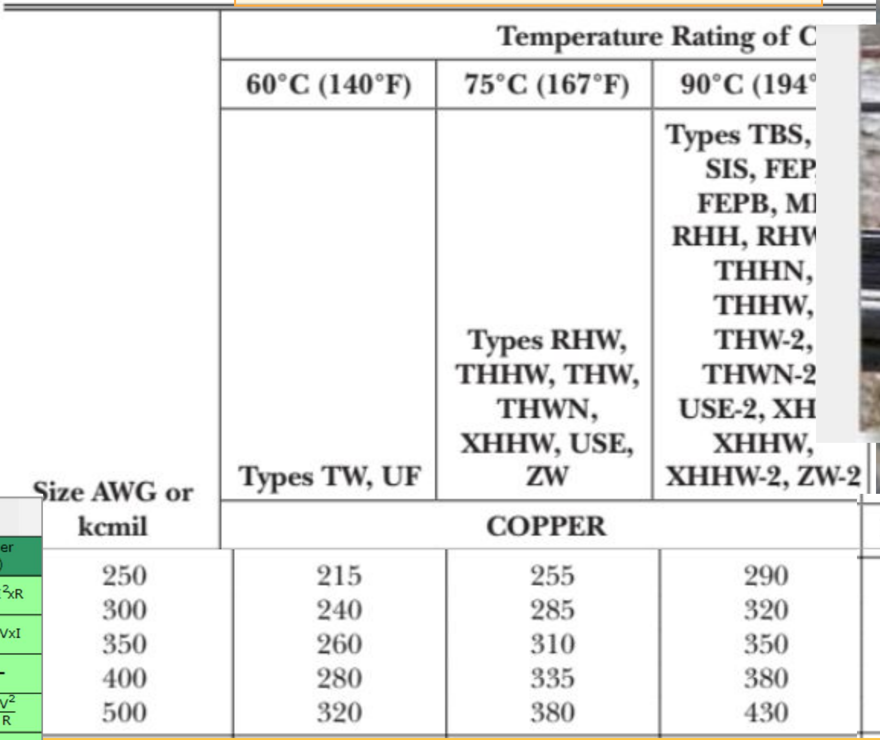
Direct bury, conduit, free air



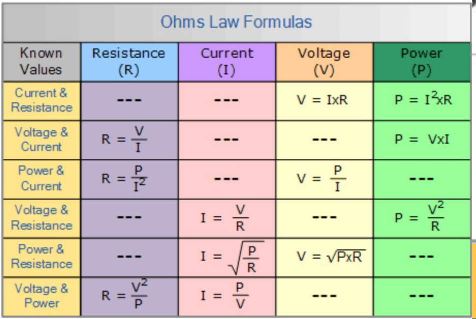
310.60 ARTICLE 310 — CONDUCTORS FOR GENERAL WIRING

Table 310.15(B)(16) (formerly Table 310.16) Allowable Ampacities of Insulated Conductors Rated Up to and Including 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)*

	Temperature Rating of Conductor [See Table 310.104(A).]					
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Ty THI T XH	
	COPPER			ALUMINUM OR CC		
18**	—	—	14	—		
16**	—	—	18	—		
14**	15	20	25	—		
12**	20	25	30	15		
10**	30	35	40	25		
8	40	50	55	35		
6	55	65	75	40		
4	70	85	95	55		
3	85	100	115	65		
2	95	115	130	75		
1	110	130	145	85		
1/0	125	150	170	100		
2/0	145	175	195	115		
3/0	165	200	225	130		
4/0	195	230	260	150		
250	215	255	290	170		
300	240	285	320	195		
350	260	310	350	210		
400	280	335	380	225		
500	320	380	430	260		
600	350	420	475	285		
700	385	460	520	315		
750	400	475	535	320		
800	410	490	555	330		
900	435	520	585	355		
1000	455	545	615	375		
1250	495	590	665	405		
1500	525	625	705	435		



	Temperature Rating of C					
	60°C (140°F)	75°C (167°F)	90°C (194°			
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SIS, FEP FEPB, MI RHH, RHW THHN, THHW, THW-2, THWN-2 USE-2, XH XHHW, XHHW-2, ZW-2			
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM		
250	215	255	290	170	205	230
300	240	285	320	195	230	260
350	260	310	350	210	250	280
400	280	335	380	225	270	305
500	320	380	430	260	310	350



Ohms Law Formulas

Known Values	Resistance (R)	Current (I)	Voltage (V)	Power (P)
Current & Resistance	---	---	$V = I \times R$	$P = I^2 \times R$
Voltage & Current	$R = \frac{V}{I}$	---	---	$P = V \times I$
Power & Current	$R = \frac{P}{I^2}$	---	$V = \frac{P}{I}$	---
Voltage & Resistance	---	$I = \frac{V}{R}$	---	$P = \frac{V^2}{R}$
Power & Resistance	---	$I = \sqrt{\frac{P}{R}}$	$V = \sqrt{P \times R}$	---
Voltage & Power	$R = \frac{V^2}{P}$	$I = \frac{P}{V}$	---	---

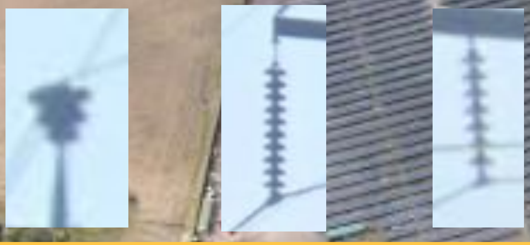
https://www.nfpa.org/NEC/About-the-NEC/Free-online-access-to-the-NEC-and-other-electrical-standards

System design for utility-scale solar PV and Battery Energy Storage Systems

Interconnection design
Voltage, Current and Power

Identifying Interconnection Voltages by Counting Utility Line Porcelain Insulators

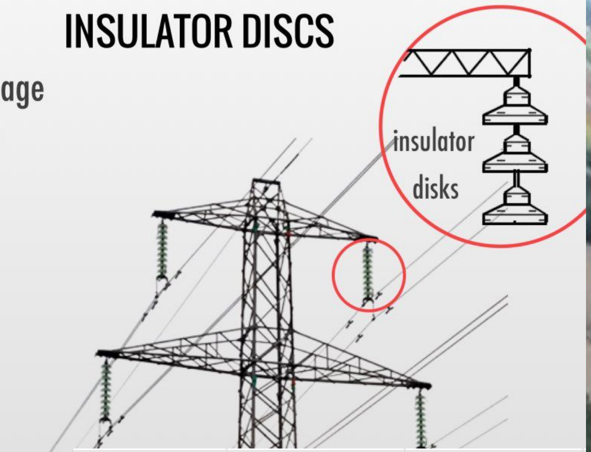
429 Garrett Rd
Ballston Spa, New York
Google Street View
Jul 2022
See more dates



3: 34.5 kV 10: 115kV 7: 115 kV

IDENTIFYING THE VOLTAGE LEVEL BY NUMBER OF INSULATOR DISCS

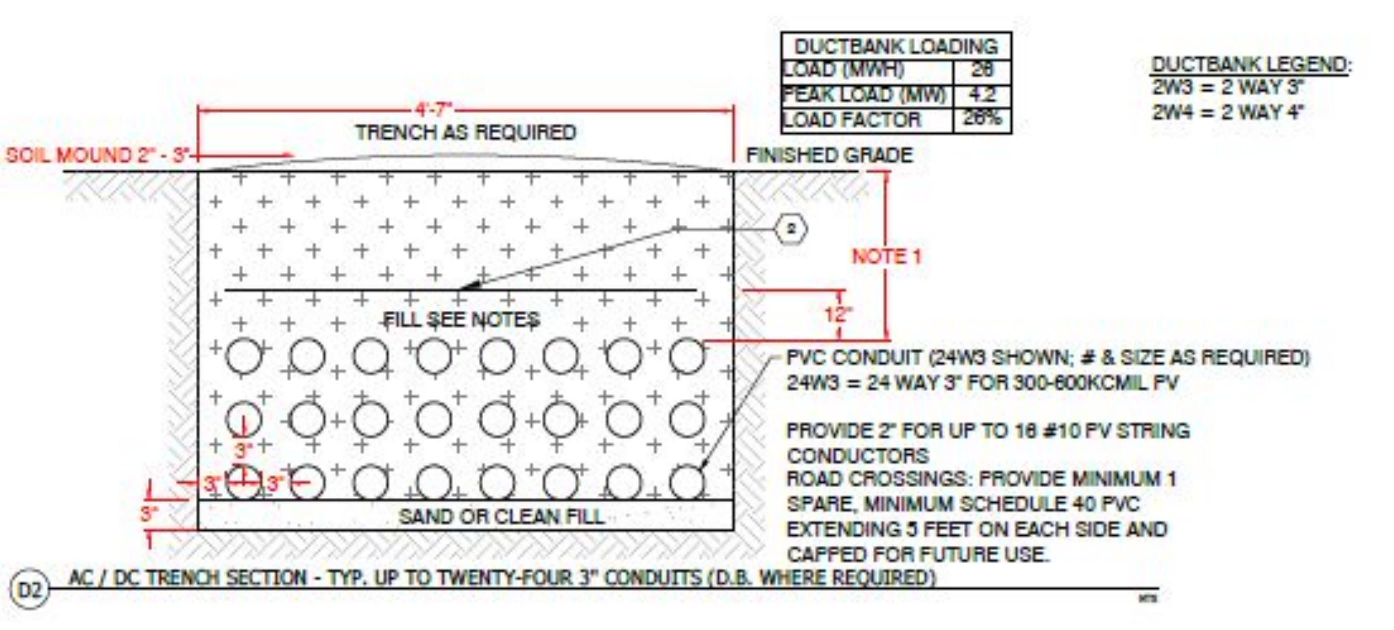
Discs	Line Voltage (kV)
3	34.5
4	69
6	115
8	138
11	161
14	230
15	287
18	345
23	360
24	400
34	500
44	600
59	750
60	765



Line kV	Current (A)	Power (MVA)
34.5	600	36
69	600	72
115	600	120
138	600	143
161	600	167
230	600	239
287	600	298
345	600	359
500	600	520

Source: World of Engineering
https://twitter.com/engineers_feed

Trench calculations



DUCTBANK LOADING	
LOAD (MWH)	28
PEAK LOAD (MW)	4.2
LOAD FACTOR	28%

DUCTBANK LEGEND:
2W3 = 2 WAY 3"
2W4 = 2 WAY 4"

PVC CONDUIT (24W3 SHOWN; # & SIZE AS REQUIRED)
24W3 = 24 WAY 3" FOR 300-600KCMIL PV

PROVIDE 2" FOR UP TO 18 #10 PV STRING CONDUCTORS
ROAD CROSSINGS: PROVIDE MINIMUM 1 SPARE, MINIMUM SCHEDULE 40 PVC EXTENDING 5 FEET ON EACH SIDE AND CAPPED FOR FUTURE USE.

AC / DC TRENCH SECTION - TYP. UP TO TWENTY-FOUR 3" CONDUITS (D.B. WHERE REQUIRED)

PV / BESS Site Design

BIRD AND BAT BOXES
These will be located around the perimeter of the site to encourage bats to roost and birds to nest.

WILDFLOWER MEADOWS
The land around and beneath the solar panels will be sown with native wildflowers and grasses to support habitats for bees and other pollinators.

EDUCATIONAL BENEFITS
We organize trips to the solar farm so children from local schools can learn about science, technology and energy generation.

SHEEP GRAZING
The land around the solar panels will be maintained where economically feasible by sheep grazing in winter, after the meadows have seeded, to keep land in food production.

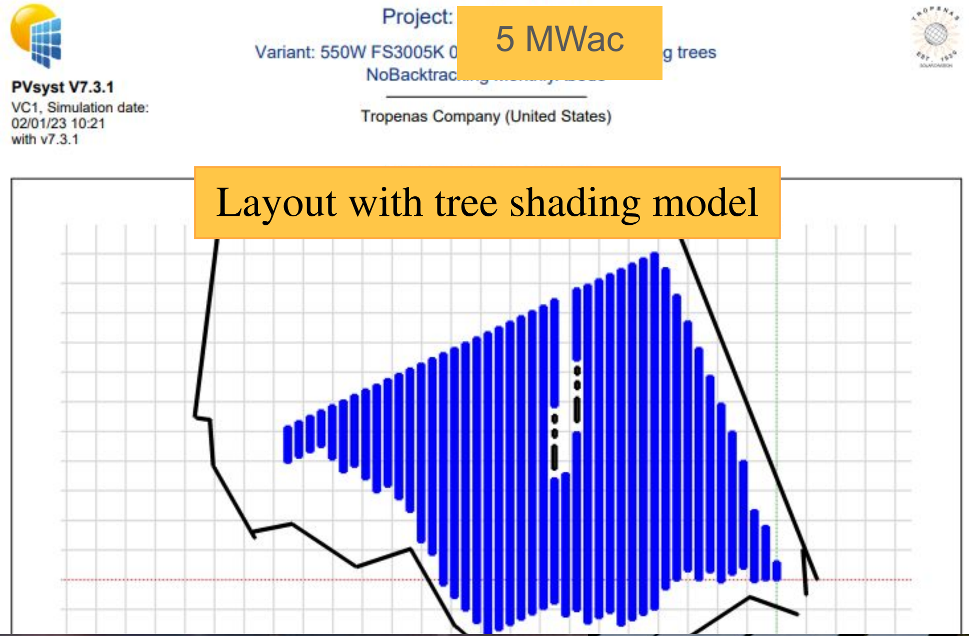
BEEHIVES
Beehives on the solar farm will provide pollination services to support local farmers and agriculture.

PV w/
DC coupled BESS

9 MWh BESS
8.3 MW DC
5 MW AC
11.3 GWh

System design for utility-scale solar PV and Battery Energy Storage Systems

Example simulations
1-Axis Tracker - NY



Project:

5 MWac

Variant: 550W FS3005K 0 g trees

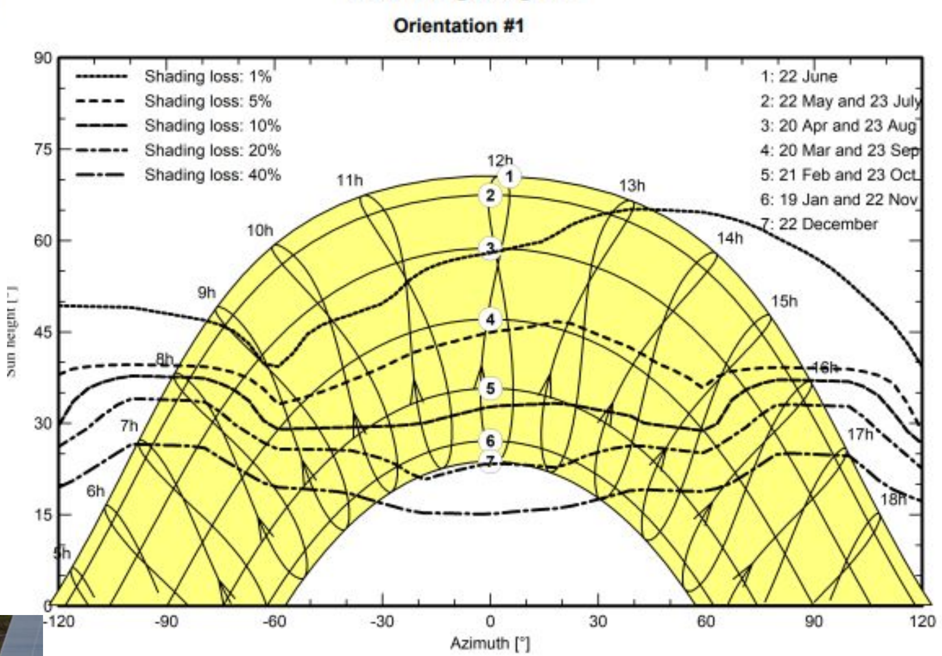
NoBacktrac

Tropenas Company (United States)

PVsyst V7.3.1

VC1, Simulation date:
02/01/23 10:21
with v7.3.1

Layout with tree shading model



Shading Losses by season / time

Example simulations
1-Axis Tracker - NY

PVsyst V7.3.1
VC1, Simulation date:
02/01/23 10:21
with v7.3.1

Project:

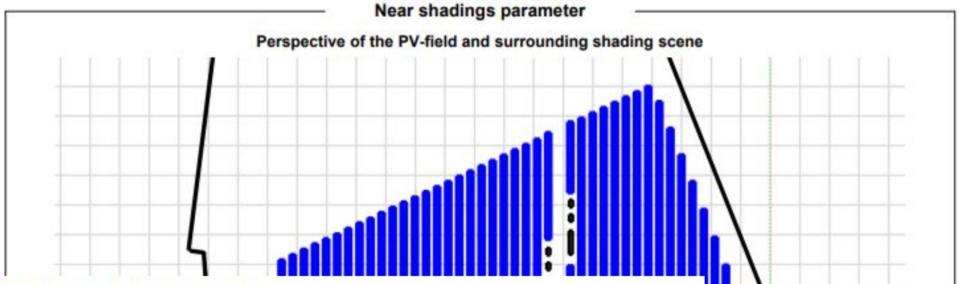
5 MWc

Variant: 550W FS3005K 0 g trees
NoBacktrack

Tropenas Company (United States)

Near shadings parameter

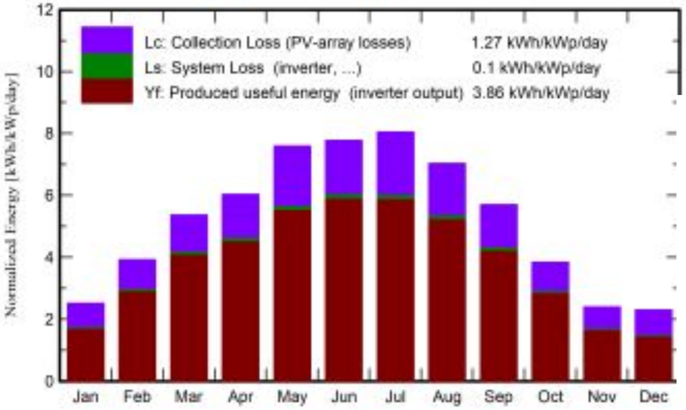
Perspective of the PV-field and surrounding shading scene



System Production

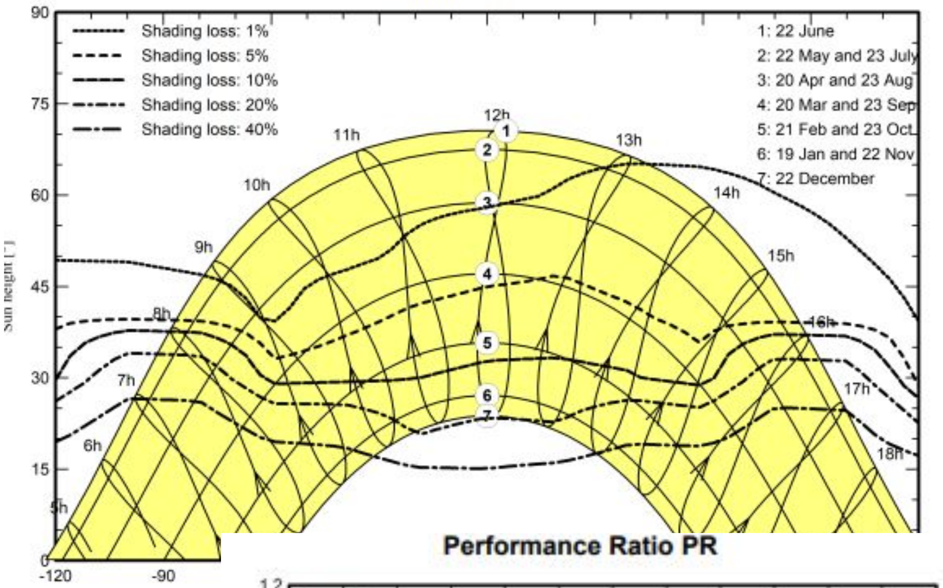
Produced Energy	10.25 GWh/year

Normalized productions (per installed kWp)

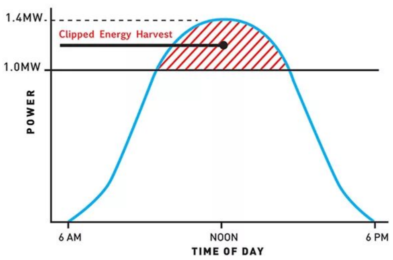


Iso-shadings diagram

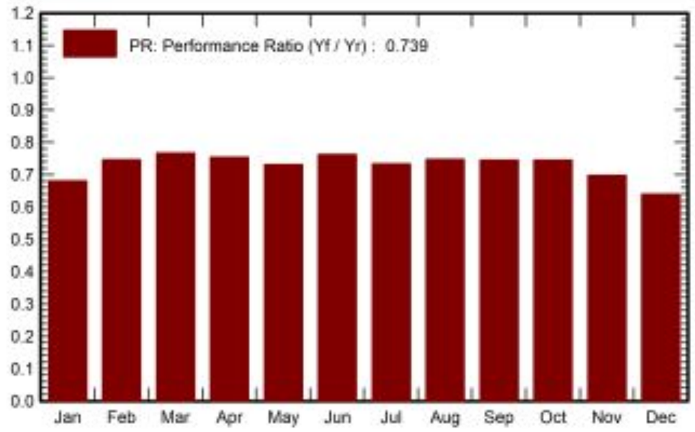
Orientation #1



DC coupled storage

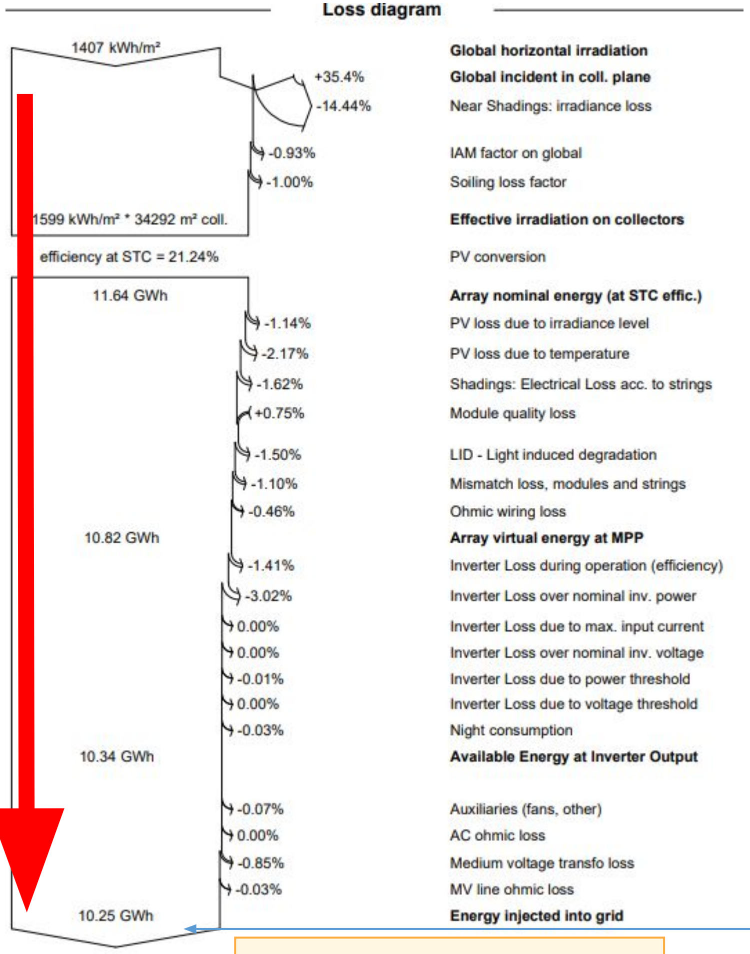


Performance Ratio PR



Example simulations
1-Axis Tracker - NY

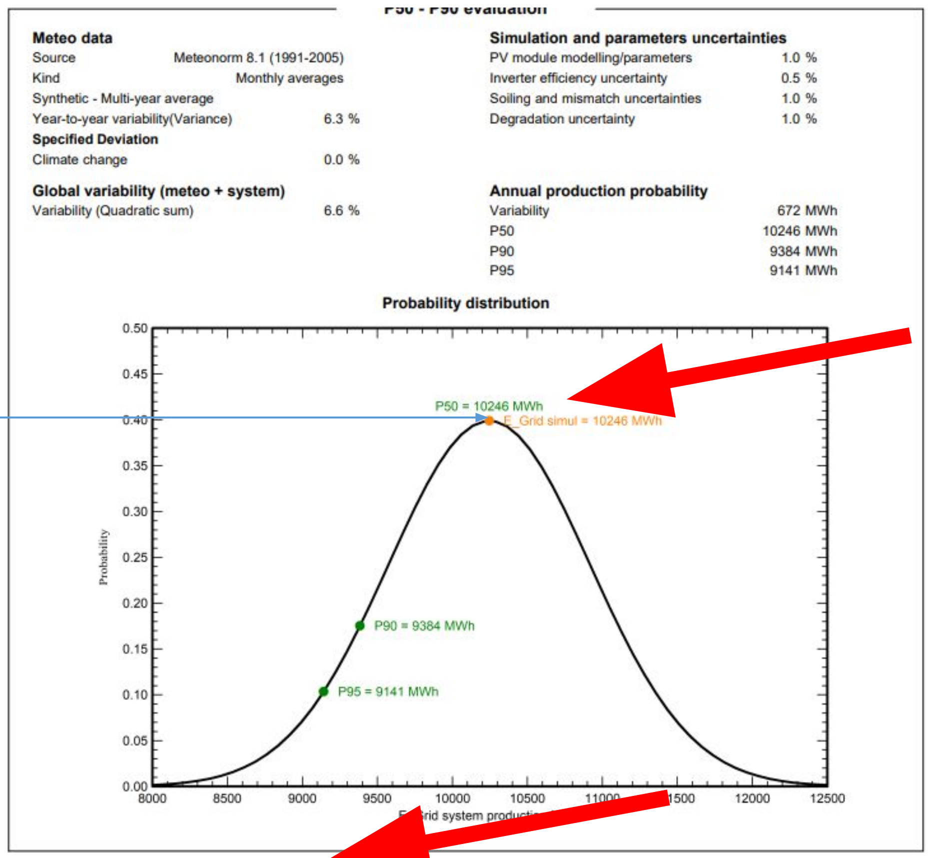
Representative Modeling Profile: Year 1 target generation for a 5MWac Project



Loss diagram

1407 kWh/m²		**Global horizontal irradiation**
	+35.4%	**Global incident in coll. plane**
	-14.44%	Near Shadings: irradiance loss
	-0.93%	IAM factor on global
	-1.00%	Soiling loss factor
1599 kWh/m² * 34292 m² coll.		**Effective irradiation on collectors**
efficiency at STC = 21.24%		PV conversion
11.64 GWh		**Array nominal energy (at STC effic.)**
	-1.14%	PV loss due to irradiance level
	-2.17%	PV loss due to temperature
	-1.62%	Shadings: Electrical Loss acc. to strings
	+0.75%	Module quality loss
	-1.50%	LID - Light induced degradation
	-1.10%	Mismatch loss, modules and strings
	-0.46%	Ohmic wiring loss
10.82 GWh		**Array virtual energy at MPP**
	-1.41%	Inverter Loss during operation (efficiency)
	-3.02%	Inverter Loss over nominal inv. power
	0.00%	Inverter Loss due to max. input current
	0.00%	Inverter Loss over nominal inv. voltage
	-0.01%	Inverter Loss due to power threshold
	0.00%	Inverter Loss due to voltage threshold
	-0.03%	Night consumption
10.34 GWh		**Available Energy at Inverter Output**
	-0.07%	Auxiliaries (fans, other)
	0.00%	AC ohmic loss
	-0.85%	Medium voltage transfo loss
	-0.03%	MV line ohmic loss
10.25 GWh		**Energy injected into grid**

Example Losses



P50 - P90 evaluation

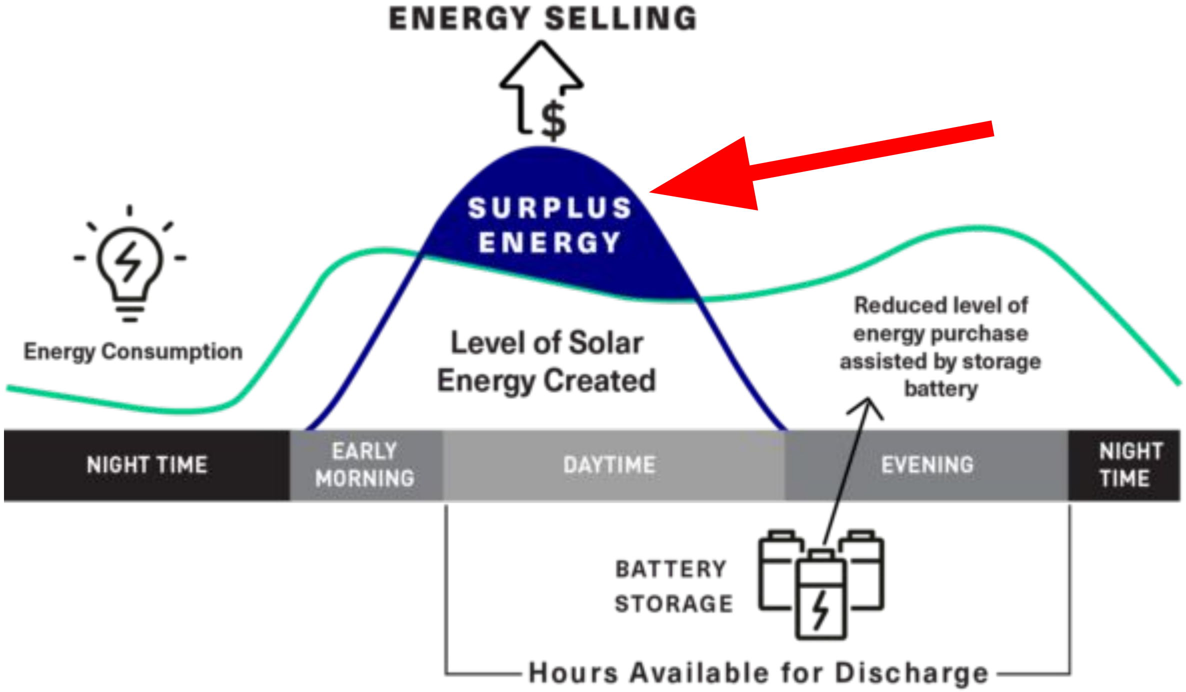
Meteo data		**Simulation and parameters uncertainties**	
Source	Meteonorm 8.1 (1991-2005)	PV module modelling/parameters	1.0 %
Kind	Monthly averages	Inverter efficiency uncertainty	0.5 %
Synthetic - Multi-year average		Soiling and mismatch uncertainties	1.0 %
Year-to-year variability(Variance)	6.3 %	Degradation uncertainty	1.0 %
Specified Deviation			
Climate change	0.0 %		
Global variability (meteo + system)		**Annual production probability**	
Variability (Quadratic sum)	6.6 %	Variability	672 MWh
		P50	10246 MWh
		P90	9384 MWh
		P95	9141 MWh

Probability distribution

Probability distributions of first year generation

NOTE: Models based on preliminary assumptions.

DC coupled storage



Example Layout
(not square)

Not ideal

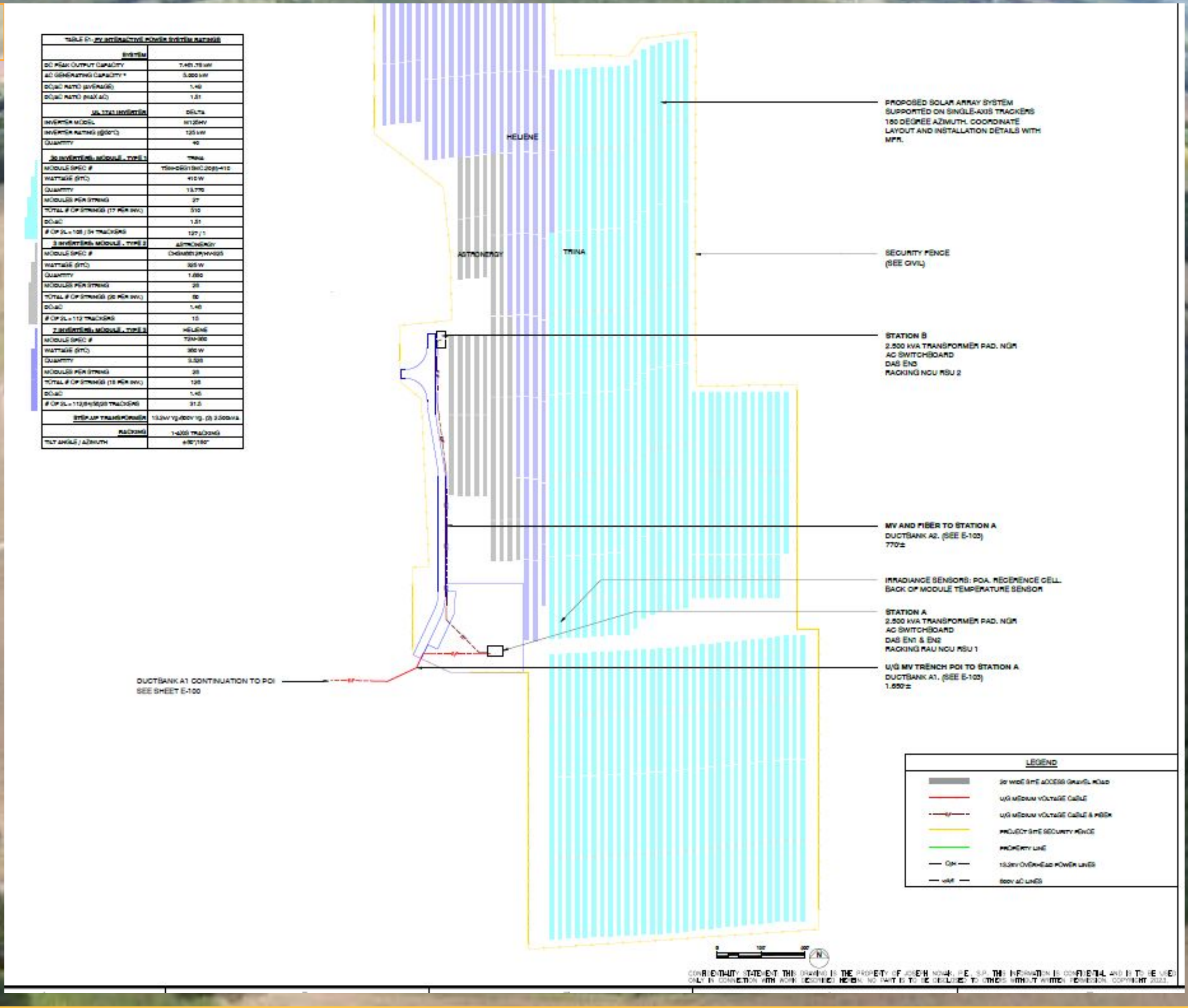


TABLE E1: PV INTERACTIVE POWER SYSTEM RATINGS	
SYSTEM	
DC PEAK OUTPUT CAPACITY	7,461.78 kW
AC GENERATING CAPACITY *	5,000 kW
DC/AC RATIO (AVERAGE)	1.49
DC/AC RATIO (MAX AC)	1.51
UL 1741 INVERTER	DELTA
INVERTER MODEL	M125HV
INVERTER RATING (@50°C)	125 kW
QUANTITY	40
30 INVERTERS, MODULE , TYPE 1	TRINA
MODULE SPEC #	TSM-DE15MC.20(II)-410
WATTAGE (STC)	410 W
QUANTITY	13,770
MODULES PER STRING	27
TOTAL # OF STRINGS (17 PER INV.)	510
DC/AC	1.51
# OF 2L = 108 / 54 TRACKERS	127 / 1
3 INVERTERS, MODULE , TYPE 2	ASTRONERGY
MODULE SPEC #	CHSM6612P/HV-325
WATTAGE (STC)	325 W
QUANTITY	1,680
MODULES PER STRING	28
TOTAL # OF STRINGS (20 PER INV.)	60
DC/AC	1.46
# OF 2L = 112 TRACKERS	15
7 INVERTERS, MODULE , TYPE 3	HELIENE
MODULE SPEC #	72M-360
WATTAGE (STC)	360 W
QUANTITY	3,528
MODULES PER STRING	28
TOTAL # OF STRINGS (18 PER INV.)	126
DC/AC	1.45
# OF 2L = 112/84/56/28 TRACKERS	31.5
STEP-UP TRANSFORMER	13.2kV YG/600V YG. (2) 2,500kVA
RACKING	1-AXIS TRACKING
TILT ANGLE / AZIMUTH	±50°/180°

PROPOSED SOLAR ARRAY SYSTEM
SUPPORTED ON SINGLE-AXIS TRACKERS
180 DEGREE AZIMUTH. COORDINATE
LAYOUT AND INSTALLATION DETAILS WITH
MFR.

SECURITY FENCE
(SEE CIVIL)

STATION B
2,500 KVA TRANSFORMER PAD. NGR
AC SWITCHBOARD
DAS EN3
RACKING NCU RSU 2

MV AND FIBER TO STATION A
DUCTBANK A2. (SEE E-103)
770'±

IRRADIANCE SENSORS: POA. REFERENCE CELL.
BACK OF MODULE TEMPERATURE SENSOR

STATION A
2,500 KVA TRANSFORMER PAD. NGR
AC SWITCHBOARD
DAS EN1 & EN2
RACKING RAU NCU RSU 1

U/G MV TRENCH POI TO STATION A
DUCTBANK A1. (SEE E-103)
1,650'±

DUCTBANK A1 CONTINUATION TO POI
SEE SHEET E-100

LEGEND	
▬	30' WIDE SITE ACCESS GRAVEL ROAD
─	U/G MEDIUM VOLTAGE CABLE
- —F— -	U/G MEDIUM VOLTAGE CABLE & FIBER
─	PROJECT SITE SECURITY FENCE
─	PROPERTY LINE
— OH —	13.2kV OVERHEAD POWER LINES
— VAF —	600V AC LINES

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System design for utility-scale solar PV and Battery Energy Storage Systems

Example Layout 2

Not ideal

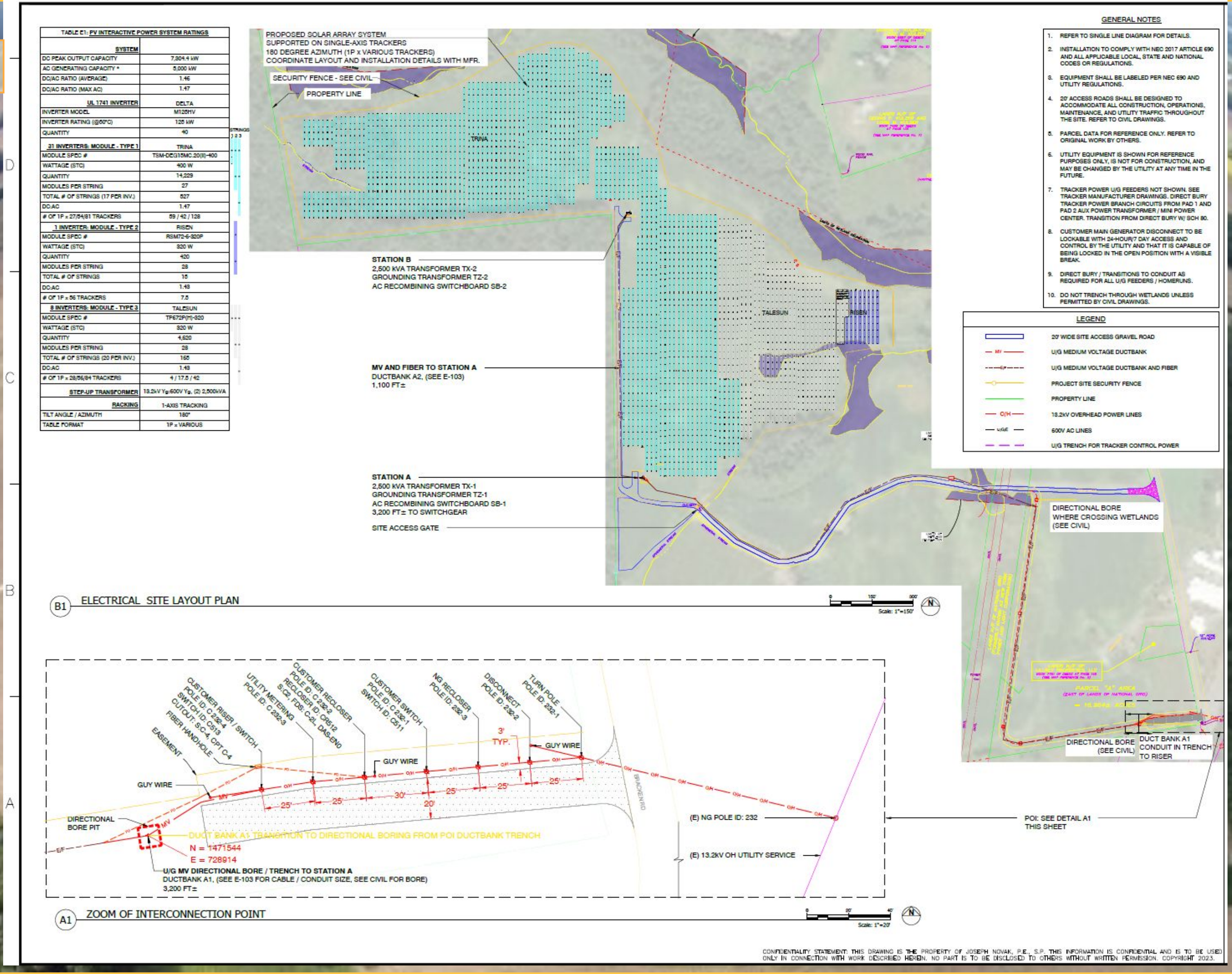

TABLE E1: PV INTERACTIVE POWER SYSTEM RATINGS	
SYSTEM	
DC PEAK OUTPUT CAPACITY	7,304.4 kW
AC GENERATING CAPACITY *	5,000 kW
DC/AC RATIO (AVERAGE)	1.46
DC/AC RATIO (MAX AC)	1.47
UL 1741 INVERTER	DELTA
INVERTER MODEL	M125HV
INVERTER RATING (@50°C)	125 kW
QUANTITY	40
31 INVERTERS: MODULE - TYPE 1	TRINA
MODULE SPEC #	TSM-DEG15MC.20(II)-400
WATTAGE (STC)	400 W
QUANTITY	14,229
MODULES PER STRING	27
TOTAL # OF STRINGS (17 PER INV.)	527
DC:AC	1.47
# OF 1P x 27/54/81 TRACKERS	59 / 42 / 128
1 INVERTER: MODULE - TYPE 2	RISEN
MODULE SPEC #	RSM72-6-320P
WATTAGE (STC)	320 W
QUANTITY	420
MODULES PER STRING	28
TOTAL # OF STRINGS	15
DC:AC	1.48
# OF 1P x 56 TRACKERS	7.5
8 INVERTERS: MODULE - TYPE 3	TALESUN
MODULE SPEC #	TP672P(H)-320
WATTAGE (STC)	320 W
QUANTITY	4,620
MODULES PER STRING	28
TOTAL # OF STRINGS (20 PER INV.)	165
DC:AC	1.48
# OF 1P x 28/56/84 TRACKERS	4 / 17.5 / 42
STEP-UP TRANSFORMER	13.2kV Yg:600V Yg, (2) 2,500kVA
RACKING	1-AXIS TRACKING
TILT ANGLE / AZIMUTH	180°
TABLE FORMAT	1P x VARIOUS

GENERAL NOTES

1. REFER TO SINGLE LINE DIAGRAM FOR DETAILS.
2. INSTALLATION TO COMPLY WITH NEC 2017 ARTICLE 690 AND ALL APPLICABLE LOCAL, STATE AND NATIONAL CODES OR REGULATIONS.
3. EQUIPMENT SHALL BE LABELED PER NEC 690 AND UTILITY REGULATIONS.
4. 20' ACCESS ROADS SHALL BE DESIGNED TO ACCOMMODATE ALL CONSTRUCTION, OPERATIONS, MAINTENANCE, AND UTILITY TRAFFIC THROUGHOUT THE SITE. REFER TO CIVIL DRAWINGS.
5. PARCEL DATA FOR REFERENCE ONLY. REFER TO ORIGINAL WORK BY OTHERS.
6. UTILITY EQUIPMENT IS SHOWN FOR REFERENCE PURPOSES ONLY, IS NOT FOR CONSTRUCTION, AND MAY BE CHANGED BY THE UTILITY AT ANY TIME IN THE FUTURE.
7. TRACKER POWER U/G FEEDERS NOT SHOWN. SEE TRACKER MANUFACTURER DRAWINGS. DIRECT BURY TRACKER POWER BRANCH CIRCUITS FROM PAD 1 AND PAD 2 AUX POWER TRANSFORMER / MINI POWER CENTER. TRANSITION FROM DIRECT BURY W/ SCH 80.
8. CUSTOMER MAIN GENERATOR DISCONNECT TO BE LOCKABLE WITH 24-HOUR/7 DAY ACCESS AND CONTROL BY THE UTILITY AND THAT IT IS CAPABLE OF BEING LOCKED IN THE OPEN POSITION WITH A VISIBLE BREAK.
9. DIRECT BURY / TRANSITIONS TO CONDUIT AS REQUIRED FOR ALL U/G FEEDERS / HOMERUNS.
10. DO NOT TRENCH THROUGH WETLANDS UNLESS PERMITTED BY CIVIL DRAWINGS.

LEGEND	
▭	20' WIDE SITE ACCESS GRAVEL ROAD
— MV —	U/G MEDIUM VOLTAGE DUCTBANK
- - - E/F - - -	U/G MEDIUM VOLTAGE DUCTBANK AND FIBER
—○—	PROJECT SITE SECURITY FENCE
——	PROPERTY LINE
— O/H —	13.2KV OVERHEAD POWER LINES
— U/G/E —	600V AC LINES
— — —	U/G TRENCH FOR TRACKER CONTROL POWER

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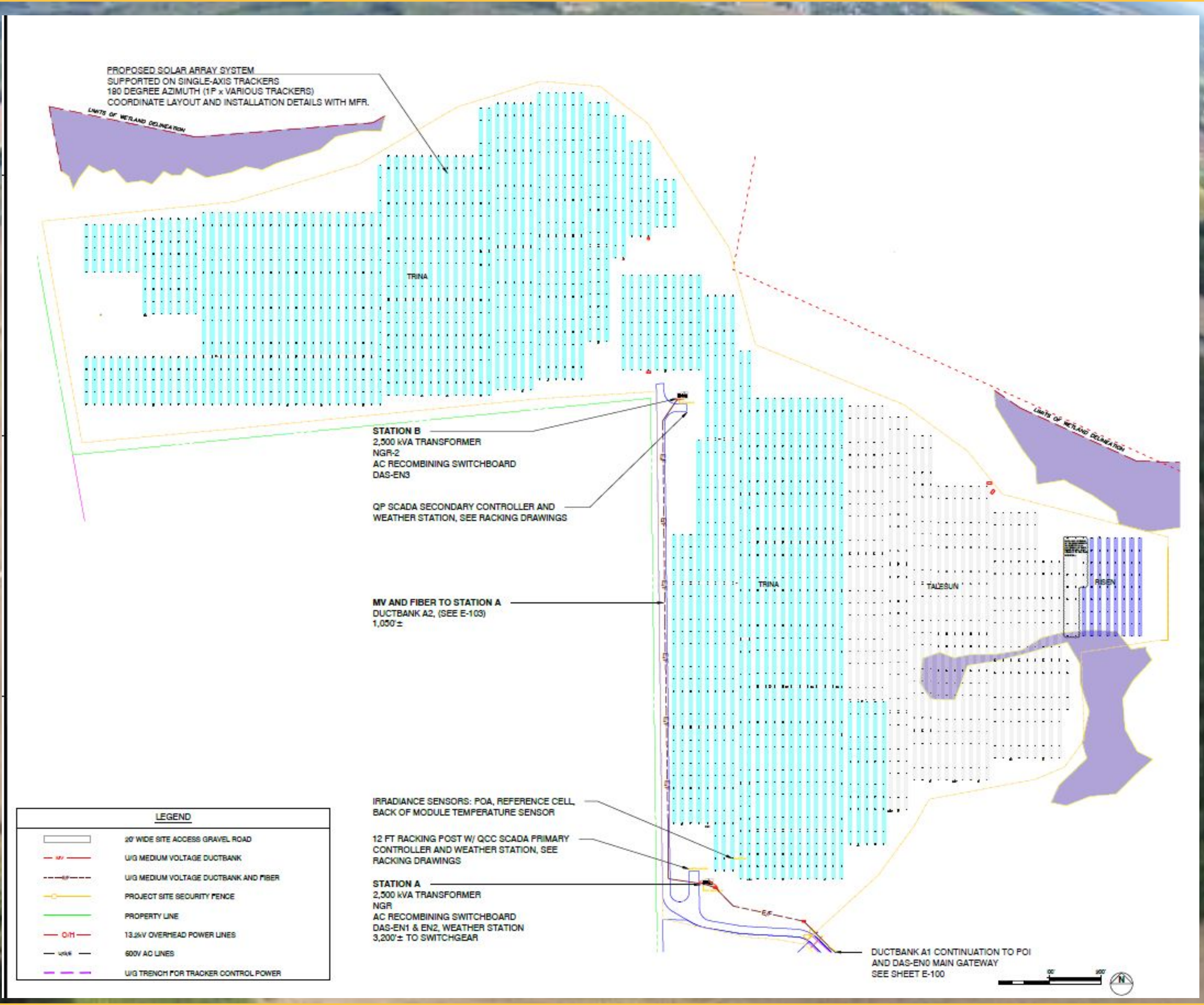
Example Layout 2
(Multiple modules)

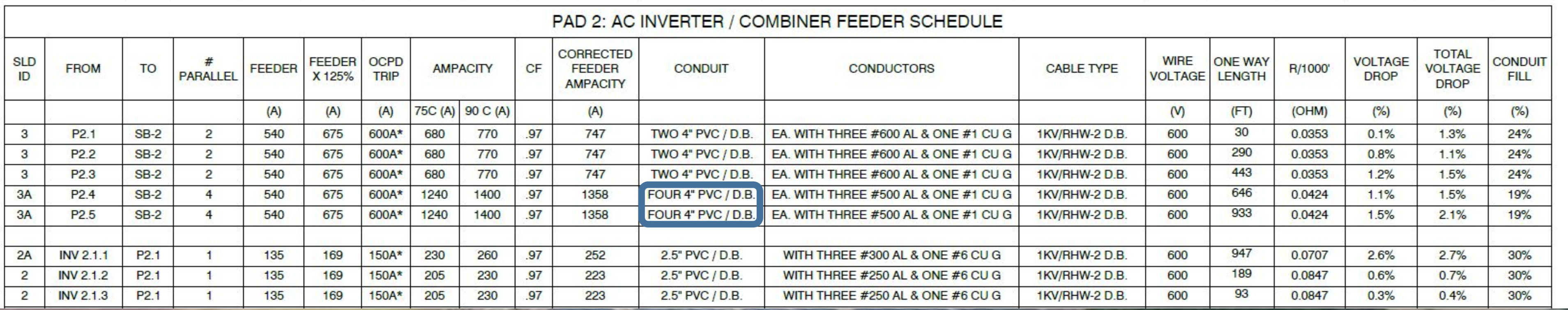


TROPENAS COMPANY ESTABLISHED 1920

System design for utility-scale solar PV and Battery Energy Storage Systems

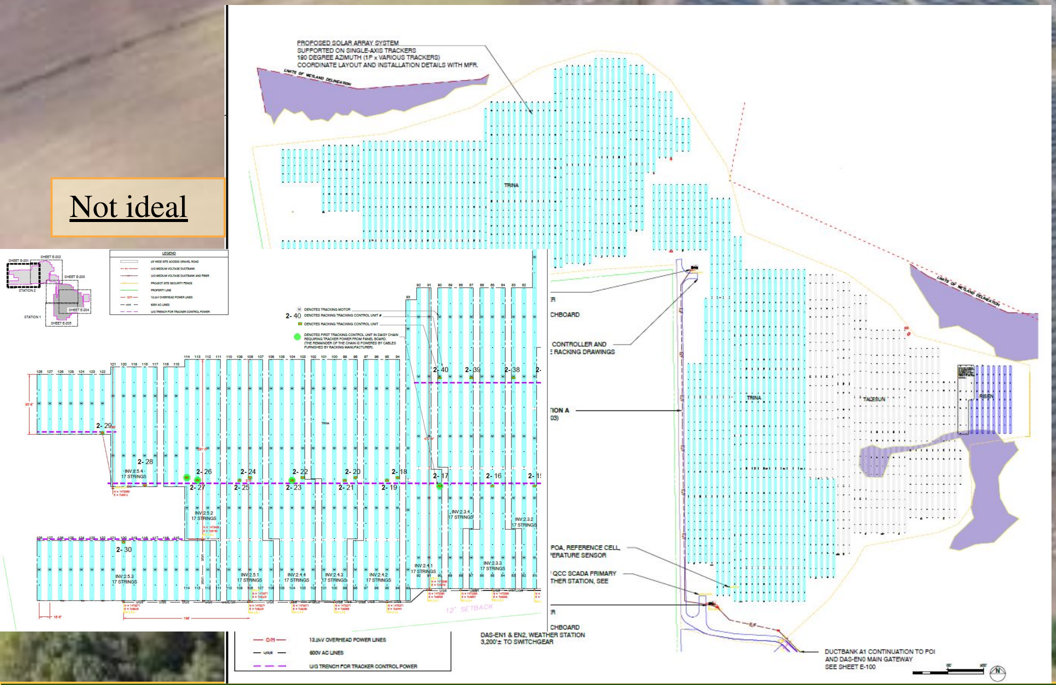
RENEWABLE ENERGY ENGINEERING

Example Layout 3
Optimizing conductors

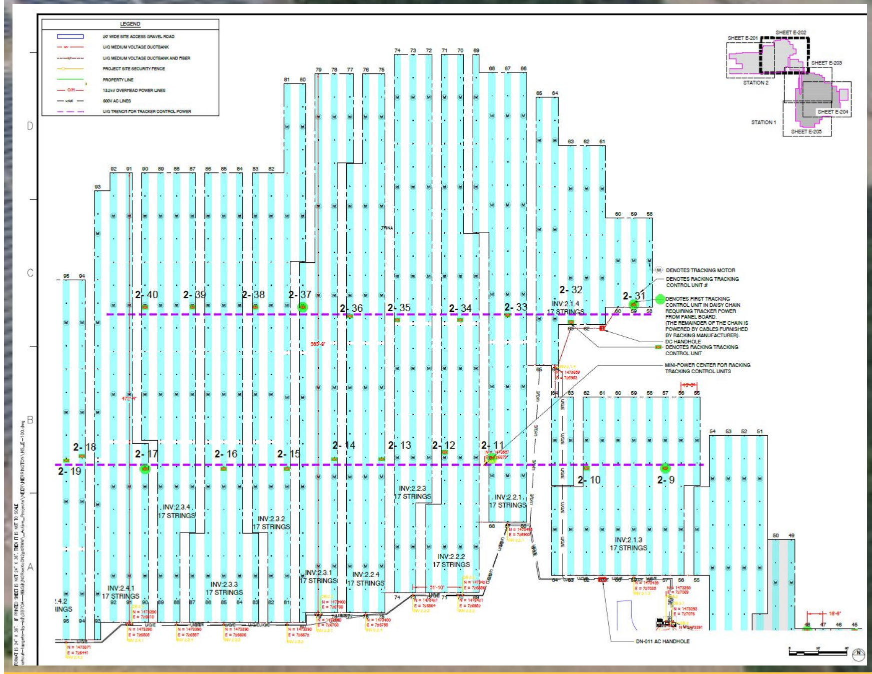


PAD 2: AC INVERTER / COMBINER FEEDER SCHEDULE

SLD ID	FROM	TO	# PARALLEL	FEEDER	FEEDER X 125%	OCPD TRIP	AMPACITY		CF	CORRECTED FEEDER AMPACITY	CONDUIT	CONDUCTORS	CABLE TYPE	WIRE VOLTAGE	ONE WAY LENGTH	R/1000'	VOLTAGE DROP	TOTAL VOLTAGE DROP	CONDUIT FILL
				(A)	(A)	(A)	75C (A)	90 C (A)		(A)				(V)	(FT)	(OHM)	(%)	(%)	(%)
3	P2.1	SB-2	2	540	675	600A*	680	770	.97	747	TWO 4" PVC / D.B.	EA. WITH THREE #600 AL & ONE #1 CU G	1KV/RHW-2 D.B.	600	30	0.0353	0.1%	1.3%	24%
3	P2.2	SB-2	2	540	675	600A*	680	770	.97	747	TWO 4" PVC / D.B.	EA. WITH THREE #600 AL & ONE #1 CU G	1KV/RHW-2 D.B.	600	290	0.0353	0.8%	1.1%	24%
3	P2.3	SB-2	2	540	675	600A*	680	770	.97	747	TWO 4" PVC / D.B.	EA. WITH THREE #600 AL & ONE #1 CU G	1KV/RHW-2 D.B.	600	443	0.0353	1.2%	1.5%	24%
3A	P2.4	SB-2	4	540	675	600A*	1240	1400	.97	1358	FOUR 4" PVC / D.B.	EA. WITH THREE #500 AL & ONE #1 CU G	1KV/RHW-2 D.B.	600	646	0.0424	1.1%	1.5%	19%
3A	P2.5	SB-2	4	540	675	600A*	1240	1400	.97	1358	FOUR 4" PVC / D.B.	EA. WITH THREE #500 AL & ONE #1 CU G	1KV/RHW-2 D.B.	600	933	0.0424	1.5%	2.1%	19%
2A	INV 2.1.1	P2.1	1	135	169	150A*	230	260	.97	252	2.5" PVC / D.B.	WITH THREE #300 AL & ONE #6 CU G	1KV/RHW-2 D.B.	600	947	0.0707	2.6%	2.7%	30%
2	INV 2.1.2	P2.1	1	135	169	150A*	205	230	.97	223	2.5" PVC / D.B.	WITH THREE #250 AL & ONE #6 CU G	1KV/RHW-2 D.B.	600	189	0.0847	0.6%	0.7%	30%
2	INV 2.1.3	P2.1	1	135	169	150A*	205	230	.97	223	2.5" PVC / D.B.	WITH THREE #250 AL & ONE #6 CU G	1KV/RHW-2 D.B.	600	93	0.0847	0.3%	0.4%	30%



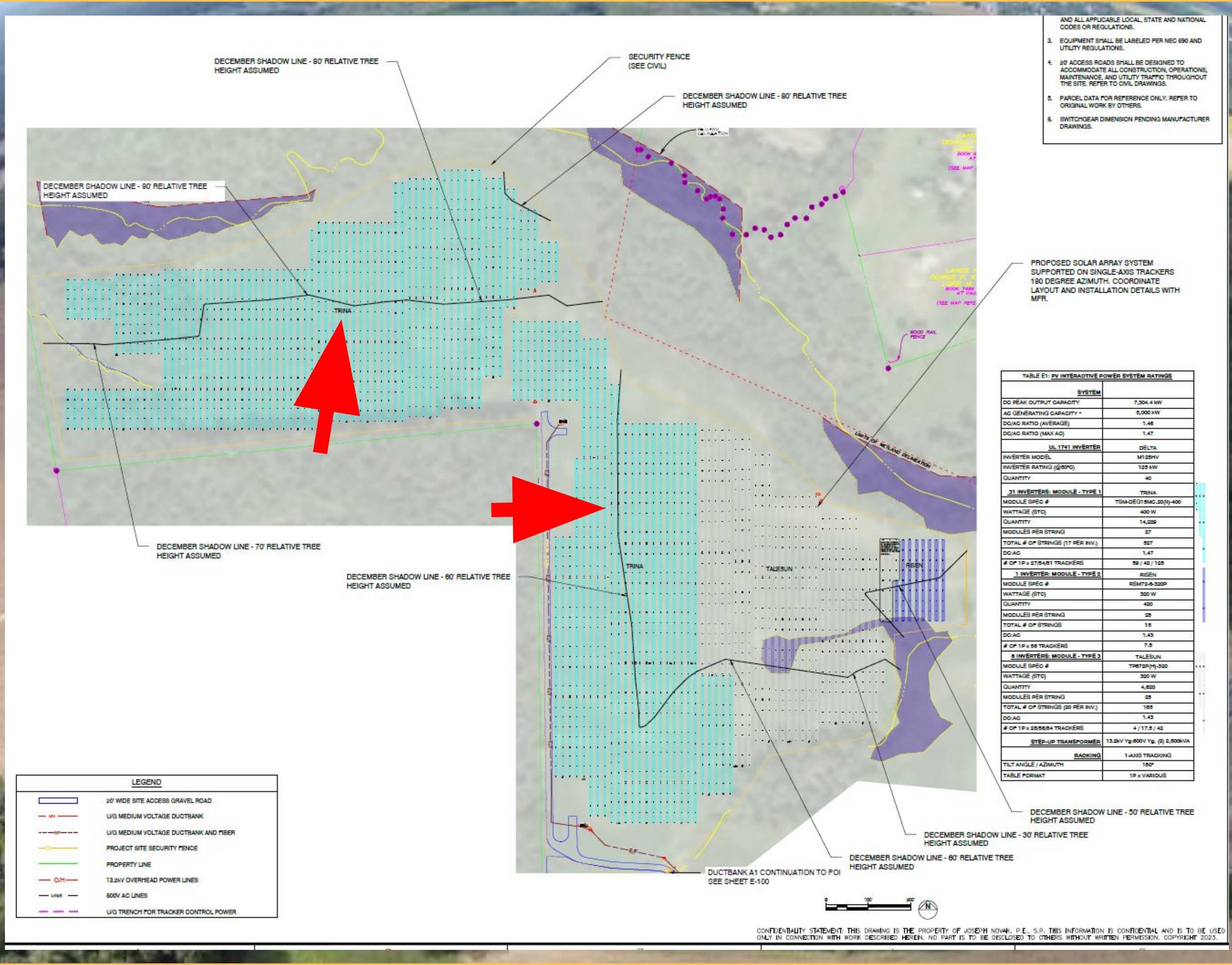
Not ideal



Bill Novak, P.E., MSE, MBA
(615) 538-8519 bill.novak@tropenas.com
Licensed Professional Engineer, S.P.: AL, AR, FL, GA, KS, KY, LA, MA, MD, ME, MI, MN, MS, NM, NY, NC, OH, SC, TN, TX, UT, VA
Tropenas Company Licensed Engineering Firm: MA, TN, TX

System design for utility-scale solar PV and Battery Energy Storage Systems

Example Layout 3
Tree shading



AND ALL APPLICABLE LOCAL, STATE AND NATIONAL CODES OR REGULATIONS.

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5. PARCEL DATA FOR REFERENCE ONLY. REFER TO ORIGINAL WORK BY OTHERS.
6. SWITCHGEAR DIMENSION PENDING MANUFACTURER DRAWINGS.

TABLE E1: PV INTERACTIVE POWER SYSTEM RATINGS

SYSTEM	
DC PEAK OUTPUT CAPACITY	7,304.4 kW
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DC/AC RATIO (MAX AC)	1.47
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INVERTER MODEL	M125HV
INVERTER RATING (@50°C)	125 kW
QUANTITY	40
31 INVERTERS: MODULE - TYPE 1	TRINA
MODULE SPEC #	TSM-DEG15MC.20(II)-400
WATTAGE (STC)	400 W
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1 INVERTER: MODULE - TYPE 2	RISEN
MODULE SPEC #	RSM72-6-320P
WATTAGE (STC)	320 W
QUANTITY	420
MODULES PER STRING	28
TOTAL # OF STRINGS	15
DC:AC	1.43
# OF 1P x 56 TRACKERS	7.5
8 INVERTERS: MODULE - TYPE 3	TALESUN
MODULE SPEC #	TP672P(H)-320
WATTAGE (STC)	320 W
QUANTITY	4,620
MODULES PER STRING	28
TOTAL # OF STRINGS (20 PER INV.)	165
DC:AC	1.43
# OF 1P x 28/56/84 TRACKERS	4 / 17.5 / 42
STEP-UP TRANSFORMER	13.2kV Yg:600V Yg, (2) 2,500kVA
RACKING	1-AXIS TRACKING
TILT ANGLE / AZIMUTH	180°
TABLE FORMAT	1P x VARIOUS

LEGEND

▭	20' WIDE SITE ACCESS GRAVEL ROAD
— MV —	U/G MEDIUM VOLTAGE DUCTBANK
- - - MF - - -	U/G MEDIUM VOLTAGE DUCTBANK AND FIBER
—○—	PROJECT SITE SECURITY FENCE
—	PROPERTY LINE
— O/H —	13.2kV OVERHEAD POWER LINES
— U/G/R —	600V AC LINES
— — —	U/G TRENCH FOR TRACKER CONTROL POWER

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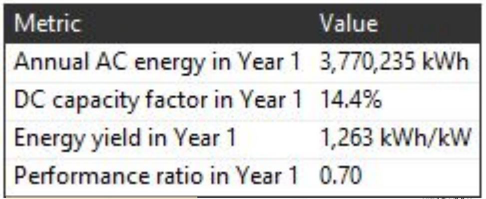
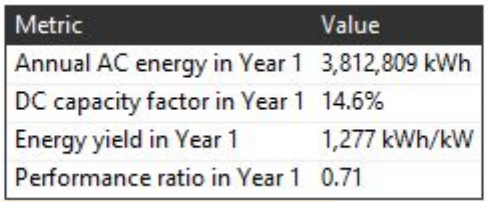
Example Layouts
Fixed Tilt - Ballasted Landfills

RENEWABLE ENERGY ENGINEERING



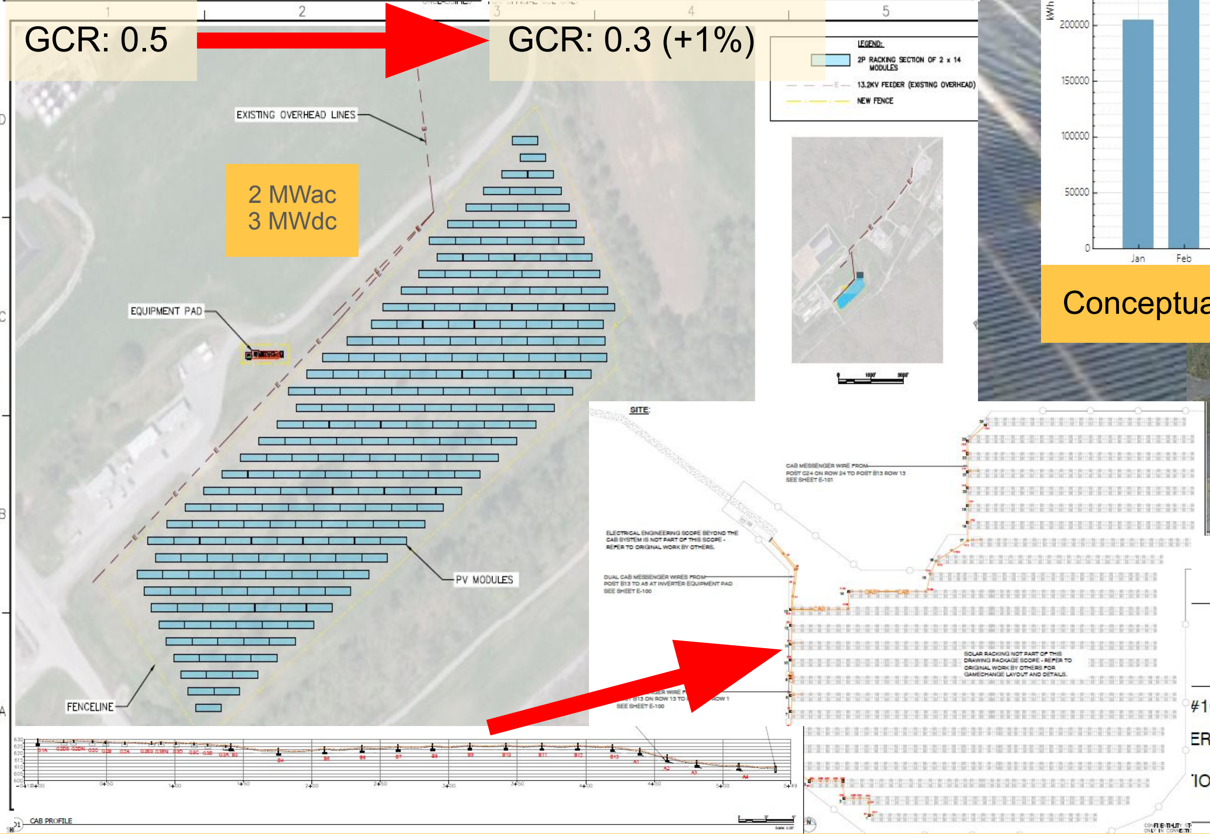
Metric	Value
Annual AC energy in Year 1	3,770,235 kWh
DC capacity factor in Year 1	14.4%
Energy yield in Year 1	1,263 kWh/kW
Performance ratio in Year 1	0.70



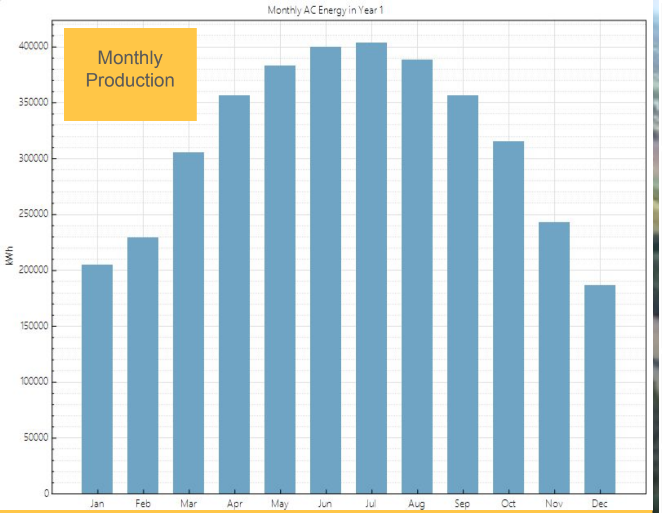
Metric	Value
Annual AC energy in Year 1	3,812,809 kWh
DC capacity factor in Year 1	14.6%
Energy yield in Year 1	1,277 kWh/kW
Performance ratio in Year 1	0.71

GCR: 0.5

GCR: 0.3 (+1%)

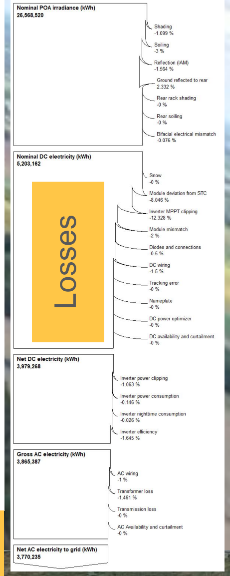


2 MWac
3 MWdc

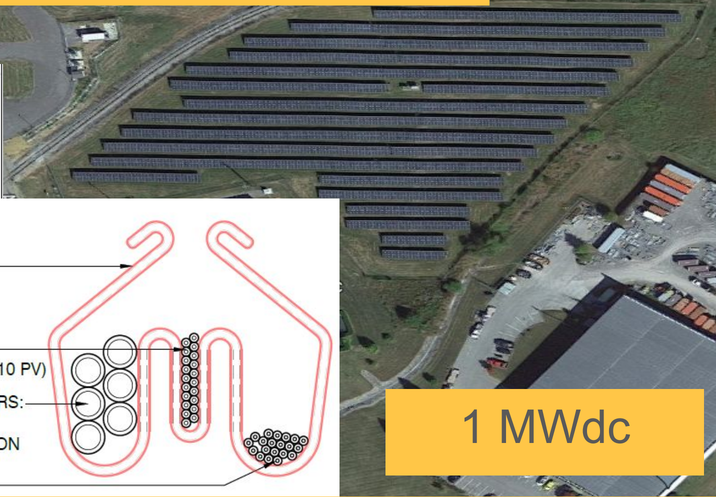


Monthly Production

Conceptual values only, plus or minus 20%



Losses



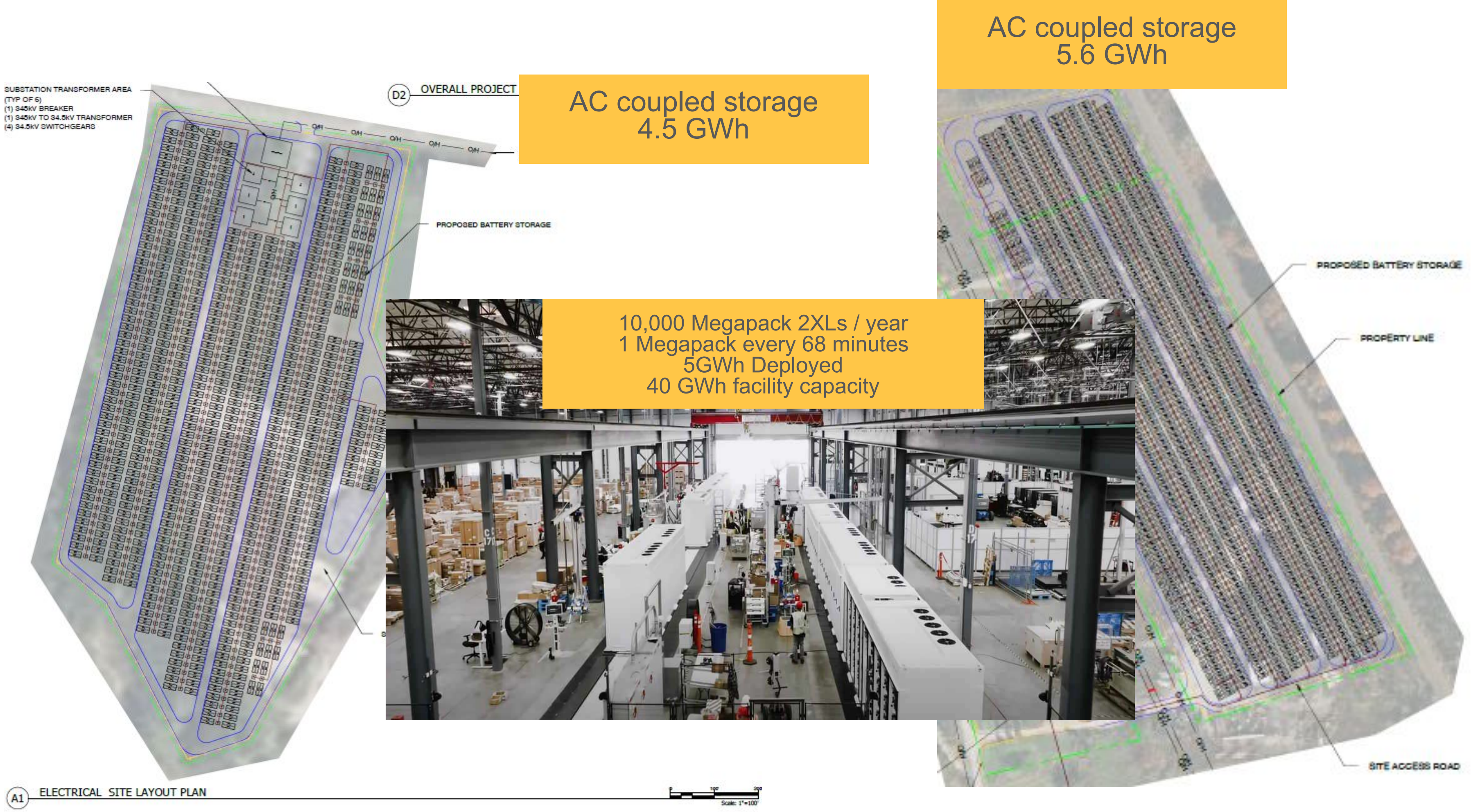
1 MWdc

Bill Novak, P.E., MSE, MBA
(615) 538-8519 bill.novak@tropenas.com
Licensed Professional Engineer, S.P.: AL, AR, FL, GA, KS, KY, LA, MA, MD, ME, MI, MN, MS, NM, NY, NC, OH, SC, TN, TX, UT, VA
Tropenas Company Licensed Engineering Firm: MA, TN, TX

AC coupled storage

System design for utility-scale solar PV and Battery Energy Storage Systems

Example AC coupled BESS



AC coupled storage
4.5 GWh

AC coupled storage
5.6 GWh

10,000 Megapack 2XLs / year
1 Megapack every 68 minutes
5GWh Deployed
40 GWh facility capacity

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System design for utility-scale solar PV and Battery Energy Storage Systems

Example Layouts
Fixed Tilt - US Navy

7 MWdc

Parking canopies

Fixed Tilt

Site overview

System design for utility-scale solar PV and Battery Energy Storage Systems

Example Layouts
Fixed Tilt - US Navy

12 MWdc

Fixed tilt - piles

Ballasted landfill

Ballasted - rock

Thank you!

Bill Novak, P.E., MSE, MBA
Tropenas Company
President and Chief Engineer
(615) 538-8519
bill.novak@tropenas.com