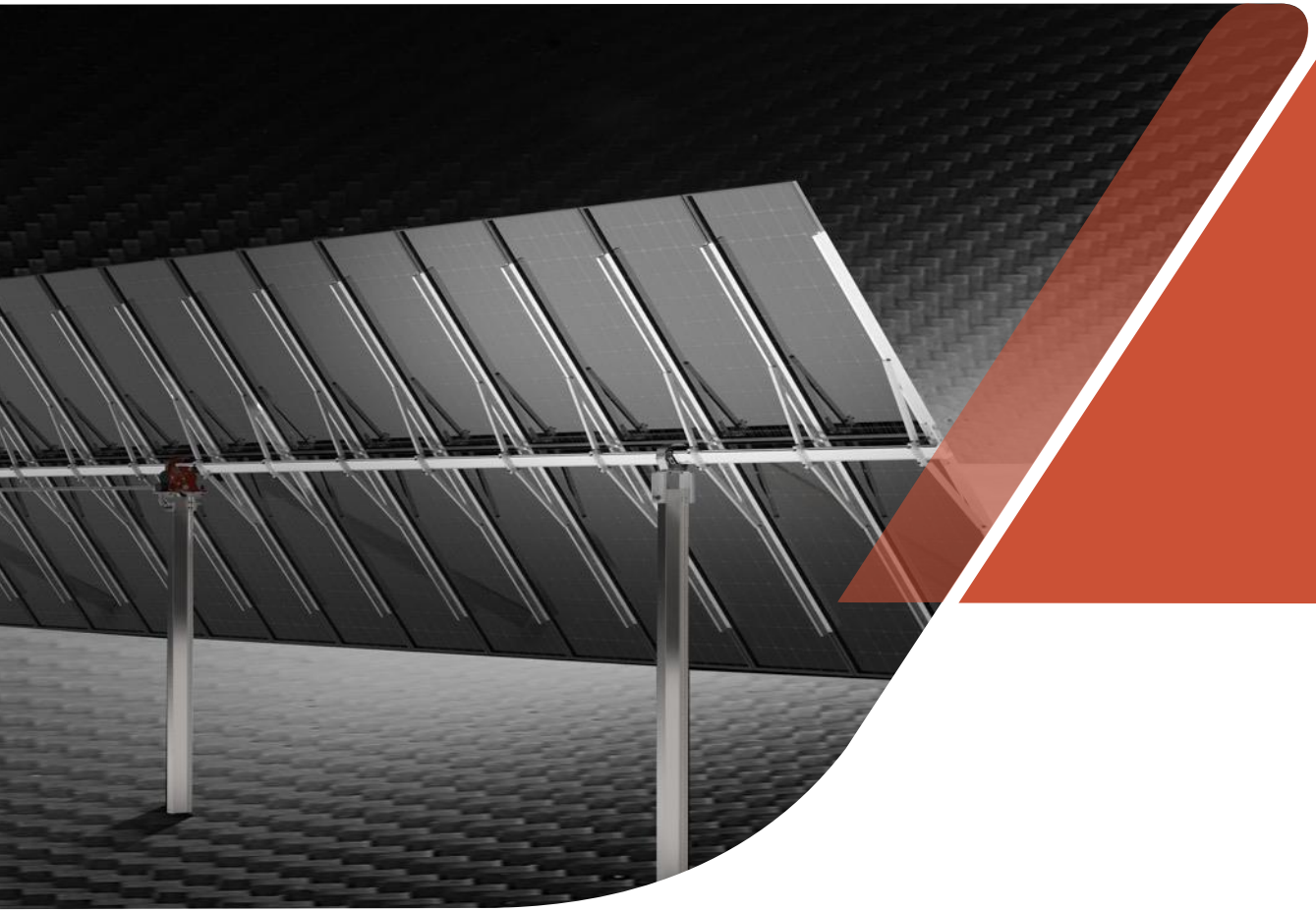
ARCTECH

SSE-STAR: 688408



How stiff trackers are safer and enable more energy generation

Pedro Magalhães
pedro.mag@arctehsolar.com

15th December 2021

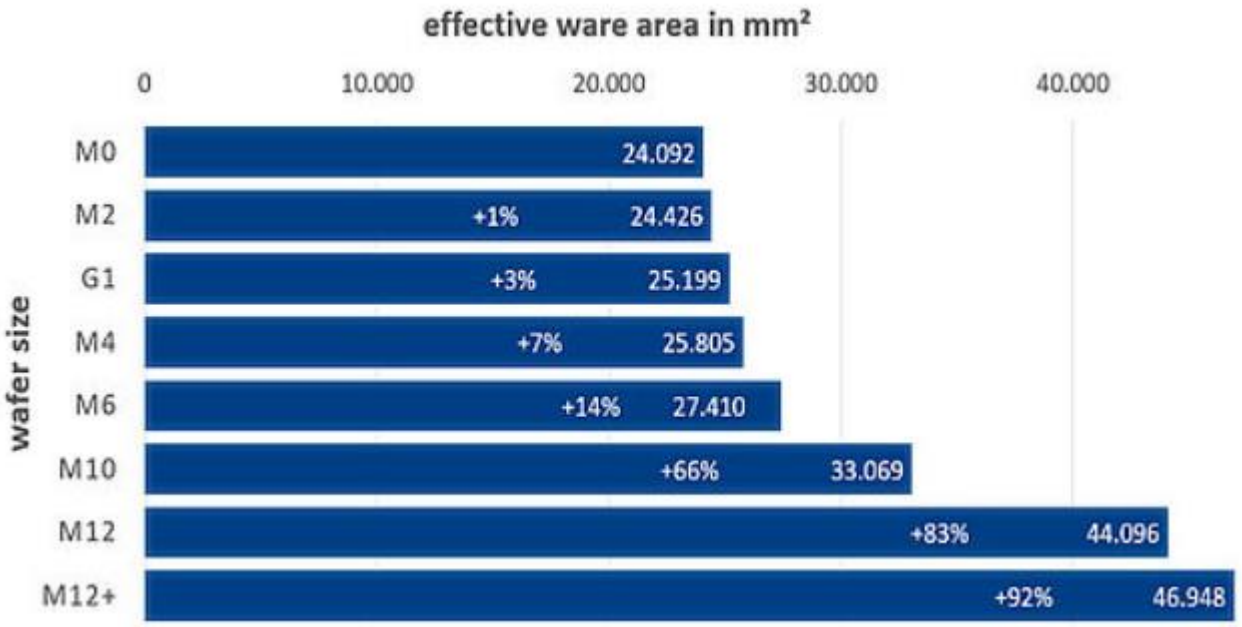
China · Japan · India · U.S. · Spain · Australia · UAE · Mexico · Chile · Brazil · Vietnam · Argentina

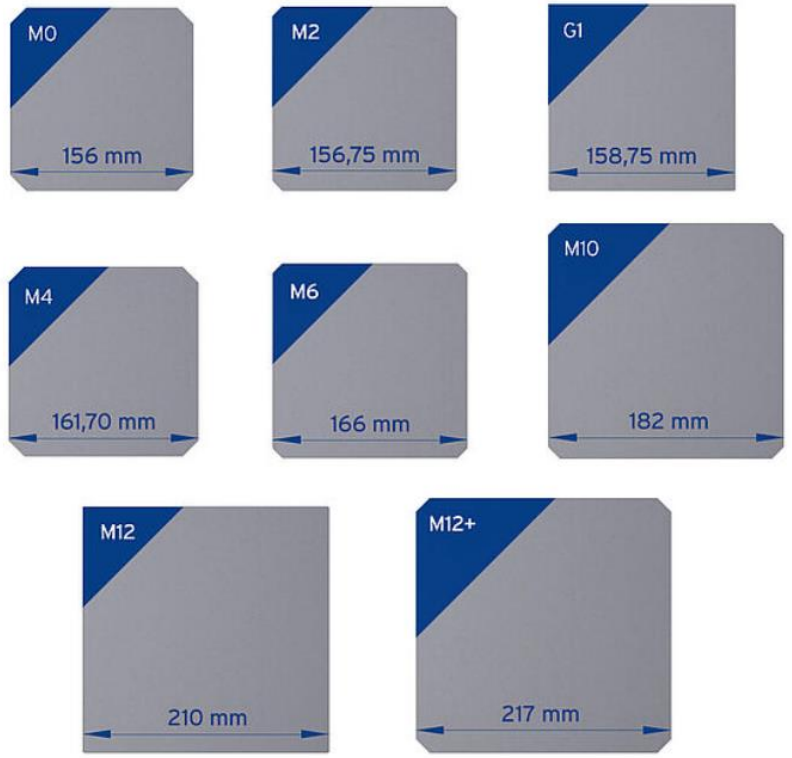
01

Current large format PV modules

PV MODULE SIZE EVOLUTION

WAFER SIZE COMPARISON





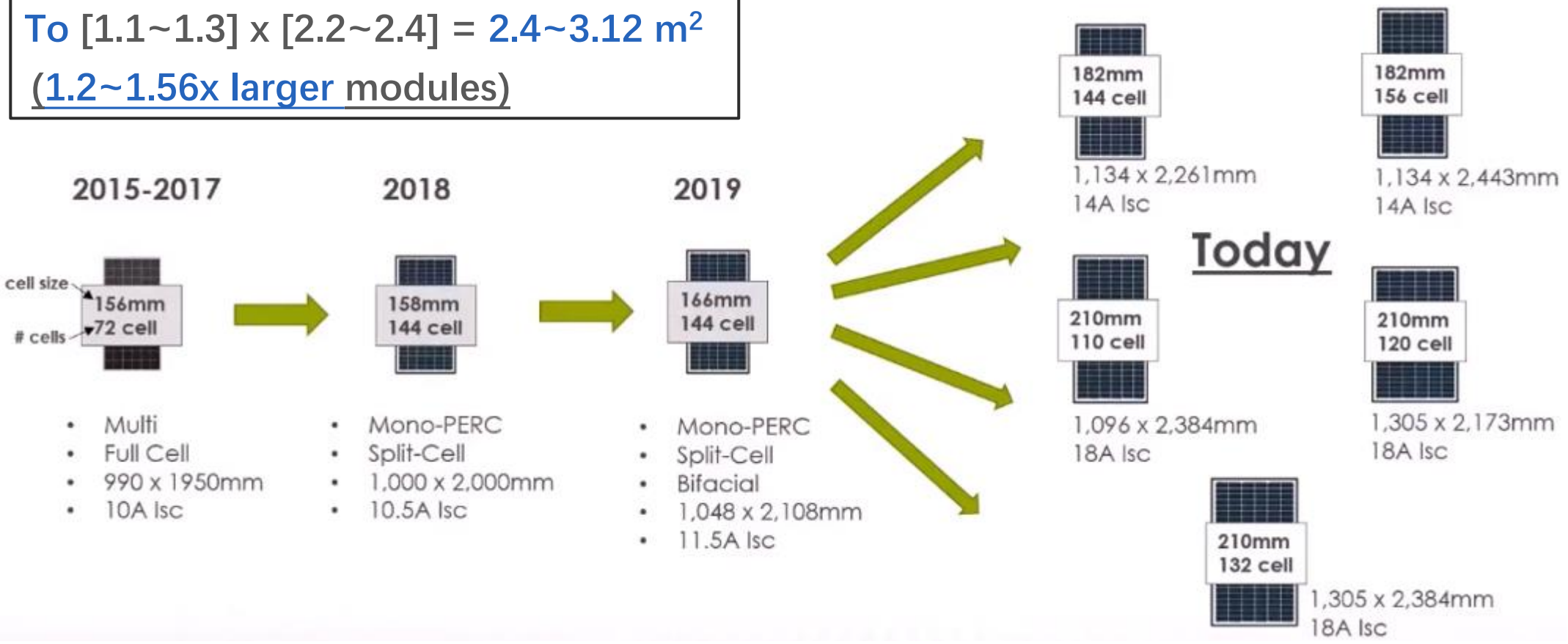
PV MODULE SIZE EVOLUTION

Cell size → Efficiency → Costs

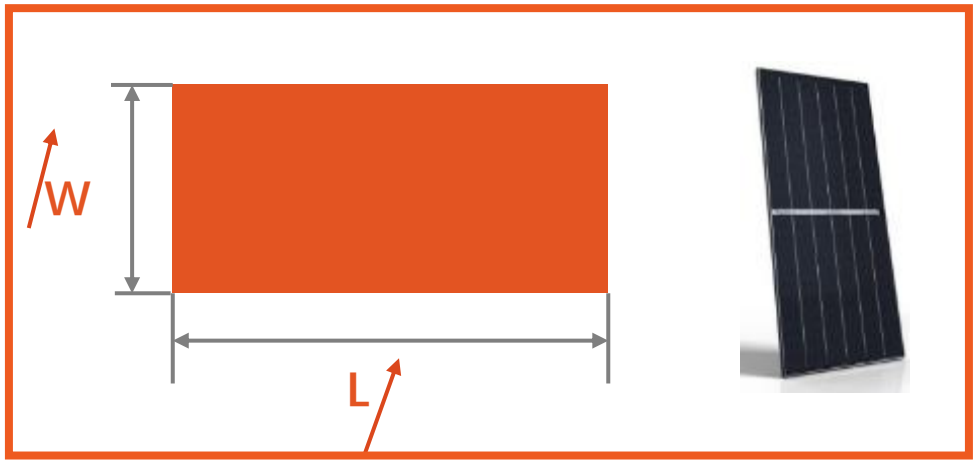
From L x W = 2 x 1 = 2 m^2

To [1.1~1.3] x [2.2~2.4] = 2.4~3.12 m^2

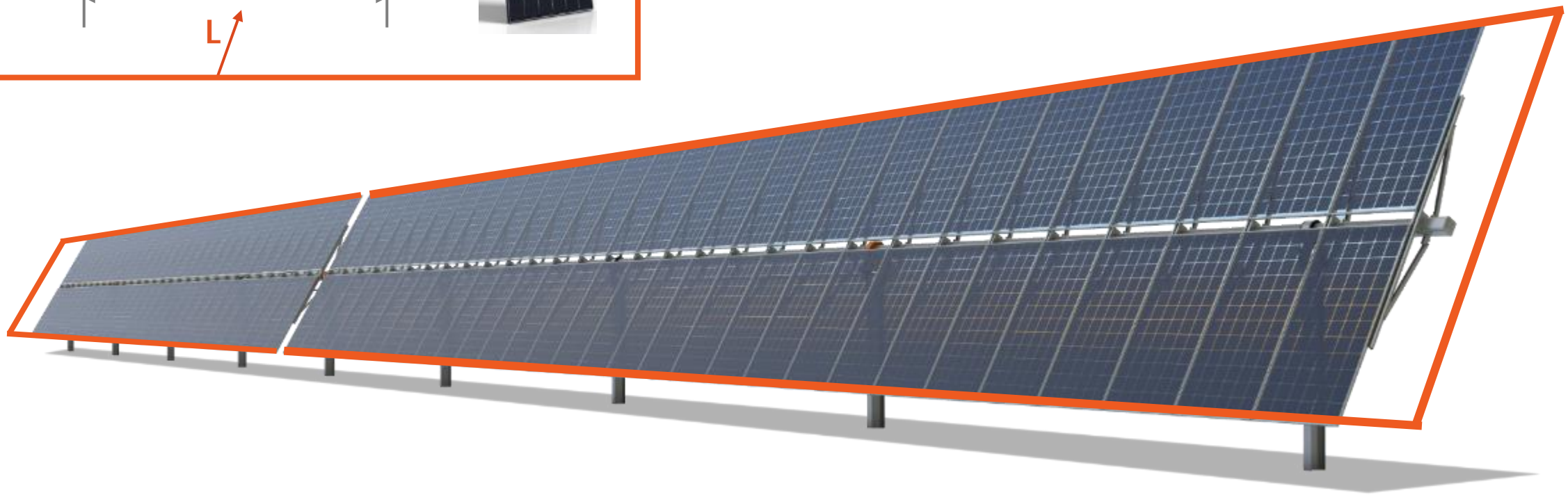
(1.2~1.56x larger modules)



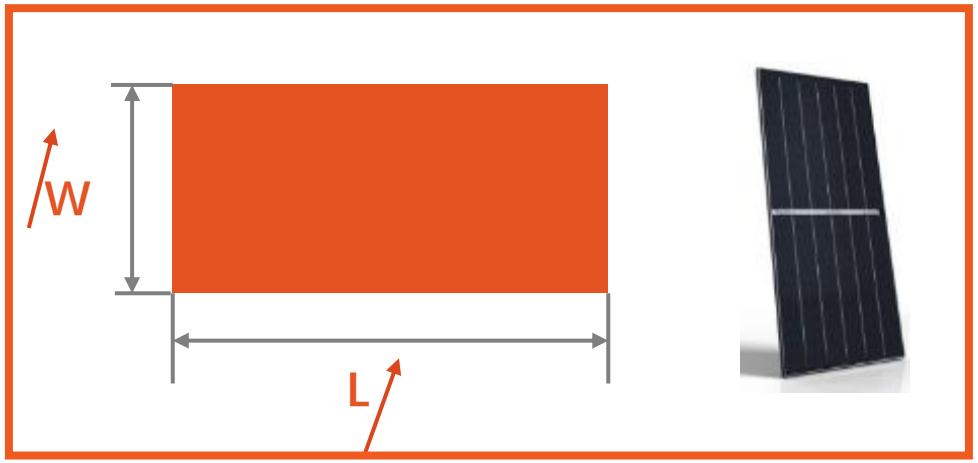
LARGE MODULES IMPACT ON TRACKERS



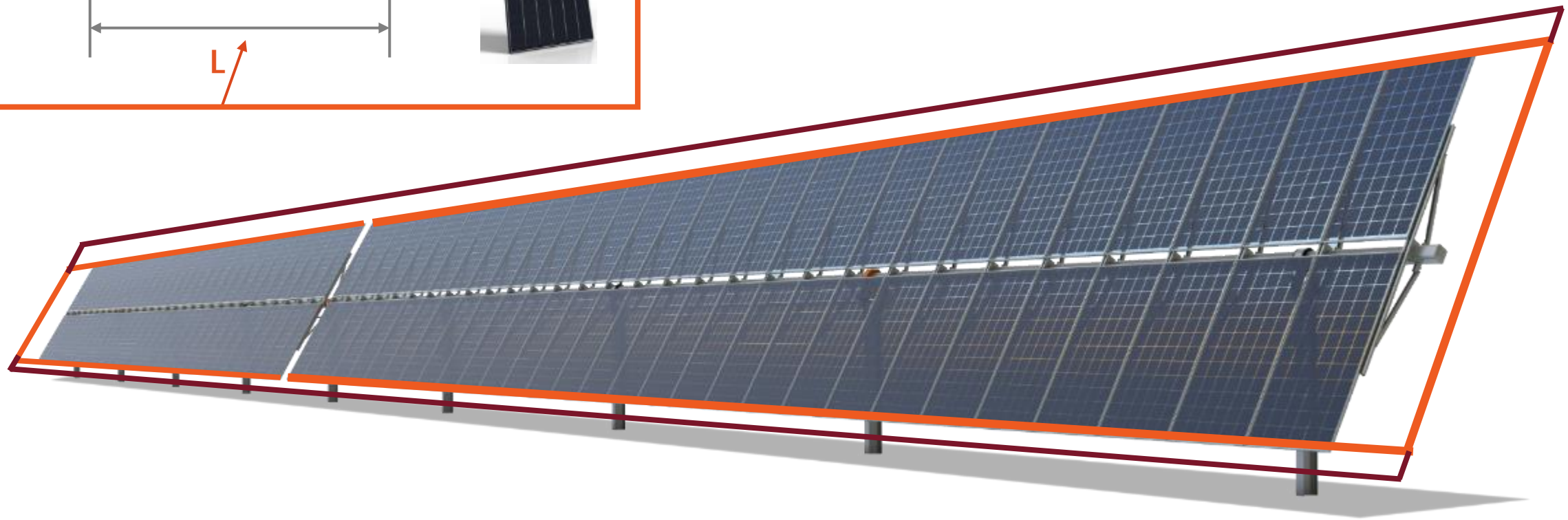
- **Longer Trackers**



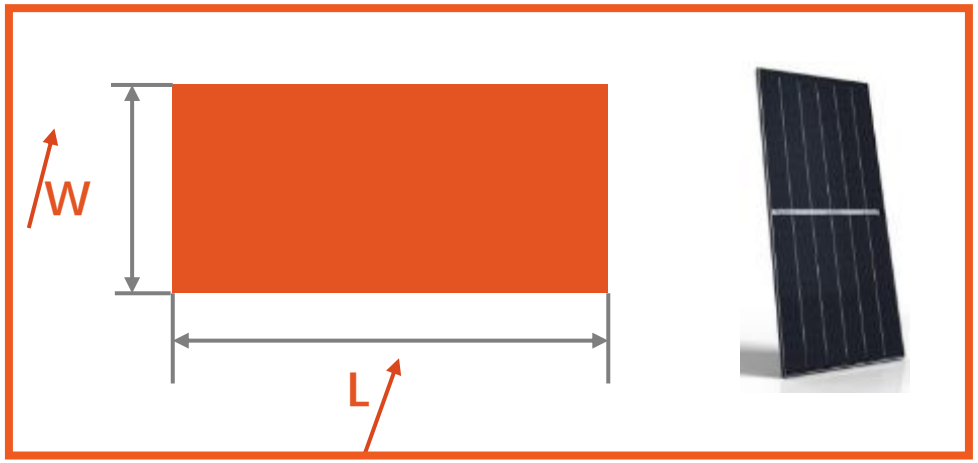
LARGE MODULES IMPACT ON TRACKERS



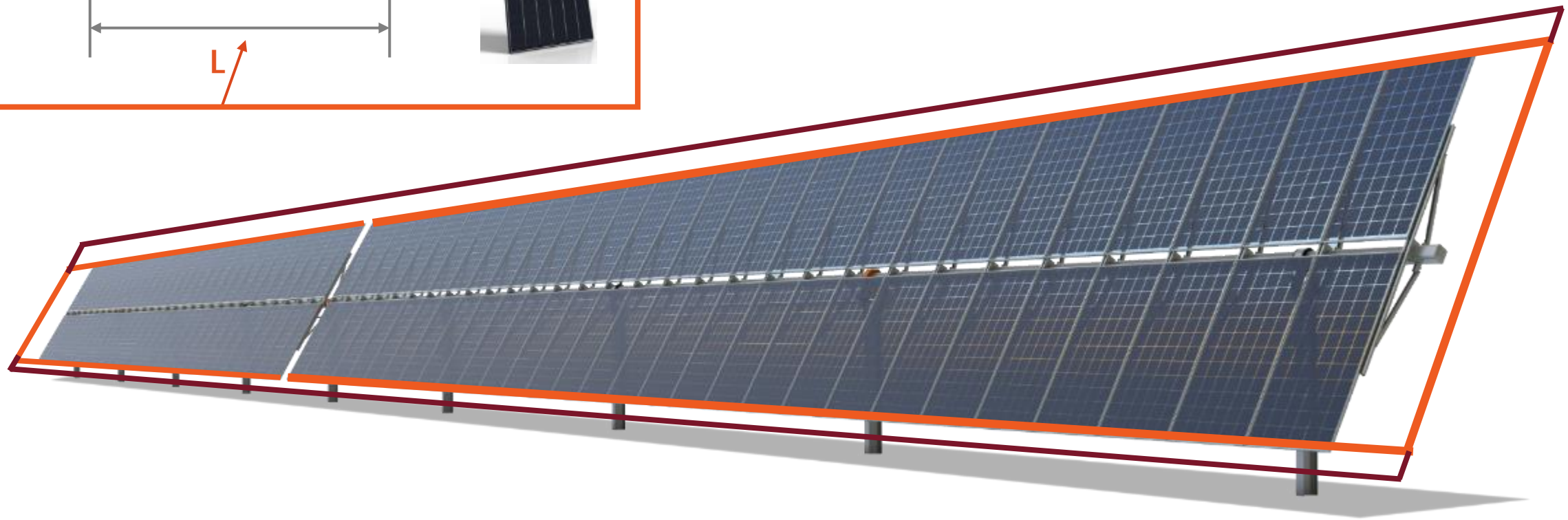
- Longer Trackers
- Taller Trackers



LARGE MODULES IMPACT ON TRACKERS

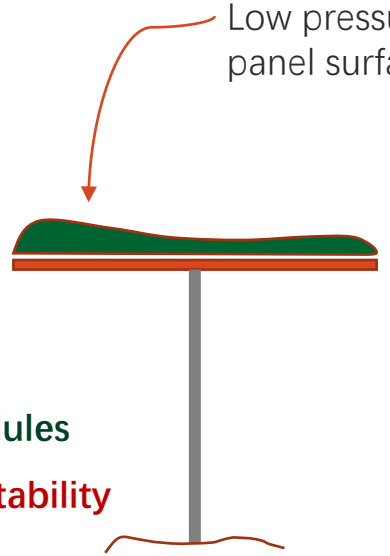


1. Larger WTT coefficients
2. Lowers critical wind speed of stability



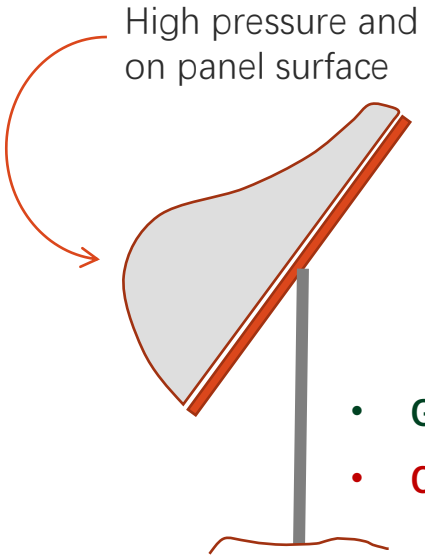
IMPACT ON MODULE PRESSURE

Region	Building Code	Wind Speed (m/s)	Basic Wind Pressure (Pa)	30 Deg Wind Pressure (Pa)	0 Deg Wind Pressure (Pa)
USA	ASCE 7-16	47	1151	3100	1800
Europe	EuroCODE	27	1307	3500	2000
Australia	AS 1170	41	1009	2700	1600



- Good for PV Modules
- Bad for Tracker Stability

Wind Stow at 0 Deg



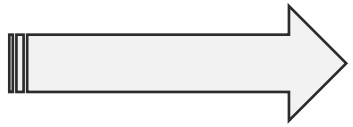
- Good for Tracker
- Challenging for PV Modules

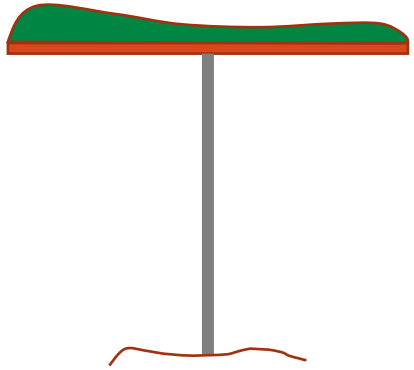
Wind Stow at 30 Deg

EFFICIENT TRACKER FOR LARGE MODULES

Tracker must be:

- Very **Rigid**
- **Low Deflection**





STOW AT 0°

How to achieve it?

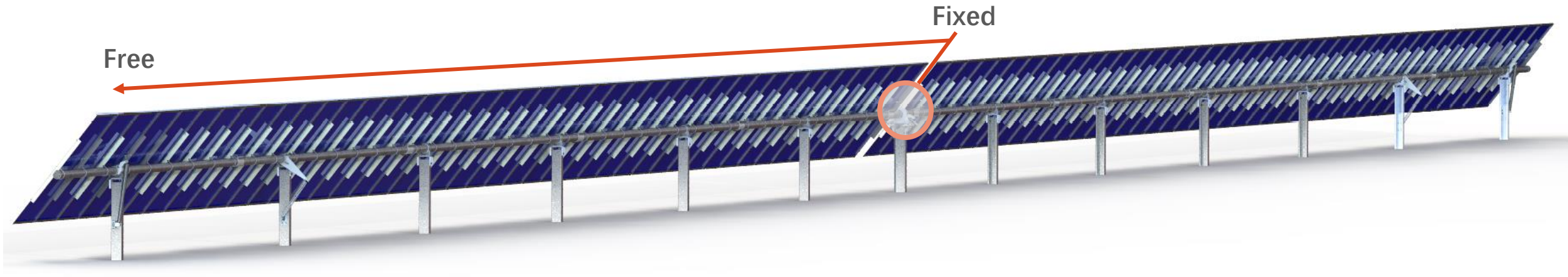
1. Throw ~~more steel~~ in
2. **Arctech's stiff design**

02

STIFF TRACKERS - the future of PV

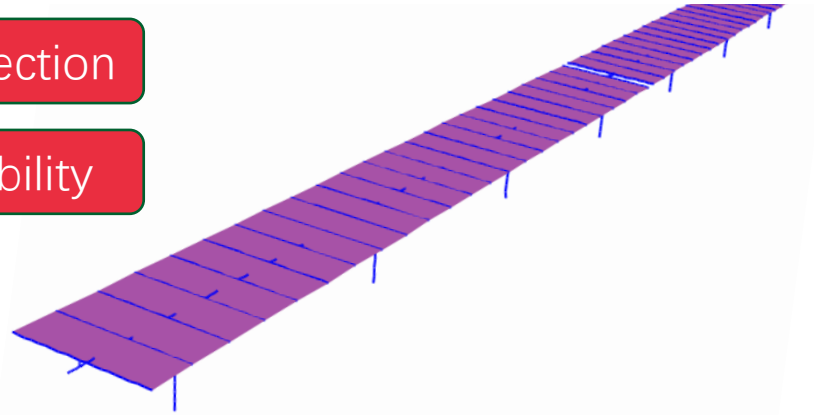
TYPICAL INSTABILITY CURVES

Traditional Trackers



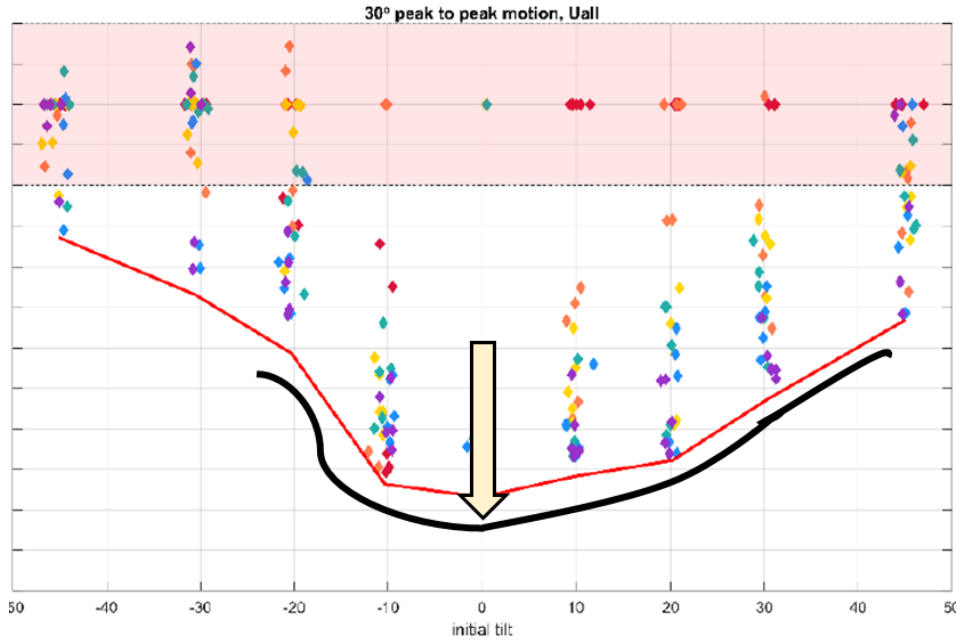
Panel size → Tracker Chord & Spans → Deflection / Stability

No Control
Depends on panel and string size



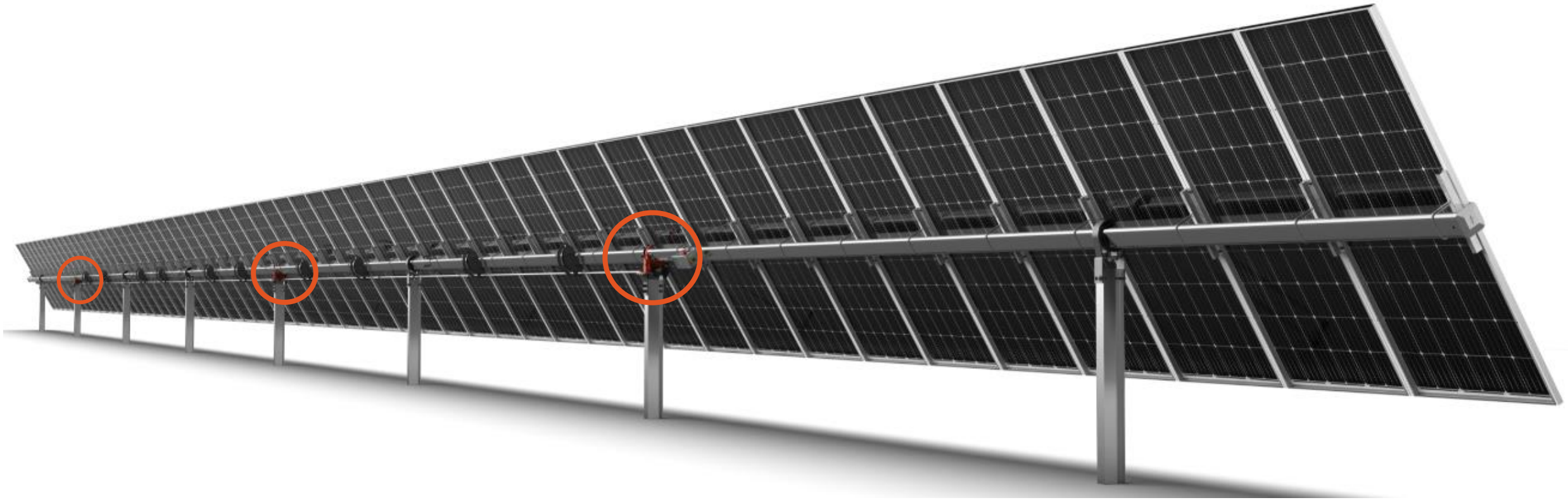
CHALLENGES OF TRADITIONAL FLEXIBLE TRACKERS

1. **Large modules lower Ucr** to less than wind stow
2. Wind **Stow at 30 Deg – bad for panels**
3. **Dampers** – expensive and questionable reliability
4. **Many post and TT types** – different sizes and thicknesses
5. **Many tracker types** – Ext, Int, Far



SOLUTION = ARCTECH'S STIFF TRACKERS

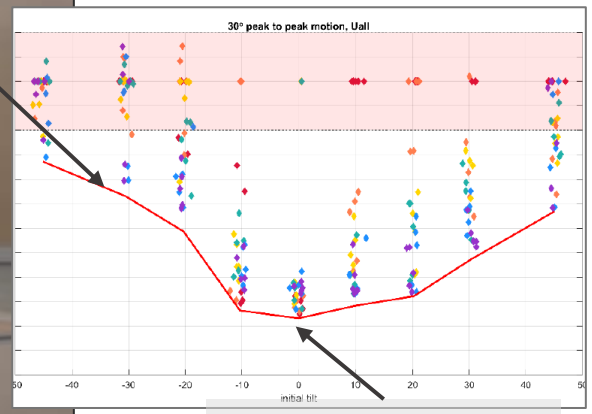
Very Stiff Tracker – Wind Stow at 0 Deg



TRADITIONAL VS NOVEL (STIFF AND MODULAR)

Traditional Tracker - Wind Stow at **30 Deg**

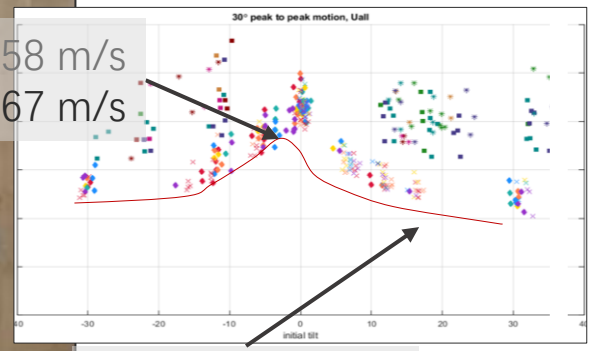
2P: Ucr = 50 m/s
1P: Ucr = 55 m/s



2P: Ucr = 23 m/s
1P: Ucr = 20 m/s

Stiff Tracker – Wind Stow at **0 Deg**

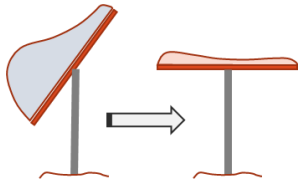
2P: Ucr = 58 m/s
1P: Ucr = 67 m/s



2P: Ucr = 35 m/s
1P: Ucr = 40 m/s

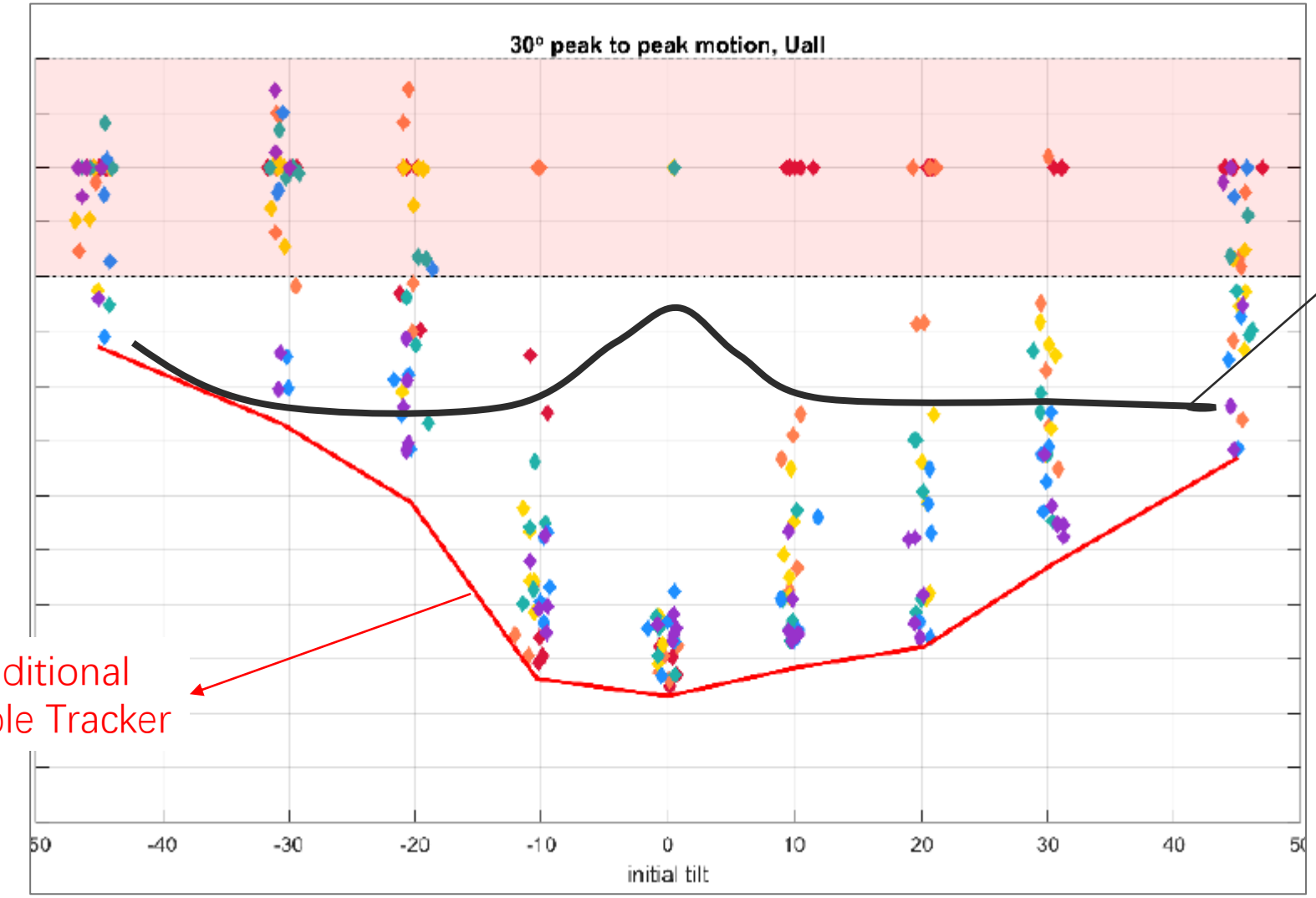
WHY VERY RIGID TRACKERS?

1. Highest **stability** at **all tilts**
2. Stow a **0deg**
   - Less steel
   - **Lower Panel pressure**



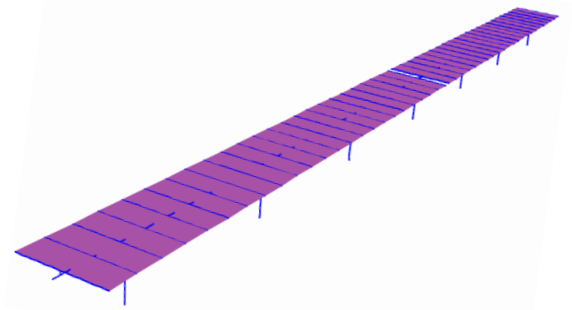
3. **Highest Stow** in the market – **22 m/s** – more energy yield
4. **Modular** construction – 1, 2, 3 & 4 strings
5. Simplicity in the field – **Only 1 tracker type** (good bye ext, int, far…)

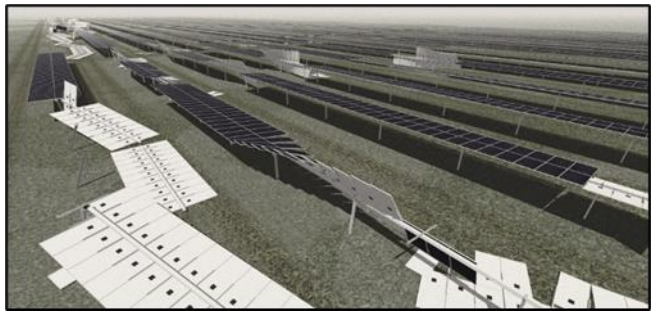
1. HIGHEST STABILITY AT ALL TILTS



Traditional
Flexible Tracker

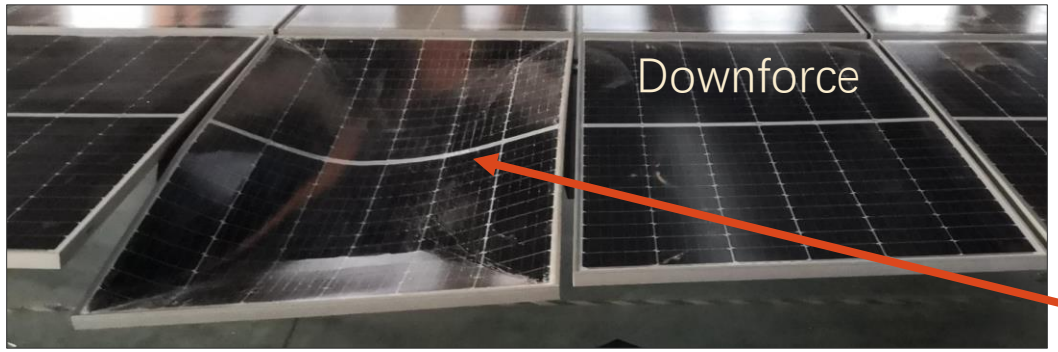
Rigid Tracker

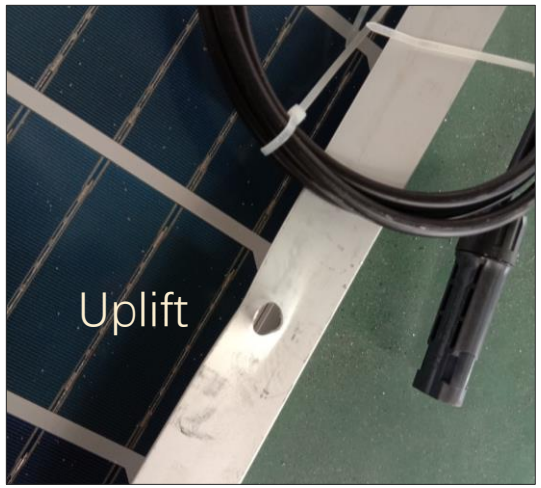


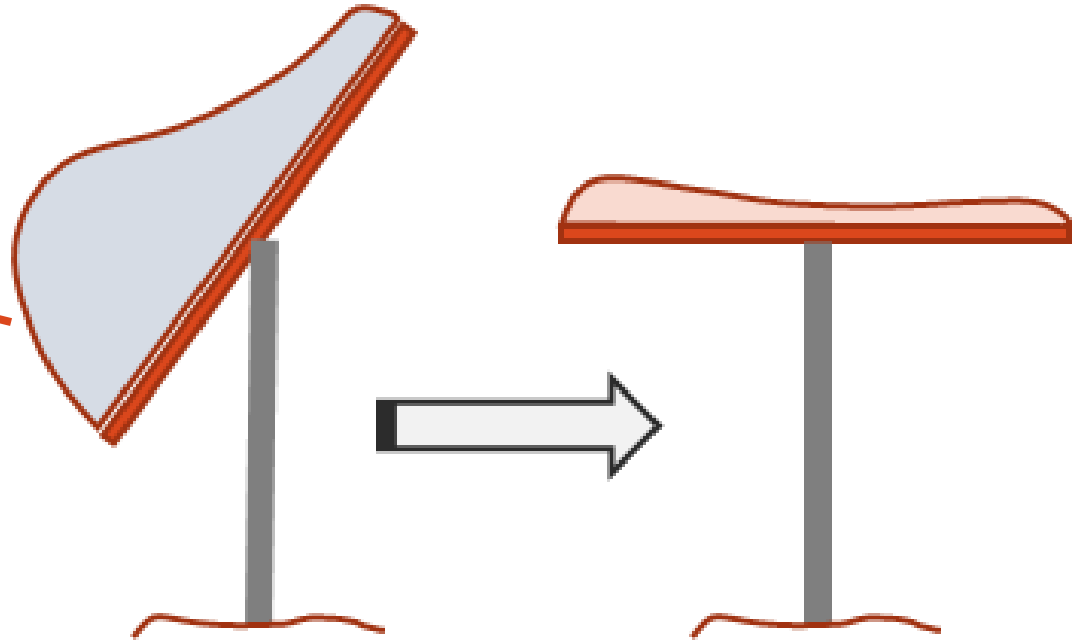


2. STOW HORIZONTALLY (0° TILT)

- Less steel
- Lower Panel pressure







3. HIGHEST STOW IN THE MARKET – 22 M/S

Low — Wind Speed Threshold → High

Stow Angle: 0° (Low) → High

14 m/s			16 m/s		18 m/s		SkySmart II		SkyLine II
-2.060%	-1.514%	-1.152%	-0.848%	-0.572%	-0.440%	-0.334%	-0.193%	-0.142%	-0.092%
-2.026%	-1.510%	-1.130%	-0.832%	-0.571%	-0.452%	-0.341%	-0.201%	-0.148%	-0.094%
-2.067%	-1.541%	-1.152%	-0.838%	-0.560%	-0.437%	-0.319%	-0.160%	-0.118%	-0.080%
-2.225%	-1.752%	-1.330%	-0.928%	-0.618%	-0.475%	-0.385%	-0.218%	-0.170%	-0.113%
-2.547%	-1.887%	-1.401%	-0.989%	-0.644%	-0.497%	-0.412%	-0.279%	-0.203%	-0.128%
-2.392%	-1.766%	-1.344%	-0.980%	-0.685%	-0.552%	-0.371%	-0.209%	-0.153%	-0.072%
-2.731%	-1.980%	-1.533%	-1.192%	-0.852%	-0.696%	-0.493%	-0.233%	-0.158%	-0.117%
-3.101%	-2.322%	-1.708%	-1.237%	-0.842%	-0.679%	-0.465%	-0.348%	-0.283%	-0.156%
-3.014%	-2.152%	-1.616%	-1.282%	-0.885%	-0.765%	-0.551%	-0.362%	-0.190%	-0.160%
-3.645%	-2.725%	-2.006%	-1.375%	-0.863%	-0.652%	-0.558%	-0.398%	-0.226%	-0.137%

Energy Losses

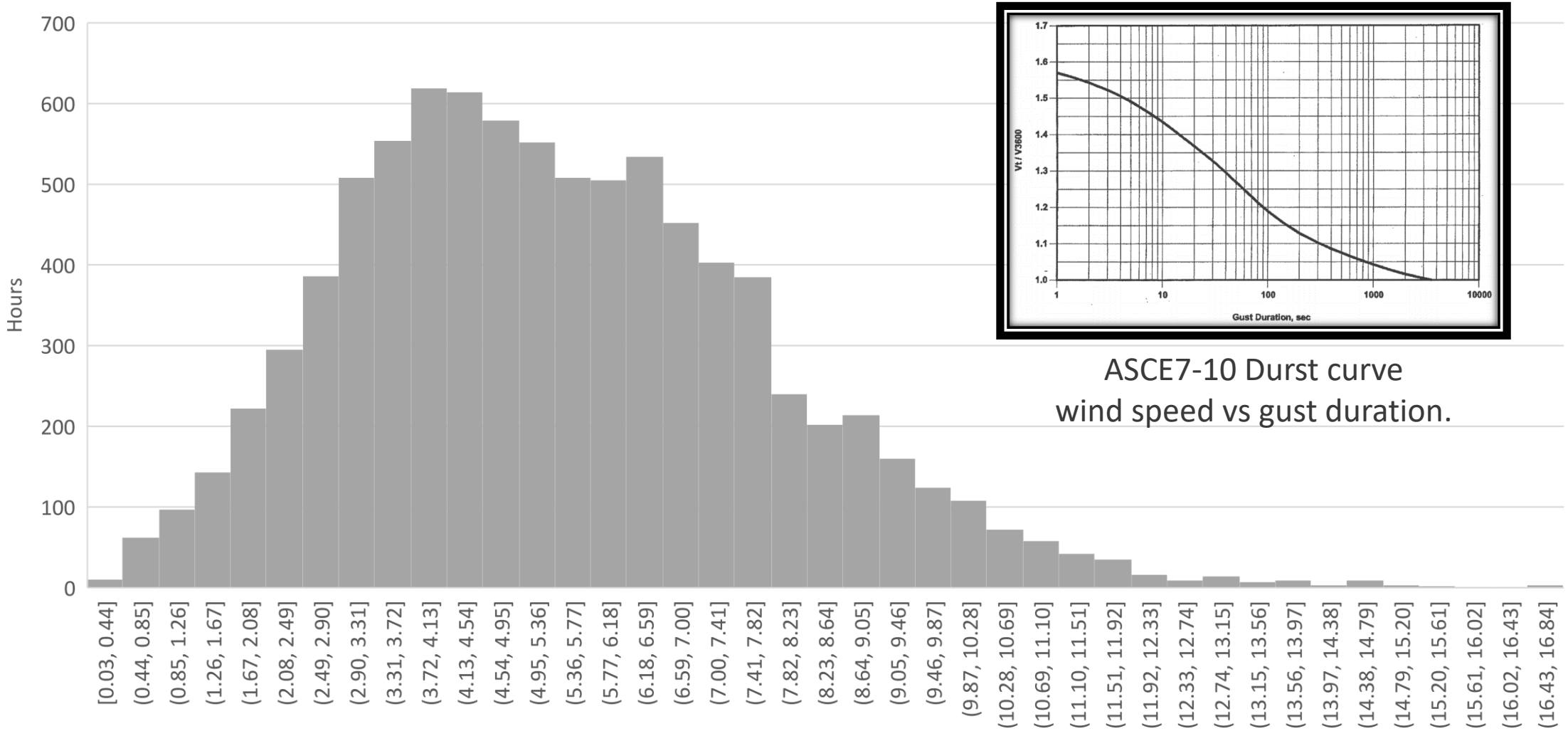
CASE STUDY – TEXAS, USA

Nearest town	Amarillo, Texas, USA
Coordinate	35.48°N, 101.34°W
Capacity	100MWdc

Model	Stow Angle (°)	Wind speed threshold (m/s, 3s gust at 10m height)	Representative
SkyLine II	0	22	Arctech 1P stiff tracker
SkySmart II	0	20	Arctech 2P stiff tracker
A	30	16	Well maintained traditional tracker
B	30	14	Flexible traditional tracker
C	45	12	Worst scenario

**Solar irradiation data: NREL NSRDB 2020*
**Wind data: MERRA-2 2020*

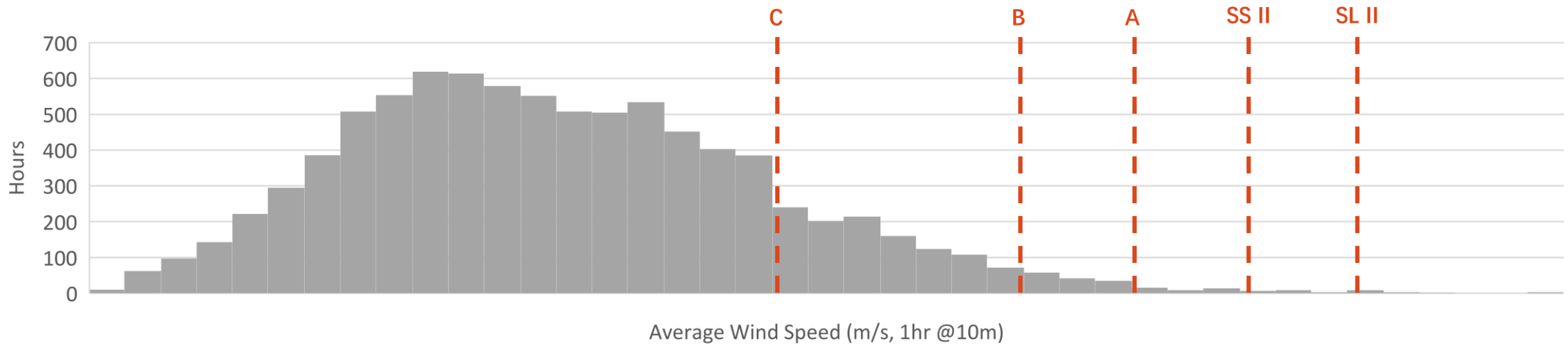
THE WIND SPEED DISTRIBUTION



ASCE7-10 Durst curve
wind speed vs gust duration.

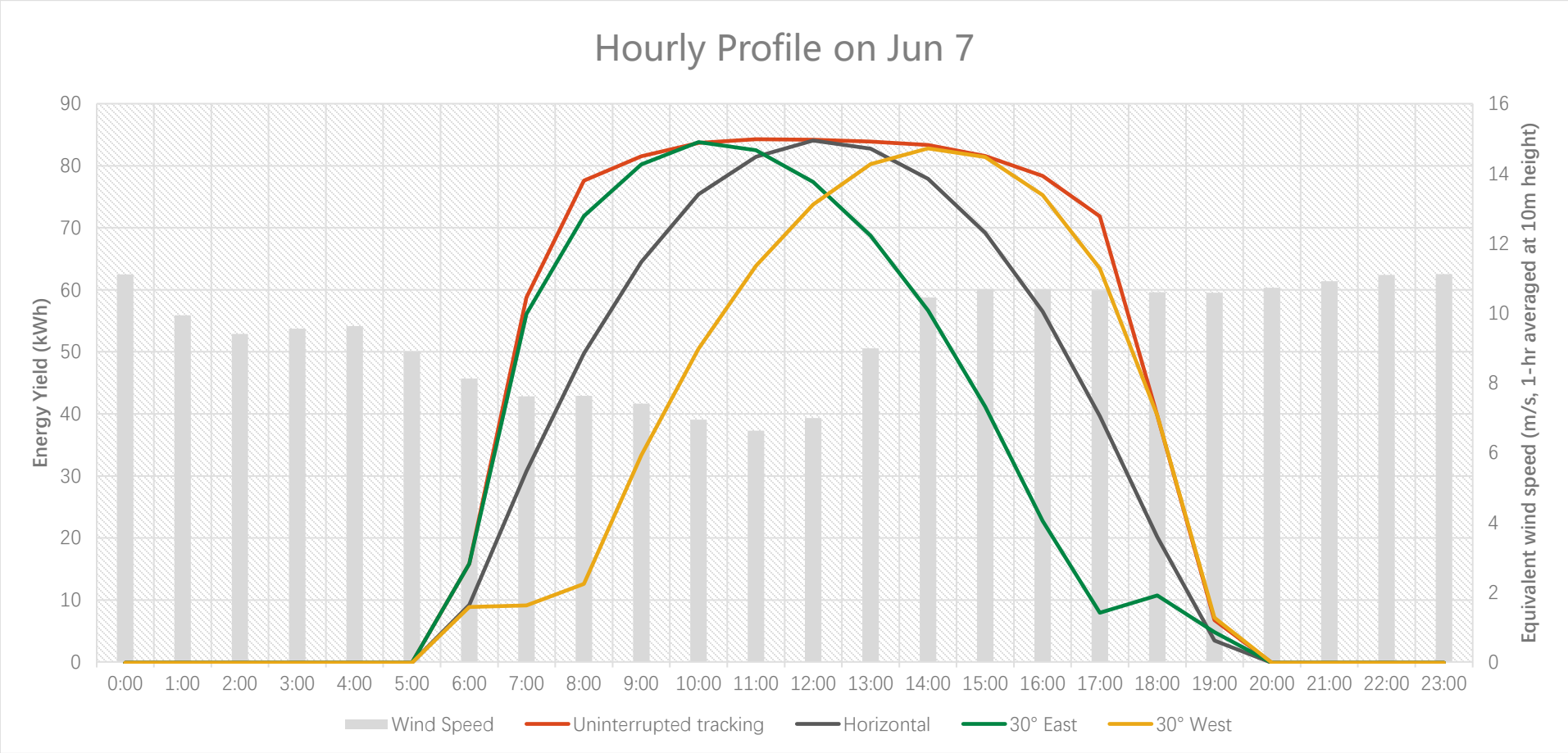
**Solar irradiation data: NREL NSRDB 2020*
**Wind data: MERRA-2 2020*

AMOUNT OF HOURS IN STOW



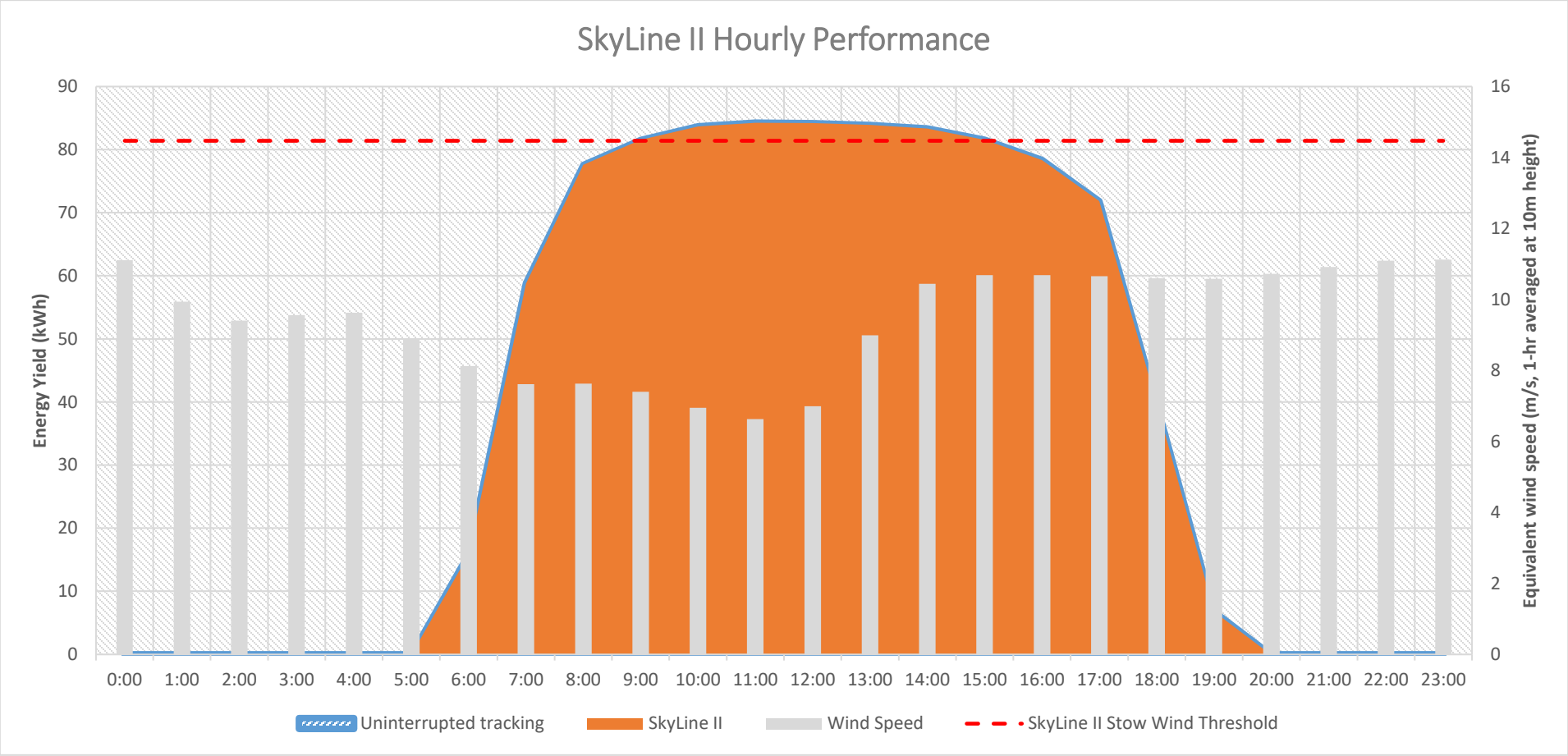
Model	Wind speed threshold (m/s, 3sec at 10m height)	Equivalent wind speed (m/s, 1-hr at 10m height)	Stow hours in total	Stow time per year (%)
SkyLine II	22	14.47	15	0.17%
SkySmart II	20	13.16	38	0.43%
A	16	10.53	243	2.77%
B	14	9.21	608	6.94%
C	12	7.89	1288	14.70%

THE HOURLY PROFILE



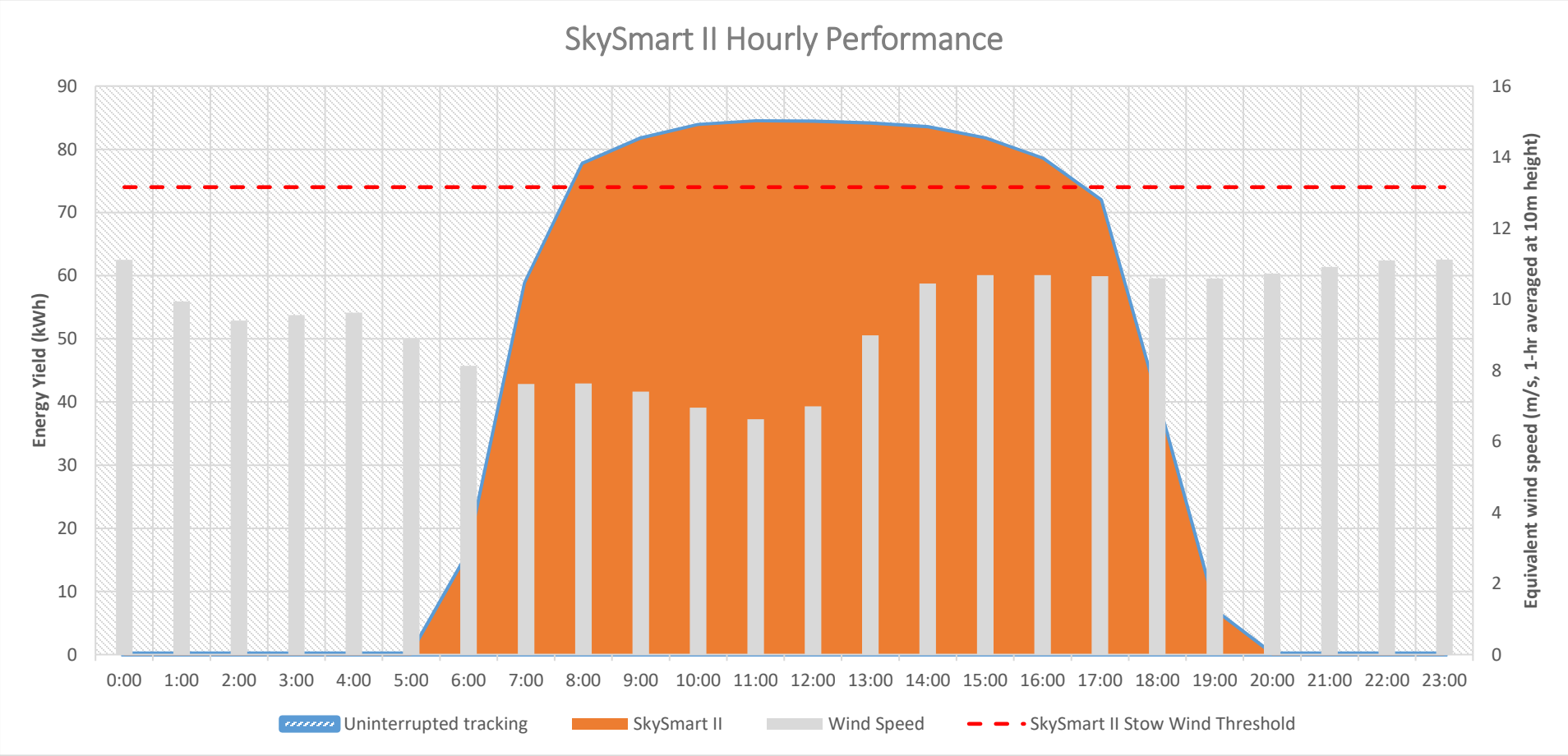
June 7th selected as a sample due to clear sky and high wind conditions.
Wind velocity stronger in the afternoon.
Northwestern wind direction the whole day except between 13:00 and 15:00.

SKYLINE II (22M/S, 0°)



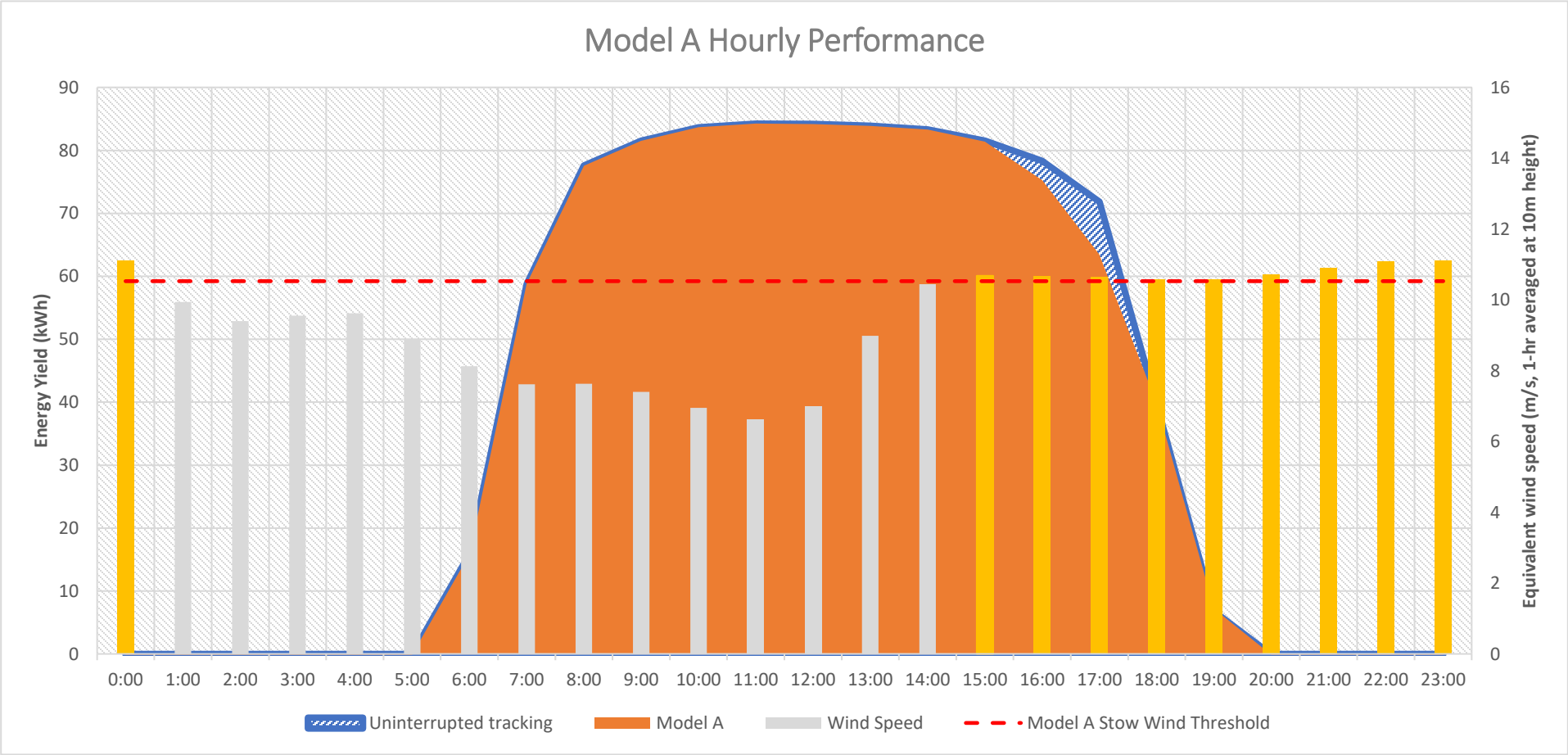
Wind speed was not high enough to reach SkyLine II and SkySmart II's threshold
So both trackers did not need to stow.
Energy output curve was the same as the uninterrupted tracking curve

SKYSMART II (20M/S, 0°)



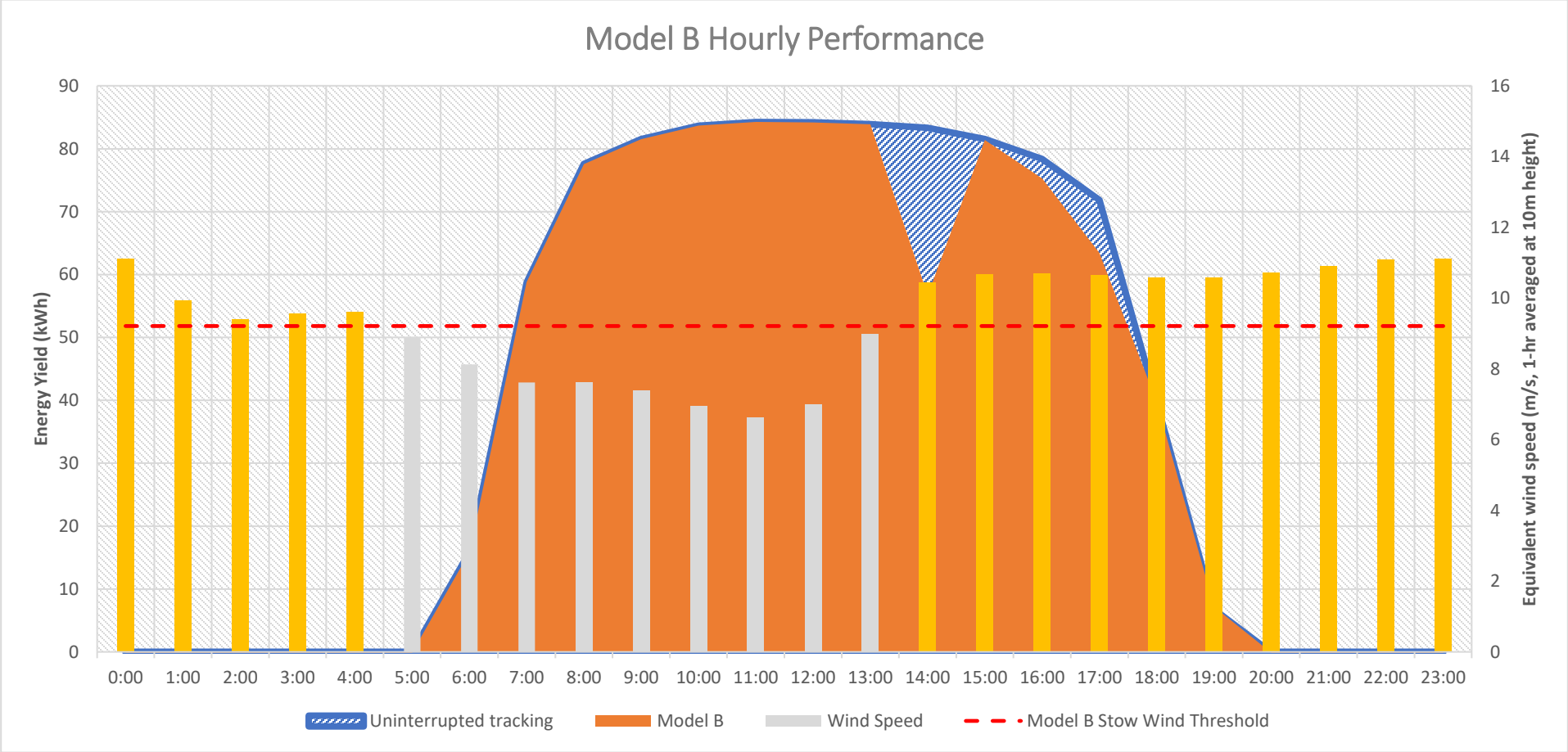
Wind speed was not high enough to reach SkyLine II and SkySmart II's threshold
So both trackers did not need to stow.
Energy output curve was the same as the uninterrupted tracking curve

TRACKER "A" (THRESHOLD=**16 M/S,** STOW TILT=**30°**)



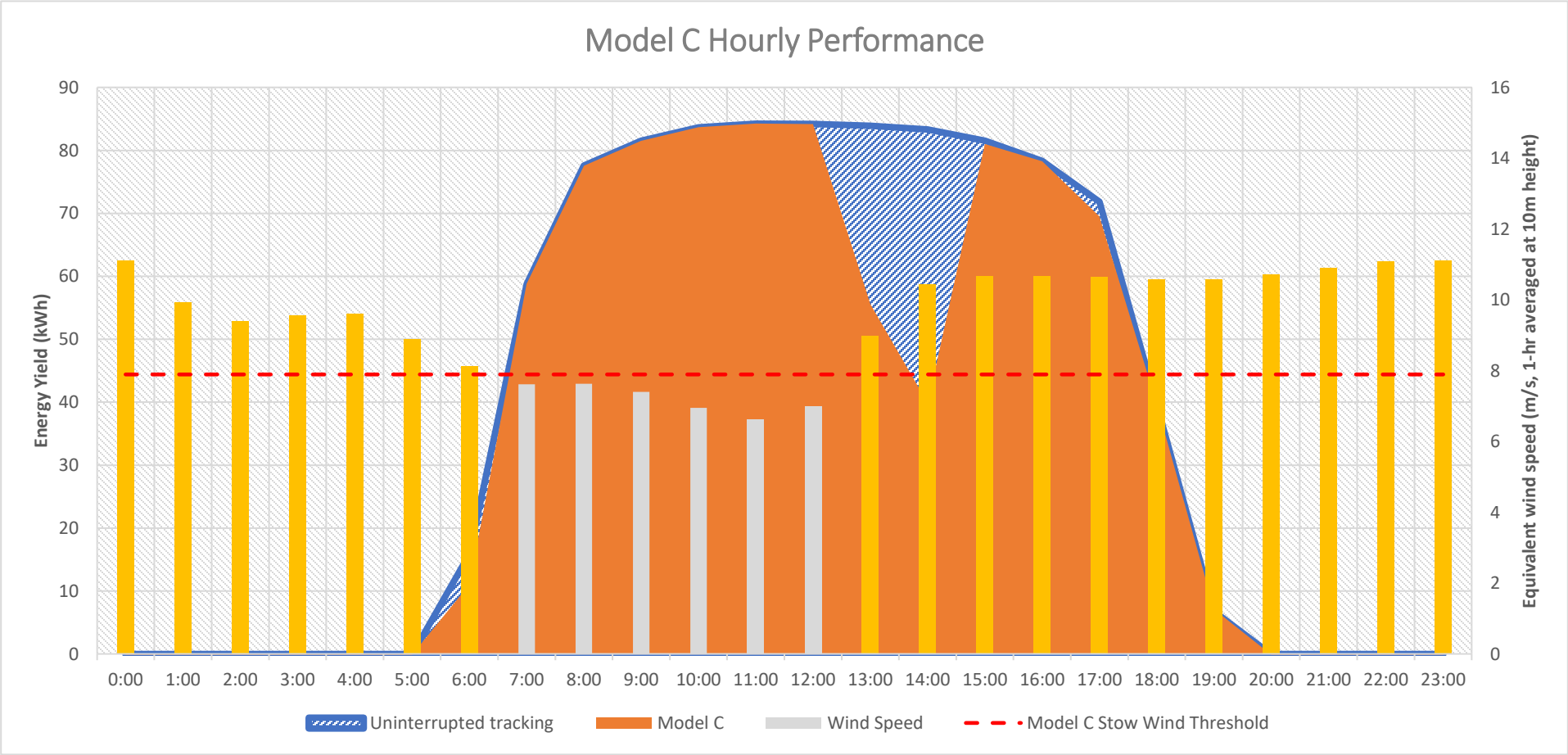
Tracker A saw its threshold exceeded after 15:00 (16m/s 3-s gust = 10.53m/s hourly, at 10m)
Tracker A stowed for several hours at 30-degree west, missing some kwh of energy (blue shade).

TRACKER B (THRESHOLD=14 M/S, STOW TILT=30°)



Tracker B has a lower threshold, hence a worse outcome. Not just the tracker had to stow from 14:00 rather 15:00, the stow position in that hourly were likely to be east facing, causing more energy loss.

TRACKER C (THRESHOLD=12 M/S, STOW TILT=45°)



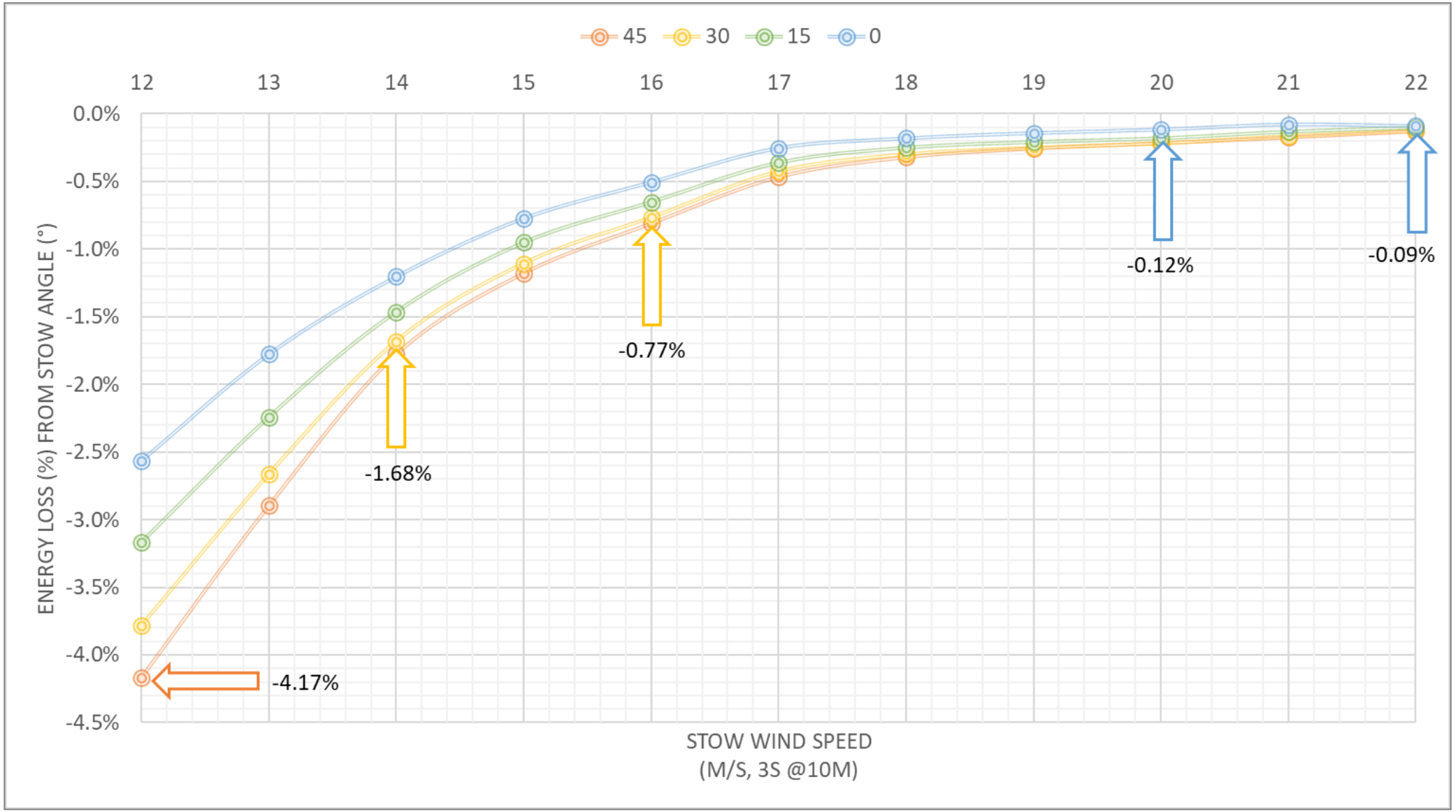
As for Tracker C, stow time included early morning and 13:00-14:00.
45-degree stow caused more energy loss at the hour 14:00-15:00.
But steep west-facing tilt improved energy yield a bit in the afternoon, when compared to tracker B.

COMPARISON OF ENERGY OUTCOME

Model	Wind speed threshold (m/s, 3s gust at 10m height)	Stow hours in total	Est. energy loss at stow mode (%)	Est. energy loss per year (MWh)	Est. financial loss per year at $28/MWh
SkyLine II	**22**	**15**	**-0.09%**	**-204**	**-$5,719**
SkySmart II	20	38	-0.12%	-262	-$7,335
A	16	243	-0.77%	-1711	-$47,920
B	**14**	**608**	**-1.68%**	**-3752**	**-$105,059**
C	12	1288	-4.17%	-9299	-$260,371

1. The lower the wind speed threshold, the less energy produced;
2. Wind induced energy loss is much higher in traditional trackers than in rigid trackers

SUMMARY CHART – AMARILLO, TEXAS, USA

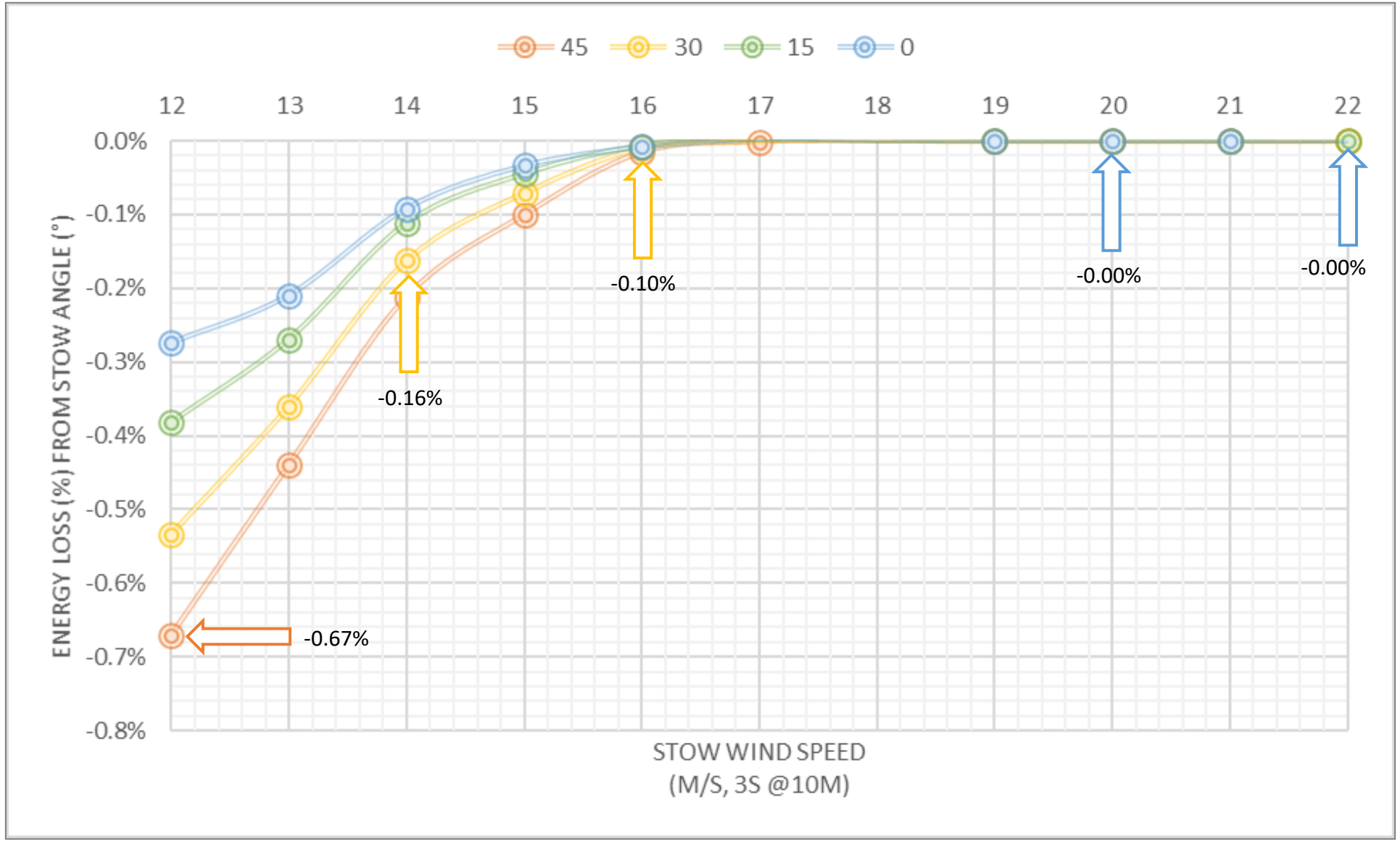


SIMPLE FINANCIAL COMPARISON

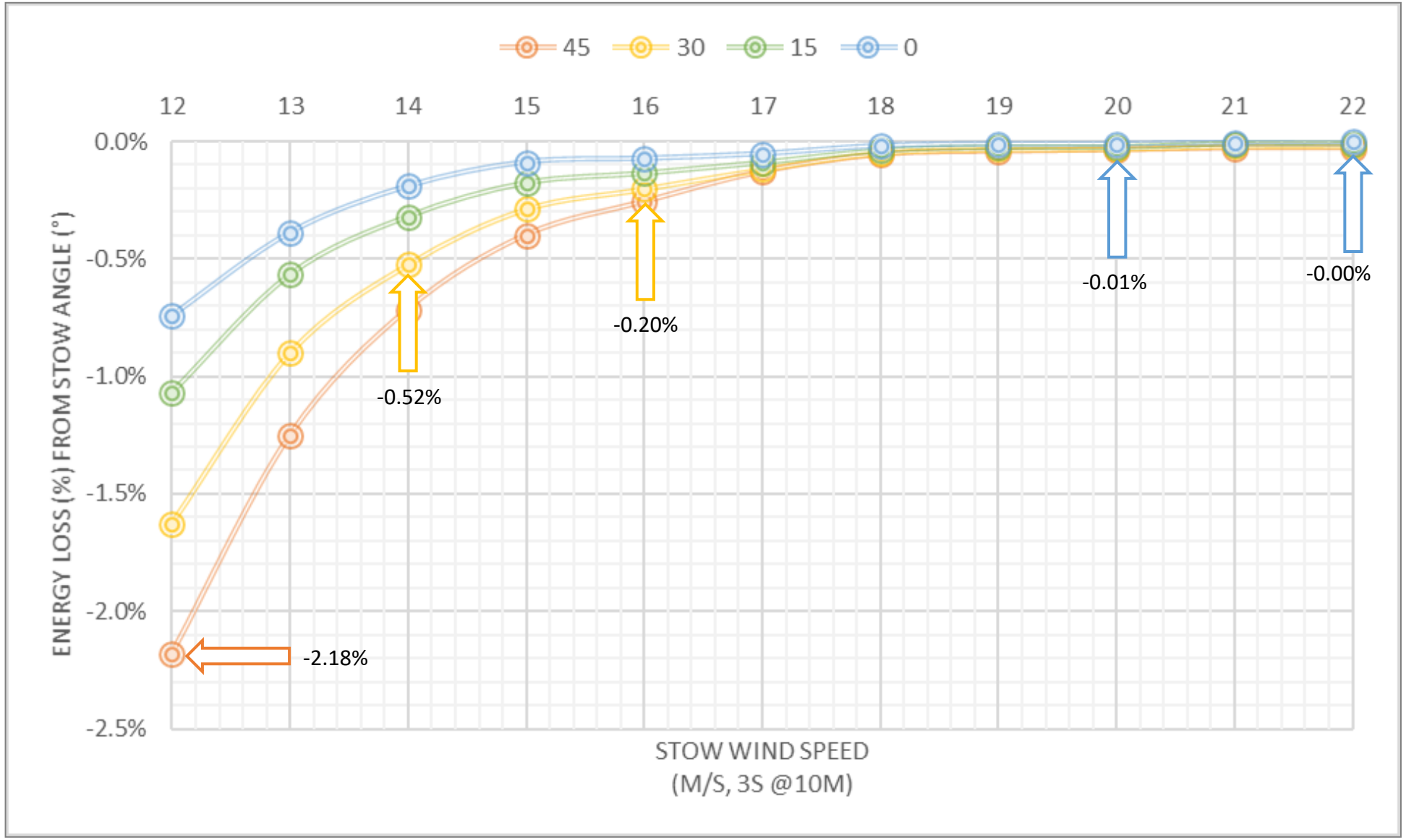
	Project (SkyLine II)	Project (Tracker B)	Delta	Project (Tracker B)+	Delta
Size (MWp)	100	100	-	100	-
Cost ($/Wp, ITC incl.)	$0.7030	$0.7030	-	$0.690	**$0.013**
Capex investment ($M)	$70.30	$70.30	-	$69.030	$1.270
1st yr Energy Yield (MWh)	**223,027**	**219,479**	3548	219479	3548
PPA ($/MWh)	$28.00	$28.00	-	$28	-
O&M Rate (/Wp/year)	$0.0070	$0.0070	-	$0.007	-
35-year Revenue ($M)	$175.38	$172.20	**$3.181**	$172.202	$3.181
Unleveraged/Project IRR	**6.609%**	**6.440%**	**0.168%**	**6.609%**	0.000%
NPV (6% dscnt rate) ($M)	**$4.595**	**$3.314**	**$1.281**	**$4.512**	$0.083

1.6% more

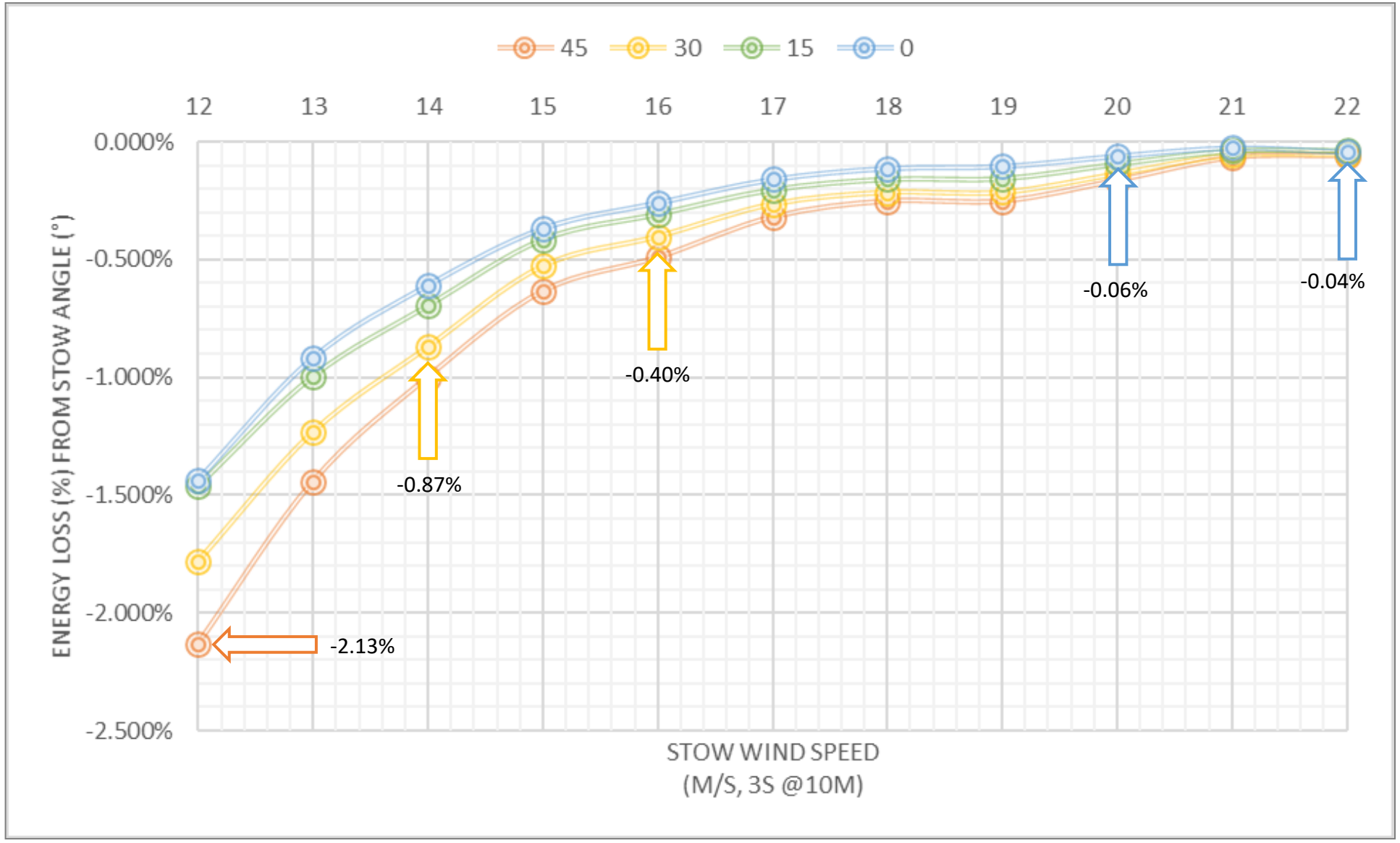
SUMMARY CHART – SYDNEY, AUSTRALIA



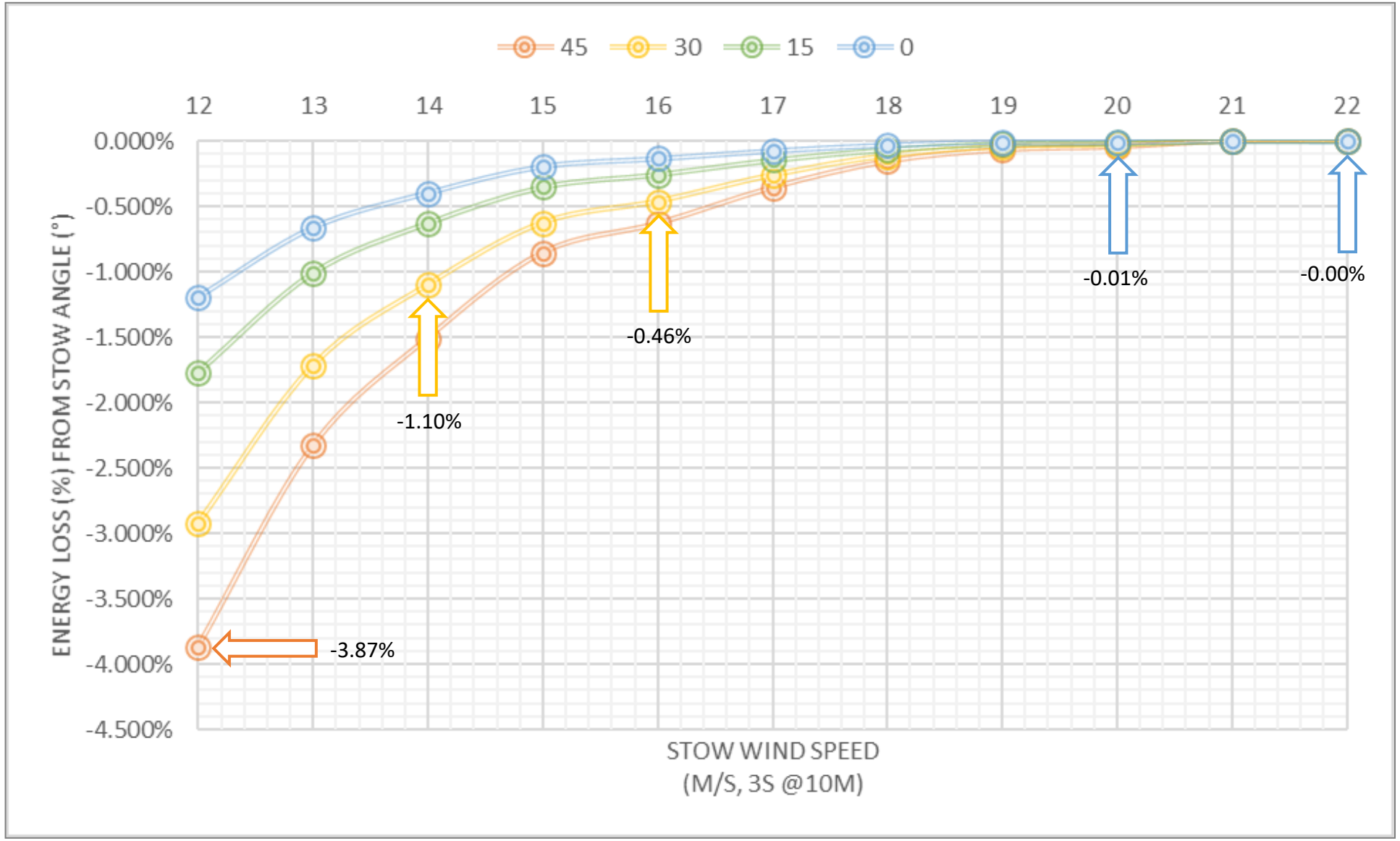
SUMMARY CHART – MADRID, SPAIN



SUMMARY CHART – GANSU, CHINA



SUMMARY CHART – MAKKAH, SAUDI ARABIA



SUMMARY AND CONCLUSIONS

- **Traditional** trackers are getting **obsolete** with the penetration of large PV modules
- With **Large panels,** trackers must **stow at 0 deg** to avoid module damage
- For that, **tracker must be stiff**
  - Span lengths within controlled intervals enabled by multiple mechanisms
- **Highest stow** in the industry **at 22 m/s**
  - Enables more energy generation
  - For Amarillo, TX, 100 MWdc:
    - **1.6% more energy** per year is equivalent to **0.168% more IRR** and **1.84% more revenue**
    - This translates in a **$1.3 cUSD/W** value **up front** (~10% tracker cost).

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Thank you!

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