Utility Scale Solar Power Plants

John C. Bean

Outline

Why focus on only Utility Scale Solar?

- Because of its strong cost advantage over Rooftop Personal Solar

Utility Scale Solar Photovoltaic (PV) Plants:

- These plants now have power capacities matching conventional power plants
  - A few even match the capacities of Nuclear & Mega-Fossil Fuel power plants
- But despite the wealth of candidate PV technologies,
  - crystalline Silicon solar cells dominate, challenged only weakly by Thin Film CdTe

Utility Scale Solar Thermal Plants:

- These plants DON'T have power capacities matching conventional power plants
  - Only one plant in the world achieves "typical" power plant capacity
    - With all others still classifiable as "small/smallish" power plants
- But over half of these achieve a green energy "holy grail:" post sunset power production
  - This enabled by their daytime stockpiling of superheated liquids

Utility Scale Plants of both types confirm solar energy's need for vast land areas

(Written / Revised: August 2022)

510 MW Solar Thermal Power Plant - with Heat Storage

Noor Quarzazate Solar Plant, Morocco

Data Source: NREL - https://solarpaces.nrel.gov/projects - (Noor I / Noor II / Noor III)

Image: Google Earth + added labels

1547 MW Solar Photovoltaic Power Plant

Tengger Dessert Solar Park, China

Data Source: Wikipedia citing Chinese language report: http://www.escn.com.cn/news/show-310093.html
Image: NASA Earth Observatory - https://earthobservatory.nasa.gov/images/145159/solar-powered-china

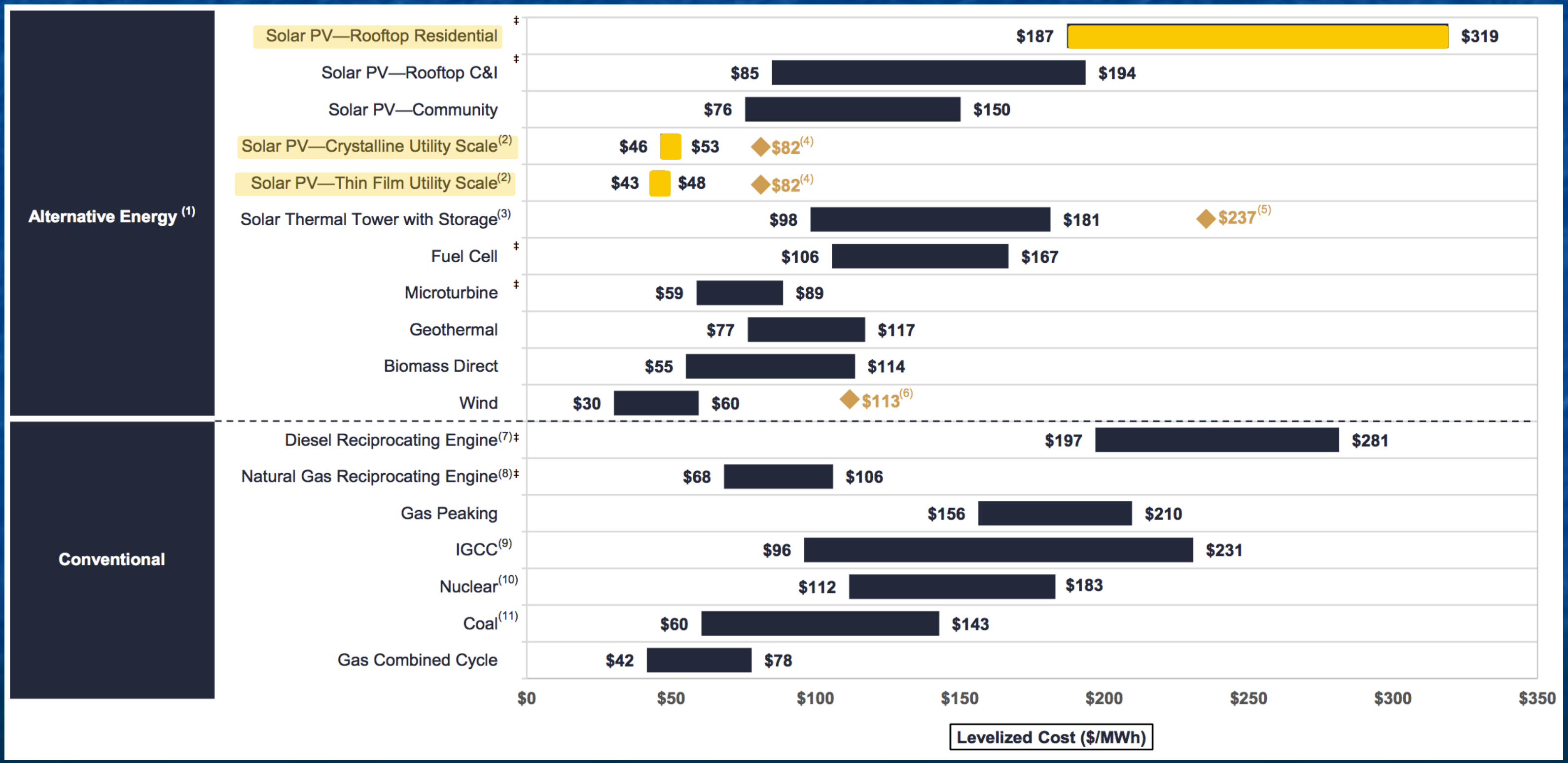
Why focus upon only "utility" (corporate or governmental) solar power?

Especially when so many dream of "going off the grid" via rooftop solar cells?

Because, as detailed in my web note set on Plant Economics (pptx / pdf / key),

Rooftop Residential PV power is now **~ four to six times** more expensive than

power from Utility Scale Solar, Wind or leading non-green alternatives: [1]

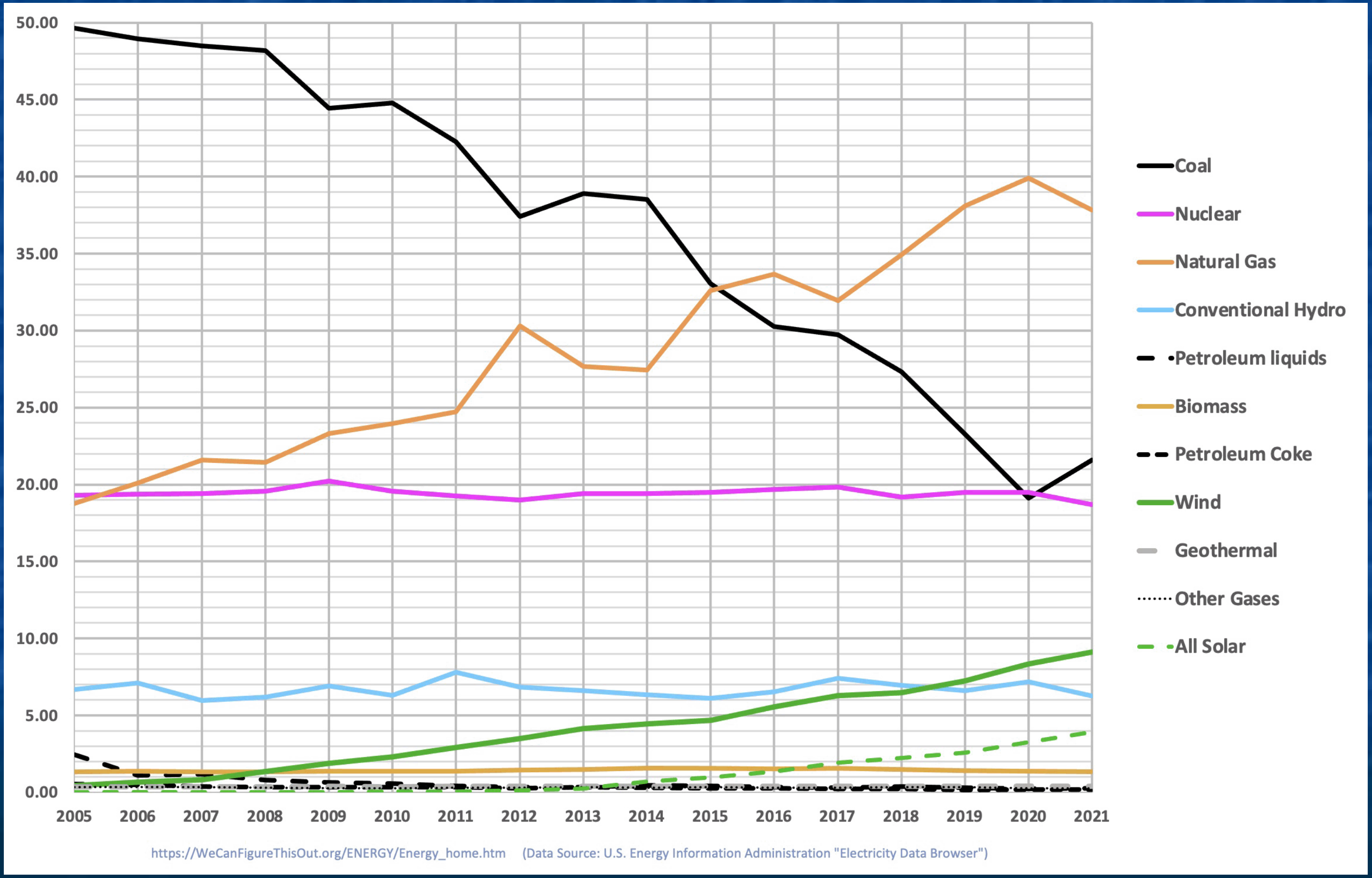


1) From the 2016 ***Lazard*** *analysis of unsubsidized levelized costs of energy (yellow highlighting added)*
"Solar Power - Rooftop C&I" = Commercial & Industrial

*And even **WITH** lower cost, Utility Scale Solar Power is **STILL** struggling:*

From my web note set on U.S. Power Production & Consumption (pptx / pdf / key):

U.S. Sources of Electrical Power (by percentage contribution)



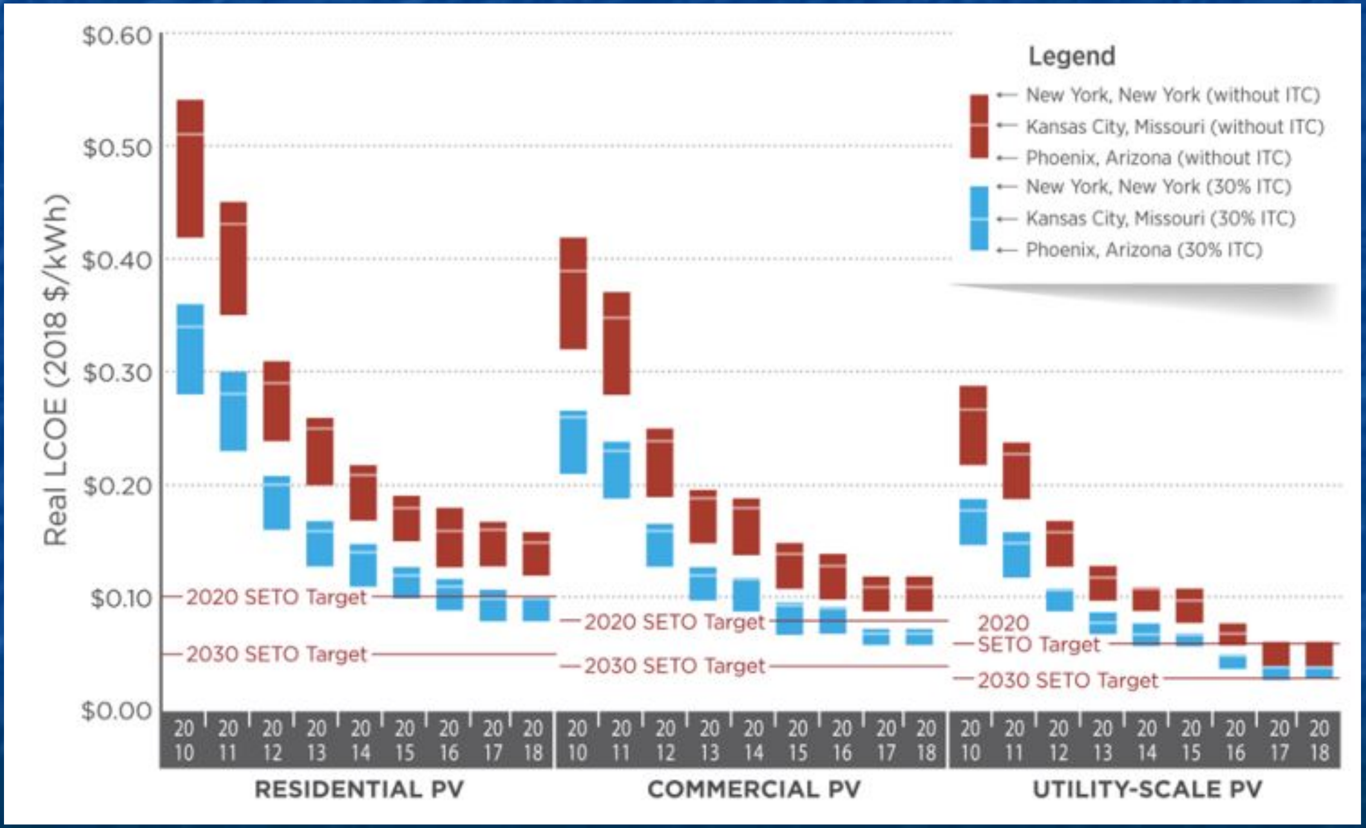
<= Utility Scale Solar 2.7%

To which you might respond:

"But I've heard that Residential PV costs are declining"

Yes, but Utility Scale PV is **maintaining** a strong cost advantage,

as reported here by the U.S. National Renewable Energy Lab (NREL): [1]

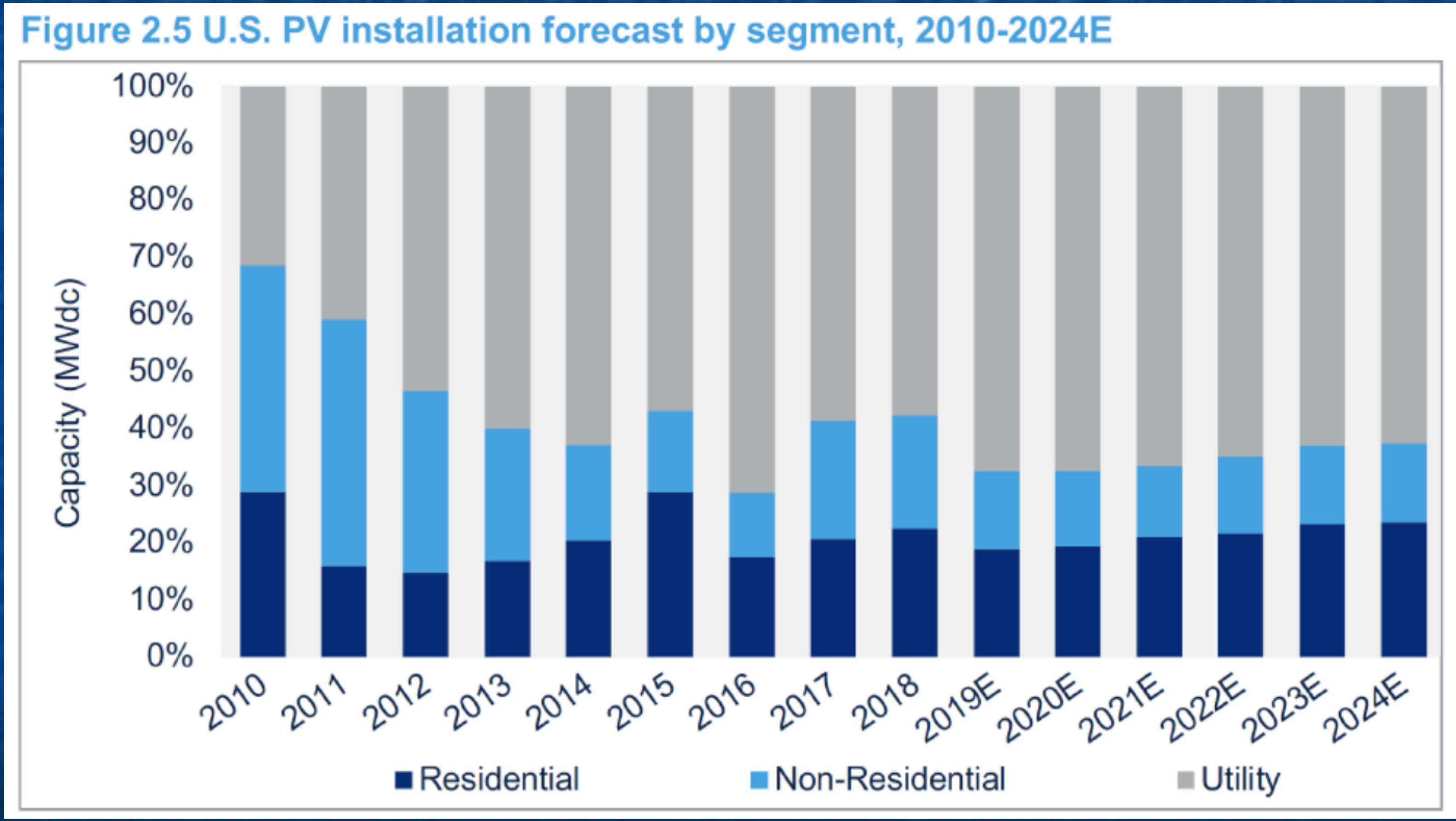


1) U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018, NREL
https://www.nrel.gov/docs/fy19osti/72133.pdf
NOTE: NREL states LCOE's in $/kW-h, rather than the more common unit of $/MW-h seen in the earlier Lazard figure

Because of Utility Scale PV's sustained cost advantage

It is projected to **remain** the dominant source of U.S. PV solar power:

2019 Projection from the Solar Energy Industry Association (SEIA) [1]



1) Solar Market Insight Report 2019 Q2 (SEIA)
https://www.seia.org/research-resources/solar-market-insight-report-2019-q2

But there is another reason to study Utility Scale Solar Power:

To make sense of the myriad solar power alternatives!

As seen in the preceding three web note sets:

Literally **dozens** of different PV cell designs are now under investigation

The science behind those PV cell designs is exceptionally complex and opaque

Making it really hard to identify those "most likely to succeed"

Add in a dozen or so Solar Thermal options and you end up with perhaps

fifty different solar power alternatives to choose from!

Utility Scale Solar has grown through both commercial AND governmental investment

Making it the product of a less than perfect "free market" competition

Nevertheless, it's been a crucible forcing choices between possible contenders

Utility Scale Solar may thus answer questions about ALL Solar Power

What sort of questions?

Some that come immediately to my mind:

Can Solar (finally!) provide enough power to displace today's power plants?

Plants that "typically" produce ~ 500-600 MW

With the larger plants now producing 1000-2000 MW [1]

Which Solar Power technologies have thrived in the Utility Scale Solar market?

For PV, which semiconductors are being used?

For Solar Thermal, which concentration schemes are favored?

What land areas will be required for competitively sized Solar Power plants?

Will energy storage allow at least Solar **Thermal** plants to produce overnight power?

Meaning (at least for now) does molten salt heat storage appear viable?

1) The capacity of "typical" power plants is discussed in my web note sets:
A Generic Power Plant and Grid *(pptx / pdf / key)*
Power Plant Requirements: Land and Water *(pptx / pdf / key)*

My search for answers:

For Solar PV, Wikipedia offers a list of power plants with capacity ≥ 200 MW [1]

- Most entries are expanded upon in linked project-by-project Wikipedia webpages
- But surprisingly, neither generally identify the PV technologies employed

For Solar PV, the trade press often reports on the "world's largest solar power plants" [1]

- But, contradicting their titles, these lists most often include ONLY PV plants
- And even more surprisingly, they ALSO fail to identify PV technologies employed

For Solar Thermal, Wikipedia offers a list of plants with capacity ≥ 100 MW [1]

- But that list fails to identify the land areas of the plants

For Solar Thermal, the U.S. National Renewable Energy Labs (NREL) offers no lists

- But provides a huge website searchable by country, project, technology or date [1]

But for Solar PV, NREL offers no comparably comprehensive website

For both technologies, my research & teaching experience supplied relevant factoids

- Some of which led me down additional avenues of investigation

*1) A complete list of the sources I used in writing this notes set (including links and cached documents) is provided on this web note set's **Resource Webpage** (link)*

I entered the data I found into a large spreadsheet [1]

Which employed these acronyms:

ACRONYMS:	ST = Solar Thermal = CSP
	CSP = Concentrated Solar Power (can be either ST or PV, but in power plants it's virtually always solar thermal)
	PV = Photovoltaic, which includes:
	c-Si = Single crystalline silicon
	poly-Si = Polycrystalline silicon (i.e. made up of microcrystallites packed together)
	a-Si = Amorphous (non-crystalline) silicon
	CdTe = Cadmium Telluride
	CIGS = Cadmium Indium Gallium Selenide
	Thin Films = Thin film of polycrystalline or amorphous seiconductor (common semiconductors include poly-Si, a-Si, CdTe, CIGS)

And drew from these references:

REFERENCES:	1) List of Photovoltaic Power Plants - Wikipedia	https://en.wikipedia.org/wiki/List_of_photovoltaic_power_stations
	2) List of Solar Thermal Power Plants - Wikipedia	https://en.wikipedia.org/wiki/List_of_solar_thermal_power_stations
	3) Cadmium Telluride Photovoltaics - Wikipedia	https://en.wikipedia.org/wiki/Cadmium_telluride_photovoltaics
	4) Best Thin Films - Energy Informative Org	https://energyinformative.org/best-thin-film-solar-panels-amorphous-cadmium-telluride-cigs/
	5) Ouarzazate Solar Power Station - Wikipedia	https://en.wikipedia.org/wiki/Ouarzazate_Solar_Power_Station
	6) Ivanpah Solar Electric Generating System - NREL	https://solarpaces.nrel.gov/ivanpah-solar-electric-generating-system
	7) Solar Energy Generating Systems (SEGS Plant) - Wikipedia	https://en.wikipedia.org/wiki/Solar_Energy_Generating_Systems
	8) Mojave Solar Project - NREL	https://solarpaces.nrel.gov/mojave-solar-project
	9) Solana Generating Station - Wikipedia	https://en.wikipedia.org/wiki/Solana_Generating_Station
	10) Genesis Solar Energy Project - Wikipedia	https://en.wikipedia.org/wiki/Genesis_Solar_Energy_Project
	11) Solanova Solar Power Station - Power Technology Com	https://www.power-technology.com/projects/solnova-solar-power-station/
	12) Andasol Solar Power Station - Wikipedia	https://en.wikipedia.org/wiki/Andasol_Solar_Power_Station
	13) Extresol Solar Power Station - Wikipedia	https://en.wikipedia.org/wiki/Extresol_Solar_Power_Station
	14) Crescent Dunes Solar Energy Project - Wikipedia	https://en.wikipedia.org/wiki/Crescent_Dunes_Solar_Energy_Project
	15) Ashalam Power Station - Wikipedia	https://en.wikipedia.org/wiki/Ashalim_Power_Station
	16) Kathu Solar Park - Wikipedia	https://en.wikipedia.org/wiki/Kathu_Solar_Park
	17) Kaxu Solar One - Wikipedia	https://en.wikipedia.org/wiki/KaXu_Solar_One
	18) Valle Solar Power Station - Wikipedia	https://en.wikipedia.org/wiki/Valle_Solar_Power_Station
	19) Shams Solar Power Station - Wikipedia	https://en.wikipedia.org/wiki/Shams_Solar_Power_Station
	20) Llanga I - NREL	https://solarpaces.nrel.gov/ilanga-i

To generate four different tables:

Utility Scale Solar PV Plants (200 MW or larger)

Utility Scale Solar Thermal Plants (100 MW or larger)

All Utility Scale Solar Plants (200 MW or larger) - sorted by SIZE OR DATE

1) That spreadsheet can be downloaded from this (link) on this note set's ***Resources Webpage***

*My Table on Utility Scale **Solar Photovoltaic** Power Plants (≥ 200 MW):*

POWER PLANT CAPACITY in MW	COMPLETED	PV	ST (CSP)	PLANT AREA in km2	PLANT NAME	COUNTRY	PV TECHNOLOGY	REFERENCES
1547	2016	X		43	Tengger Desert	China	(c-Si ?)	1
1515	2019	X		40	Bhadla Solar	India	(c-Si ?)	1
1400	2019	X		53	Pavagada	India	(c-Si ?)	1
1177	2019	X			Noor Abu Dhabi	UAE	(c-Si ?)	1
1000	2017	X		24	Kurnool Ultra Mega	India	(c-Si ?)	1
1000	2016	X			Dataong Solar Power Top	China	(c-Si ?)	1
850	2015	X		23	Longyangxia	China	(c-Si ?)	1
828	2018	X		24	Villanueva	Mexico	(c-Si ?)	1
750	2018	X			Rewa Ultra Mega	India	(c-Si ?)	1
690	2012	X		20	Charanka	India	(c-Si ?)	1
648	2016	X		10.1	Kamuthi	India	(c-Si ?)	1
613	2019	X			Mohammed bin Rashid	UAE	(c-Si ?)	1
579	2015	X		13	Solar Star	US	(c-Si ?)	1
552	2016	X		16.2	Copper Mountain	US	(c-Si ?)	1
550	2015	X		16	Desert Sunlight	US	(c-Si ?)	1
550	2014	X		19	Topaz	US	CdTe Thin Film	1, 3
500	2014	X		23	Huanghe	China	(c-Si ?)	1
500	2018	X			NP Kunta	India	(c-Si ?)	1
500	2018	X			Three Gorges Golmud	China	(c-Si ?)	1
500	2018	X			Three Gorges Delingha	China	(c-Si ?)	1
460	2018	X		15.9	Mount Signal	US	(c-Si ?)	1
400	2016	X		9.3	Mesquite	US	(c-Si ?)	1
400	2018	X			Pirapora	Brazil	(c-Si ?)	1
400	2019	X		17	Ananthapurama	India	(c-Si ?)	1
380	2016	X			Yanchi	China	(c-Si ?)	1
350	2019	X		5.7	Springbok	US	(c-Si ?)	1
300	2015	X		2.5	Cestas	France	(c-Si ?)	1
300	2019	X		9.3	Techren	US	(c-Si ?)	1
292	2017	X			Nova Olinda	Brazil	(c-Si ?)	1
290	2014	X		9.7	Aqua Caliente	US	CdTe Thin Film	1, 3
280	2017	X		11.7	California Flats	US	(c-Si ?)	1
260	2018	X			Don Jose	Mexico	(c-Si ?)	1
254	2017	X			Ituverava	Barzil	(c-Si ?)	1
250	2017	X			Mandsaur	India	(c-Si ?)	1
250	2016	X		9.3	McCoy	US	(c-Si ?)	1
250	2016	X		11.7	Silver State	US	(c-Si ?)	1
250	2013	X		7.96	California Valley	US	(c-Si ?)	1
250	2016	X		6.82	Stateline	US	(c-Si ?)	1
250	2016	X		8.1	Moapa Southern Paiute	US	(c-Si ?)	1
246	2016	X			El Romero	US	(c-Si ?)	1
246	2019	X			Nikpol	Ukraine	(c-Si ?)	1
240	2019	X			Pokrovske	Ukraine	(c-Si ?)	1
240	2016	X		7.7	Escalante	US	(c-Si ?)	1
236	2019	X		6.1	Midway	US	(c-Si ?)	1
235	2016	X		8.1	Blythe	US	(c-Si ?)	1
235	2018	X		2.6	Setouchi Kirei	Japan	(c-Si ?)	1
235	2017	X		7.7	Upton Solar 2	US	(c-Si ?)	1
230	2015	X		8.5	Antelope Valley	US	CdTe Thin Film	1, 4
212	2016	X		5.3	Roserock	US	(c-Si ?)	1
202	2018	X		5.1	Buckthorn	US	(c-Si ?)	1
200	2017	X		3	Cixi	China	(c-Si ?)	1
200	2019	X		8.1	GA Solar 4	US	(c-Si ?)	1
200	2013	X			Gansu Jintai	China	(c-Si ?)	1
200	2016	X		8.1	Garland	US	(c-Si ?)	1
200	2013	X			Gonghe I	China	(c-Si ?)	1
200	2018	X		6.5	Great Valley	US	(c-Si ?)	1
200	2016	X		7.7	Tranquility	US	(c-Si ?)	1

Questions & observations suggested by that PV Plant table:

First, why all of the question marks in the semi-final "PV Technology" column?

BECAUSE Wikipedia, trade press and plant websites OMITTED that information

MY GUESS: Single crystal silicon (c-Si) so completely dominates Utility Scale PV

that its near universal use is just being taken for granted

WHY would c-Si dominate?

Because of its high PV efficiencies (up to 25%) [1] and exceptional cell lifetimes

Which is why I chose "c-Si ?" as the default "PV Technology" entry in my table

But thin film CdTe PV is **almost** as efficient (21%) [1] and because its PV cells

are THIN films, they require far less (usually costly) semiconductor material

For which reasons I knew at least one plant ("Topaz" in CA) had installed thin film CdTe PV

By Googling CdTe PV I then identified several other thin film CdTe PV Plants [2]

*1) See discussion of NREL data in my note set **Tomorrow's Solar Cells** (pptx / pdf / key)*

2) https://en.wikipedia.org/wiki/Cadmium_telluride_photovoltaics

But is thin film CdTe the ONLY successful challenger to c-Si?

Amorphous & polycrystalline Si PV are ALSO very well established technologies

PV efficiencies: a-Si PV 13.4% poly-Si PV 20.4% c-Si PV 25% [1]

As **Si** thin films, they require not only less expensive material but also less of it

Nevertheless, they have had little success in Utility Scale PV [2]

Likely because their less stable atomic structures promote cell degradation

Thin film CIGS (Cadmium Indium Gallium Selenide) PV is also fairly well established

But unlike the Si technologies above, its PV cells are still improving rapidly,

climbing in recent years to 21.7% sunlight to electricity conversion efficiency [1]

But while the smallish 82 MW PV "Catalina" plant was commissioned in 2013 [3, 4]

CIGS PV cell manufacturing subsequently crashed

It's been reported that CIGS PV cell manufacturing has recently revived [5]

but I could find no examples of new Plants yet committed to CIGS's use

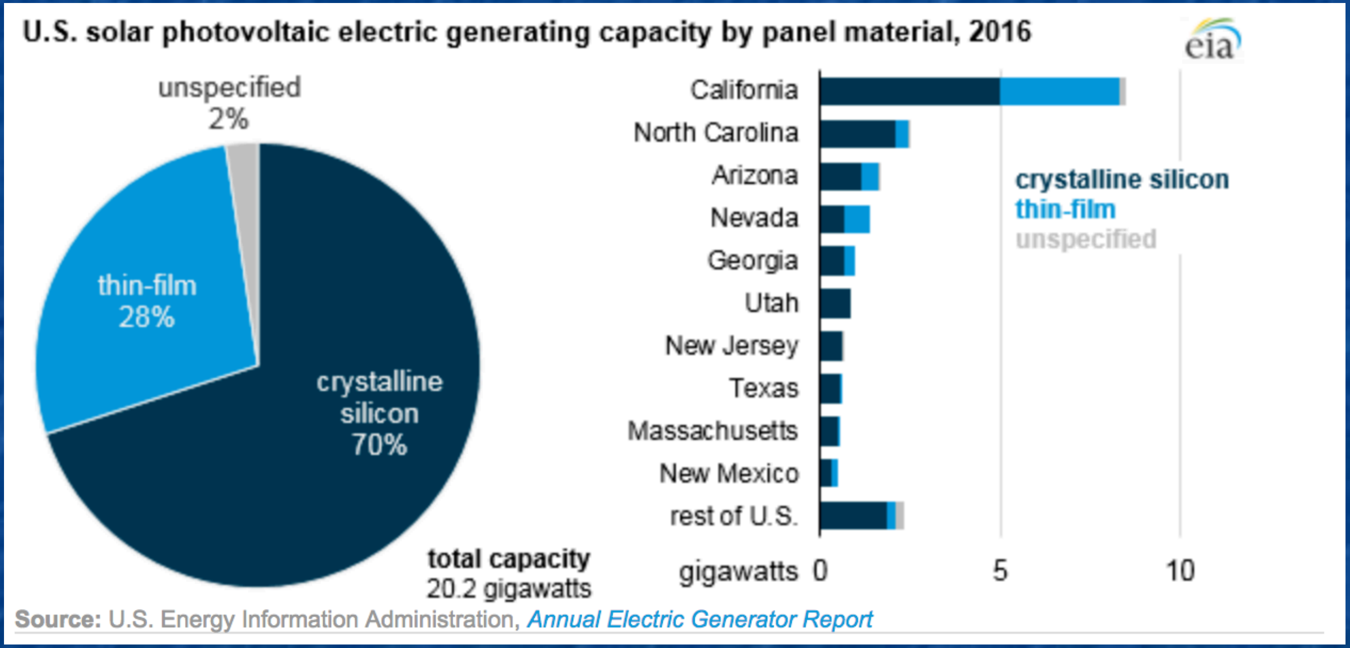
1) See discussion of NREL data in my note set ***Tomorrow's Solar Cells*** *(pptx / pdf / key)*
2) https://energyinformative.org/best-thin-film-solar-panels-amorphous-cadmium-telluride-cigs/
3) https://www.reuters.com/article/us-solar-frontier-idUSTRE80G1VK20120117
4) https://www.power-technology.com/projects/catalina-solar-project-kern-county-california/
5) https://www.pv-magazine.com/2018/07/21/the-weekend-read-cigs-is-back-back-again/

Had I thereby succeeded in identifying ~ ALL of the non "c-Si" PV Plants?

Confirmation was suggested by the title of a U.S. Energy Information Agency (EIA) webpage: [2]

"Utility Solar Photovoltaic Capacity is
Dominated by Crystalline Silicon Panel Technology"

But that webpage included this figure:



70% crystalline silicon PV use falls well short of complete domination,

driving me to sort out what made up the figure's 28% thin film contribution

1)) https://www.eia.gov/todayinenergy/detail.php?id=34112

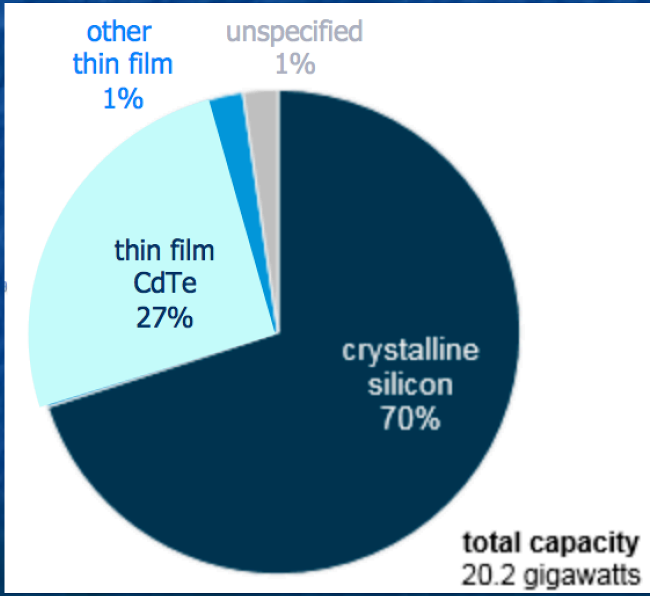
Additional information was provided in the webpage's text:

"CdTe is the most commonly used thin-film PV technology, making up 97% of the total installed thin-film capacity in the United States"

By simply multiplying the figure's "other thin film 28%" by 97%

you find that film thin CdTe accounted for 27% of U.S. 2017 capacity

Allowing me to create this **much more informative** version of that EIA figure:



Is that consistent with my table of Utility PV Plants (≥ 200 MW)?

My table identified 1070 MW worth of thin film CdTe U.S. plants

vs. 8197 MW for ALL U.S. plants

implying a thin film CdTe share of 13%

which is approximately half of what EIA claimed

Suggesting that some plants I labeled "c-Si?" are NOT c-Si

Or that my 200 MW lower limit overlooks a lot of U.S. capacity

including smaller plants apparently using thin film CdTe

The latter IS supported by the EIA figure's statement that

total U.S. PV capacity in 2017 = 20 GW (20,000 GW)

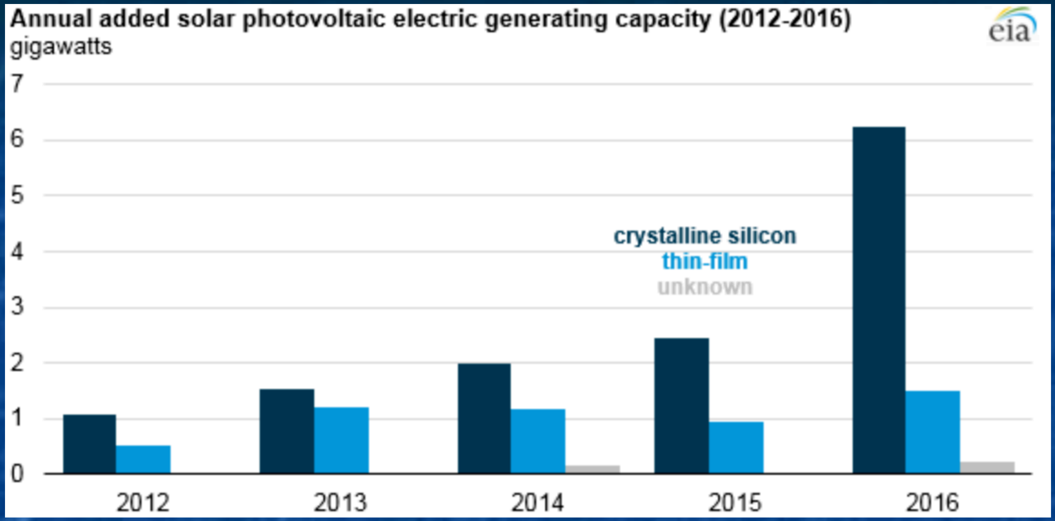
which is ~ twice the capacity included in my table

Calling for a much longer table (adding data on smaller plants)

plus unambiguous identification ALL plant PV technologies

POWER PLANT CAPACITY in MW	COUNTRY	PV TECHNOLOGY
1547	China	(c-Si ?)
1515	India	(c-Si ?)
1400	India	(c-Si ?)
1177	UAE	(c-Si ?)
1000	India	(c-Si ?)
1000	China	(c-Si ?)
850	China	(c-Si ?)
828	Mexico	(c-Si ?)
750	India	(c-Si ?)
690	India	(c-Si ?)
648	India	(c-Si ?)
613	UAE	(c-Si ?)
579	US	(c-Si ?)
552	US	(c-Si ?)
550	US	(c-Si ?)
550	US	CdTe Thin Film
500	China	(c-Si ?)
500	India	(c-Si ?)
500	China	(c-Si ?)
500	China	(c-Si ?)
460	US	(c-Si ?)
400	US	(c-Si ?)
400	Brazil	(c-Si ?)
400	India	(c-Si ?)
380	China	(c-Si ?)
350	US	(c-Si ?)
300	France	(c-Si ?)
300	US	(c-Si ?)
292	Brazil	(c-Si ?)
290	US	CdTe Thin Film
280	US	(c-Si ?)
260	Mexico	(c-Si ?)
254	Barzil	(c-Si ?)
250	India	(c-Si ?)
250	US	(c-Si ?)
250	US	(c-Si ?)
250	US	(c-Si ?)
250	US	(c-Si ?)
250	US	(c-Si ?)
246	US	(c-Si ?)
246	Ukraine	(c-Si ?)
240	Ukraine	(c-Si ?)
240	US	(c-Si ?)
236	US	(c-Si ?)
235	US	(c-Si ?)
235	Japan	(c-Si ?)
235	US	(c-Si ?)
230	US	CdTe Thin Film
212	US	(c-Si ?)
202	US	(c-Si ?)
200	China	(c-Si ?)
200	US	(c-Si ?)
200	China	(c-Si ?)
200	US	(c-Si ?)
200	China	(c-Si ?)
200	US	(c-Si ?)
200	US	(c-Si ?)

*But that EIA webpage **also** included this figure:*



Which, while it still obscures plant and thin film technology specifics,

shows unambiguously that **thin film PV is LOOSING market share to c-SI PV**

According to this figure, thin film PV's share of **NEW** installations has declined roughly as:

30% (2012)

44% (2013)

34% (2014)

27% (2015)

19% (2016)

What ELSE is shown (or at least suggested by) my PV Plant table?

Very Significantly: Single PV plants are no longer just diminutive curiosities:

Recent plants rival "typical" non-green plants in size (500-600 MW capacity)

Some even **match** nuclear & large fossil fuel plants (>1000 MW capacity)

(at least in China, India, and the Middle East)

POWER PLANT CAPACITY in MW	COMPLETED	PV	ST (CSP)	PLANT AREA in km2	PLANT NAME	COUNTRY	PV TECHNOLOGY
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1177	2019	X			Noor Abu Dhabi	UAE	(c-Si ?)
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1000	2016	X			Dataong Solar Power Top	China	(c-Si ?)
850	2015	X		23	Longyangxia	China	(c-Si ?)
828	2018	X		24	Villanueva	Mexico	(c-Si ?)
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690	2012	X		20	Charanka	India	(c-Si ?)
648	2016	X		10.1	Kamuthi	India	(c-Si ?)
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500	2018	X			NP Kunta	India	(c-Si ?)
500	2018	X			Three Gorges Golmud	China	(c-Si ?)
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400	2016	X		9.3	Mesquite	US	(c-Si ?)
400	2018	X			Pirapora	Brazil	(c-Si ?)
400	2019	X		17	Ananthapurama	India	(c-Si ?)
380	2016	X			Yanchi	China	(c-Si ?)
350	2019	X		5.7	Springbok	US	(c-Si ?)
300	2015	X		2.5	Cestas	France	(c-Si ?)
300	2019	X		9.3	Techren	US	(c-Si ?)
292	2017	X			Nova Olinda	Brazil	(c-Si ?)
290	2014	X		9.7	Aqua Caliente	US	CdTe Thin Film
280	2017	X		11.7	California Flats	US	(c-Si ?)
260	2018	X			Don Jose	Mexico	(c-Si ?)
254	2017	X			Ituverava	Barzil	(c-Si ?)
250	2017	X			Mandsaur	India	(c-Si ?)
250	2016	X		9.3	McCoy	US	(c-Si ?)
250	2016	X		11.7	Silver State	US	(c-Si ?)
250	2013	X		7.96	California Valley	US	(c-Si ?)
250	2016	X		6.82	Stateline	US	(c-Si ?)
250	2016	X		8.1	Moapa Southern Paiute	US	(c-Si ?)
246	2016	X			El Romero	US	(c-Si ?)
246	2019	X			Nikpol	Ukraine	(c-Si ?)
240	2019	X			Pokrovske	Ukraine	(c-Si ?)
240	2016	X		7.7	Escalante	US	(c-Si ?)
236	2019	X		6.1	Midway	US	(c-Si ?)
235	2016	X		8.1	Blythe	US	(c-Si ?)
235	2018	X		2.6	Setouchi Kirei	Japan	(c-Si ?)
235	2017	X		7.7	Upton Solar 2	US	(c-Si ?)
230	2015	X		8.5	Antelope Valley	US	CdTe Thin Film
212	2016	X		5.3	Roserock	US	(c-Si ?)
202	2018	X		5.1	Buckthorn	US	(c-Si ?)
200	2017	X		3	Cixi	China	(c-Si ?)
200	2019	X		8.1	GA Solar 4	US	(c-Si ?)
200	2013	X			Gansu Jintai	China	(c-Si ?)
200	2016	X		8.1	Garland	US	(c-Si ?)
200	2013	X			Gonghe I	China	(c-Si ?)
200	2018	X		6.5	Great Valley	US	(c-Si ?)
200	2016	X		7.7	Tranquility	US	(c-Si ?)

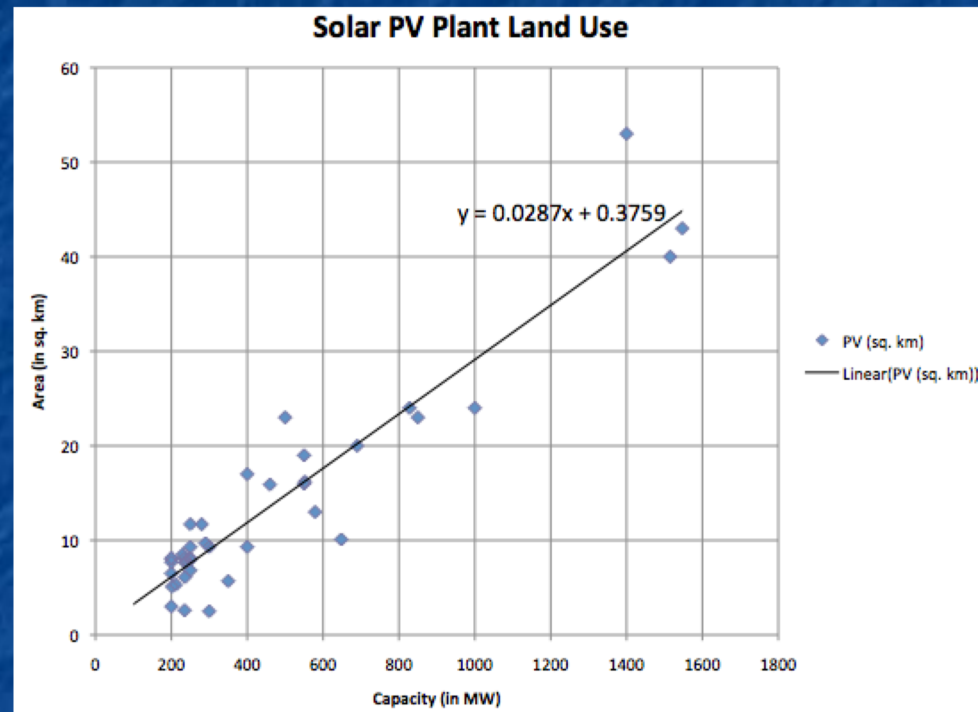
What are the land areas required for such Solar PV Plant capacity?

Remembering that "capacity" refers to maximum possible (noonish / cloud-free) power output

For plants with identified land areas:

POWER PLANT CAPACITY in MW	PLANT AREA in km2	PLANT NAME	COUNTRY
1547	43	Tengger Desert	China
1515	40	Bhadla Solar	India
1400	53	Pavagada	India
1000	24	Kurnool Ultra Mega	India
850	23	Longyangxia	China
828	24	Villanueva	Mexico
690	20	Charanka	India
648	10.1	Kamuthi	India
579	13	Solar Star	US
552	16.2	Copper Mountain	US
550	16	Desert Sunlight	US
550	19	Topaz	US
500	23	Huanghe	China
460	15.9	Mount Signal	US
400	9.3	Mesquite	US
400	17	Ananthapurama	India
350	5.7	Springbok	US
300	2.5	Cestas	France
300	9.3	Techren	US
290	9.7	Aqua Caliente	US
280	11.7	California Flats	US
250	9.3	McCoy	US
250	11.7	Silver State	US
250	7.96	California Valley	US
250	6.82	Stateline	US
250	8.1	oapa Southern Paiut	US
240	7.7	Escalante	US
236	6.1	Midway	US
235	8.1	Blythe	US
235	2.6	Setouchi Kirei	Japan
235	7.7	Upton Solar 2	US
230	8.5	Antelope Valley	US
212	5.3	Roserock	US
202	5.1	Buckthorn	US
200	3	Cixi	China
200	8.1	GA Solar 4	US
200	8.1	Garland	US
200	6.5	Great Valley	US
200	7.7	Tranquility	US

Land Area vs. Plant Capacity plots as:



With surprisingly little scatter, the land use of these diverse Solar PV plants

can be fitted by a line with slope = **0.0287 km² / MW,**

equivalent to **35 Watts of solar electricity OUTPUT per square meter**

(vs. ~1000 Watts of **sunlight INPUT power** per square meter)

Why has PV Plant land use (per MW of capacity) not evolved?

First, despite a greater than 2:1 range in available PV cell conversion efficiencies,

Utility Scale Plants rely strongly on PV cells with nearly identical efficiencies:

c-Si PV peaking at 25% & Thin Film CdTe peaking at 21%

Second, while differing local weather can easily alter PV power by more than 2:1,

today's PV plants are still almost all located in high ~ cloudless desserts

Finally, despite alternate ways of positioning PV cell panels on the ground,

today's Utility PV plants are apparently using very similar panel arrangements

Which suggests their use of similar "sun tracking" schemes

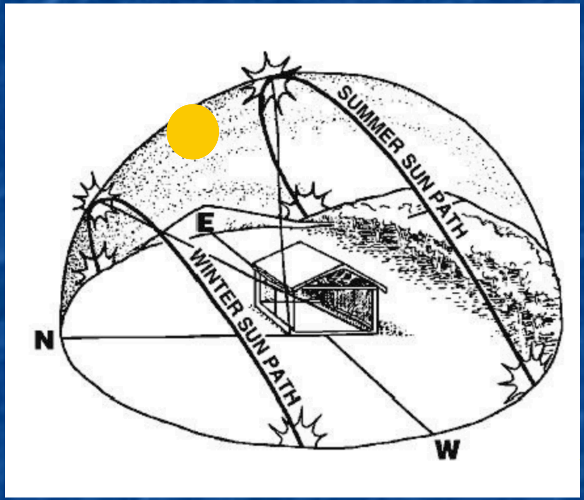
What exactly is "sun tracking," and what are the alternatives?

PV Sun Tracking (a.k.a., Solar Tracking):

From a PV cell's perspective, the sun moves east to west from dawn to dusk,

shifting lower to higher in the sky from local winter to local summer

Here as seen from Australia (which supplied this and the figures to follow): [1]



With sunlight peaking midday, the simplest way to mount a PV panel is

facing south (in the northern hemisphere) or north (in the southern hemisphere)

with a north-south tilt between the sun's winter and summer paths

(i.e., pointing toward the yellow circle I've added to this figure)

1) Figure: https://www.solarchoice.net.au/blog/solar-trackers/

But most of the time a fixed panel would NOT directly face the sun

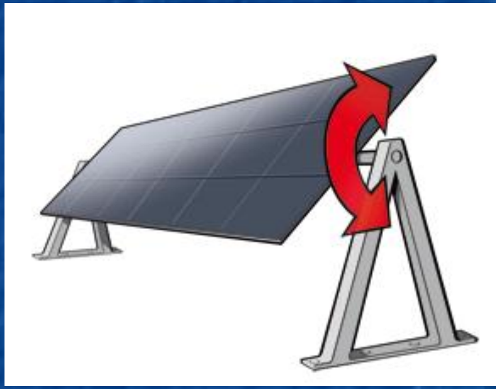
It would thus intercept a narrower beam of sunlight (containing less solar power)

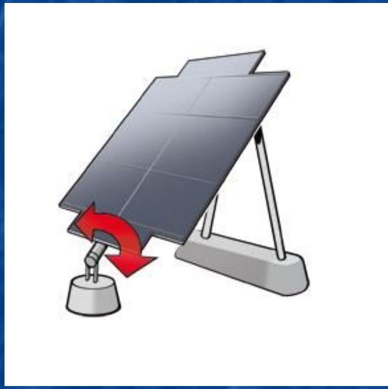
Further, Its non-perpendicular surface would **reflect away** more of that beam

Seasonally varying N-S tilt captures a LITTLE more solar power (left figure)

Daily varying E-W tilt captures a LOT more solar power (center figure)

Combining both captures the MOST solar power (right figure)





The obvious downside: N-S or E-W "single-axis" tilting adds cost

N-S plus E-W "dual-axis" tilting adds even MORE cost

Figures: https://www.solarchoice.net.au/blog/solar-trackers/

Another tracking downside / cost: Shadowing

Tracking's benefit diminishes if panels end up spending time in each other's shadows

- Aggressive tracking thus requires greater panel separation (=> more land)

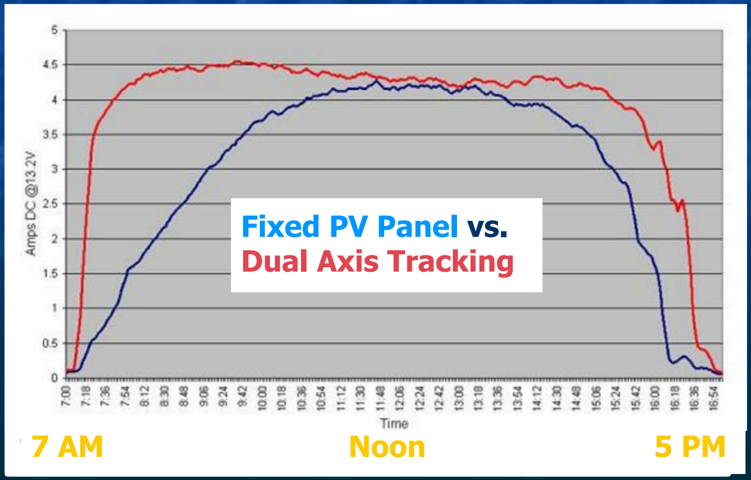
However, if the PV cells are very costly, tracking's added cost can still make sense

- Because tracking might allow for use of FEWER of those expensive cells

Meaning that today's declining PV cell cost should drive **reduced** use of tracking

But tracking does something else VERY IMPORTANT to power companies:

- Tracking increases a Solar PV Plant's power output morning & early evening
  - Which are two times we consumers especially WANT electrical power

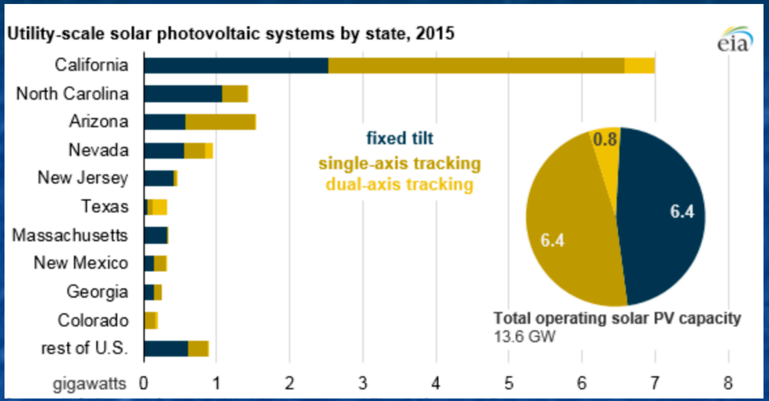


Based on a figure from: https://www.solarchoice.net.au/blog/solar-trackers/

So do Utility Scale PV plants track or not?

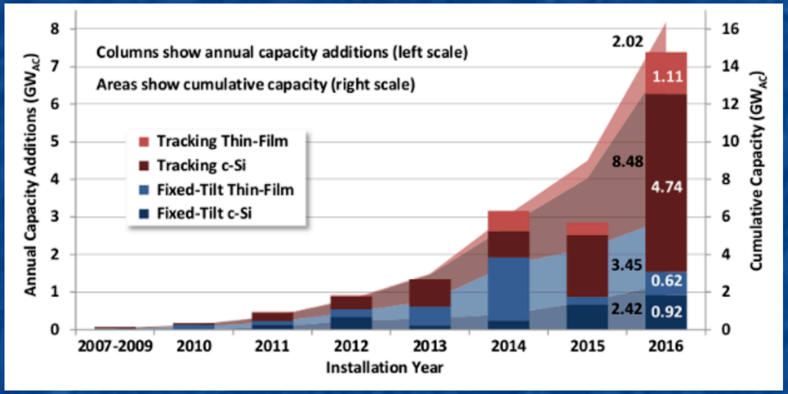
U.S. EIA data on ALL U.S. PV Plants:

https://www.eia.gov/todayinenergy/detail.php?id=30912



PV Magazine (lines = all plants, columns = plants added in a specific year):

https://pv-magazine-usa.com/2017/09/20/trackers-dominate-u-s-utility-scale-solar-wcharts/



EXISTING U.S. plants are ~ evenly split between **no tracking & single axis tracking**

But NEW U.S. plants are making much more use of **some form of tracking**

PV TAKEAWAYS *- As Suggested by Utility Scale Plants:*

- Utility Scale PV is **much cheaper** than Residential Rooftop PV

  At least for today's Plants located almost entirely in ~ cloudless desert locations

- Of the literally **dozens** of PV cell types & schemes, two now rule Utility Scale PV:

  Single crystalline Si PV cells

  and to a lesser (and apparently falling) extent, **Thin film CdTe** PV cells

- Dual axis (daily E-W + seasonal N-S) tracking is seldom worthwhile

- Use of **Single Axis E-W Tracking** & No-Tracking are now about even

  But the former is growing at the expense of the latter

- Narrow range of options used => Near uniform PV land use of ~ **0.0287 km^2 / MW**,

  => ~ **35 Watts Solar Electricity per square meter** of land (not cell) area

  This is MW CAPACITY = PEAK (noonish / cloud-free) - NOT AVERAGE POWER

Moving on to:

Utility Scale ***Solar Thermal*** *Plants*

THE outstanding information source on Solar Thermal Plants:

The U.S. National Renewable Energy Lab's website: https://solarpaces.nrel.gov/

Concentrating Solar Power Projects

NREL
Transforming ENERGY

- Home
- By Country
- By Project Name
- By Technology
- By Status

Working with member countries, SolarPACES—Solar Power and Chemical Energy Systems—has compiled data on concentrating solar power (CSP) projects around the world that have plants that are either operational, under construction, or under development. CSP technologies include parabolic trough, linear Fresnel reflector, power tower, and dish/engine systems.

For individual concentrating solar power projects, you will find profiles that include background information, a listing of participants in the project, and data on the power plant configuration.

These pages should help utilities, financiers, manufacturers, and anyone interested in renewable-energy options to find information on the growing number of concentrating solar power projects around the world.

Browse the Project Profiles

You can browse project profiles under the following categories:

- Country—listing by one of 23 countries
- Project name—alphabetical listing by full project name
- Technology—listing by parabolic trough, linear Fresnel reflector, power tower, or dish/engine systems
- Status—listing by whether projects have plants that are operational, under construction, under development, request for offer, or currently non-operational.

You can also download comma-delimited data on all projects.

About the Project Profiles

The National Renewable Energy Laboratory's CSP Program assists SolarPACES in maintaining the projects database behind this Web site.

SolarPACES Snapshot

SolarPACES, an international program of the International Energy Agency, furthers collaborative development, testing, and marketing of concentrating solar power plants. Activities include testing large-scale systems and developing advanced technologies, components, instrumentation, and analysis techniques.

Founded in 1977, SolarPACES now has 19 members: Australia, Austria, Brazil, Chile, China, European Commission (DG RESEARCH & INNOVATION and DG ENERGY), France, Germany, Greece, Israel, Italy, Mexico, Morocco, Republic of Korea, South Africa, Spain, Switzerland, United Arab Emirates and United States of America.

My Table on Grid Scale Solar Thermal Power Plants (≥ 100 MW):

This table covers worldwide Solar Thermal Plants of capacity ≥ 100 MW

It merges information from Wikipedia's List of Solar Thermal Power Stations

with project-by-project data from NREL's Concentrating Solar Power website

(When sources disagreed, I favored NREL data and/or data from governments & plant contractors)

POWER PLANT CAPACITY in MW	COMPLETED	PV	ST (CSP)	PLANT AREA in km2	PLANT NAME	COUNTRY	PV TECHNOLOGY	ST TECHNOLOGY	HEAT STORAGE in hours	REFERENCES
510 Thermal + 72 PV	2013-18	X	X	4.5 Trough + 6.8 Trough + 5.5 Tower	Noor Quarzazate	Morocco	(c-Si ?)	Tower + Trough + Tower	3 / 7 / 7.5	2, 5
392	2014		X	14.2	Ivanpah	US		Tower		2, 6
354	1984-90		X		SEGS	US		Trough		2,7
280	2014		X	7.14	Mojave	US		Trough		2, 8
280	2013		X	7.8	Solana	US		Trough	6	2, 9
250	2014		X	7.8	Genesis	US		Trough		2, 10
200	2012-13		X		Solaben	Spain		Trough		2
150	2010		X	3.45	Solnova	Spain		Trough		2, 11
150	2008-11		X	6	Andasol	Spain		Trough	7.5	2,12
150	2010-12		X	6	Extresol	Spain		Trough	7.5	2, 13
125	2014		X		Dhursar	India		Fresnel		2
121	2019		X	3.15	Ashalim	Israel		Trough	4.5	2, 15
121	2019		X		Megalim	Israel		Tower		2
110	2015		X	6.7	Crescent Dunes	US		Tower	10	2, 14
100	2018		X	0.8	Kathu	S. Africa		Trough	4.5	2, 16
100	2015		X	11	KaXu Solar One	S. Africa		Trough	2.5	2, 17
100	2017		X		Xina Solar One	S. Africa		Trough	5.5	2
100	2011		X		Manchasol	Spain		Trough	7.5	2
100	2011		X	1.02	Valle	Spain		Trough	7.5	2, 18
100	2011-12		X		Helioenergy	Spain		Trough		2
100	2012		X		Aste	Spain		Trough	8	2
100	2012		X		Solacor	Spain		Trough		2
100	2012		X		Helios	Spain		Trough		2
100	2013		X	2.5	Shams	UAE		Trough		2, 19
100	2013		X		Termosol	Spain		Trough		2
100	2010		X		Palma del Rio	Spain		Trough		2
100	2018		X		Llanga 1	S. Africa		Trough	5	2, 20
100	2018		X		Shouhang Dunhuang	China		Tower	7.5	2

1) https://en.wikipedia.org/wiki/List_of_solar_thermal_power_stations
2) https://solarpaces.nrel.gov/

Questions & observations suggested by that Solar Thermal Plant table:

Observation #1: The Solar Thermal table is MUCH shorter than earlier Solar PV table

28 Solar Thermal Plants vs. 57 Solar PV Plants

Observation # 2: Had I leveled the playing field by using the same 200 MW lower limit,

the comparison would have been:

7 Solar Thermal Plants vs. 57 Solar PV Plants

Observation #2: I could **also** have invoked a more rigorous definition of "Utility Scale,"

i.e., that MOST of today's power plants have 500-2000 MW capacities,

Which would have made the comparison of ***truly*** utility scale plants:

1 Solar Thermal Plant vs. 20 Solar PV Plants

Indicating a severe shortfall in today's Solar Thermal Power Plant capacities

HOWEVER: For Solar (and Wind) power, there is an elephant in the room:

As detailed in my note set **Power Cycles and Energy Storage** (pptx / pdf / key):

Demand for electrical power peaks strongly in the evening

When the sun has set (or is setting) and onshore winds are diminishing

Solar & onshore wind power thus naturally support **only** daytime power demand

With solar tracking only helping slightly in the early morning & late afternoon

Today's solution is construction of additional special "peaking" power plants

Which are turned on ONLY in the evenings

These are now usually "Open Cycle Gas Turbine" (OCGT) plants [1]

which, because of their simplicity, are cheap to build

But which waste much of the natural gas's energy

by sending it up a chimney as hot (greenhouse) gases

*1) For details on OCGT plants, see my notes set on **Fossil Fuels** (pptx / pdf / key)*

A much more desirable solution:

As also discussed in **Power Cycles and Energy Storage** (pptx / pdf / key):

Build more, clean, ecologically sensible, daytime power plants

To maximize their efficiency, keep them running **full bore all of the time**,

transforming them into what are called "base load" power plants

Then **store** their excess midday & overnight power output

for use during the high power-demand evenings

But for such a "Base Load + Energy Storage (only)" scenario to work,

MASSIVE amounts of energy must be stored for many hours

Pumped Storage Hydro has done this successfully in a few locations

Compressed air, flywheel, super battery & capacitor schemes are being tested

But power storage cost now matches or exceeds the original power production cost

Making today's stored power AT LEAST twice as expensive

*But Solar Thermal plants heat **storable** liquids*

Some heat special liquids (such as nitrate salts) stable to almost 600 ºC

During the day some super-heated liquid can be pumped into insulated storage tanks

Then, for many evening hours, it can be pumped back out of those tanks

to continue boiling water into the steam

driving the plant's electricity-generating turbines

Those storage tanks are centered in Noor Quarzazate's three Solar Thermal fields:

How much super-heated liquid can be stored during the day?

The quantity is (usefully) stated in terms of

how many hours it can sustain evening electrical power generation

Those durations are listed in my table's semi-final "Heat Storage" column:

POWER PLANT CAPACITY in MW	COMPLETED	PV	ST (CSP)	PLANT AREA in km2	PLANT NAME	COUNTRY	PV TECHNOLOGY	ST TECHNOLOGY	HEAT STORAGE in hours	REFERENCES
510 Thermal + 72 PV	2013-18	X	X	4.5 Trough + 6.8 Trough + 5.5 Tower	Noor Quarzazate	Morocco	(c-Si ?)	Tower + Trough + Tower	3 / 7 / 7.5	2, 5
392	2014		X	14.2	Ivanpah	US		Tower		2, 6
354	1984-90		X		SEGS	US		Trough		2,7
280	2014		X	7.14	Mojave	US		Trough		2, 8
280	2013		X	7.8	Solana	US		Trough	6	2, 9
250	2014		X	7.8	Genesis	US		Trough		2, 10
200	2012-13		X		Solaben	Spain		Trough		2
150	2010		X	3.45	Solnova	Spain		Trough		2, 11
150	2008-11		X	6	Andasol	Spain		Trough	7.5	2,12
150	2010-12		X	6	Extresol	Spain		Trough	7.5	2, 13
125	2014		X		Dhursar	India		Fresnel		2
121	2019		X	3.15	Ashalim	Israel		Trough	4.5	2, 15
121	2019		X		Megalim	Israel		Tower		2
110	2015		X	6.7	Crescent Dunes	US		Tower	10	2, 14
100	2018		X	0.8	Kathu	S. Africa		Trough	4.5	2, 16
100	2015		X	11	KaXu Solar One	S. Africa		Trough	2.5	2, 17
100	2017		X		Xina Solar One	S. Africa		Trough	5.5	2
100	2011		X		Manchasol	Spain		Trough	7.5	2
100	2011		X	1.02	Valle	Spain		Trough	7.5	2, 18
100	2011-12		X		Helioenergy	Spain		Trough		2
100	2012		X		Aste	Spain		Trough	8	2
100	2012		X		Solacor	Spain		Trough		2
100	2012		X		Helios	Spain		Trough		2
100	2013		X	2.5	Shams	UAE		Trough		2, 19
100	2013		X		Termosol	Spain		Trough		2
100	2010		X		Palma del Rio	Spain		Trough		2
100	2018		X		Llanga 1	S. Africa		Trough	5	2, 20
100	2018		X		Shouhang Dunhuang	China		Tower	7.5	2

Fully HALF of these plants now incorporate super-heated liquid heat storage

HALF of that half store enough super-heated liquid to BOTH:

Generate evening power AND pre-heat water back to boiling the next morning

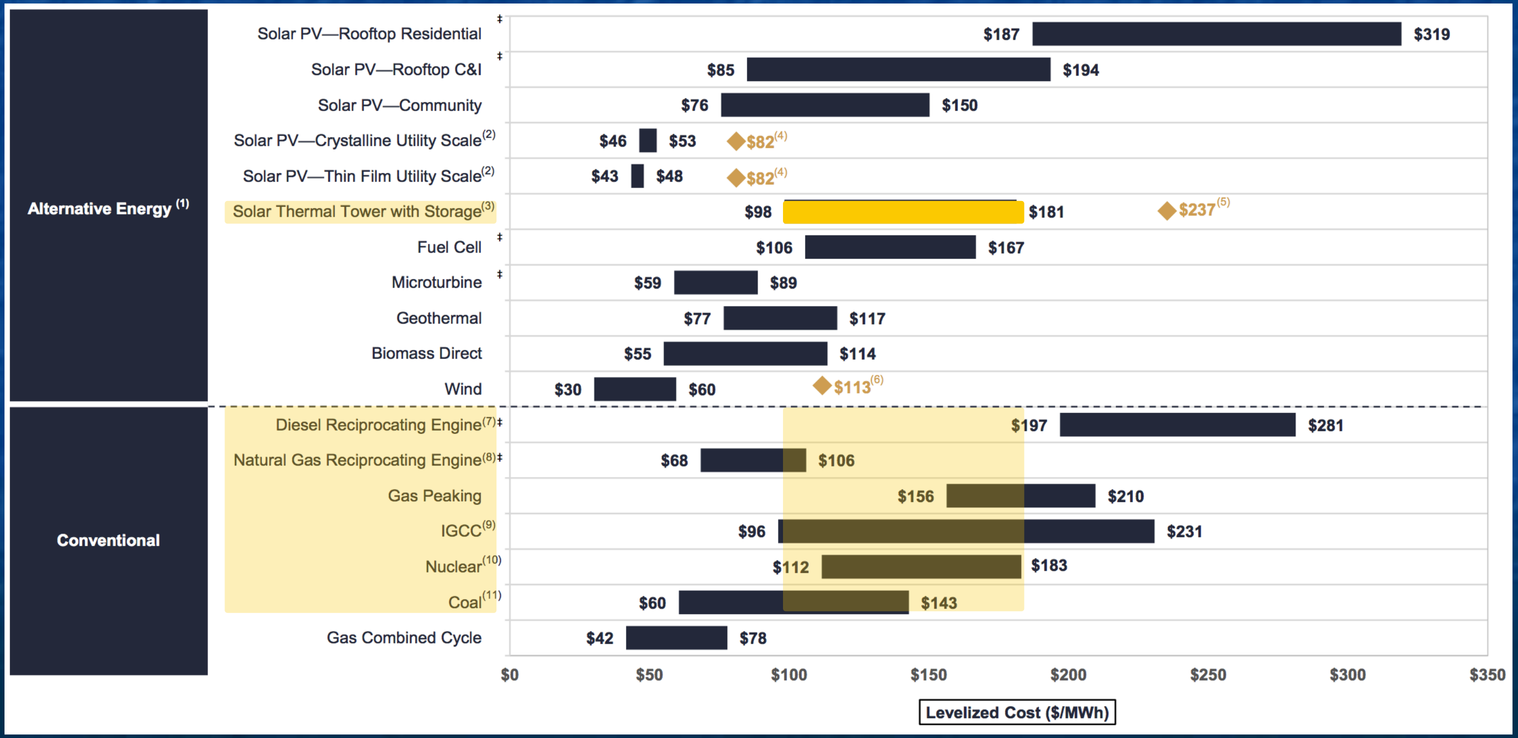
eliminating the gas burning pre-heaters used at Ivanpah & other plants

Do the economics of stored power then begin to make sense?

YES (finally) - at least according to industry-respected sources such as Lazard: [1]

Solar Thermal with integrated Heat Storage can already compete with conventional around-the-clock power sources as gas, coal & nuclear power

While other forms of solar (and at least onshore wind) require huge investment in **separate** storage technologies to provide non-daytime power



*1) From the 2016 **Lazard** analysis of unsubsidized levelized costs of energy (yellow highlighting added)*

Energy Storage will be ESSENTIAL in a Green / Nuclear-free Grid

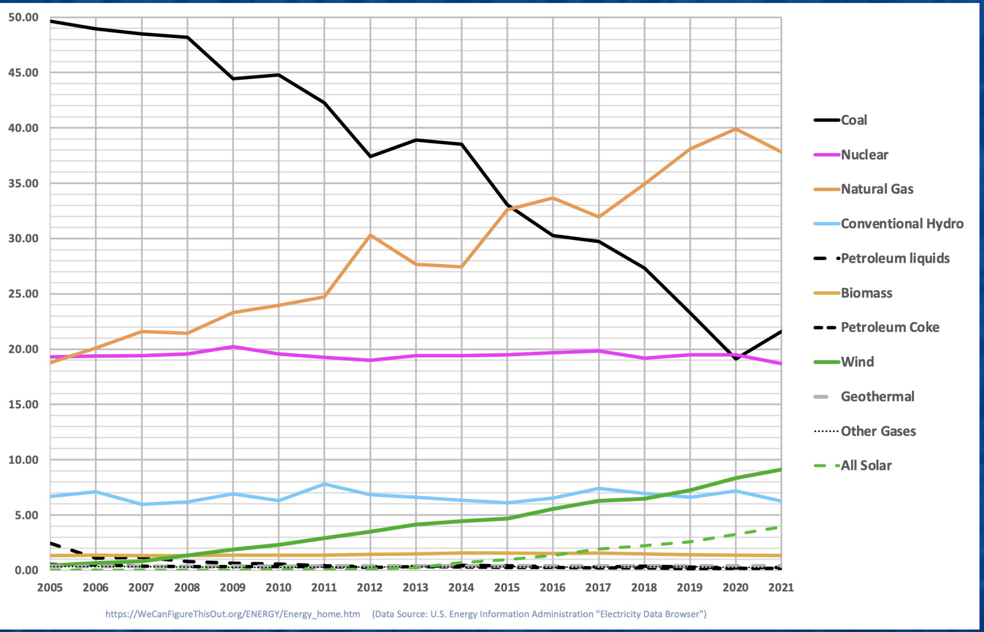
"But with minimal energy storage, wind power (at least) is already thriving!"

But it "thrives" now **only** because we use **so little** wind & solar power (~ 13%)

and thus have **lots of other sources** (mostly dirty and/or undesirable)

still providing our evening power:

Figure from my note set:
U.S. Power Production & Consumption
(pptx / pdf / key)



But when the solar + wind power contribution rises above ~ 20%

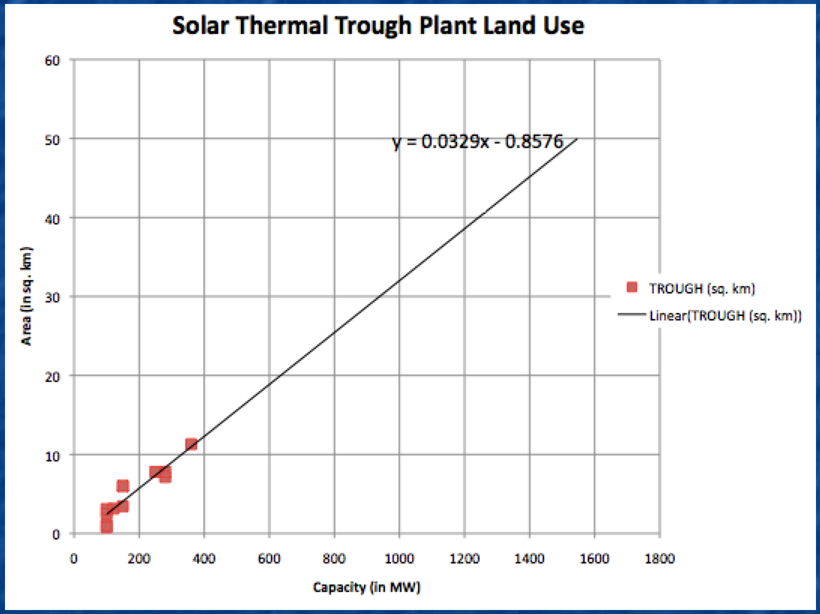
the Grid will begin to fail without massive daytime energy storage!

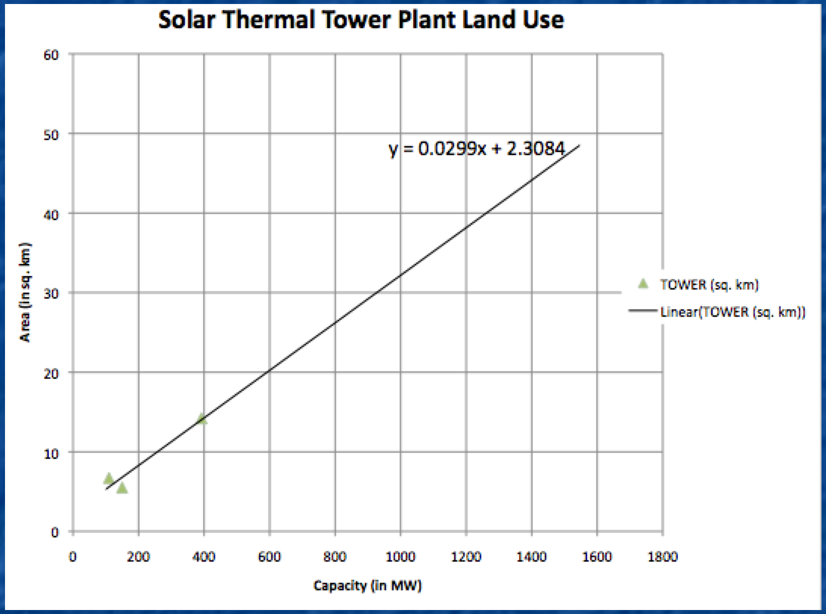
OK, but what about Solar Thermal's land use?

Drawing data from the above Solar Thermal & Solar PV tables:

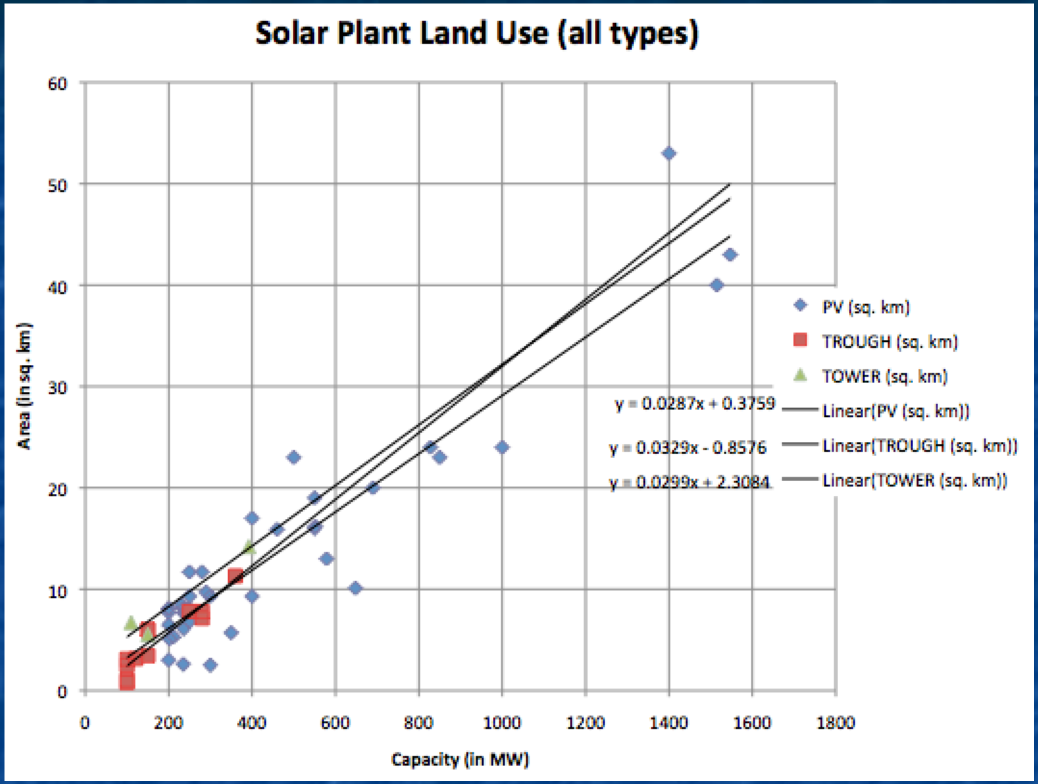
The land use of **Solar Thermal Power Plants**

is virtually identical to that of Solar PV Power Plants





*A cross comparison of land use for **all solar** technologies*



Solar PV:
0.029 km² / MW
=> 34 Watts / m²

Thermal Troughs:
0.033 km² / MW
=> 30 Watts / m²

Thermal Towers:
0.030 km² / MW
=> 33 Watts / m²

Effectively for all: Land use ~ 0.03 km² / MW => Capacity of ~ 30 Watts / m²

That comparison required some arbitration between data sources:

Mostly having to do with misunderstandings about the difference between:

Site area vs. Area occupied by collectors/reflectors vs. Total collector/reflector area

For instance, a trade magazine reported that the 100 MW Kaxu Solar Plant was:

"constructed on a 1,100 hectare site" (11 km^2) [1]

Which was the same area cited by Wikipedia [2]

While a second trade magazine clarified matters by reporting that

"project facilities have a footprint of approximately 310 hectare (3.1km^2) on a 1,100 hectare (11 km^2) site" [3]

Or for the 100 MW Kathu Solar plant site, where you can just take your pick:

Wikipedia reported the area as 0.8 km^2 (unconfirmed in any of their cited sources) [4]

While a trade magazine (not even specifying sources) reported that:

"Kathu Solar Park stretches over 4.5 square kilometers of a 10 km^2 site" [5]

1) https://www.power-technology.com/projects/kaxu-solar-one-northern-cape/
2) https://en.wikipedia.org/wiki/KaXu_Solar_One
3) https://www.renewable-technology.com/projects/kaxu-solar-one-pofadder-northern-cape/
4) https://en.wikipedia.org/wiki/Kathu_Solar_Park
5) https://www.powermag.com/solar-baseload-in-the-kalahari-kathu-solar-park/

Finally: MY table of All Solar Power Plants (≥ 200 MW) - Sorted by capacity:

POWER PLANT CAPACITY in MW	COMPLETED	PV	ST (CSP)	PLANT AREA in km2	PLANT NAME	COUNTRY	PV TECHNOLOGY	ST TECHNOLOGY	HEAT STORAGE in hours	REFERENCES
1547	2016	X		43	Tengger Desert	China	(c-Si ?)			1
1515	2019	X		40	Bhadia Solar	India	(c-Si ?)			1
1400	2019	X		53	Pavagada	India	(c-Si ?)			1
1177	2019	X			Noor Abu Dhabi	UAE	(c-Si ?)			1
1000	2017	X		24	Kurnool Ultra Mega	India	(c-Si ?)			1
1000	2016	X			Dataong Solar Power Top	China	(c-Si ?)			1
850	2015	X		23	Longyangxia	China	(c-Si ?)			1
828	2018	X		24	Villanueva	Mexico	(c-Si ?)			1
750	2018	X			Rewa Ultra Mega	India	(c-Si ?)			1
690	2012	X		20	Charanka	India	(c-Si ?)			1
648	2016	X		10.1	Kamuthi	India	(c-Si ?)			1
613	2019	X			Mohammed bin Rashid	UAE	(c-Si ?)			1
579	2015	X		13	Solar Star	US	(c-Si ?)			1
552	2016	X		16.2	Copper Mountain	US	(c-Si ?)			1
550	2015	X		16	Desert Sunlight	US	(c-Si ?)			1
550	2014	X		19	Topaz	US	CdTe Thin Film			1, 3
510 Thermal + 72 PV	2013-18	X	X	4.5 Trough + 6.8 Trough + 5.5 Tower	Noor Quarzazate	Morocco	(c-Si ?)	Tower + Trough + Tower	3 / 7 / 7.5	2, 5
500	2014	X		23	Huanghe	China	(c-Si ?)			1
500	2018	X			NP Kunta	India	(c-Si ?)			1
500	2018	X			Three Gorges Golmud	China	(c-Si ?)			1
500	2018	X			Three Gorges Delingha	China	(c-Si ?)			1
460	2018	X		15.9	Mount Signal	US	(c-Si ?)			1
400	2016	X		9.3	Mesquite	US	(c-Si ?)			1
400	2018	X			Pirapora	Brazil	(c-Si ?)			1
400	2019	X		17	Ananthapurama	India	(c-Si ?)			1
392	2014		X	14.2	Ivanpah	US		Tower		2, 6
380	2016	X			Yanchi	China	(c-Si ?)			1
350	2019	X		5.7	Springbok	US	(c-Si ?)			1
310	1984-90		X	6.5	SEGS	US		Trough		2,7
300	2015	X		2.5	Cestas	France	(c-Si ?)			1
300	2019	X		9.3	Techren	US	(c-Si ?)			1
292	2017	X			Nova Olinda	Brazil	(c-Si ?)			1
290	2014	X		9.7	Aqua Caliente	US	CdTe Thin Film			1, 3
280	2017	X		11.7	California Flats	US	(c-Si ?)			1
280	2014		X	7.14	Mojave	US		Trough		2, 8
280	2013		X	7.8	Solana	US		Trough	6	2, 9
280	2014		X	7.8	Genesis	US		Trough		2, 10
260	2018	X			Don Jose	Mexico	(c-Si ?)			1
254	2017	X			Ituverava	Barzil	(c-Si ?)			1
250	2017	X			Mandsaur	India	(c-Si ?)			1
250	2016	X		9.3	McCoy	US	(c-Si ?)			1
250	2016	X		11.7	Silver State	US	(c-Si ?)			1
250	2013	X		7.96	California Valley	US	(c-Si ?)			1
250	2016	X		6.82	Stateline	US	(c-Si ?)			1
250	2016	X		8.1	Moapa Southern Paiute	US	(c-Si ?)			1
246	2016	X			El Romero	US	(c-Si ?)			1
246	2019	X			Nikpol	Ukraine	(c-Si ?)			1
240	2019	X			Pokrovske	Ukraine	(c-Si ?)			1
240	2016	X		7.7	Escalante	US	(c-Si ?)			1
236	2019	X		6.1	Midway	US	(c-Si ?)			1
235	2016	X		8.1	Blythe	US	(c-Si ?)			1
235	2018	X		2.6	Setouchi Kirei	Japan	(c-Si ?)			1
235	2017	X		7.7	Upton Solar 2	US	(c-Si ?)			1
230	2015	X		8.5	Antelope Valley	US	CdTe Thin Film			1, 4
212	2016	X		5.3	Roserock	US	(c-Si ?)			1
202	2018	X		5.1	Buckthorn	US	(c-Si ?)			1
200	2017	X		3	Cixi	China	(c-Si ?)			1
200	2019	X		8.1	GA Solar 4	US	(c-Si ?)			1
200	2013	X			Gansu Jintai	China	(c-Si ?)			1
200	2016	X		8.1	Garland	US	(c-Si ?)			1
200	2013	X			Gonghe I	China	(c-Si ?)			1
200	2018	X		6.5	Great Valley	US	(c-Si ?)			1
200	2016	X		7.7	Tranquility	US	(c-Si ?)			1
200	2012-13		X		Solaben	Spain		Trough		2

Or Sorted by date:

CAPACITY in MW				in km2					STORAGE in hours	
310	1984-90		X	6.5	SEGS	US		Trough		2,7
690	2012	X		20	Charanka	India	(c-Si ?)			1
200	2012-13		X		Solaben	Spain		Trough		2
250	2013	X		7.96	California Valley	US	(c-Si ?)			1
200	2013	X			Gansu Jintai	China	(c-Si ?)			1
200	2013	X			Gonghe I	China	(c-Si ?)			1
280	2013		X	7.8	Solana	US		Trough	6	2, 9
510 Thermal + 72 PV	2013-18	X	X	4.5 Trough + 6.8 Trough + 5.5 Tower	Noor Quarzazate	Morocco	(c-Si ?)	Tower + Trough + Tower	3 / 7 / 7.5	2, 5
550	2014	X		19	Topaz	US	CdTe Thin Film			1, 3
500	2014	X		23	Huanghe	China	(c-Si ?)			1
290	2014	X		9.7	Aqua Caliente	US	CdTe Thin Film			1, 3
392	2014		X	14.2	Ivanpah	US		Tower		2, 6
280	2014		X	7.14	Mojave	US		Trough		2, 8
280	2014		X	7.8	Genesis	US		Trough		2, 10
850	2015	X		23	Longyangxia	China	(c-Si ?)			1
579	2015	X		13	Solar Star	US	(c-Si ?)			1
550	2015	X		16	Desert Sunlight	US	(c-Si ?)			1
300	2015	X		2.5	Cestas	France	(c-Si ?)			1
230	2015	X		8.5	Antelope Valley	US	CdTe Thin Film			1, 4
1547	2016	X		43	Tengger Desert	China	(c-Si ?)			1
1000	2016	X			Dataong Solar Power Top	China	(c-Si ?)			1
648	2016	X		10.1	Kamuthi	India	(c-Si ?)			1
552	2016	X		16.2	Copper Mountain	US	(c-Si ?)			1
400	2016	X		9.3	Mesquite	US	(c-Si ?)			1
380	2016	X			Yanchi	China	(c-Si ?)			1
250	2016	X		9.3	McCoy	US	(c-Si ?)			1
250	2016	X		11.7	Silver State	US	(c-Si ?)			1
250	2016	X		6.82	Stateline	US	(c-Si ?)			1
250	2016	X		8.1	Moapa Southern Paiute	US	(c-Si ?)			1
246	2016	X			El Romero	US	(c-Si ?)			1
240	2016	X		7.7	Escalante	US	(c-Si ?)			1
235	2016	X		8.1	Blythe	US	(c-Si ?)			1
212	2016	X		5.3	Roserock	US	(c-Si ?)			1
200	2016	X		8.1	Garland	US	(c-Si ?)			1
200	2016	X		7.7	Tranquility	US	(c-Si ?)			1
1000	2017	X		24	Kurnool Ultra Mega	India	(c-Si ?)			1
292	2017	X			Nova Olinda	Brazil	(c-Si ?)			1
280	2017	X		11.7	California Flats	US	(c-Si ?)			1
254	2017	X			Ituverava	Barzil	(c-Si ?)			1
250	2017	X			Mandsaur	India	(c-Si ?)			1
235	2017	X		7.7	Upton Solar 2	US	(c-Si ?)			1
200	2017	X		3	Cixi	China	(c-Si ?)			1
828	2018	X		24	Villanueva	Mexico	(c-Si ?)			1
750	2018	X			Rewa Ultra Mega	India	(c-Si ?)			1
500	2018	X			NP Kunta	India	(c-Si ?)			1
500	2018	X			Three Gorges Golmud	China	(c-Si ?)			1
500	2018	X			Three Gorges Delingha	China	(c-Si ?)			1
460	2018	X		15.9	Mount Signal	US	(c-Si ?)			1
400	2018	X			Pirapora	Brazil	(c-Si ?)			1
260	2018	X			Don Jose	Mexico	(c-Si ?)			1
235	2018	X		2.6	Setouchi Kirei	Japan	(c-Si ?)			1
202	2018	X		5.1	Buckthorn	US	(c-Si ?)			1
200	2018	X		6.5	Great Valley	US	(c-Si ?)			1
1515	2019	X		40	Bhadla Solar	India	(c-Si ?)			1
1400	2019	X		53	Pavagada	India	(c-Si ?)			1
1177	2019	X			Noor Abu Dhabi	UAE	(c-Si ?)			1
613	2019	X			Mohammed bin Rashid	UAE	(c-Si ?)			1
400	2019	X		17	Ananthapurama	India	(c-Si ?)			1
350	2019	X		5.7	Springbok	US	(c-Si ?)			1
300	2019	X		9.3	Techren	US	(c-Si ?)			1
246	2019	X			Nikpol	Ukraine	(c-Si ?)			1
240	2019	X			Pokrovske	Ukraine	(c-Si ?)			1
236	2019	X		6.1	Midway	US	(c-Si ?)			1
200	2019	X		8.1	GA Solar 4	US	(c-Si ?)			1

BUILT SINCE 2014: Solar PV ONLY

Final sort seems to throw "cold water" on my heat storage discussion:

In that Solar Thermal Plants,

which are the **only** type of Solar Plants capable of Heat Storage

(and thus capable of non-daylight electrical power generation)

seem to have now fallen distinctly out of favor!

The likely explanation?

Massive energy storage is required when wind + solar level reaches ~ 20%

That level may have been reached in Morocco due to Noor Quarzazate

But in larger / heavily developed countries that level has not been reached

E.G., the U.S.'s present day wind + solar level is less than 9%

Thereby relieved of the need for **immediate** action it appears that

in "developed" countries heads are still buried firmly in the ground

***Solar Thermal TAKEAWAYS** - As Suggested by Utility Scale Plants:*

In contrast to Utility Scale PV plants,

Solar Thermal Plants are still small / smallish

With only Noor Quarzazate achieving "typical" power plant capacity

The number of Solar Thermal plants is also comparatively small

For plants ≥ 200 MW: 7 Solar Thermal Plants vs. 57 Solar PV Plants

Most Solar Thermal Plants now employ parabolic trough reflectors

rather than fields of "heliostat" mirrors directing sunlight at solar towers

But Solar Thermal Plants are the only substantially sized "green" power plants

to achieve sustained post-daylight power production

And surprisingly, this capability (achieved via superheated liquid storage)

has been incorporated in over half of these nominally "first generation" plants

Including the very largest of these plants

Including BOTH distributed trough and central tower plants

A key TAKEAWAY about ALL Solar Power:

Heavy reliance on solar power will require huge land areas

In my earliest note set: **Power Plant Requirements: Land and Water** (pptx / pdf / key)

I estimated the minimum land area required for ANY single power technology

to meet 100% of the U.S.'s present day electricity demand

(which requires about 1 TW of power plant capacity)

For Solar PV I based my estimate upon only PV cell efficiency

For Solar Thermal I used early power production data from the Ivanpah CA plant

For both technologies I ended up assuming ~ cloud free high desert plant locations

I concluded that full U.S. power would require:

At least 20,000 km^2 of solar cells (equivalent to ALL of New Jersey)

Or ~ 100,000 km^2 of solar thermal fields (equivalent to ALL of Virginia)

Utility Plant information now facilitates a much more solid estimate:

From that real-life power plant operational experience,

for BOTH Solar PV and Solar Thermal Power Plants

I now calculate land use of ~ 0.03 km^2 / MW of plant capacity

Multiplying that by the total required U.S. capacity of ~ 1 TW:

$0.03\ km^2 / MW \times 1\ TW = 0.03\ km^2 / MW \times 1{,}000{,}000\ MW = 30{,}000\ km^2$

which falls between my much earlier Solar PV & Solar Thermal estimates

and is roughly equivalent to every single square inch of Maryland [1]

But given Maryland's non-high-desert non-cloud-free weather

built on the East Coast, you'd instead need at least two Marylands

or, for instance, every single square inch of West Virginia [2]

1) See Wikipedia's webpage on the sizes of U.S. states:
https://en.wikipedia.org/wiki/List_of_U.S._states_and_territories_by_area

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This set of notes was authored by John C. Bean who also created all figures not explicitly credited above.