Utility Scale Solar Power Plants

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<u>Outline</u>

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

Noor III (2018) - 150 MW

Solar Thermal Central Tower

7 hr molten salt heat storage

City

2 km

Noor I (2015) - 160 MW Parabolic Trough Thermal Collectors 3 hr molten salt heat storage

Noor 1 Ouarzazate 📍

Noor II (2018) - 200 MW Parabolic Trough Thermal Collectors 7 hr molten salt heat storage

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Noor IV (2018) - 72 MW Photovoltaic Cells

> Data Source: NREL - https://solarpaces.nrel.gov/projects - (Noor I / Noor II / Noor II) Image: Google Earth + added labels

1547 MW Solar Photovoltaic Power Plant Tengger Dessert Solar Park, China



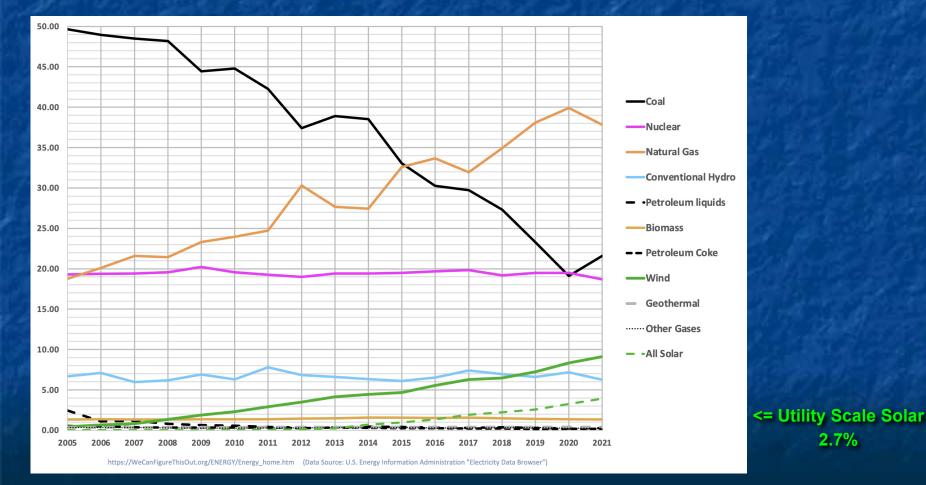
Data Source: Wikipedia citing Chinese language report: http://www.escn.com.cn/news/show-310093.html Image: NASA Earth Observatory - https://earthobservatory.nasa.gov/images/145159/solar-powered-china Why focus upon only "utility" (corporate or governmental) solar power? Especially when so many dream 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)



An Introduction to Sustainable Energy Systems: WeCanFigureThisOut.org/ENERGY/Energy home.htm

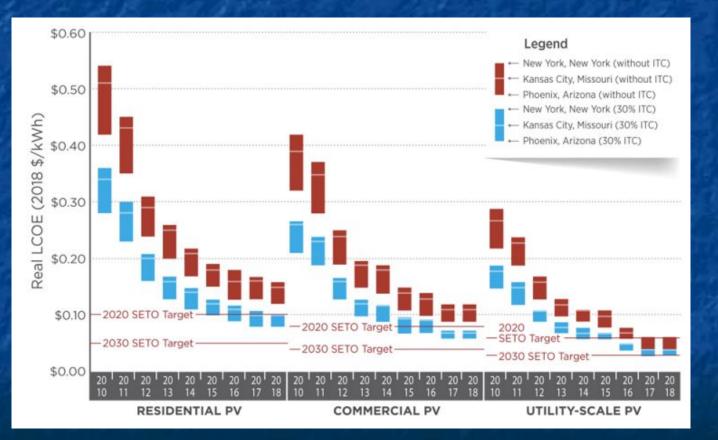
2.7%

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,

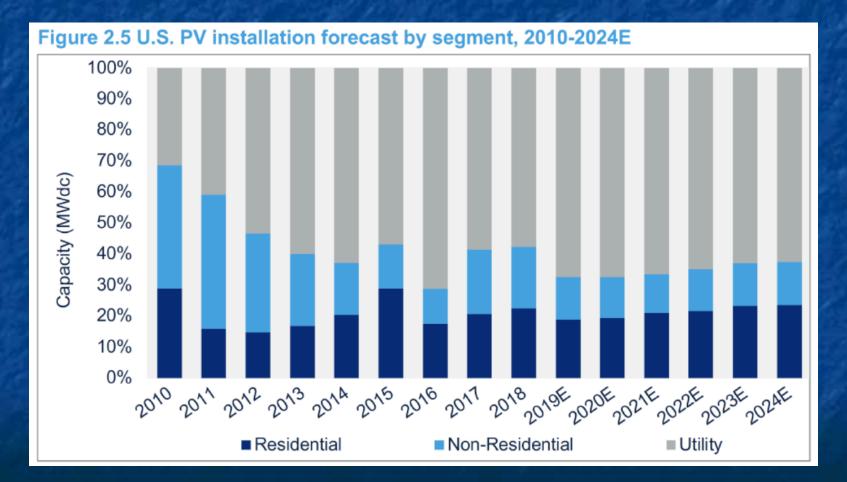
as reported here by the U.S. National Renewable Energy Lab (NREL): 1



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 An Introduction to Sustainable Energy Systems: WeCanFigureThisOut.org/ENERGY/Energy home.htm

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 MW¹ 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 \geq 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 \geq 100 MW¹ 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** (<u>link</u>)

I entered the data I found into a large spreadsheet ¹

Which employed these acronyms:

ST = Solar Thermal = CSP								
CSP = Concentrated Solar Power (ca	n be either ST or I	V, but in power plants it's virtually alw	ays solar thermal)					
PV = Photovoltaic, which includes:								
		c-Si = Single crystalline silicon						
				es packed together)				
		a-Si = Amorphous (non-crystalline)	silicon					
		CdTe = Cadmium Telluride						
		CIGS = Cadmium Indium Gallium Se	lenide					
		Thin Films = Thin film of polycrystall	ine or amorphous selcond	uctor (common semic	conductors include poly	y-Si, a-Si, CdTe, CIGS)		
	CSP = Concentrated Solar Power (car	CSP = Concentrated Solar Power (can be either ST or F	CSP = Concentrated Solar Power (can be either ST or PV, but in power plants it's virtually alw PV = Photovoltaic, which includes: C-Si = Single crystalline silicon poly-Si = Polycrystalline silicon (i.e. a-Si = Amorphous (non-crystalline)) CdTe = Cadmium Telluride CIGS = Cadmium Indium Gallium Se	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 microcrystallit a-Si = Amorphous (non-crystalline) silicon CdTe = Cadmium Telluride CIGS = Cadmium Telluride	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 CIGE = Cadmium Telluride CIGE = Cadmium Gallium Selenide	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 PV = Photovoltaic, which includes: C-Si = Single crystalline silicon poly-Si = Polycrystalline silicon a-Si = Amorphous (non-crystalline) silicon CdTe = Cadmium Telluride CdTe = Cadmium Indium Gallium Selenide	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 PV = Photovoltaic, which includes: C-Si = Single crystalline silicon POWER (c.e. made up of microcrystallites packed together) PV = Photovoltaic, which includes: C-Si = Single crystalline silicon POWER (c.e. made up of microcrystallites packed together) PV = Photovoltaic, which includes: C-Si = Single crystalline silicon POWER (c.e. made up of microcrystallites packed together) PV = Photovoltaic, which includes: CoTe = Cadmium Telluride POWER (c.e. made up of microcrystallites packed together)	CSP = Concentrated Solar Power (can be either ST or PV, but in power plants it's virtually always solar thermal) Image: CSP = Concentrated Solar Power (can be either ST or PV, but in power plants it's virtually always solar thermal) PV = Photovoltaic, which includes: Image: C-Si = Single crystalline silicon Image: C-Si = Single crystalline silicon Image: C-Si = Polycrystalline silicon Image: C-Si = Polycrystalline silicon Image: C-Si = Polycrystalline silicon Image: C-Si = Amorphous (non-crystalline) silicon Image: C-Si = C-C-Si = C-C-Si = C-C-Si = Single crystalline) silicon Image: C-Si = C-Si

And drew from these references:

REFERENCES: 1) List of Photovoltaic Power Plants - Wikipedia		https://en.wikipedia.org/wiki/List_of_photovoltaic_power_stations
 List of Solar Thermal Power Plants - Wikipedia 		https://en.wikipedia.org/wiki/List_of_solar_thermal_power_stations
 Cadmium Telluride Photovoltaics - Wikipedia 		https://en.wikipedia.org/wiki/Cadmium_telluride_photovoltaics
 Best Thin Films - Energy Informative Org 		https://energyinformative.org/best-thin-film-solar-panels-amorphous-cadmium-telluride-cigs
 Ouarzazate Solar Power Station - Wikipedia 		https://en.wikipedia.org/wiki/Ouarzazate_Solar_Power_Station
 Ivanpah Solar Electric Generating System - NREL 		https://solarpaces.nrel.gov/ivanpah-solar-electric-generating-system
 Solar Energy Generating Systems (SEGS Plant) - Wik 	ipedia	https://en.wikipedia.org/wiki/Solar_Energy_Generating_Systems
 Mojave Solar Project - NREL 		https://solarpaces.nrel.gov/mojave-solar-project
 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 Co	m	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 (<u>link</u>) on this note set's **Resources Webpage**

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

POWER PLANT	COMPLETED	PV	ST (CSP)	PLANT AREA	PLANT NAME	COUNTRY	PV TECHNOLOGY	REFERENCES
CAPACITY	COMPLETED	PV	ST (CSP)	in km2	PLANT NAME	COUNTRY	PVTECHNOLOGY	REFERENCES
in MW				IN KM2				
1547	2016	х		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
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	<u>×</u>		2.5	Cestas	France	(c-Si ?)	1
300	2019	<u>×</u>		9.3	Techren	US	(c-Si ?)	1
292	2017 2014	<u>×</u>		9.7	Nova Olinda	Brazil	(c-Si ?)	1
290		X			Aqua Caliente	US	CdTe Thin Film	1, 3
280	2017	X		11.7	California Flats		(c-Si ?)	1
254	2018 2017	X			Don Jose Ituverava	Mexico Barzil	(c-Si ?) (c-Si ?)	1
254	2017	÷			Mandsaur	India	(c-Si ?)	1
250	2017	÷		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	2013	- x		6.82	Stateline	US	(c-Si ?)	1
250	2016	- x	-	8.1	Moapa Southern Paiute	US	(c-Si ?)	1
246	2010	- x		0.1	El Romero	US	(c-Si ?)	1
246	2010	- x			Nikpol	Ukraine	(c-Si ?)	1
240	2019	x			Pokrovske	Ukraine	(c-Si ?)	1
240	2016	x	1	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	1	2.6	Setouchi Kirei	Japan	(c-Si ?)	1
235	2017	х		7.7	Upton Solar 2	US	(c-Si ?)	1
230	2015	х		8.5	Antelope Valley	US	CdTe Thin Film	1, 4
212	2016	Х		5.3	Roserock	US	(c-Si ?)	1
202	2018	Х		5.1	Buckthorn	US	(c-Si ?)	1
200	2017	Х		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	Tranguility	US	(c-Si ?)	1
500	0107	×.		1.1	λιυσύμεμ	02	(6-21-5)	т

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 Plants²

See discussion of NREL data in my note set **Tomorrow's Solar Cells** (<u>pptx</u> / <u>pdf</u> / <u>key</u>)
 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 a-Si PV 13.4% PV efficiencies: 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 PV² 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

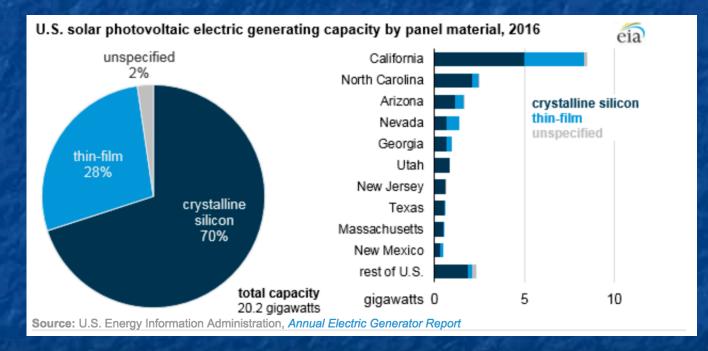
See discussion of NREL data in my note set **Tomorrow's Solar Cells** (<u>pptx</u> / <u>pdf</u> / <u>key</u>)
 https://energyinformative.org/best-thin-film-solar-panels-amorphous-cadmium-telluride-cigs/
 https://www.reuters.com/article/us-solar-frontier-idUSTRE80G1VK20120117
 https://www.power-technology.com/projects/catalina-solar-project-kern-county-california/
 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

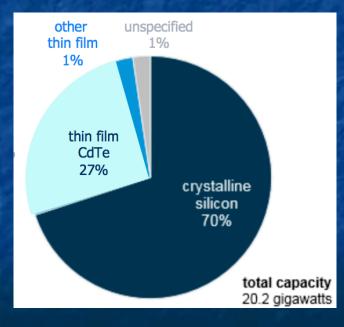
Additional information was provided in the webpage's text:

"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:

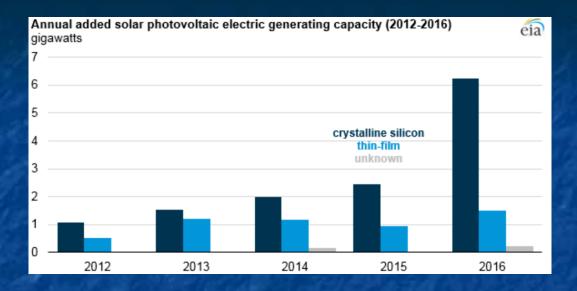


Is that consistent with my table of Utility PV Plants (\geq 200 MW)?

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 \sim 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	COUNTRY	PV TECHNOLOGY
CAPACITY		
in MW		
1547	China	(c-Si ?)
1515	India	(c-Si ?)
1400	India	(c-Si ?)
1177	UAE	(c-Si ?)
1000	India China	(c-Si ?) (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 US	(c-Si ?)
460	US	(c-Si ?) (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 ?) (c-Si ?)
250	US	(c-Si ?) (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 ?) (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	COMPLETED	PV	ST (CSP)	PLANT AREA	PLANT NAME	COUNTRY	PV TECHNOLOG
in MW							
1547	2016	X		43	Tengger Desert	China	(c-Si ?)
1515	2019	X		40	Bhadia Solar	India	(c-Si ?)
1400	2019	X		53	Pavagada	India	(c-Si ?)
1177	2019	X			Neor Abu Dhabi	UAE	(c-Si ?)
1000	2017	x		24	Kurnool Ultra Mega	India	(c-Si ?)
1000	2016	X			Dataong Solar Power Top	China	(c-Si ?)
850	2015	x		23	Longvangxia	China	(c-Si ?)
828	2018	x		24	Villanueva	Mexico	(c-Si ?)
750	2018	x		24	Rewa Ultra Mega	India	(c-Si ?)
690	2010	x		20	Charanka	India	(c-Si ?)
648	2012	x		10.1	Kamuthi	India	(c-Si ?)
613	2010	x		10.1	Mohammed bin Rashid	UAE	(c-Si ?)
579	2015	x		13	Solar Star	US	(c-Si ?)
552	2015	x		15	Copper Mountain	US	
552	2016	X		16.2	Desert Sunlight	US	(c-Si ?) (c-Si ?)
550	2015			16		US	
550	2014	X		19	Topaz	China	CdTe Thin Film
500		X		23	Huanghe NP Kunta		(c-Si ?)
	2018					India	(c-Si ?)
500 500	2018	X			Three Gorges Golmud	China China	(c-Si ?)
					Three Gorges Delingha		(c-Si ?)
460	2018	X		15.9	Mount Signal	US	(c-Si ?)
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	Agua 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 ?)
	2018	x		5.1	Buckthorn	US	(c-Si ?)
202	2010	x		3	Cixi	China	(c-Si ?)
202					GA Solar 4	US	(c-Si ?)
200		X					
200 200	2019	X		8.1			
200 200 200	2019 2013	X			Gansu Jintai	China	(c-Si ?)
200 200 200 200	2019 2013 2016	XX		8.1	Gansu Jintai Garland	China US	(c-Si ?) (c-Si ?)
200 200 200	2019 2013	X			Gansu Jintai	China	(c-Si ?)

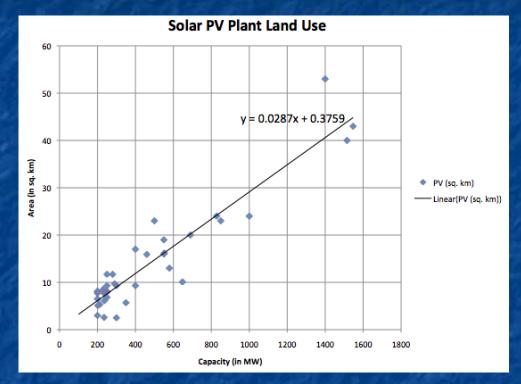
What are the land areas required for such Solar PV Plant capacity?

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

For plants with identified land areas:

	and the second second				
POWER PLANT	PLANT AREA	PLANT NAME	COUNTRY		
CAPACITY	in km2				
in MW					
1547	43	Tengger Desert	China		
1515	40	Bhadia 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	Tranguility	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?

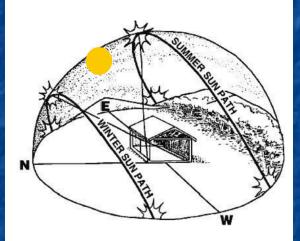
First, despite a greater than 2:1 range in available PV cell conversion efficiencies, Utility Scale Plants rely strongly on PV cells with nearly identical efficiencies: c-Si PV peaking at 25% & Thin Film CdTe peaking at 21% Second, while differing local weather can easily alter PV power by more than 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?

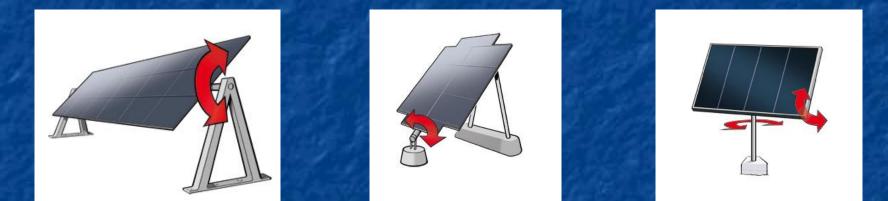
PV Sun Tracking (a.k.a., Solar Tracking):

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)



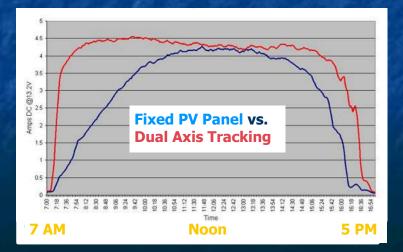
The obvious downside: N-S or E-W "single-axis" tilting adds cost

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

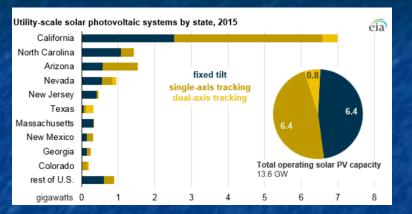


Based on a figure from: https://www.solarchoice.net.au/ blog/solar-trackers/

So do Utility Scale PV plants track or not?

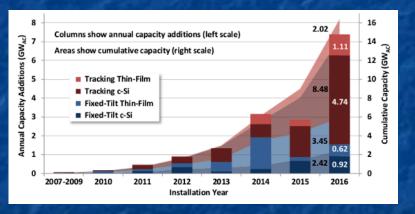
U.S. EIA data on ALL U.S. PV Plants:

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-solarwcharts/



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 km² / 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



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)

	OMPLETED									
		F #	ST (CSP)		PLANT NAME	COUNTRY	PV TECHNOLOGY	ST TECHNOLOGY	HEAT	REFERENCES
CAPACITY				in km2					STORAGE	
in MW									in hours	
	2013-18	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
	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** (<u>pptx</u> / <u>pdf</u> / <u>key</u>)

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

A much more desirable solution:

But Solar Thermal plants heat storable liquids Some heat special liquids (such as nitrate salts) stable to almost 600 °C 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:

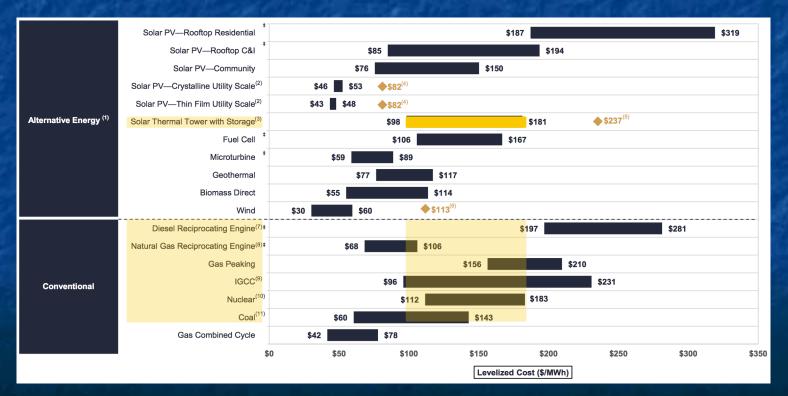
POWER PLANT	COMPLETED	PV	ST (CSP)	PLANT AREA	PLANT NAME	COUNTRY	PV TECHNOLOGY	ST TECHNOLOGY	HEAT	REFERENCES
CAPACITY				in km2					STORAGE	
in MW									in hours	
								i		
510 Thermal + 72 PV	2013-18	X	X	4.5 Trough + 6.8 Trough + 5.5 Tower	Noor Quarzazate	Morocco	(c-Si ?)	Tower + Trough + Tower	3/7/7.5	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

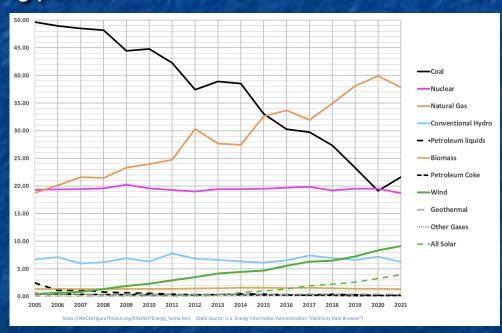
Do the economics of stored power then begin to make sense? YES (finally) - at least according to industry-respected sources such as Lazard: ¹ Solar Thermal with integrated Heat Storage can already compete with conventional around-the-clock power sources as gas, coal & nuclear power While other forms 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:

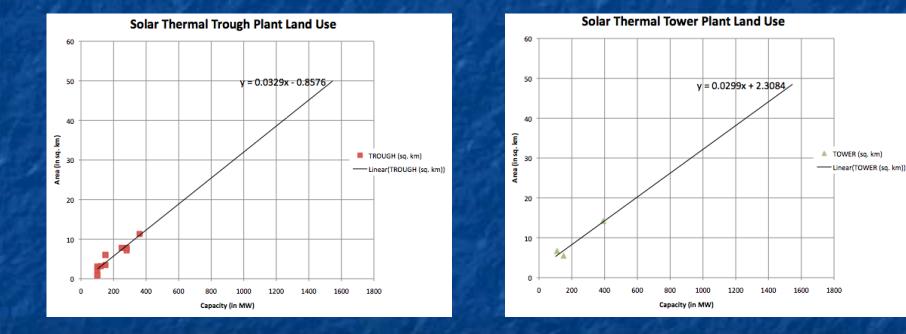
Figure from my note set: U.S. Power Production & Consumption (<u>pptx</u> / <u>pdf</u> / <u>key</u>)



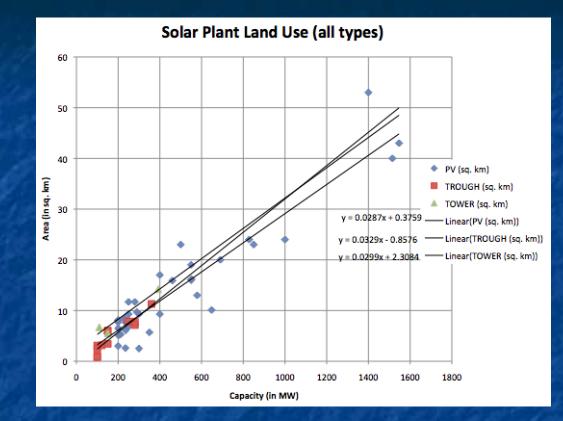
But when the solar + wind power contribution rises above $\sim 20\%$

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 km²)¹ Which was the same area cited by Wikipedia² While a second trade magazine clarified matters by reporting that "project facilities have a footprint of approximately 310 hectare (3.1km²) on a 1,100 hectare (11 km²) 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 km² (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 km² site" ⁵

https://www.power-technology.com/projects/kaxu-solar-one-northern-cape/
 https://en.wikipedia.org/wiki/KaXu_Solar_One
 https://www.renewable-technology.com/projects/kaxu-solar-one-pofadder-northern-cape/
 https://en.wikipedia.org/wiki/Kathu_Solar_Park
 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	COMPLETED	DW	ST (CSD)	PLANT AREA	PLANT NAME	COUNTRY	PV TECHNOLOGY	ST TECHNOLOGY	HEAT	REFERENCES
CAPACITY	COMPLETED	PV	ST (CSP)	in km2	PLANT NAME	COUNTRY	PVTECHNOLOGY	STTECHNOLOGY	STORAGE	REFERENCES
in MW				III KIII2					in hours	
									mnours	
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:

In WW P C P <th>CAPACITY</th> <th></th> <th></th> <th></th> <th></th> <th>in km2</th> <th></th> <th></th> <th></th> <th></th> <th>STORAGE</th> <th></th>	CAPACITY					in km2					STORAGE	
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660 2012 X X 20 Obversion for a second region for a second												
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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 $\sim 20\%$ 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 \geq 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 km² of solar cells (equivalent to ALL of New Jersey) $Or \sim 100,000 \text{ km}^2$ 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 km² / MW of plant capacity Multiplying that by the total required U.S. capacity of \sim 1 TW: 0.03 km^2 / MW x 1 TW = 0.03 km^2 / MW x 1,000,000 MW = $30,000 \text{ km}^2$ 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 Virginia²

> 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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