Photos Credit: NYSERDA

NYSERDA Buy American Supplemental Study Onshore Wind, and Utility-Solar Component Analysis

New York State Energy Research and Development Authority

September 2022

Advisian
Worley Group

Contents

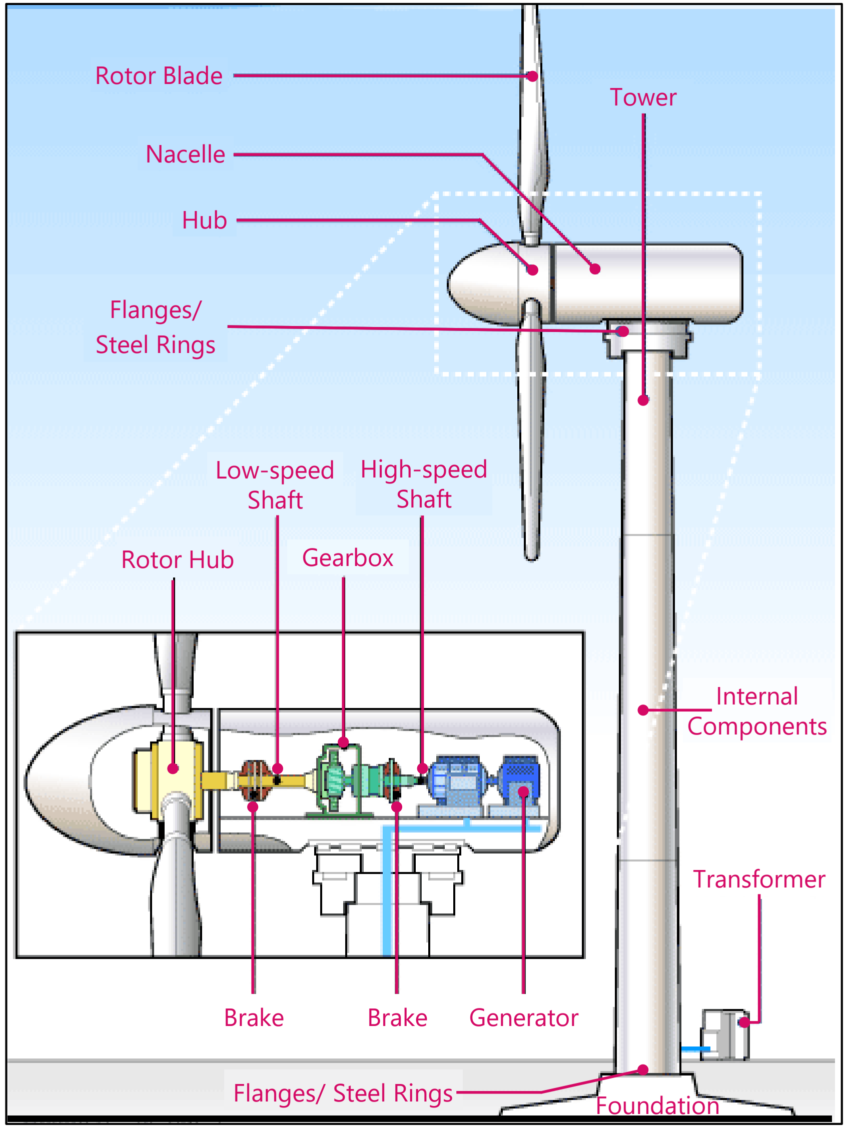
Onshore Wind **Components**

Photo Credit: NYSERDA

Components in Analysis

- **Rotor Blade** *Not included, not structural, mainly fiberglass, balsa wood, and/or carbon fiber*
- **Nacelle*** (including contents)
- **Hub***
- **Flanges/steel rings –** Included
- **Internal components –** Included
- **Tower –** Included
- **Foundation –** Included
- **Nuts, bolts and fasteners –** Included
- **Transformer***

***Not included in the analysis –** not structural; consists of a specialty manufacturing process where the developer has little to no ability to influence subcomponent country of origin/source



Onshore Wind
Forecast Methodology

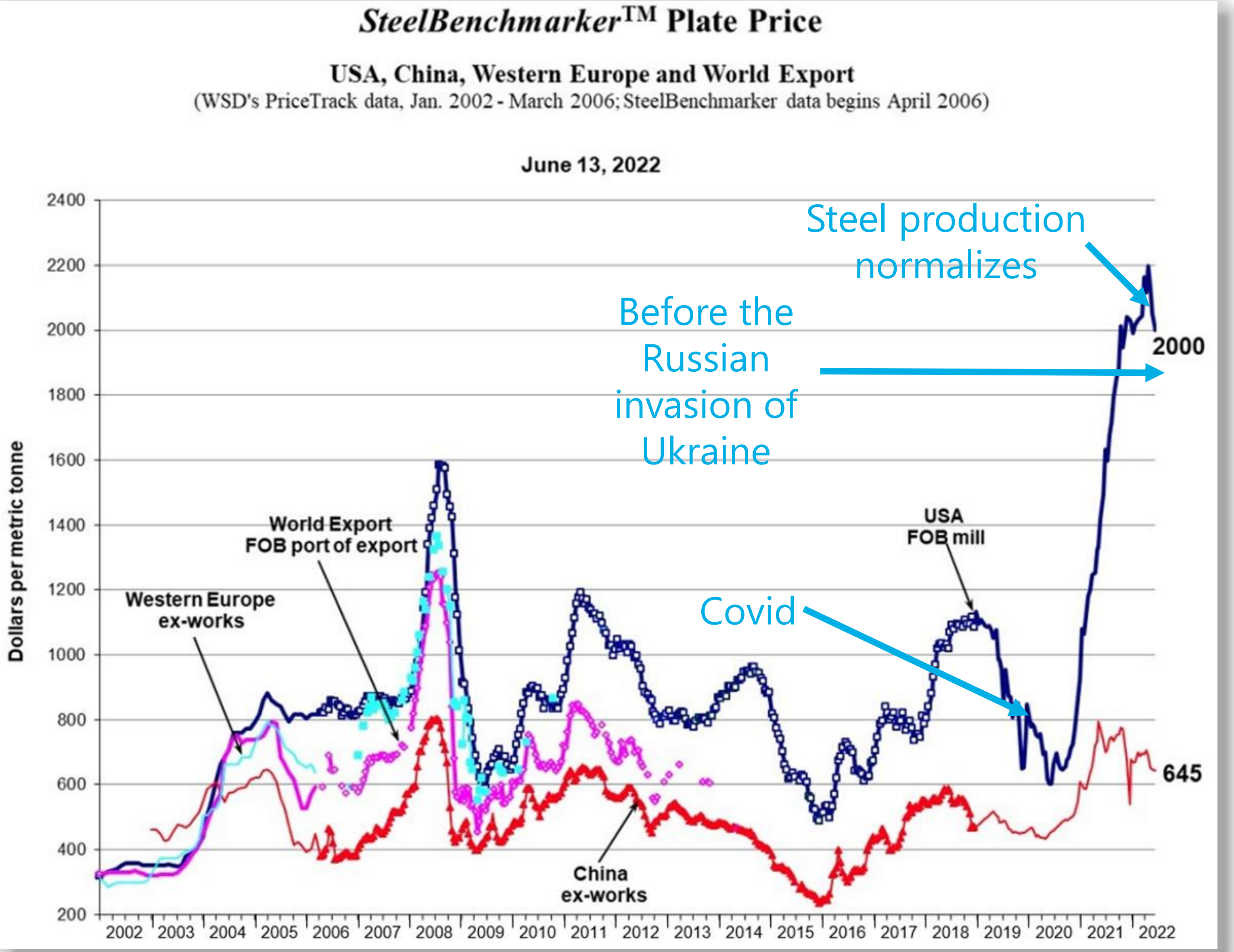
Photo Credit: NYSERDA

Plate Steel Global Price Increases Since COVID

Key Takeaways:

- The pre-COVID plate steel price in the U.S. was the lowest in Q2'20 (~$600/MT). However, the impact of COVID-19 drove prices to their peak by October 2021 ($2,200/MT).
- The prices have since started to move back down from the previous high and are currently at $2,000/MT, which is still over triple the pre-COVID level cost of $600/MT in the U.S.
- Longer-term forecasts predict that prices are trending down yet above pre-COVID levels
- Price Levels ($/MT):
  - 2019 Price Range ~625 to 1,100
  - 2020 Price Range ~600 to ~1,050
  - 2021 Price Range ~1,050 to ~2,200
  - 2022 Price Range ~2,000 (most recent) to 2,200

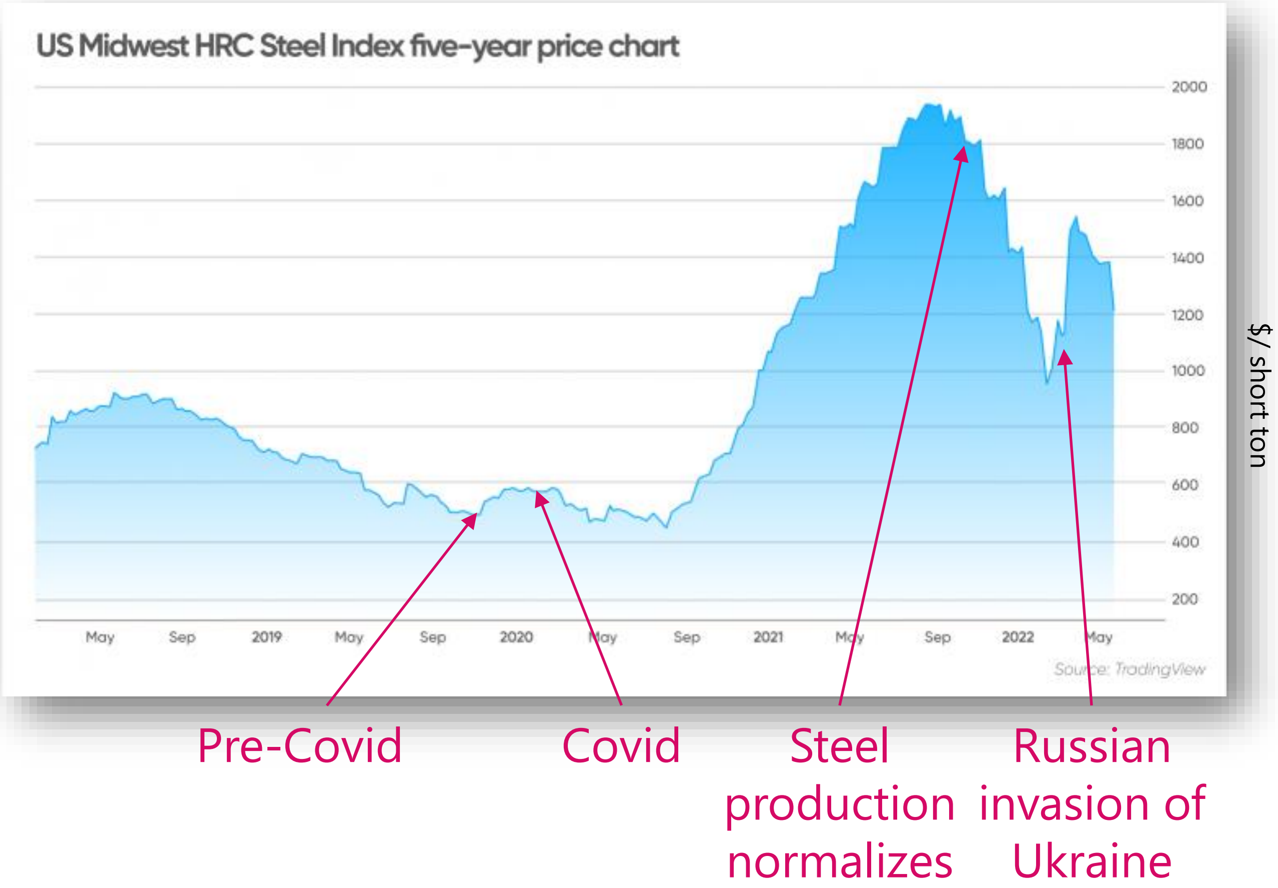
Source: http://steelbenchmarker.com/history.pdf



HRC U.S. Steel Price Down Trend Reverses Course Due to Russian Invasion of Ukraine

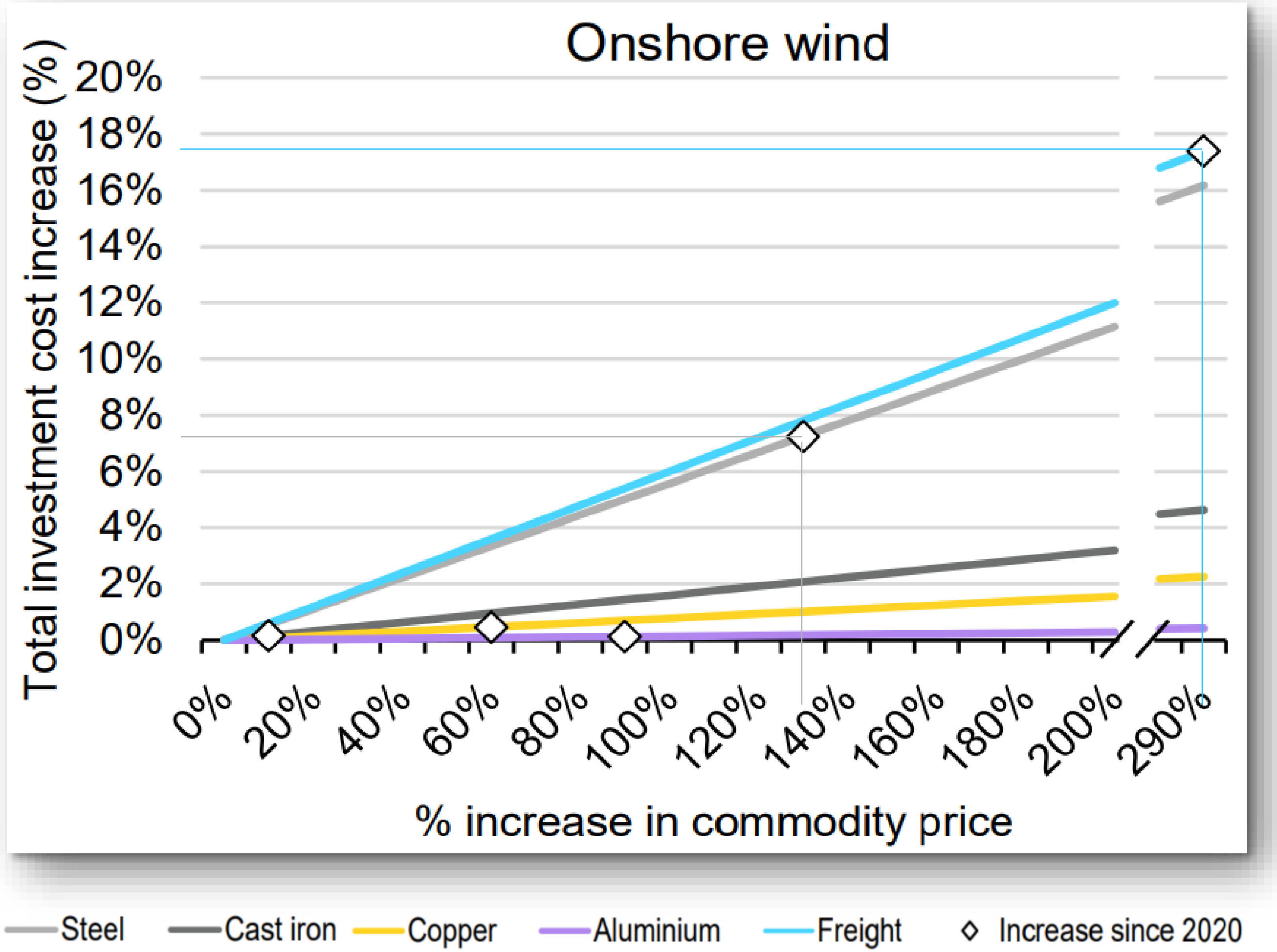
Key Takeaways:

- The hot-rolled coil (HRC) steel price in North America was the lowest in Q4’19. However, the impact of COVID-19 drove prices to their peak of ~$1,950/T by October ‘21. Then prices started to trend back down to ~ $950/T
- However, the Russian Invasion of Ukraine drove the price from ~$950/T to ~$1,550/T. The price begins to take another decline to ~$1,375/T, which is still almost triple the pre-COVID level cost of $475/T
- Longer-term forecasts predict that prices are trending down yet will remain above pre-COVID levels



Steel price forecast 2022: Weak demand outlook pressures market (capital.com)

High Steel and Freight Costs Increase CapEx and LCOE



Key Takeaways:

- The steel cost has increased by ~134%. As a result, the investment cost (CapEx) has increased by ~7%.
- The shipping cost has almost tripled. As a result, the investment cost (CapEx) has increased by ~18%.
- Per a recent report by IEA, onshore wind project investment cost has increased by around 7-8% since 2020 compared to 2019 investment cost due to steel price.

Impact on Steel Price Increase on Onshore Wind	Estimated Increase in Cost
Effect on CapEx	6.5% - 6.7%
Effect on LCOE	4.7% - 4.12%

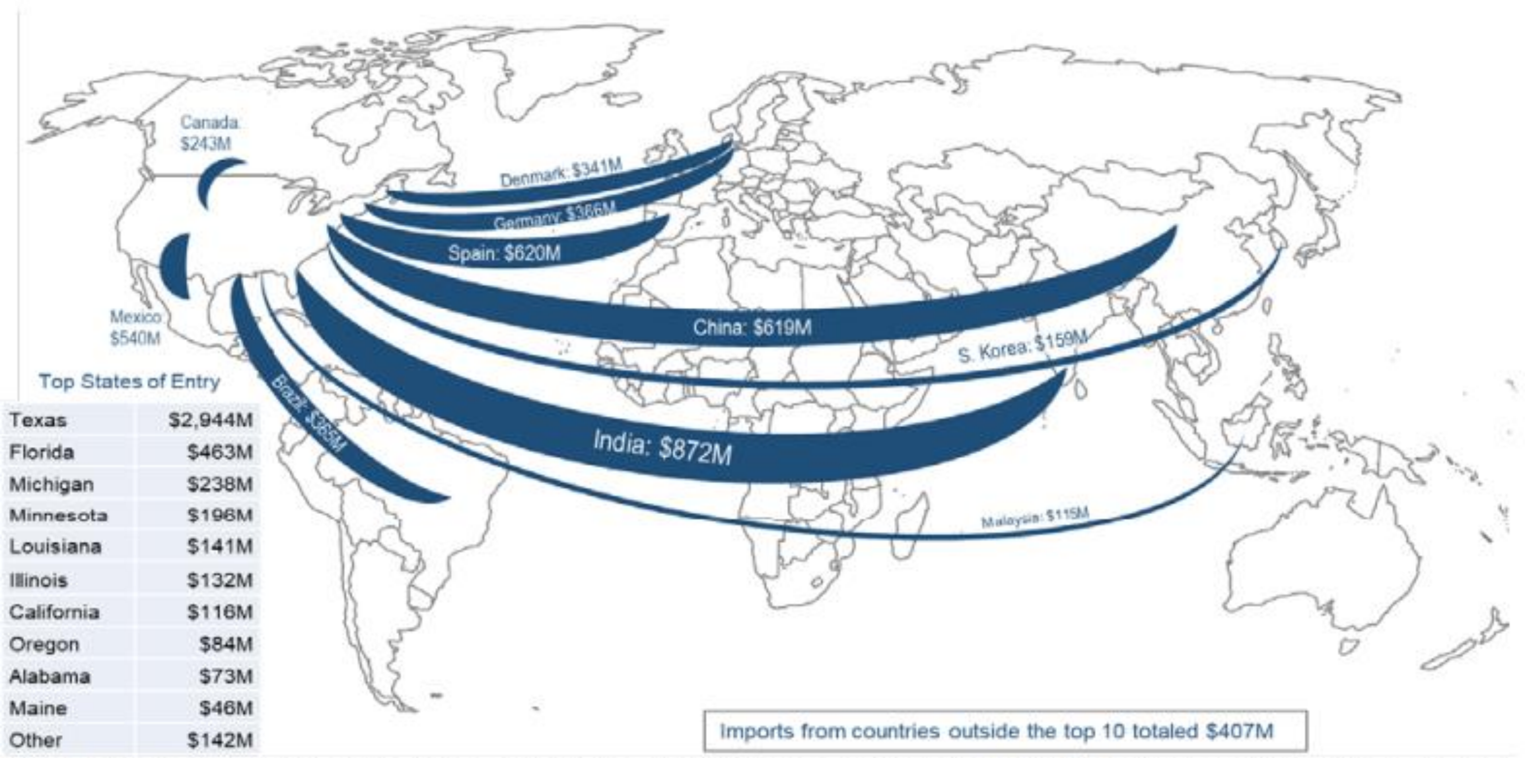
Source: https://iea.blob.core.windows.net/assets/5ae32253-7409-4f9a-a91d-1493ffb9777a/Renewables2021-Analysisandforecastto2026.pdf

IEA - International Energy Agency

Onshore Wind Component Imports Into the U.S.

Key Takeaways:

- GE and Vestas are the leading suppliers of onshore/land-based wind turbines. They supplied 87% of the MW capacity installed in 2020.
- Domestic manufacturing content is strong for some onshore wind turbine components, but the U.S. wind industry remains reliant on imports.
- U.S. wind equipment is sourced globally. In 2020, the predominant countries were India, Spain, China and Mexico.



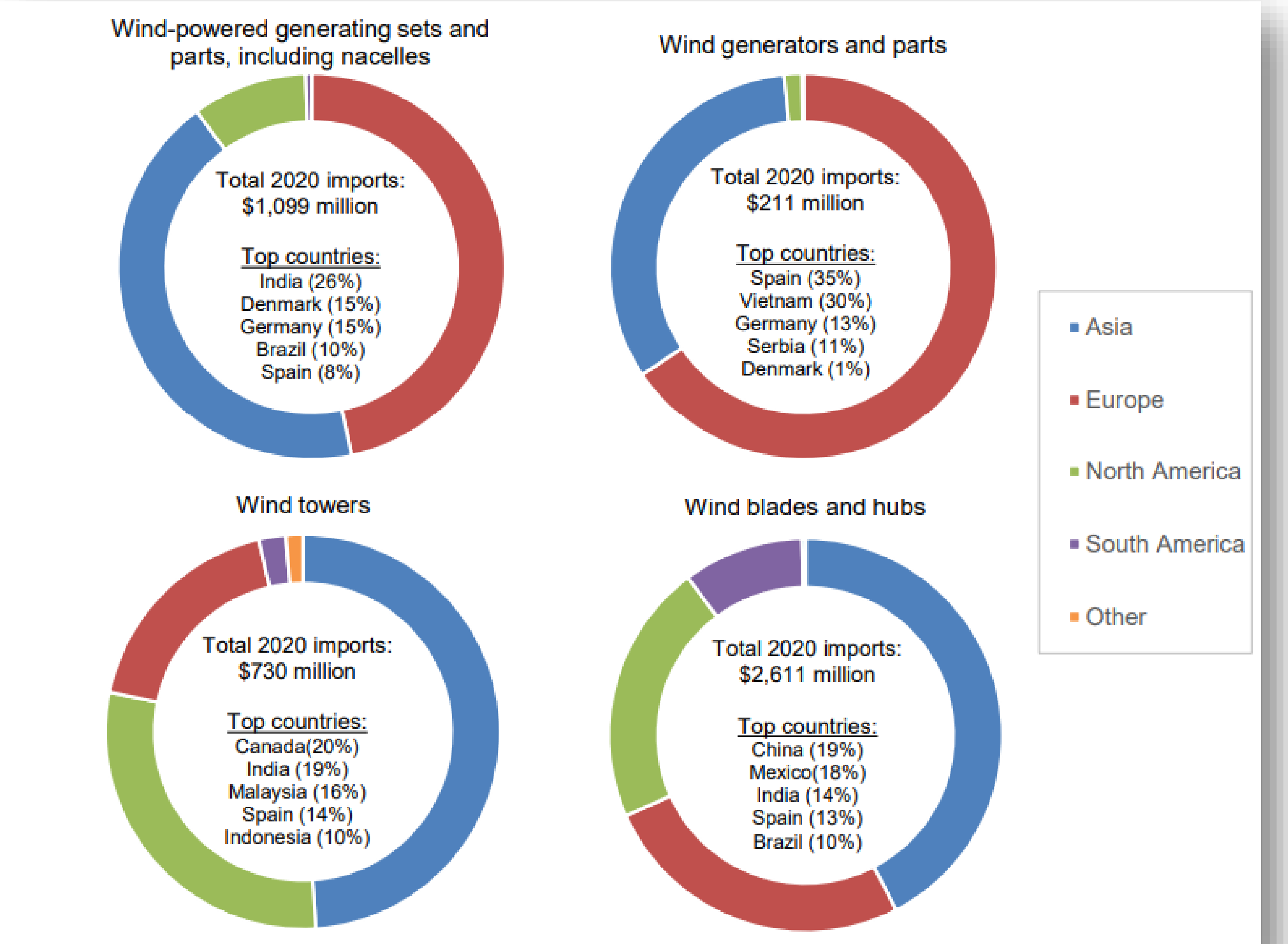
Top States of Entry

Texas	$2,944M
Florida	$463M
Michigan	$238M
Minnesota	$196M
Louisiana	$141M
Illinois	$132M
California	$116M
Oregon	$84M
Alabama	$73M
Maine	$46M
Other	$142M

Note: Line widths are proportional to import amount by country. Figure does not intend to depict the destination of these imports, by state.

Source: Berkeley Lab analysis of data from USA Trade Online, https://usatrade.census.gov
(Report: Land-Based Wind Market Report: 2021 Edition, U.S. DOE)

Onshore Wind Steel Components - U.S. is a Major Importer



Source: Berkeley Lab analysis of data from USA Trade Online, https://usatrade.census.gov

Reference: Land-Based Wind Market Report: 2021 Edition (U.S. DOE)

The U.S. is a significant importer of wind project components:

- Complete Nacelles, including generator sets, are mainly imported from India, Denmark, Germany and Brazil.
- Separate wind generators and other parts are mainly imported from Spain, Vietnam and Germany.
- Blades and hubs are the highest dollar amount of the imported onshore wind components. These parts are primarily sourced from China, Mexico, India, Spain and Brazil.
- Most wind towers are imported from Canada, India, Malaysia, Spain and Indonesia.

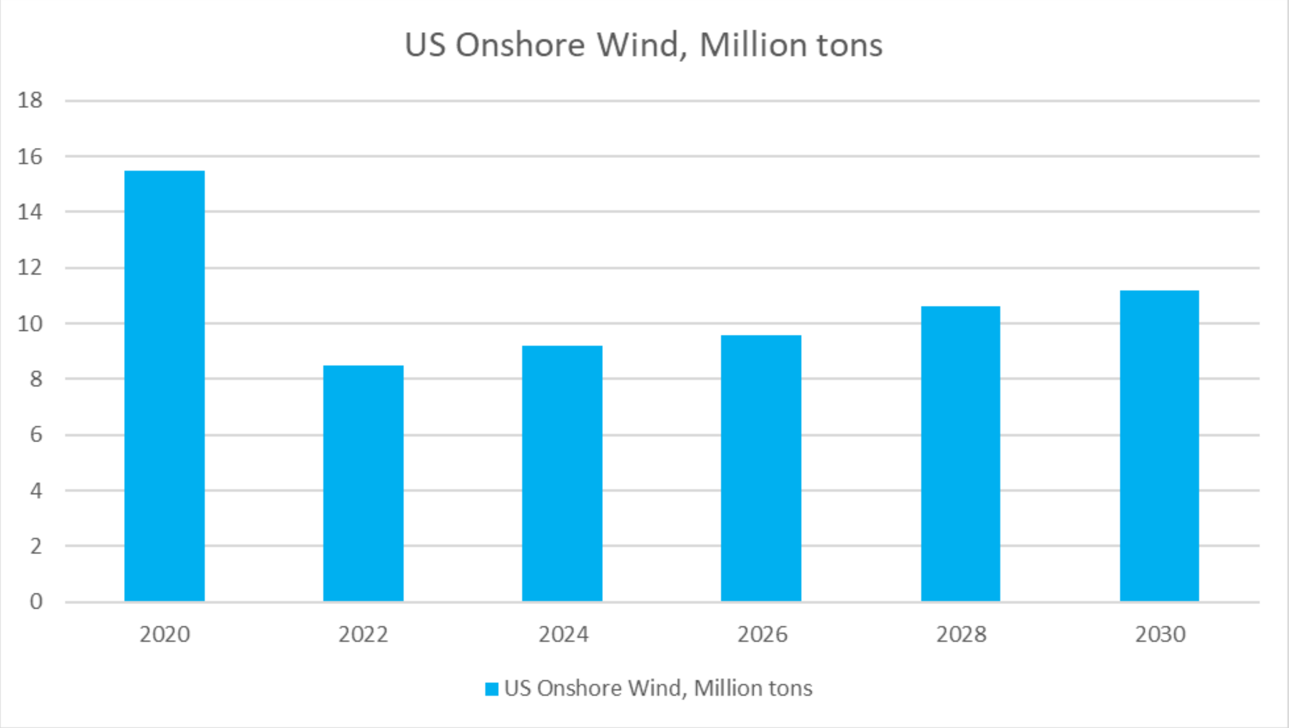
U.S. Onshore Wind Forecast - Continued Growth

Key Takeaways:

- Estimated steel consumption in the onshore wind sector ranges between 8 - 11 Million tons/yr. for the current decade.
- 2020 was an exceptional year, with 16.84 GWac of new wind capacity added and $24.6 Billion invested; onshore steel demand was around 15 million tons.
- Based on the projected wind installation from different sources, Advisian has predicted the steel usage in onshore and offshore wind sectors.
- This projection can be used to estimate the opportunity of the U.S. steel production increase.

Average Expected Steel Usage in Million Tons

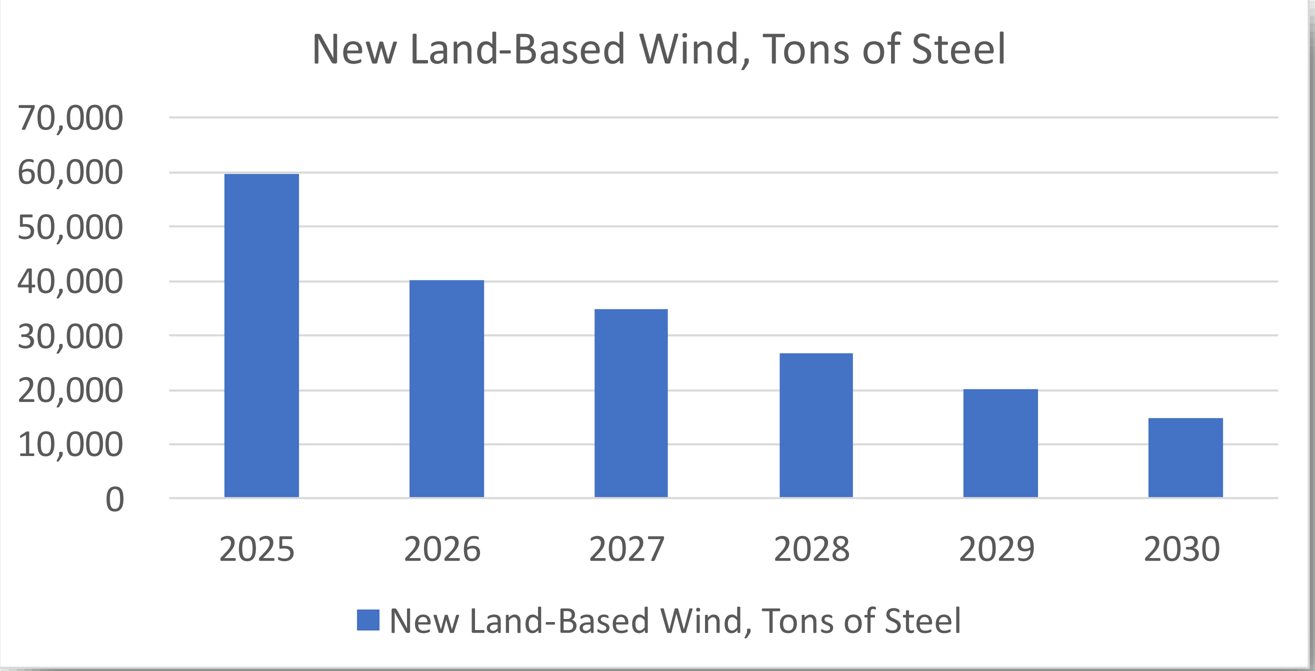
Onshore Wind	2020	2022	2024	2026	2028	2030
	15.5	8.5	9.2	9.6	10.6	11.2



Data Source: US Land-Based Wind Report, NREL Wind Forecast Scenarios, and other online reports from research companies

New York Onshore Wind Forecast - Leveraged to Earlier Projects

Procurement Year	2021	2022	2023	2024	2025	2026
Deployment Year	2025	2026	2027	2028	2029	2030
New Land-Based Wind Capacity, MW	543	365	316	244	183	134
New Land-Based Wind, Tons of Steel	59,730	40,150	34,760	26,840	20,130	14,740

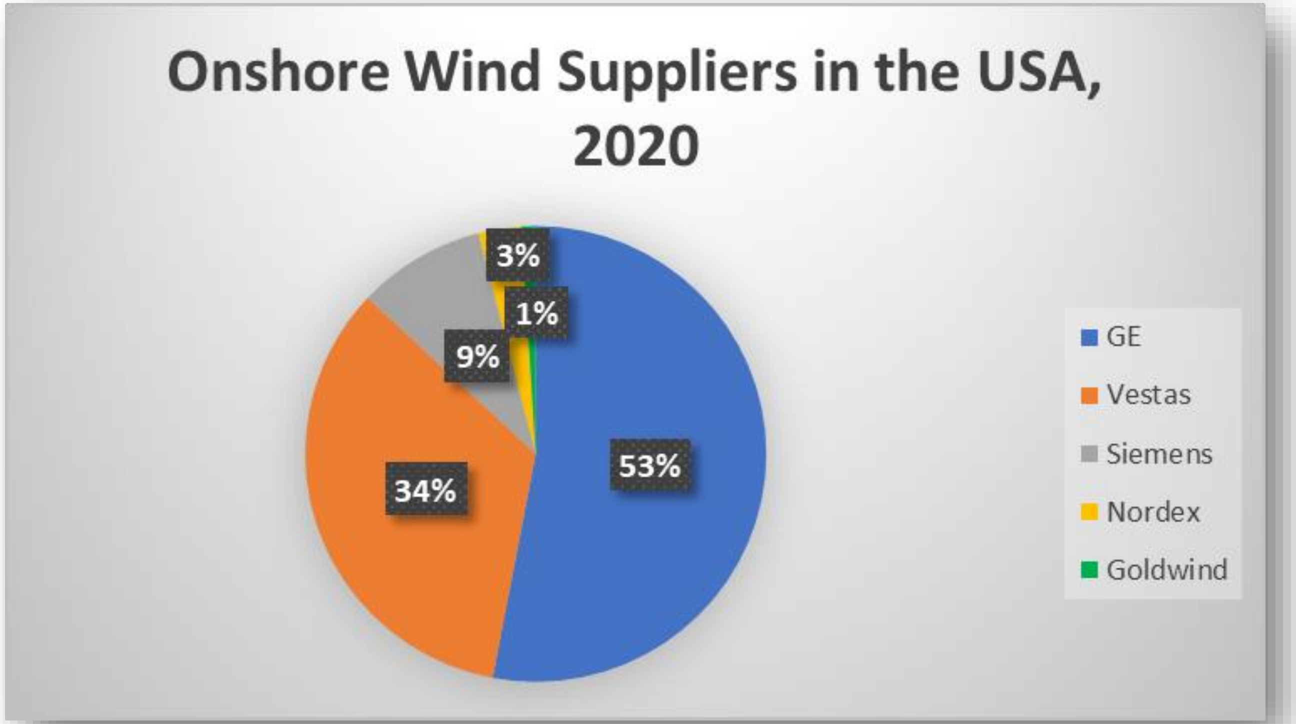


Key Takeaways:

- Using NYS DPS and NYSERDA procurement glide path from June 18, 2020, White Paper on Clean Energy Standard Procurements to Implement New York's Climate Leadership and Community Protection Act for new onshore wind projects, Base Case (Table 24)
- New York is continuing to plan for onshore wind to achieve its renewable goals
- On average, 110 tons/MW of steel is used for an onshore wind project

Source: https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={DCA9763C-D2DA-4FD1-9801-D859E7ED8FE3}

U.S. Onshore Wind Turbine Manufacturers Predominantly Led by 2 (two) OEMs



The largest U.S. onshore wind tower manufacturer in North America recently developed a 134 m (~440 feet), 450-ton onshore wind tower. Another manufacturer has a wind turbine head and hub assembly that is made in the U.S. The choice of tower manufacturer is an OEM decision; the developer has limited influence on the source of steel. This component is typically included in the purchase of a wind turbine package

Projected onshore installations in the U.S. each year (GWac)					
Onshore Wind	2022	2024	2026	2028	2030
	8	8.5	9.8	10.1	9.9

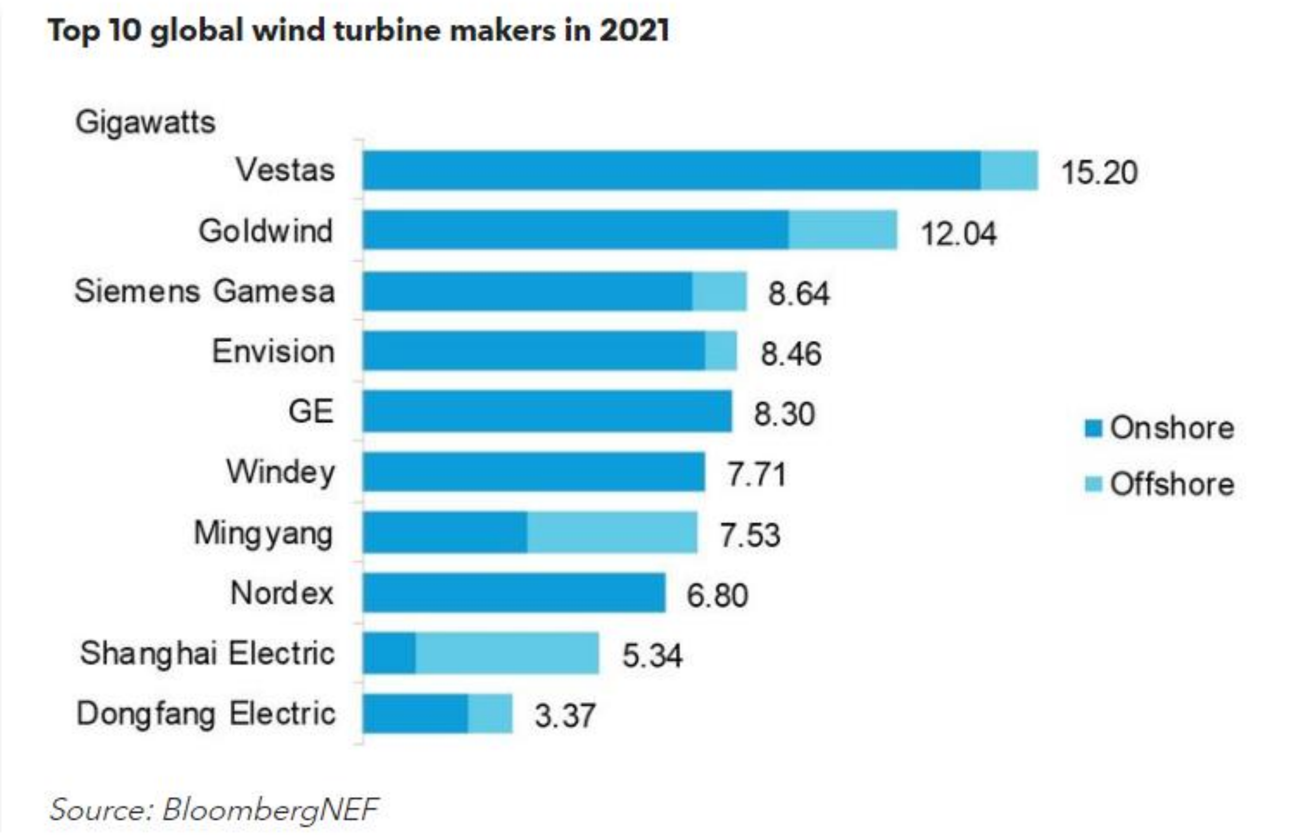
- GE had the largest market share for U.S. onshore wind turbine supply in 2020 with 53%.
- Vestas has a 34% market share.
- Together, these two companies maintain about 87% of onshore wind turbine supply in the U.S. market.
- Siemens is third with a 9% market share.

Reference: Land-Based Wind Market Report: 2021 Edition (U.S. DOE)

Global Market Share is Spread More Evenly

Key Takeaways:

- Vestas had the most significant global market share for wind turbines in 2021 with 15.3%.
- In 2020, Vestas had 34% of the U.S. market share, followed by Goldwind at 12.1%.
- In the U.S., Goldwind only accounts for ~1% of the projects; however, they are the second globally at 12.1%.



- It was another record year for wind build in 2021, with 82.3 gigawatts of new onshore turbines online, and 16.8GW built at sea. Annual wind build is now about 75% higher than the average between 2015-19.

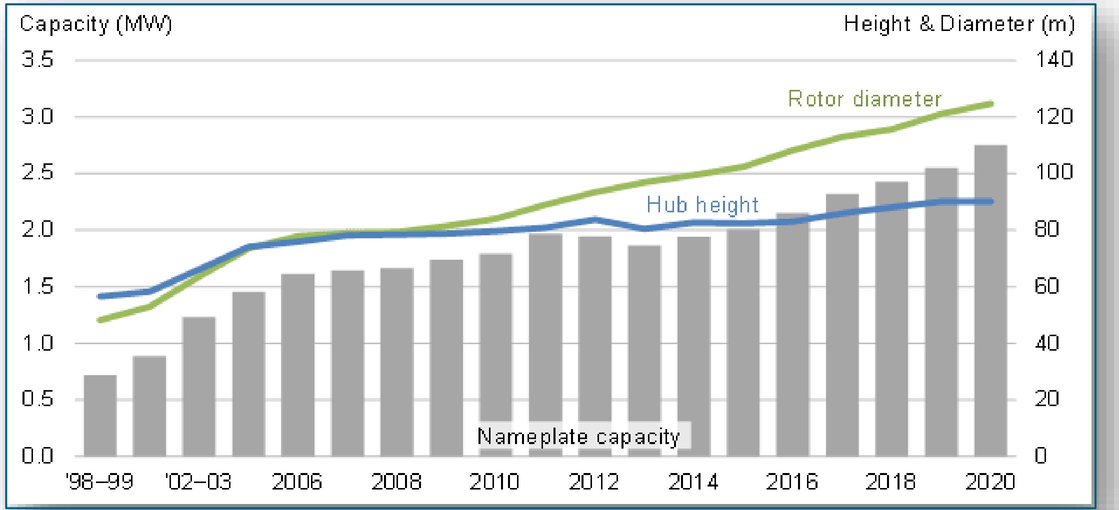
Chart Source: https://www.bnef.com/insights/28593

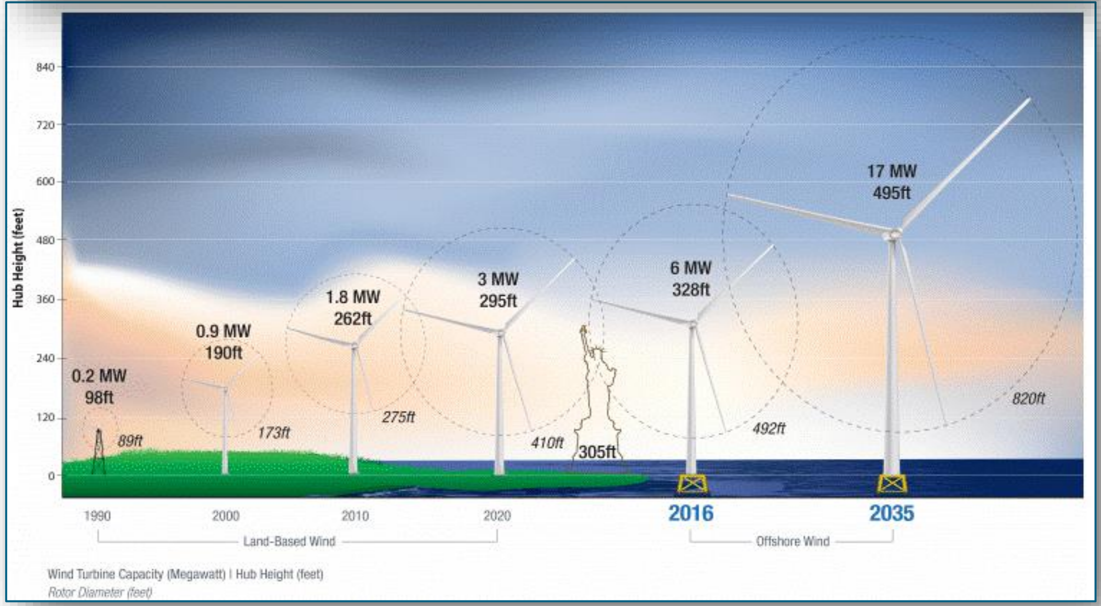
Continued Innovation on Onshore Wind Turbine Sizes

PROJECT SIZES ARE INCREASING, WITH MORE STEEL REQUIRED

- Average U.S. onshore wind turbine size in 2020 was 2.75 MW. [hub height 90.1m (~295 ft) and rotor diameter 124.8m (~410 ft)]
- Forecasted onshore wind turbine size for 2025 is 4 to 5 MW. hub height 109 (~357 feet) to 161 m (~528 feet), and rotor diameter 105 (~344 feet) to 158 m (~518 feet); the hub height and rotor diameter are highly dependent on site
- At a hub height of 140 m (~549 feet), the onshore wind turbine can harvest the most energy yield from existing wind technology.
- Manufacturers are increasing output (MW) with lower hub heights:
  - Siemens Gamesa currently has a 6.6 MW turbine with site-specific tower heights between 100m (~328 feet) to 165 m (~541 feet)
  - GE 6.0-164 Cypress turbine is 6.0 MW with site-specific tower height between 112 m (~367 feet) to 167 m (~547 feet)
  - Vestas V172-7.2 MW turbine produces 7.2 MW with a site-specific tower height between 112 m (~367 feet) to 166 m (~545 feet)

Source: Wind Turbines: the Bigger, the Better | Department of Energy





Onshore Wind
Evaluation Methodology

Photo Credit: NYSERDA

Approach for a $/MWac Threshold for Domestic Steel

Objective: Align with the policy of the 2021 Buy American Act (Public Service Law 66-r).
NYSERDA is investigating a domestic steel threshold requirement for onshore wind projects.

- Through public pricing data, internal data, and primary research interviews we developed a framework to evaluate a reasonable domestic steel threshold across four (4) metrics:
    1. Availability of U.S. manufacturing capabilities
    2. Availability of U.S. steel and supply chain
    3. Global market dynamics
    4. Availability of non-steel alternatives
- Each metric category determines a component value percentage to attribute to a domestic steel requirement.
- Each metric category aggregates the percentage values across four (4) metric categories resulting in a single $/MWac threshold. This provides flexibility for onshore wind developers' procurement processes while encouraging the domestic steel industry.
- This assessment would be undertaken before each procurement to allow for adjustments due to changes in the U.S. and global steel markets.
- All dollars in the analysis are from January 2022 before the Russian invasion of Ukraine.
  These values are conservative. Subsequent slides show more information on steel pricing.

The 4 Metrics' Definitions

1. **Availability of U.S. manufacturing capabilities** The number of U.S. manufacturers currently making the component and U.S. manufacturers with the capacity to begin producing the components.

   Example: Towers – numerous tower manufacturers can supply the onshore market.

2. **Availability of U.S. steel and supply chain** The number of U.S. steel mills producing raw steel, slabs, plates, and coils used in manufacturing the final product. The U.S. mills' current capacity to supply future products, including the number of additional steel mills necessary to meet the forecasted demand.

   Example: Flanges and steel rings – the steel is not currently made in U.S. steel mills.

3. **Global market dynamics** are the variables that influence the originating countries for a particular product. Examples of market dynamics include the magnitude of the market share of non-U.S. manufacturers, their manufacturing processes, and supply chain considerations. These may impede the development of a U.S. supply chain that utilizes U.S. iron and steel for a particular component. This factor is independent of U.S. steel supply and manufacturing capabilities and focuses on current market dynamics from a global supply chain perspective.

   Example: Onshore wind towers are currently manufactured by many non-U.S. entities participating in a global supply chain.

4. **Availability of non-steel alternatives** The alternatives to steel in manufacturing a similar component that is cost-effective and can be used in a particular application. Non-steel alternative components might compete with steel for market share.

   Example: Internal components (platforms, stairways, ladders, doors, railings, cable trays) – Some of these components can be made from aluminum, and other components can be made with fiberglass and plastic.

Evaluation Methodology

	Availability of U.S. Manufacturers	U.S. Steel Feedstock and Supply Chain	Global Market Dynamics	Non-Steel Alternatives
25% Score	M	S	D	A
	Very Low, not currently made in the U.S., and no plans to manufacture	Steel grade or dimensions are not currently made in the U.S., need to add more mills to meet the demand	Component is primarily imported, due to pricing or offshore manufacturing	Non-Metal Alternatives, e.g., fiberglass, concrete, wood, etc.
50% Score	M	S	D	A
	Low, not currently manufactured in the U.S., but there are public commitments/plans to start manufacturing in the U.S.	Steel grade or dimensions are made by a few mills, but need to add more mills to meet demand	Competition is with an imported product; although, there are a few U.S. manufacturers that compete	Metal alternatives (e.g., aluminum)
75% Score	M	S	D	A
	Medium, currently manufactured or easy to begin manufacturing in the U.S.	Steel grade or dimensions are made by mills, but not enough to meet the forecasted demand with an entirely U.S. made product	Competition is with imported products with many U.S. manufacturers that do compete	Different metal mixed structures are possible
100% Score	M	S	D	A
	High, readily available, excess or unused capacity	The existing mills can meet current and future demand	The U.S.-made components are made with U.S. steel and are competitive globally	Must be made with steel

Evaluation Metrics

	Availability of U.S. **M**anufacturers	U.S. Steel Feedstock and **S**upply Chain	Global Market **D**ynamics	Non-Steel **A**lternatives
1 – Foundation: Rebar	M 100%	S 75%	D 50%	A 75%
	Numerous manufacturers readily available in the U.S.	Good supply of raw steel available in the U.S.	U.S. sourced rebar not always being procured by developers; Cost of the rebar is the major driver; U.S. rebar can be more expensive than imported rebar	Fiberglass rebar is an option; although, it is not currently used in many applications
2 - Flanges and steel rings	M 10%	S 10%	D 50%	A 100%
	Some milling and welding capabilities available in U.S. for smaller flanges. Full milling, bending and welding capabilities are needed for larger tower sizes are not currently available in the U.S. However, there are multiple U.S. manufactures working to enter this market.	No U.S. mills are currently making the quality of steel required.	Most flanges and rings are imported as part of the wind turbine package; Large flanges are all imported	No non-steel alternatives available; Requires high strength weldable steel

Evaluation Metrics (continued)

	Availability of U.S. **M**anufacturers	U.S. Steel Feedstock and **S**upply Chain	Global Market **D**ynamics	Non-Steel **A**lternatives
3 – Tower	M 75%	S 75%	D 50%	A 75%
	There are manufacturers that currently make towers and are currently in production	Raw materials are available, size requirements may be an issue as turbines become larger	The manufacturers can use domestic or imported steel for the towers; Turbine manufacturers determine requirements and if domestic steel is necessary	Towers are still primarily made with steel; However, concrete is being used in some applications; In the future, concrete may be used more widely
4 – Internal components	M 100%	S 100%	D 75%	A 25%
	More than 6 manufacturers are available	Existing supply chain can meet the demand including steel and aluminum	Turbine manufacturers determine requirements; Primarily imported materials	Aluminum, fiberglass, wood and several alternatives are available
5 - Nuts, bolts, and fasteners	M 100%	S 100%	D 75%	A 100%
	High, readily available	The existing supply chain can meet the demand	Commodity product, source driven by price, U.S. and imported parts compete	Must be made with stainless steel

Onshore Wind
Key Insights and Individual Component Evaluation

Photo Credit: NYSERDA

Foundation: Rebar

M S D A

Key Takeaways:

- The primary foundations used in New York onshore wind projects are shallow mat extension and spreading footing
- The diameter of the foundation ranges for 2 to 4 MW turbines from 15m (~50 feet) to 22m (~72 feet)
- There is no shortage of rebar manufacturers in the U.S. and numerous suppliers in New York, providing different sizes, strengths and materials
- The amount of rebar and steel rings used for the foundation varies based on the type of foundation and height of the tower
- Advancements in design have reduced the amount of rebar required in the foundations


Photo Credit: NYSERDA

Metric	Calc	Market
Total Foundation Costs @ $/MWac		$130k-$380k; $255k Avg
Only rebar cost @ $/MWac		$6k-$57k, $32k Avg
Manufacturers	100%	Numerous U.S. manufacturers have the capabilities to make rebar
Supply Chain	75%	ASTM A416 / ASTM A1064 / ASTM A615 or ASTM A706 – U.S. steel is used to manufacture rebar
Global Market **D**ynamics	50%	Rebar competition is global, being very price sensitive; Imported rebar is commonly used
Alternatives to Steel	75%	Fiberglass rebar is an option, but is not widely used

Turbine Size (MWac)	1	2	2.3	2.75	3.81	4	5	6
Rebar (kg)	8,955	9,955	26,731	26,800	27,300	40,000	41,565	49,878
Rebar (Metric Ton)	~9	~10	~27	~27	~27	~40	~42	~50
Cost	$31,343	$34,844	$93,559	$93,800	$95,550	$140,000	$145,476	$174,571
Unit Cost ($/MWac)	$31,343	$17,422	$40,678	$34,109	$25,079	$35,000	$29,095	$29,095

The rebar requirement is highly dependent on foundation type, tower height, total weight, and soil conditions. Usually, grade 60 #5 rebar is used. The availability of higher strength rebar will reduce the amount of rebar needed. The early foundations for 1-3 MW turbines used more rebar than required in foundation designs today. This is reflected in the rebar weight needed for the 2.3 - 3.81 MW turbines.

Flanges and Steel Rings

Key Takeaways:

- There are no manufacturing facilities in the U.S. that can machine large-size flanges after welding; a significant investment is needed
- There are no mills in the U.S. that currently produce the S355 EN10.113-2 NL steel used in large flanges; however, nothing is preventing this material from being made in the U.S.
- Common flange thickness for onshore wind towers (2-4 MW) is 91 mm (~3.5") to 150 mm (~6")
- U.S. steel manufacturers can support small flanges under 5m (16 ft) in diameter, which is adequate for tower heights below 100m (~328 ft) but not for projects that are over 130m (~426 feet) or higher

Metric	Calc	Market
Current Costs @ $/MWac		$32k-$54k; $43k Avg
Manufacturers	10%	None in the U.S. for the New York pipeline of projects. There are more than three globally. Flanges are generally forged and rolled from specific grade steel with weld necks to improve the weld fatigue and need to be treated with an anti-corrosive agent. Tower top flanges are machined post welded to ensure top flange flatness is within tolerances.
Supply Chain	10%	No U.S. steel is being used; Requires specialized steel (S355 EN10.113-2 NL) that is not manufactured in the U.S. Primary suppliers are Germany, China and India
Global Market **D**ynamics	50%	This product is primarily imported. There is a global competition in the flange market, and the U.S. does not have a competitive product
Alternatives to Steel	100%	None

Photo Credit: https://pemamek.com/us/welding-solutions/wind-energy/onshore-wind-tower-and-foundation-manufacturing/

Tower

Key Takeaways:

- Wind turbine tower is an assembly of several tubular cylindrical segments (cans) made of steel and welded together
- Tower section diameters range from the top 3.1m (~10 ft) to 4.4m (~14.5 ft) and the base is from 4.3m (14 ft) to 9.6m (~31.5 ft), depending on the hub height/turbine size
- The can wall thickness: top ~10 mm (~0.4") and base ~18 mm (~0.7")
- For a 2.75 MW turbine, the complete tower weighs ~257.4 MT [90m (~295 ft) - 98.3m (~322 ft) hub height]
- Tower is mounted to the foundation with nuts and bolts

Photos Credit: NYSERDA

M S D A

Metric	Calc	Market
Current costs @ $/MWac		$158k-$188k; $173k Avg
Manufacturers	75%	There are ~5 manufacturers in the U.S. today. Each manufacturer can make 10 to 15 tower sections (cans) per week. Primary sources for onshore towers are Spain, Indonesia and Vietnam.
Supply Chain	75%	Steel grades S235 and S355 are mainly used, and S420 and S650 are options; S235 is manufactured in the U.S., but raw material is mostly imported from Canada and India.
Global Market **D**ynamics	50%	The steel used in tower manufacturing can be from domestic or imported sources. The turbine manufacturer determines the requirements and the source (domestic or import). Steel quality, size, price and availability are factors used to make this decision. Imported steel is very competitive.
Alternatives to Steel	75%	Concrete is being used in some applications and could continue to take market share.

Internal Components
platforms, stairways, ladders, doors, railings and cable trays

Key Takeaways:

- These components can be made in the U.S. today; however, aluminum is lighter and less expensive
- Ladders are a commodity and sourced globally
- Currently, the industry uses wood, fiberglass, and aluminum, so specifications for steel will be costly
- Readily available and can leverage existing supply chain. Internal ladders are mostly made of AL ($5-6/ft)
- Typically, all these components are imported

Photos Credit: NYSERDA

Metric	Calc	Market
Current Costs @ $/MWac		$9k-$11k; $10k Avg
Manufacturers	100%	Many manufacturers can supply steel ladders, which can be made in the U.S. today; however, aluminum ladders are more standard since they are lighter and less expensive. Domestic manufacturers 5 - 8 (Stainless) and 2-4 (Aluminum)
Supply Chain	100%	Not difficult to source domestic steel for ladders. Limited opportunity for adoption due to a wide variety of alternative materials
Global Market **D**ynamics	75%	Imported components have most of the market share for these components. If steel is required, U.S. parts are competitive
Alternatives to Steel	25%	Wide range of ladder materials in use today for wind turbines, including wood, fiberglass, and aluminum

M S D A

Nuts, Bolts, and Fasteners

Key Takeaways:

- Three main types of bolts (25,000 bolts/turbine) are used in onshore wind turbines:
  1. *Tower bolts (GB/T 1228-1231, DIN6914-6916 and DAST)*
  2. *Foundation bolts (hexagonal GB/T 5782-5783, 70.1, 6170, 97)*
  3. *Blade bolts (double-headed studs and T-round nuts)*
- Most of these bolts are attached on-site.
- Numerous manufacturers are making these products and are readily available from U.S. manufacturers.
- A hindrance to using U.S. products would be an increase in cost compared to an imported product. Many view this market as commoditized and very cost-sensitive.

Photo Credit: Powermag.com

Metric	Calc	Market
Current Costs @ $/MWac		$8k-$10k; $9k Avg
Manufacturers	100%	Many U.S. manufacturers (5-8+) already support this market, with hundreds more globally. The heaviest infrastructure uses similar fasteners.
Supply Chain	100%	Many manufacturers support this product, and there is a lot of flexibility with the products required to support wind turbines. The size and quality of the steel are readily available in the U.S.
Global Market **D**ynamics	75%	There is global competition for these products and the U.S. does compete.
Alternatives to Steel	100%	None; must be made with high strength steel.

Usually, the tower bolts are included in the tower cost, the blade bolts are included in the blade cost, and the foundation bolts are included in the foundation cost.

Onshore Wind Recommendations

Photo Credit: NYSERDA

Onshore Wind Calculation Methodology Example

	Onshore Wind	Average $/MW		US Manufacturers – Metric (%)		US Steel Supply – Metric (%)		Market Dynamics – Metric (%)		Steel Alternatives – Metric (%)		Minimum $/ MW
1	Foundation: Rebar	$31,818		100%		75%		50%		75%		$8,949
2	Flanges, Steel rings	$43,000		10%		10%		50%		100%		$215
3	Towers	$173,000	X	75%	X	75%	X	50%	X	75%	=	$36,492
4	Internal Components	$10,000		100%		100%		75%		25%		$1,875
5	Nuts, Bolts, & Fasteners	$9,000		100%		100%		75%		100%		$6,750
											∑Total	$54,281

Recommendations $/MWac of U.S. Steel

	Onshore Wind	Average $/MWac	US Manufacturers – Metric (%)	US Steel Supply – Metric (%)	Market Dynamics – Metric (%)	Steel Alternatives – Metric (%)	Minimum $/MWac
1	Foundation: Rebar	$31,818	100%	75%	50%	75%	$8,949
2	Flanges, Steel rings	$43,000	10%	10%	50%	100%	$215
3	Towers	$173,000	75%	75%	50%	75%	$36,492
4	Internal Components	$10,000	100%	100%	75%	25%	$1,875
5	Nuts, Bolts, & Fasteners	$9,000	100%	100%	75%	100%	$6,750
							$54,281

Utility-scale Solar
Fixed-Tilt and Single Axis Tracker Systems

Photo Credit: NYSERDA

Components for Utility-Scale Solar Photovoltaic Fixed-Tilt and Single Axis Trackers

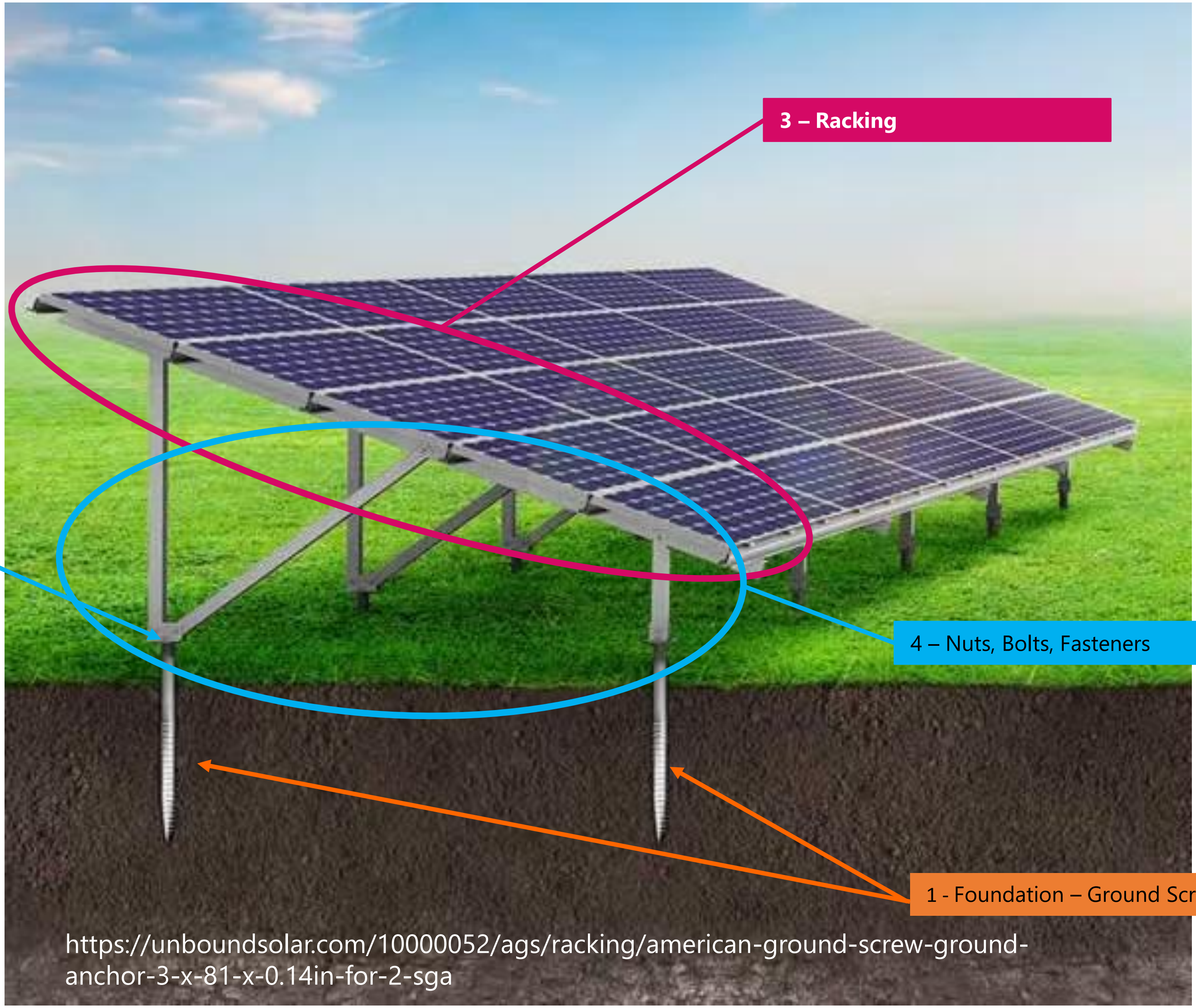
- Solar Ground Mount (typical)
  - Foundations:
    - Ground Screw (including Helical Anchors)
    - Driven Pile (e.g., I-Beam, H-Beam, C-Channels)
  - Remaining components:
    - Racking - nuts, bolts, clamps and fasteners
    - Unique for Single Axis Tracker (SAT)
      - Torque Tube and Bearings

Photo Credit: NYSERDA

Solar PV, Ground Mount Fixed-Tilt

Mounting on top of Ground screw

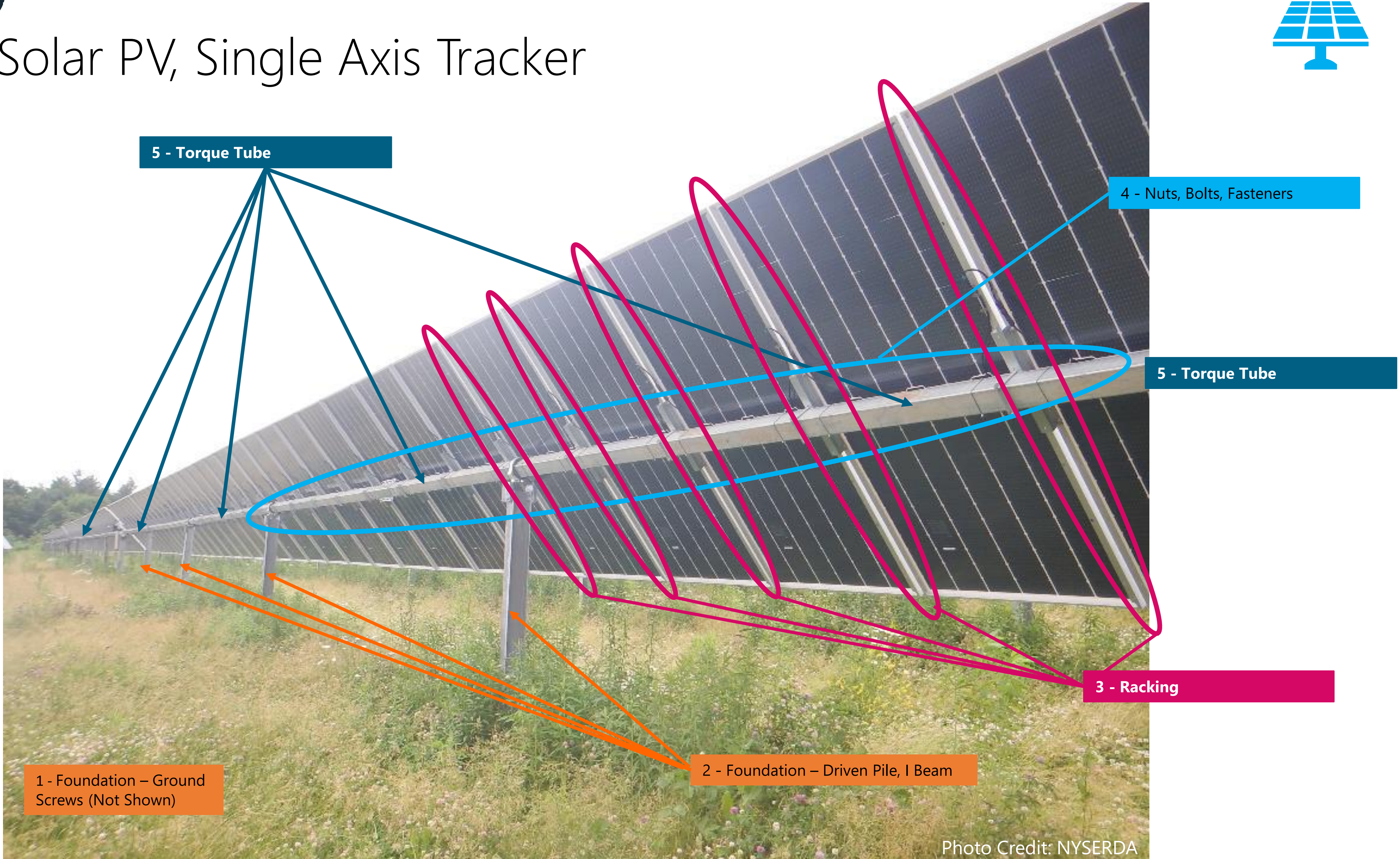
2 - Foundation – I Beam – Driven Pile (not shown)



Helical screw

Ground screw

Solar PV, Single Axis Tracker



Utility-scale Solar Forecast Methodology

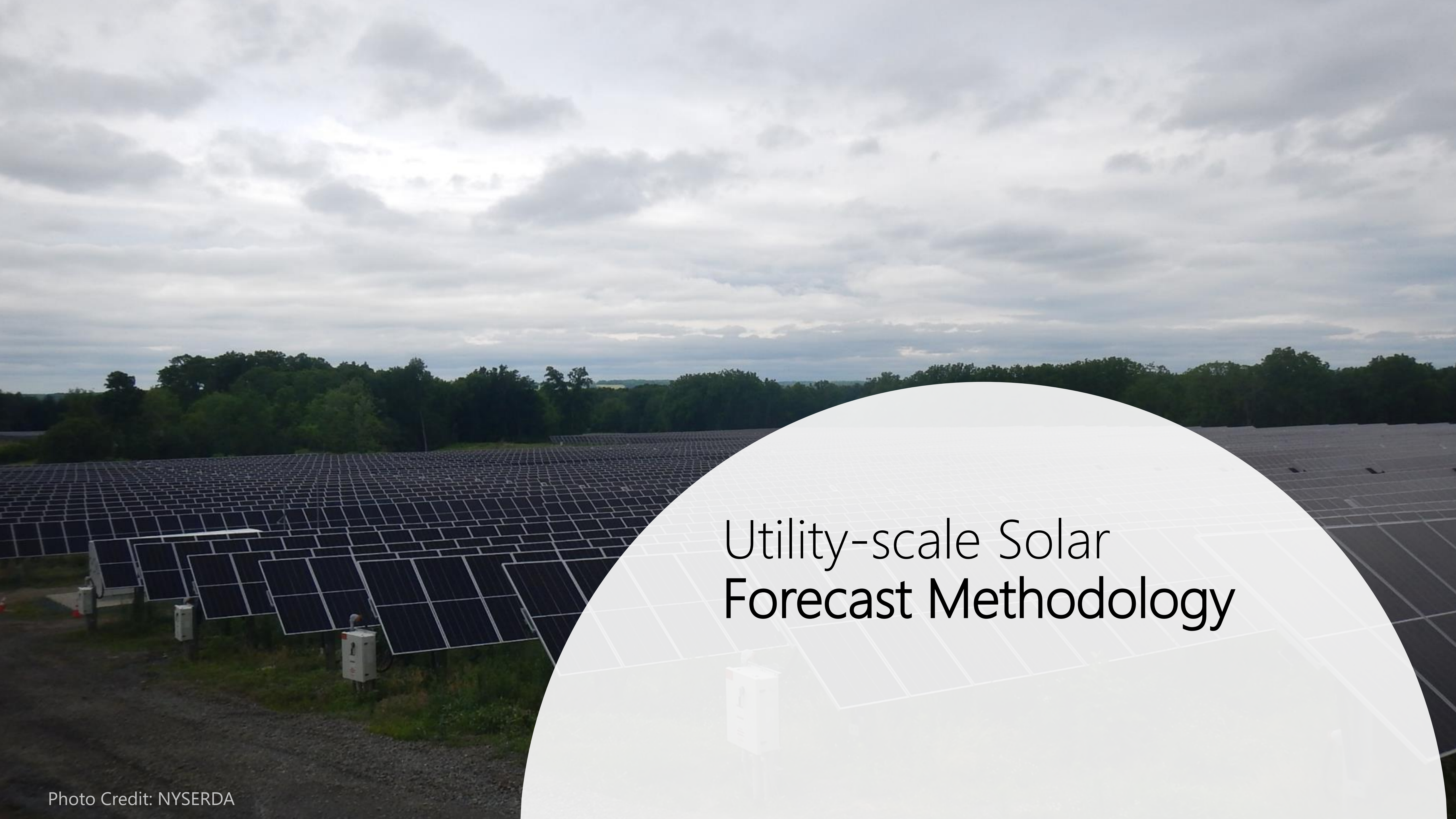


Photo Credit: NYSERDA

Steel Forecast Methodology - Continued Growth for Solar PV

Table 1: Forecasted total capacity of all U.S. utility-scale PV Systems installed based on three scenarios.

Scenario	Capacity (GWac)			
	2024	2026	2028	2030
Electrification	83	103	179	197
High Demand Growth	84	129	151	188
Lower Growth Due to Higher Costs	73	85	99	122
Average	**80**	**106**	**143**	**169**

Table 1 Source: NREAL Scenario Viewer 2021, https://scenarioviewer.nrel.gov/?project=c85d86ff-f6ec-4812-925b-ceb9a1465506&mode=view&layout=DAC%20View

Chart 1: % of all U.S. utility-scale PV systems installed. 2020 data was used to understand the market share split between Fixed-Tilt, Single and Dual Axis Tracker solar PV systems.

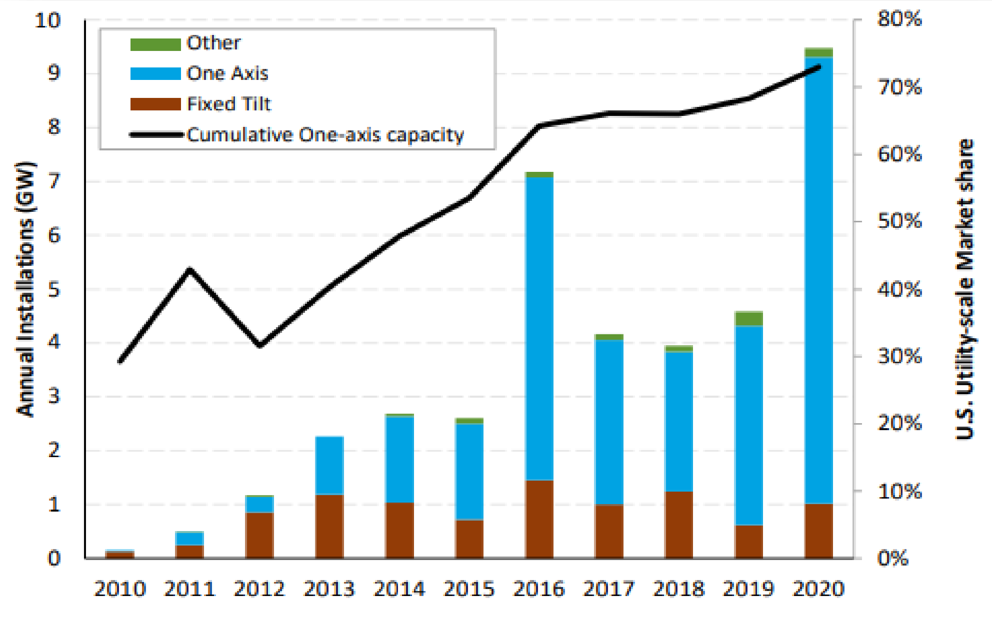


Chart 1 Source: U.S. EIA, Form EIA-860 2020ER https://www.nrel.gov/docs/fy21osti/80427.pdf

Utility-Scale Solar PV: Steel Forecast Methodology

- In 2020, Fixed-Tilt systems accounted for 11% (NREL)[1] of all U.S. utility-scale PV systems
- In 2020, Single Axis Tracker systems accounted for 87% (NREL) [1] of all U.S. utility-scale PV systems
- In 2020, Dual Axis tracking systems and others make up the remaining 2% (NREL) [1] of all U.S. utility-scale PV systems
- These figures were used to forecast the additional capacity of utility-scale PV systems from 2024 to 2030 if these proportion splits remain consistent.
- Each new MW of solar will require 35 – 45 tons of steel [2]. The necessary additional tonnage for Fixed-Tilt and Single Axis Tracker solar PV systems is highlighted in Chart 2.

Type of Utility-Scale PV System		Capacity (GWac)			
	%	2024	2026	2028	2030
Fixed-Tilt	11%	1.0	2.8	4.0	2.9
Single Axis	87%	8.2	22.6	32.1	22.6
Dual Axis and Other	2%	0.2	0.5	0.8	0.5
2-Yearly Additional Capacity	100%	9.4	26.0	36.9	26.0

***Table 2**: Forecasted additional capacity of U.S. utility-scale for fixed and tracking solar PV systems.*
Source: NREL Scenario Viewer & U.S. EIA, Form EIA-860 2020ER
1- https://www.nrel.gov/docs/fy21osti/80427.pdf
2- https://corporate.arcelormittal.com/media/case-studies/steel-is-the-power-behind-renewable-energy

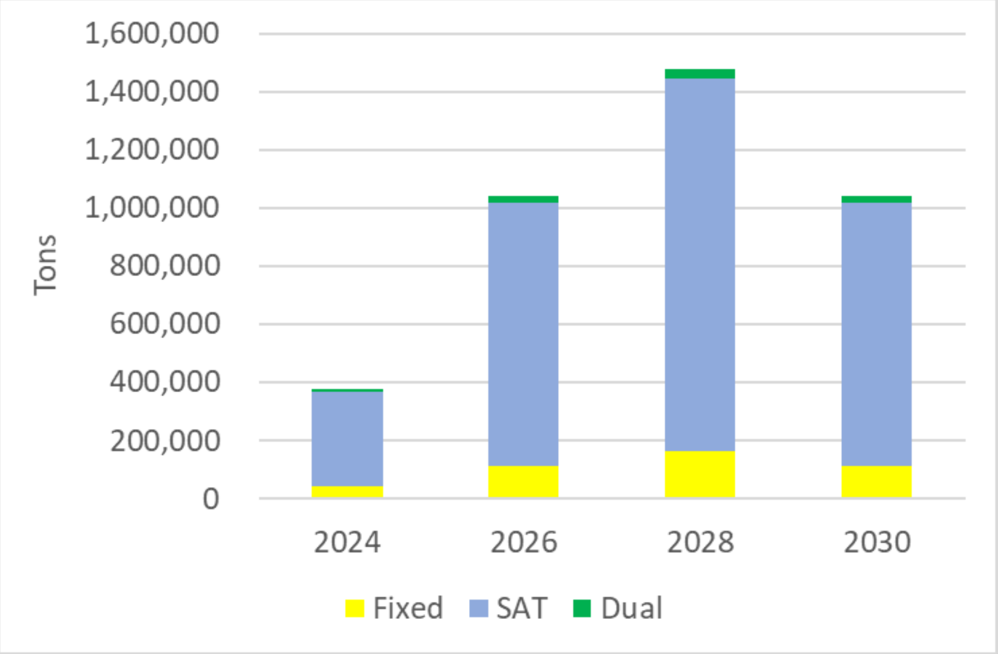
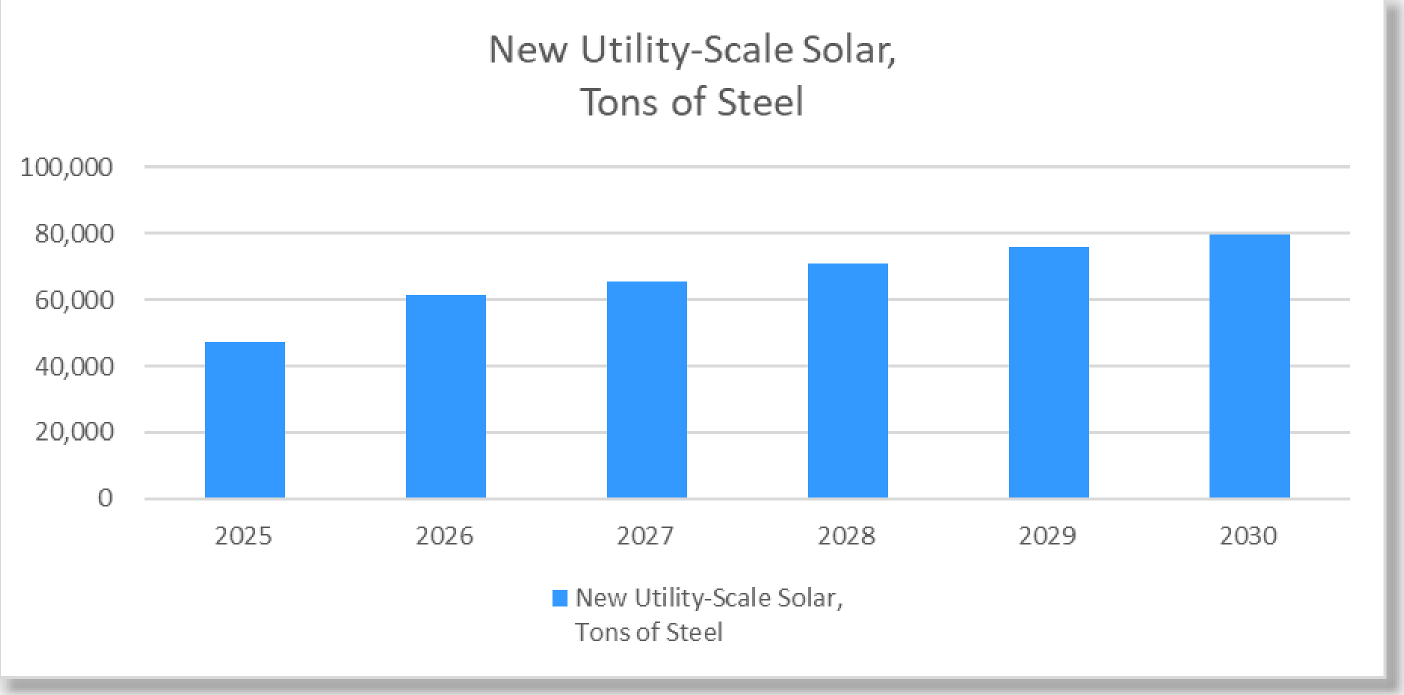


***Chart 2**: Forecasted tonnage for utility scale PV systems*

NY Utility-Scale Solar PV Expected Capacity Awards Under Renewable Energy Standard

Procurement Year	2021	2022	2023	2024	2025	2026
Deployment Year	2025	2026	2027	2028	2029	2030
New Utility-Scale Solar Capacity, MW	1,186	1,541	1,634	1,773	1,897	1,994
New Utility-Scale Solar, Tons of Steel	47,440	61,640	65,360	70,920	75,880	79,760



Key Takeaways:

- Using NYS DPS and NYSERDA procurement glide path from June 18, 2020, White Paper on Clean Energy Standard Procurements to Implement New York's Climate Leadership and Community Protection Act for new Solar projects, Base Case (Table 24)
- New York is continuing to plan for solar to achieve its renewable goals
- On an average, ~ 40 tons/MW of steel is used for a solar project

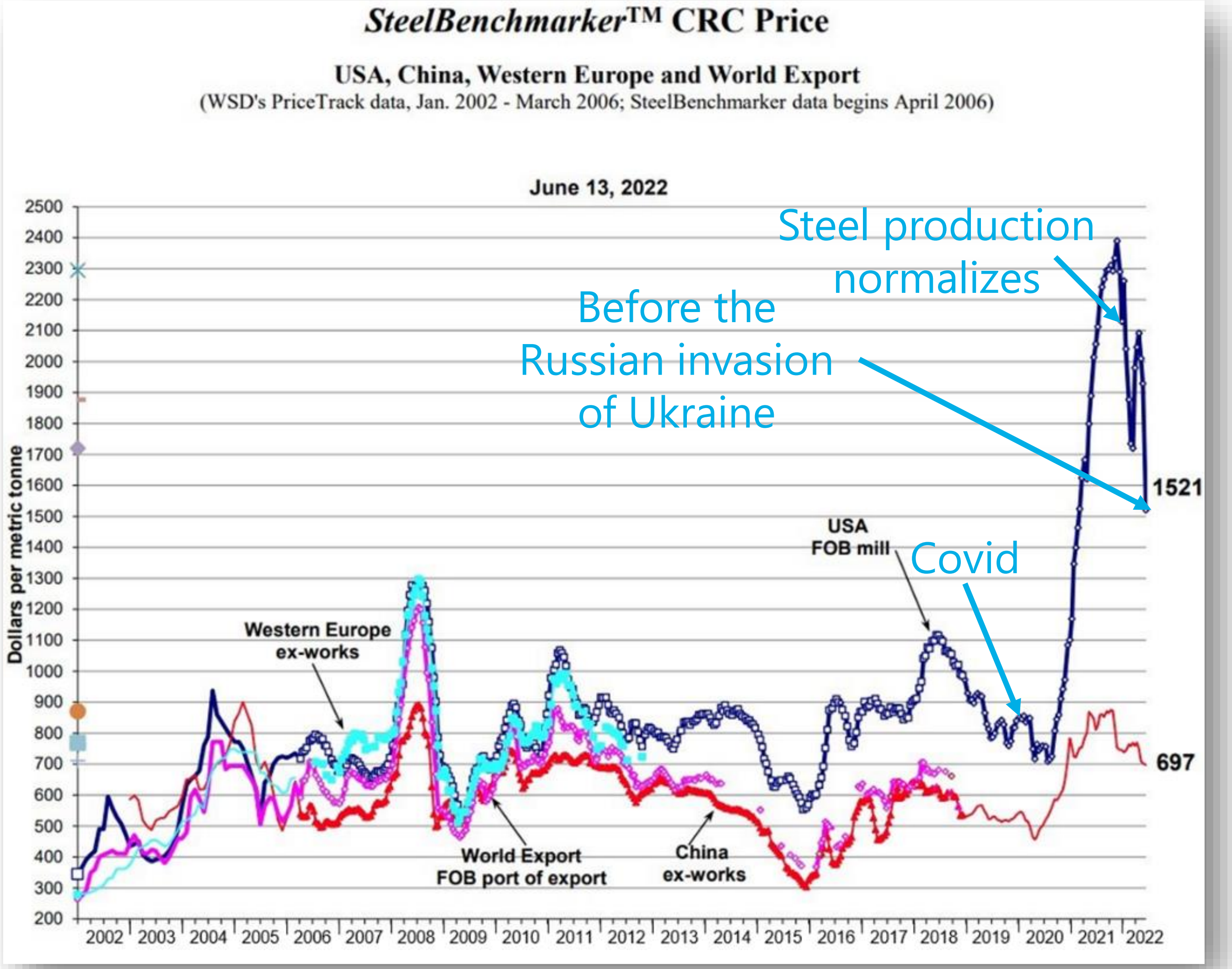
Source
https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={DCA9763C-D2DA-4FD1-9801-D859E7ED8FE3}

CRC Steel Global Price Overview and Impacts of Covid

Key Takeaways:

- The Pre-covid Cold-Rolled Coil (CRC) steel price in the U.S. was the lowest in Q1'20 (~$760/MT). However, the impact of Covid-19 drove prices to their peak by October 2021 ($2,390/MT). Prices dropped and reached $1720/MT by March 2022.
- Longer-term forecasts predict that prices are trending down yet above pre-Covid levels.
- Price levels:
  - 2019 price range ~$750 to ~ $925
  - 2020 price range ~$700 to ~$1100
  - 2021 price range ~$1,100 to ~$2400
  - 2022 price range ~$1,525 (most recent) to ~$2275

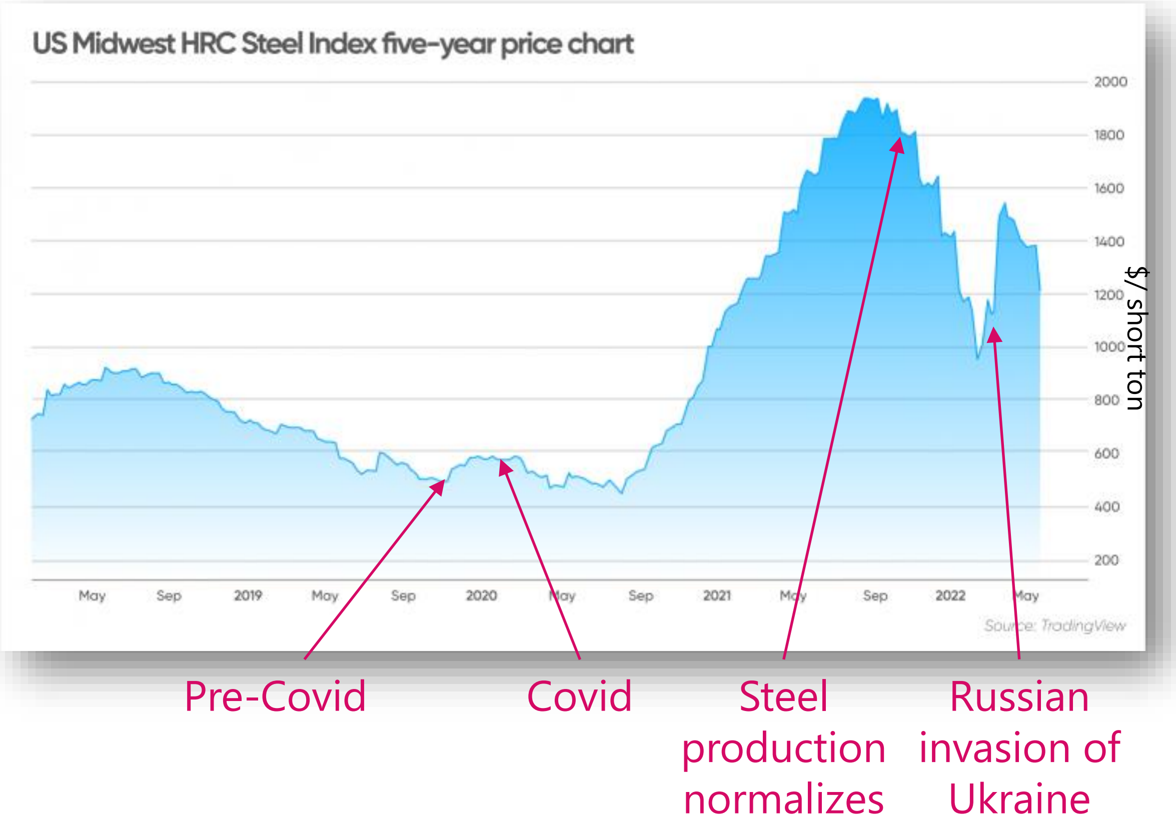
Source: http://steelbenchmarker.com/history.pdf



HRC U.S. Steel Price Overview, Impacts of Covid and Russian Invasion of Ukraine

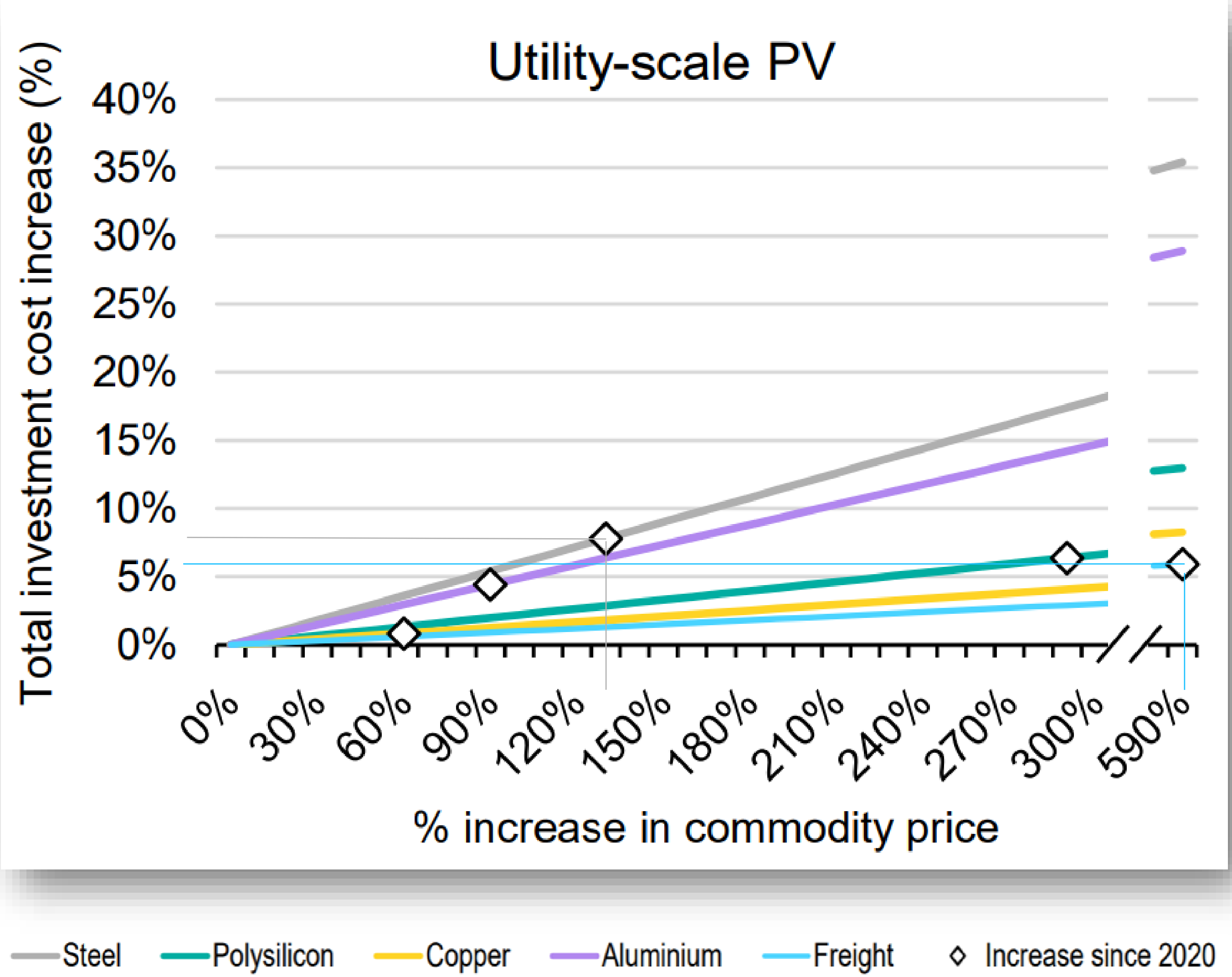
Key Takeaways:

- The Hot-Rolled Coil (HRC) steel price in North America was the lowest in Q4'19. However, the impact of Covid-19 drove prices to their peak of ~$1,950/T by October '21. Then it took a dive to ~$950/T.
- However, the Russian invasion of Ukraine drove the price from ~$950/T to ~$1,550/T. The price takes another decline to ~$1,375/T, which is still almost triple the pre-Covid level cost of $475/MT in the U.S.
- Longer-term forecasts predict that prices are trending down yet will remain above pre-Covid levels by a large margin.



[Steel price forecast 2022: Weak demand outlook pressures market (capital.com)]

Impacts of Steel Price and Freight Costs

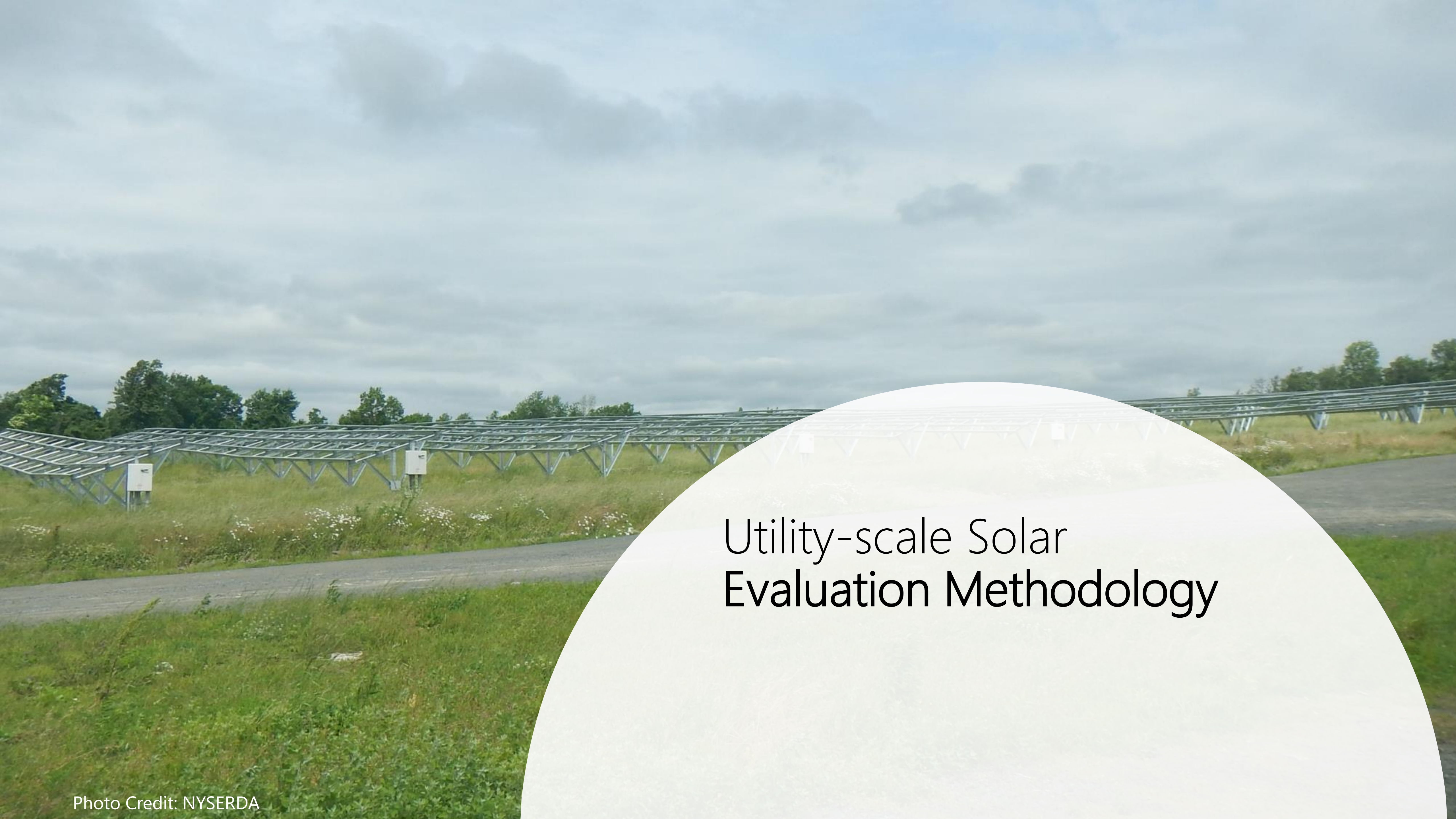


Source: https://iea.blob.core.windows.net/assets/5ae32253-7409-4f9a-a91d-1493ffb9777a/Renewables2021-Analysisandforecastto2026.pdf)

Key Takeaways:

- In interviewing suppliers, the supply chain uncertainty and shipping volatility have increased interest in local steel supply. However, for all manufacturers, the price of delivered steel is the primary factor in purchase decisions.
- As per a recent report by IEA, the utility-scale solar PV project's investment cost has increased by around ~8% since 2020 compared to the 2019 investment cost (CapEx) due to steel price.
- The shipping cost increase approximately tripled and increased the investment cost (CapEx) by ~6%.

Impact on Steel Price Increase on Solar PV	Estimated Increase in Cost
Effect on CapEx	7%- 8%
Effect on LCOE	4.65%- 5.3%



Utility-scale Solar
Evaluation Methodology

Photo Credit: NYSERDA

Approach for a $/MWdc Threshold for Domestic Steel

Objective: Align with the policy of the 2021 Buy American Act (Public Service Law 66-r).
NYSERDA is investigating a required domestic steel threshold for Utility-Scale Solar PV Fixed-Tilt and Single Axis Tracker Systems

- Through public pricing data, internal data, and primary research interviews we developed a framework to evaluate a reasonable domestic steel threshold across four (4) metrics:
    1. Availability of U.S. manufacturing capabilities
    2. Availability of U.S. steel and supply chain
    3. Global market dynamics
    4. Availability of non-steel alternatives
- Each metric category determines a component value percentage to attribute to a domestic steel requirement.
- Each metric category aggregates the percentage values across four (4) metric categories resulting in a single $/MWdc threshold. This provides flexibility for onshore wind developers' procurement processes while encouraging the domestic steel industry.
- This assessment would be undertaken before each procurement to allow for adjustments due to changes in the U.S. and global steel markets.
- All dollars in the analysis are from January 2022 before the Russian invasion of Ukraine.
  These values are conservative. Subsequent slides show more information on steel pricing.

The 4 Metrics' Definitions

1. **Availability of U.S. manufacturing capabilities** The number of U.S. manufacturers currently making the component and U.S. manufacturers with the capacity to begin producing the components.

   Example: Racking – numerous manufacturers can manufacture racking parts.

2. **Availability of U.S. steel and supply chain** The number of U.S. steel mills producing raw steel, slabs, plates, and coils used in manufacturing the final product. The U.S. mills' current capacity to supply future products, including the number of additional steel mills necessary to meet the forecasted demand.

   Example: Driven Piles – numerous mills can supply steel used in a Driven Pile.

3. **Global market dynamics** are the variables that influence the originating countries for a particular product. Examples of market dynamics include the magnitude of the market share of non-U.S. manufacturers, their manufacturing processes, and supply chain considerations. These may impede the development of a U.S. supply chain that utilizes U.S. iron and steel for a particular component. This factor is independent of U.S. steel supply and manufacturing capabilities and focuses on current market dynamics from a global supply chain perspective.

   Example: Torque Tubes – Many suppliers use imported torque tubes and are unlikely to switch.

4. **Availability of non-steel alternatives** The alternatives to steel in manufacturing a similar component that is cost-effective and can be used in a particular application. Non-steel alternative components might compete with steel for market share.

   Example: Racking – High-strength aluminum alloy is the primary alternative.

Evaluation Methodology

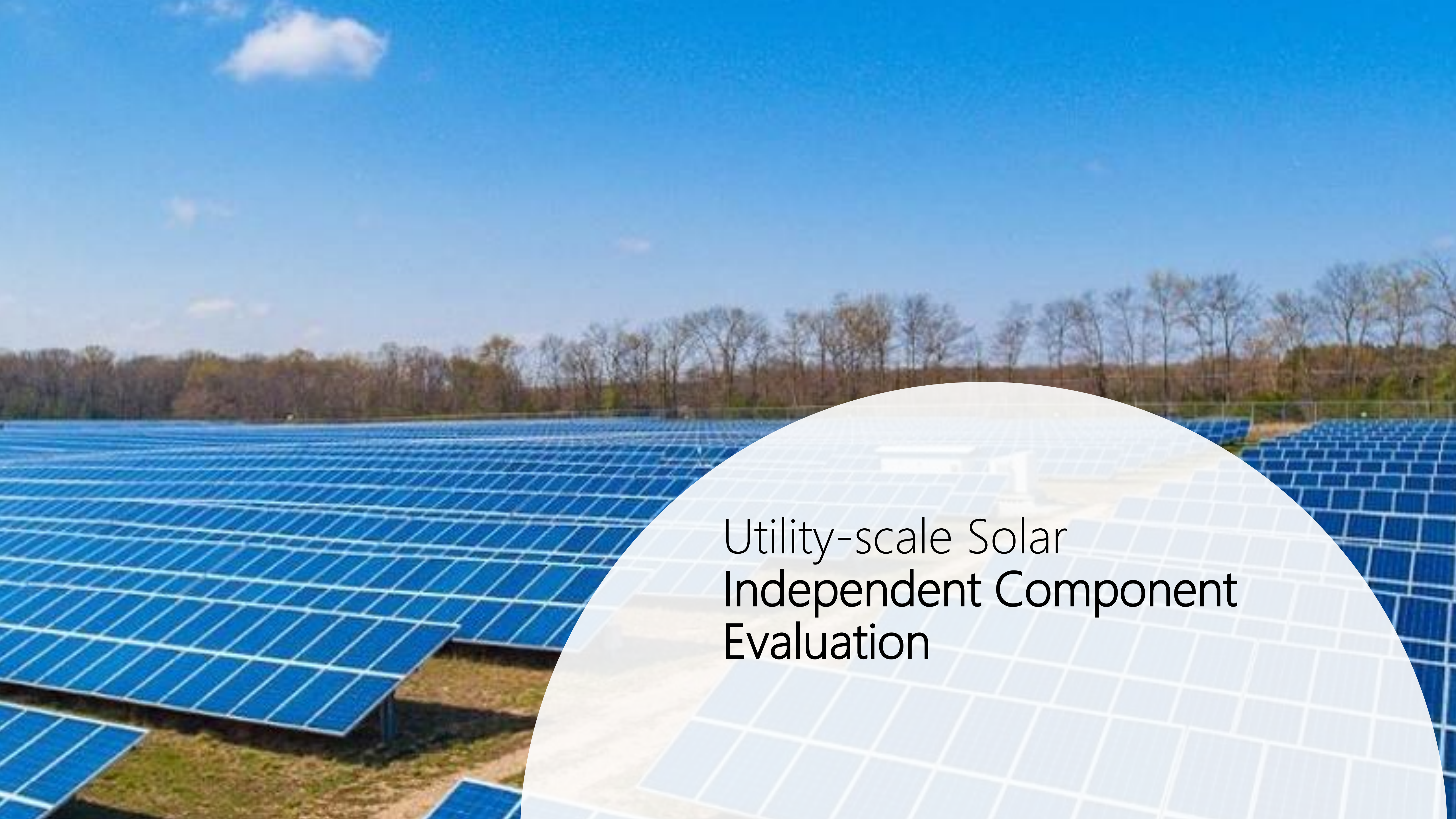
	Availability of U.S. **M**anufacturers	U.S. Steel Feedstock and **S**upply Chain	Global Market **D**ynamics	Non-Steel **A**lternatives
25% Score	M	S	D	A
	Very Low, not currently made in the U.S., and no plans to manufacture	Steel grade or dimensions are not currently made in the U.S., need to add more mills to meet the demand	Component is primarily imported, due to pricing or offshore manufacturing	Non-Metal Alternatives, e.g., fiberglass, concrete, wood, etc.
50% Score	M	S	D	A
	Low, not currently manufactured in the U.S., but there are public commitments/plans to start manufacturing in the U.S.	Steel grade or dimensions are made by a few mills, but need to add more mills to meet demand	Competition is with an imported product; although, there are a few U.S. manufacturers that compete	Metal alternatives (e.g., aluminum)
75% Score	M	S	D	A
	Medium, currently manufactured or easy to begin manufacturing in the U.S.	Steel grade or dimensions are made by mills, but not enough to meet the forecasted demand with an entirely U.S. made product	Competition is with imported products with many U.S. manufacturers that do compete	Different metal mixed structures are possible
100% Score	M	S	D	A
	High, readily available, excess or unused capacity	The existing mills can meet current and future demand	The U.S.-made components are made with U.S. steel and are competitive globally	Must be made with steel

Evaluated Metrics for Fixed-Tilt & Single Axis Tracking

	Availability of U.S. Manufacturers	U.S. Steel Feedstock and Supply Chain	Global Market Dynamics	Non-Steel Alternatives
1 – Ground Screws (& Helical)	M 100%	S 100%	D 50%	A 75%
	High, over 20 U.S. manufacturers identified. Milling and welding capabilities available in U.S. Helical welding can be difficult.	A36 steel is readily produced by U.S. steel mills.	Component is primarily imported. Germany is a major importer.	Steel and Steel alloys are the major components. No real alternatives. Ballasted foundations are an option, but not typical in utility-scale projects.
2 - Driven Piles	M 100%	S 100%	D 75%	A 75%
	High, over 10 U.S. manufacturers identified. Hot rolling capabilities in the U.S. are plenty	A500 steel is readily produced by U.S. steel mills.	U.S. steel competes against imported products. Some companies spec U.S. driven piles even when the rest of the components are imported.	Steel and Steel alloys are the major components. No real alternatives. Concrete columns are an option, but not typical in utility-scale projects.

Evaluated Metrics for Fixed-Tilt & Single Axis Tracking

	Availability of U.S. **M**anufacturers	U.S. Steel Feedstock and **S**upply Chain	Global Market **D**ynamics	Non-Steel **A**lternatives
3 - Racking	M 100%	S 100%	D 50%	A 50%
	High, over 18 U.S. manufacturers identified. Racking is not difficult to make, manufactured through extrusion	A500 and A653 steel typically used, both of which are readily produced by U.S. steel mills	Majority of the components are imported. Few manufacturers can compete sourcing U.S. steel	High strength aluminum alloy
4 - Nuts, bolts, fasteners	M 100%	S 100%	D 75%	A 100%
	High, readily available	The existing supply chain can meet the demand	Commodity product, source driven by price, U.S. and imported parts compete	Must be made with steel
5 - Torque Tube	M 100%	S 75%	D 50%	A 50%
	High, over 12 U.S. manufacturers identified. Hot rolling capabilities in the U.S. are plentiful	Bearings need a special steel alloy which can be difficult to find in the U.S. Domestic steel for other components are not difficult to source	Majority of the components are imported. Difficult for U.S. steel products to compete	High strength aluminum alloy

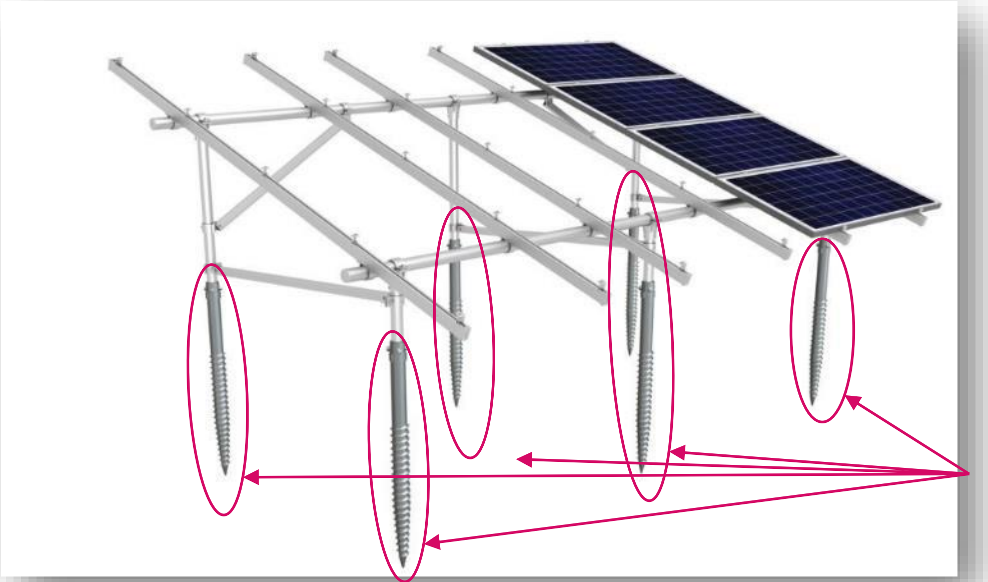


Utility-scale Solar
Independent Component Evaluation

Foundation: Ground Screws including Helical Piers

Key Takeaways:

- Numerous manufacturers in the U.S. were identified for manufacturing helical piers/anchors.
- A36 steel is typically used for utility-scale mounting structures and is readily available across the U.S. from many mills.
- For utility-scale applications, there are generally twice as many foundation elements required, and as such, they represent the most significant contributor to the total cost of steel on a $/MWdc for utility-scale solar PV systems.



Metric	Calc	Market
Current Costs @ $/MWdc		Fixed: $13k-$17k, $15k Avg SAT: $18k-$27k, $22.5k Avg
Manufacturers	100%	Over 15 U.S. manufacturers identified, all with manufacturing facilities in the U.S.
Supply Chain	100%	Utility-scale mounting structures are typically made from A500 structural steel. U.S. steel mills readily produce A36 steel. Q235 Galvanized is also used.
Global Market **D**ynamics	50%	Helical pier/anchors are primarily imported. Price and availability are significant factors. U.S. manufacturers are not yet competitive.
Alternatives to Steel	75%	The primary alternative to steel is concrete for ballast-type foundations. However, for utility-scale applications, steel is preferred.

Photo Credit: SunModo, https://sunmodo.com/sunturf-ground-mount/

Foundation Driven Pile (e.g., I-Beam, H-Beam, C-Channels)

Key Takeaways:

- Numerous manufacturers in the U.S. were identified that produce the products used for driven piles.
- A500 steel is typically used for I beams.
- There are other imported standards that meet similar requirements; a manufacturer can specify different steel e.g., A36, which has similar mechanical properties to A500.
- For utility-scale applications in New York, driven piles are the preferred foundation due to the soil conditions.

Photos Credit: NYSERDA

Metric	Calc	Market
Current Costs @ $/MWdc		Fixed: $18k-$22k, $20k Avg SAT: $25k-$39k, $32k Avg
Manufacturers	100%	Numerous U.S. manufacturers identified, all with manufacturing facilities in the U.S. The manufacturing difficulty of I-beams is low. I-beams are manufactured through hot rolling, a common and well-known process.
Supply Chain	100%	Utility-scale mounting structures are typically made from A500 structural steel. Many U.S. steel mills readily produce A500 steel.
Global Market **D**ynamics	75%	The U.S. products made for driven pile foundations are competitive with imports. Some companies still use U.S. piles when all other components are imported.
Alternatives to Steel	75%	The primary alternative to steel is concrete for ballast-type foundations. However, for utility-scale applications, steel is preferred.

Racking (Mounting Frame)

M S D A

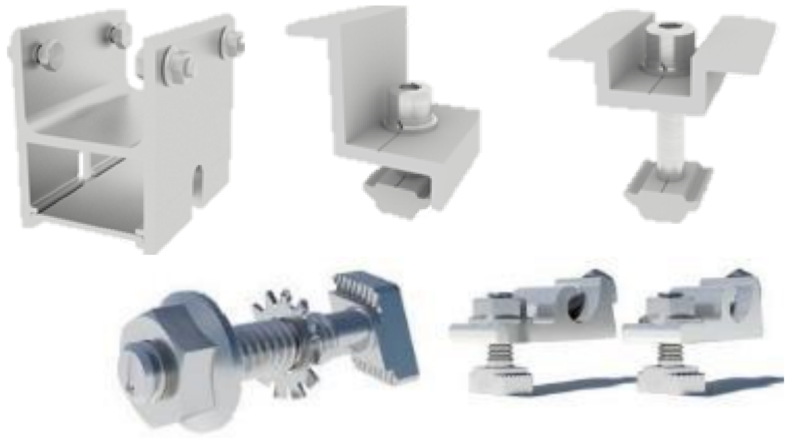
Key Takeaways:
• There are a few U.S. manufacturers that make racking; although, there are numerous facilities that can or do currently make similar parts. • Demand for fixed-tilt PV systems is forecasted to decline with the increasing popularity of Single Axis Tracking systems. • Fixed-Tilt systems use fewer foundation elements, but more racking components.

Photos Credit: NYSERDA

Metric	Calc	Market
Current Costs @ $/MWdc		Fixed: $47k-$53k, $50k Avg SAT: $9k-$20k, $14.5k Avg
Manufacturers	100%	Many manufacturing facilities can make racking materials. There are few that do make products specifically for solar racking. The country of origin for the steel has not been confirmed.
Supply Chain	100%	A500 steel, A653 steel and Cold-formed steel (CFS) are typically used. Steel grades are not specialized and are readily produced by U.S. steel mills.
Global Market **D**ynamics	50%	Imported products compete with U.S.-manufactured components. Imports do have an impact on U.S. producers' competitiveness.
Alternatives to Steel	50%	High strength aluminum alloy

Nuts, Bolts, and Fasteners

Key Takeaways:
• There are many manufacturers of nuts, bolts, clamps, and fasteners throughout the U.S. • High-quality steel nuts are produced in the U.S. easily. • Nuts, bolts, and clamps can also be manufactured using aluminum; however, steel is the preferred option. • For stainless steel products, imported nuts, bolts, clamps, and fasteners are preferred due to the price. • The ability for companies to manufacture the components is high, but there are additional processes involved.



Metric	Calc	Market
Current Costs @ $/MWdc		Fixed: $4k-$8k, $6k Avg SAT: $3k-$6k, $4.5k Avg
Manufacturers	100%	Over 7 U.S. companies are identified that manufacture nuts, bolts, and clamps specifically for solar PV applications. U.S. manufacturers can develop high-quality steel nuts.
Supply Chain	100%	There are plenty of mills in the U.S. that make the steel needed for the nuts, bolts, clamps, and fasteners.
Global Market **D**ynamics	75%	The U.S. products must compete against imported products in price. Stainless steel products are primarily imported due to the improved pricing.
Alternatives to Steel	100%	The primary alternative to steel is aluminum. However, for utility-scale applications, steel is the preferred option.

Source: Ironridge, https://www.ironridge.com/component/hardware/

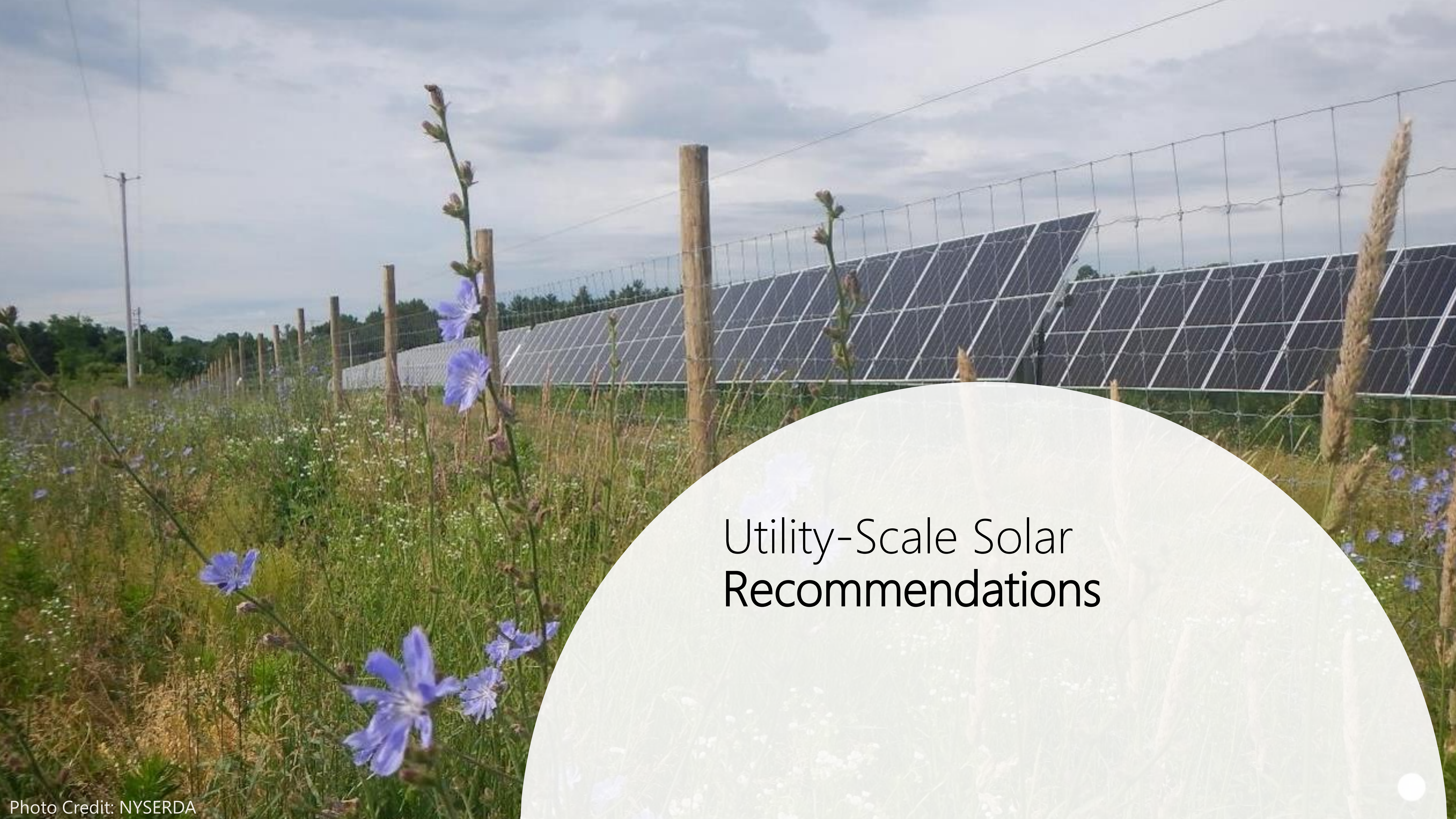
Torque Tube for Single Axis Tracker Systems

Key Takeaways:

- Single Axis Tracking systems are forecasted to dominate the U.S. utility-scale market.
- Biggest challenges at present are supply chain issues and shipping volatility due to the ongoing political tensions. This is creating a solid push for localized production.
- U.S.-based manufacturers account for over 40% of the global market demand. Top manufacturers have a strong partnership with local steel mills.

Photos Credit: NYSERDA

Metric	Calc	Market
Current Costs @ $/MWdc		Range: $35k-$56k, $45.5k Avg
Manufacturers	100%	Many U.S. manufacturers were identified. Hot rolled steel, steel tubes that are standard shapes and sized, none that warrant any special or unique manufacturing.
Supply Chain	75%	Not difficult to source domestic steel. Steel mills can meet the demand for long products. Bearings require special steel that now is imported, as many mills stopped producing due to lower demand.
Global Market **D**ynamics	50%	U.S. products are competing with imports. Price and product availability are major drivers.
Alternatives to Steel	50%	Mostly steel is in the current market for utility-scale applications. High-strength aluminum alloy is a possibility, but not common in utility-scale projects.



Utility-Scale Solar Recommendations

Photo Credit: NYSERDA

Solar Calculation Methodology Example

	Solar Fixed	NY Weight	Average $/MWdc		US Manufacturers – Metric (%)		US Steel Supply – Metric (%)		Market Dynamics – Metric (%)		Steel Alternatives – Metric (%)		Minimum $/MWdc
1	Foundation - Ground Screw	10%	$15,000		100%		100%		50%		75%		$5,625
2	Foundation - Driven Pile	90%	$20,000	X	100%	X	100%	X	75%	X	75%	=	$11,250
	Weighted Average	100%	$19,500										$10,688
3	Racking		$50,000		100%		100%		50%		50%		$12,500
4	Nuts, Bolts, Fasteners	90%	$6,000		100%		100%		75%		100%		$4,500
												∑ Total	$27,688

Weighted Average Calculation

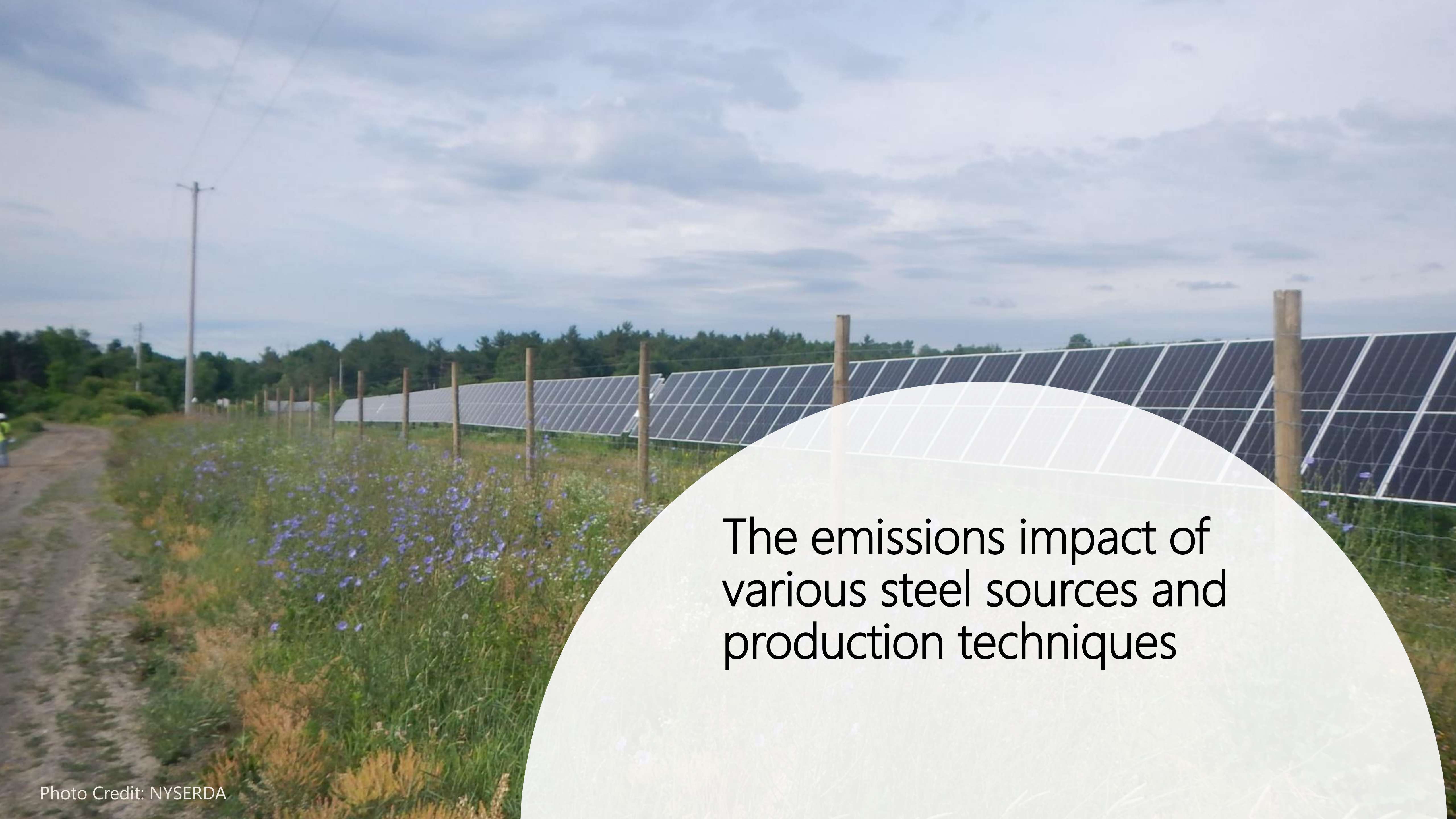
Solar Fixed	NY Weight		Average $/MWdc		Weighted Average $/MWdc
Foundation - Ground Screw	10%	X	$15,000	=	$1,500
Foundation - Driven Pile	90%		$20,000		$18,000
Weighted Average				∑ Total	$19,500

Recommendations $/MWdc of U.S. Steel - Solar Ground Mount Fixed-Tilt

	Solar Fixed	NY Weight	Average $/MWdc	US Manufacturers – Metric (%)	US Steel Supply – Metric (%)	Market Dynamics – Metric (%)	Steel Alternatives – Metric (%)	Minimum $/MWdc
1	Foundation - Ground Screw	10%	$15,000	100%	100%	50%	75%	$5,625
2	Foundation - Driven Pile	90%	$20,000	100%	100%	75%	75%	$11,250
	Weighted Average	100%	$19,500				Weighted Average	$10,688
3	Racking		$50,000	100%	100%	50%	50%	$12,500
4	Nuts, Bolts, Fasteners	90%	$6,000	100%	100%	75%	100%	$4,500
								$27,688

Recommendations $/MWdc of U.S. Steel – Solar Single Axis Tracking

	Solar Single Axis Tracking	NY Weight	Average $/MWdc	US Manufacturers – Metric (%)	US Steel Supply – Metric (%)	Market Dynamics – Metric (%)	Steel Alternatives – Metric (%)	Minimum $/MWdc
1	Foundation - Ground Screw	10%	$22,500	100%	100%	50%	75%	$8,438
2	Foundation - Driven Pile	90%	$32,000	100%	100%	75%	75%	$18,000
	Weighted Average	100%	$31,050			Weighted Average		$17,044
3	Racking		$14,500	100%	100%	50%	50%	$3,625
4	Nuts, Bolts, Fasteners		$4,500	100%	100%	75%	100%	$3,375
5	Torque Tube		$45,500	100%	75%	50%	50%	$8,531
								$32,575



The emissions impact of various steel sources and production techniques

Photo Credit: NYSERDA

Cleanest and Dirtiest Countries for Secondary Steel Production

India, Vietnam, and China have the highest electric grid CO_2 emissions factors due to large share of coal generation.

High CO_2

Low CO_2

France, Brazil, and Canada have the lowest electricity grid CO_2 emissions factors due to large nuclear (in France) and hydro (in Brazil and Canada) power generation.

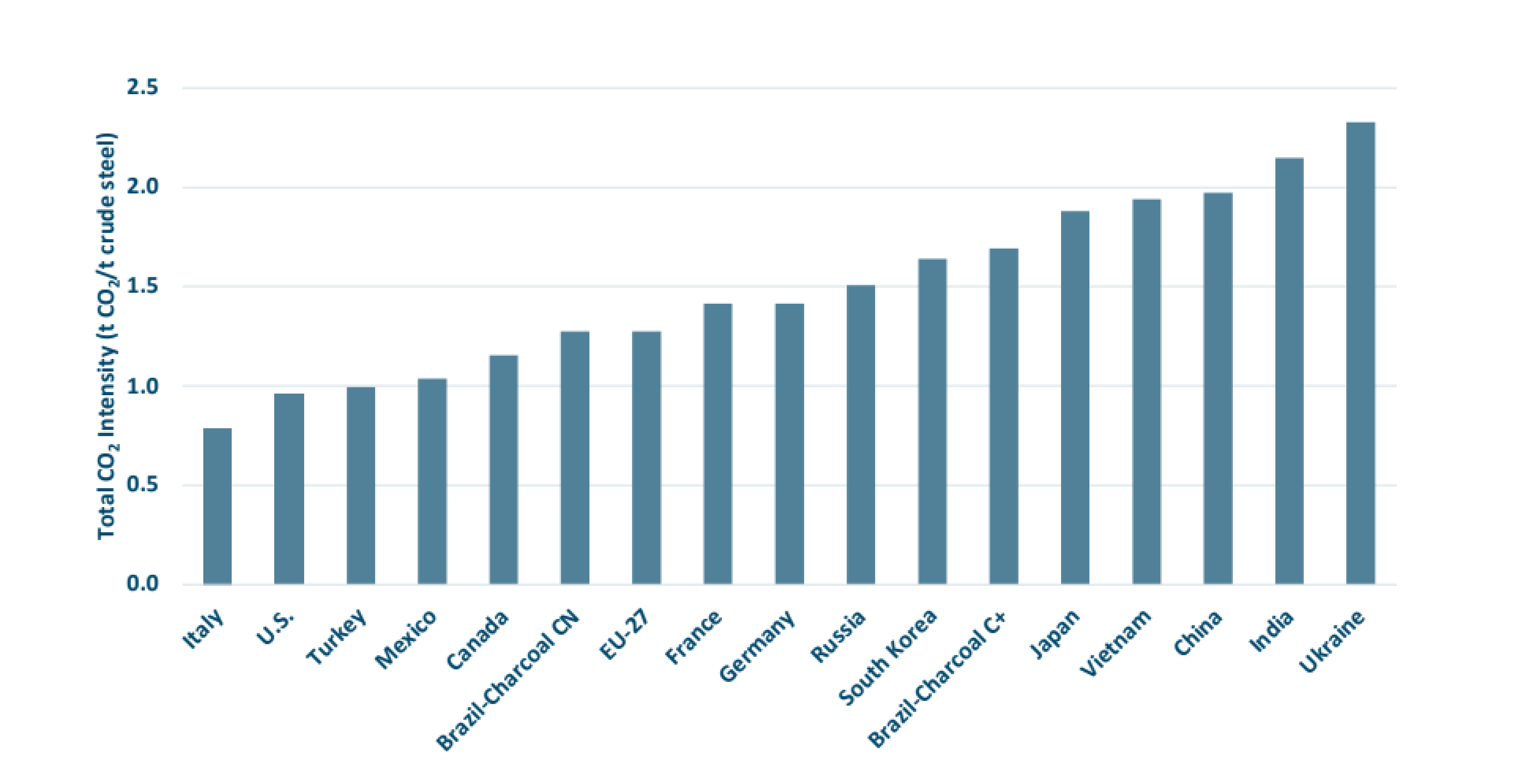
India and Mexico use a substantial amount of Direct Reduced Iron (DRI), (India ~50% and Mexico ~ 40%) as feedstock in EAFs.
In China, instead of DRI, pig iron is used (~ 50%), produced via blast furnace. Both DRI and pig iron production are highly energy intensive processes, which result in higher energy and CO_2 intensity of EAF steel production when used as feedstock in EAFs.

High CO_2

Low CO_2

Steel scrap is the primary feedstock for EAF.

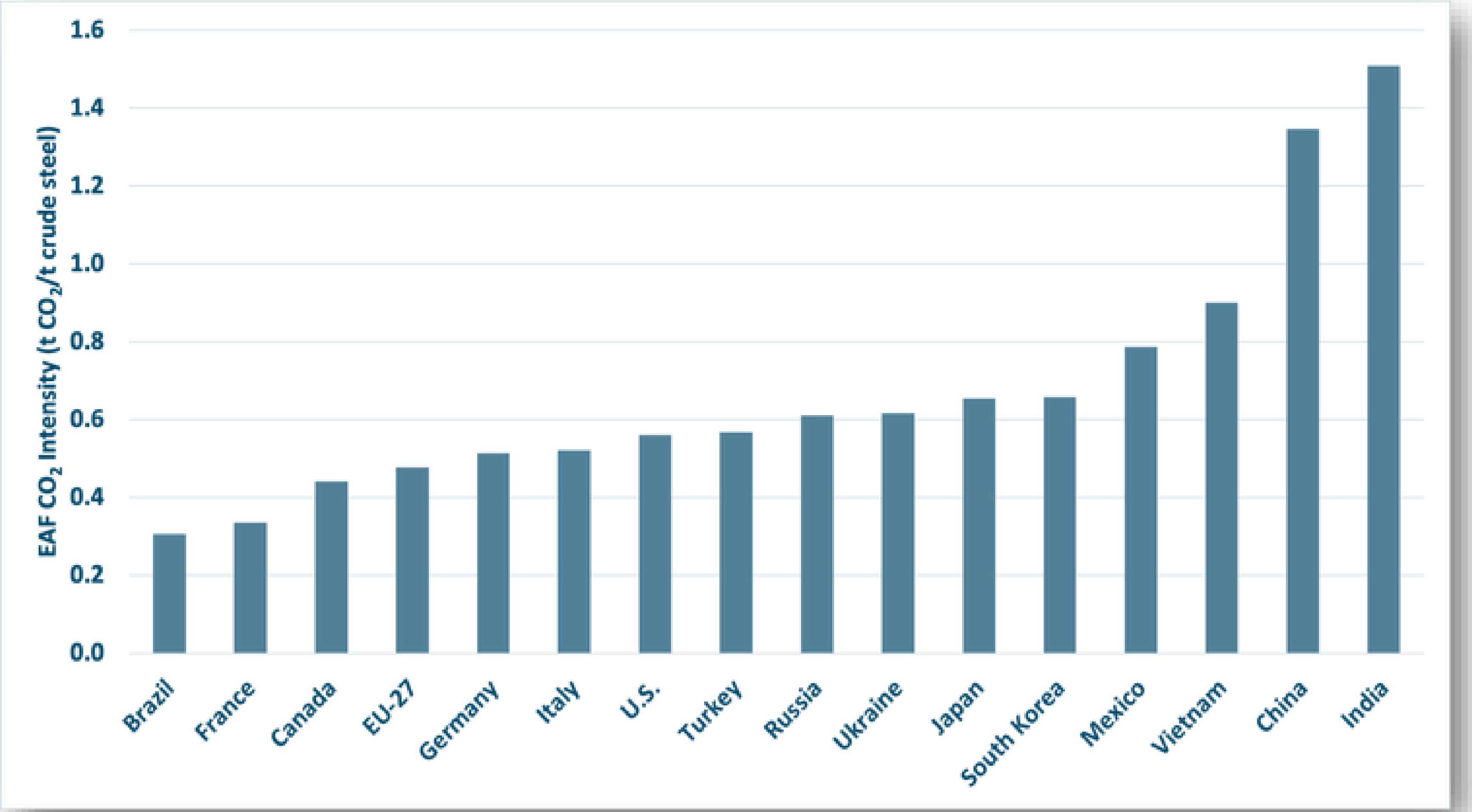
Total Carbon Intensity of Steel Production



The graph shows total carbon intensity of steel production.

Taken from Hasanbeigi, A. 2022. Steel Climate Impact - An International Benchmarking of Energy and CO2 Intensities. Global Efficiency Intelligence.

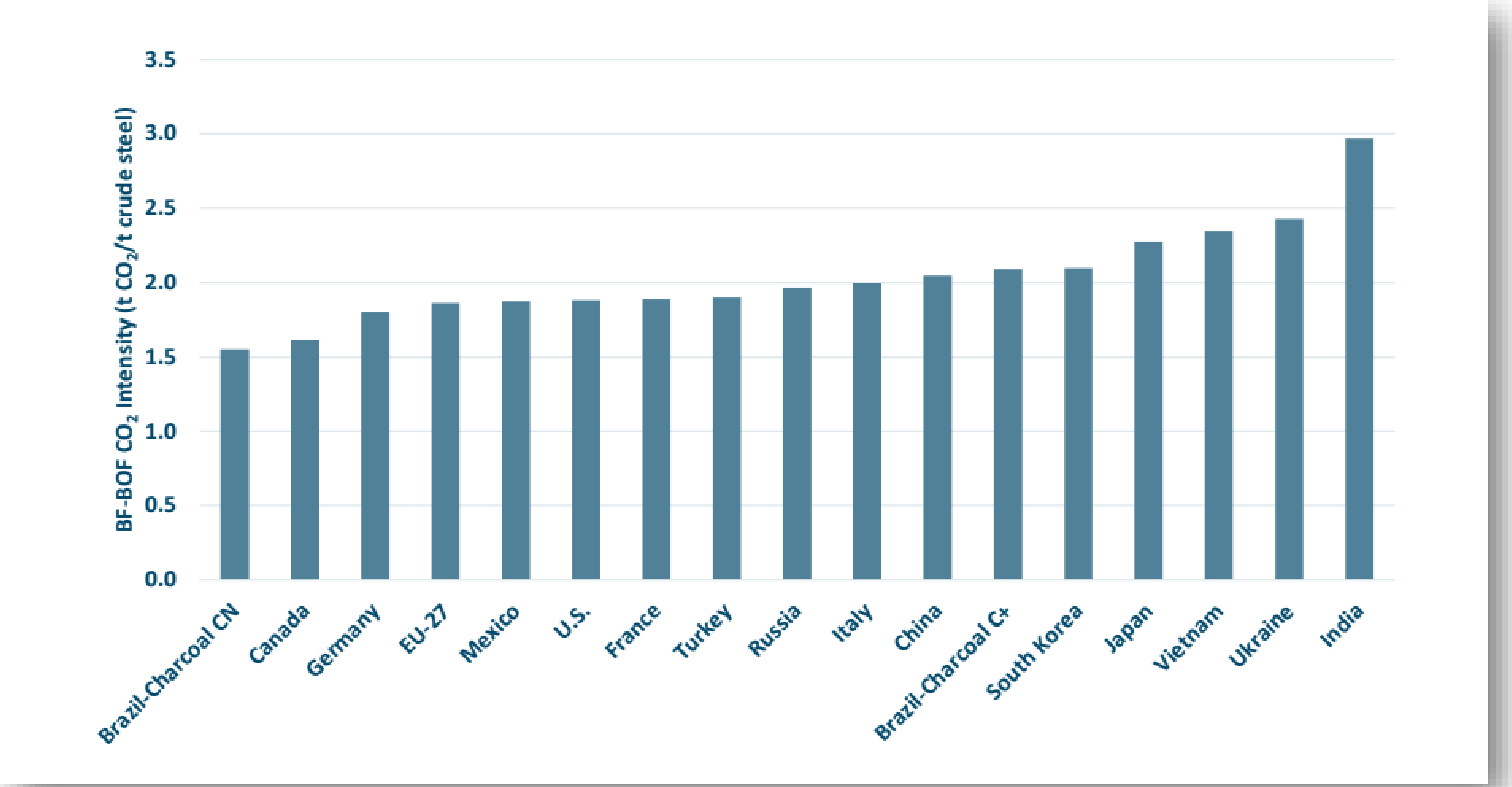
Carbon Intensity of Steel Production for Electric Arc Furnace



The graph shows secondary steel production using EAF. The feedstock is primarily recycled steel, with makeup materials from DRI, and pig iron (produced from BOF). The graph does not consider BOF-only steel production, which would have higher CO_2 intensities.

Taken from Hasanbeigi, A. 2022. Steel Climate Impact - An International Benchmarking of Energy and CO2 Intensities. Global Efficiency Intelligence.

Carbon Intensity of Steel Production for Basic Oxygen Furnace



The graph shows secondary steel production using BOF-only steel production, which would have higher CO_2 intensities.

Taken from Hasanbeigi, A. 2022. Steel Climate Impact - An International Benchmarking of Energy and CO2 Intensities. Global Efficiency Intelligence.

Global Steel and CO_2

- The iron and steel industry accounts for around 7% of global greenhouse gas (GHG) emissions and 11% of global carbon dioxide (CO_2) emissions. *See*, Hasanbeigi, A. 2022. Steel Climate Impact - An International Benchmarking of Energy and CO_2 Intensities. Global Efficiency Intelligence.
- The total carbon intensity of steel production in the U.S. is second lowest.
- The carbon intensity of electric arc furnace (EAF) steel production in the U.S. is seventh lowest.
- The carbon intensity of basic oxygen furnaces (BOF) steel production in the U.S. is sixth lowest.
- The renewables industry currently relies upon a global supply chain, and as such it is difficult to accurately predict and cost the carbon intensity of the industry's steel consumption given that specific manufacturers to be utilized for upcoming procurements are not known, nor are existing manufacturer's steel feedstock choices static.
- It is possible, albeit unlikely, that steel could be imported with a lower carbon intensity than that produced in the U.S.
- NYSERDA has nonetheless adopted a procurement preference for domestically-produced steel, subject to practical feasibility and availability limitations, in part because of the likelihood that such a preference will result in utilization of steel with a lower carbon intensity.

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