Two Paths to US Competitiveness in Clean Technologies

Publication Appendix

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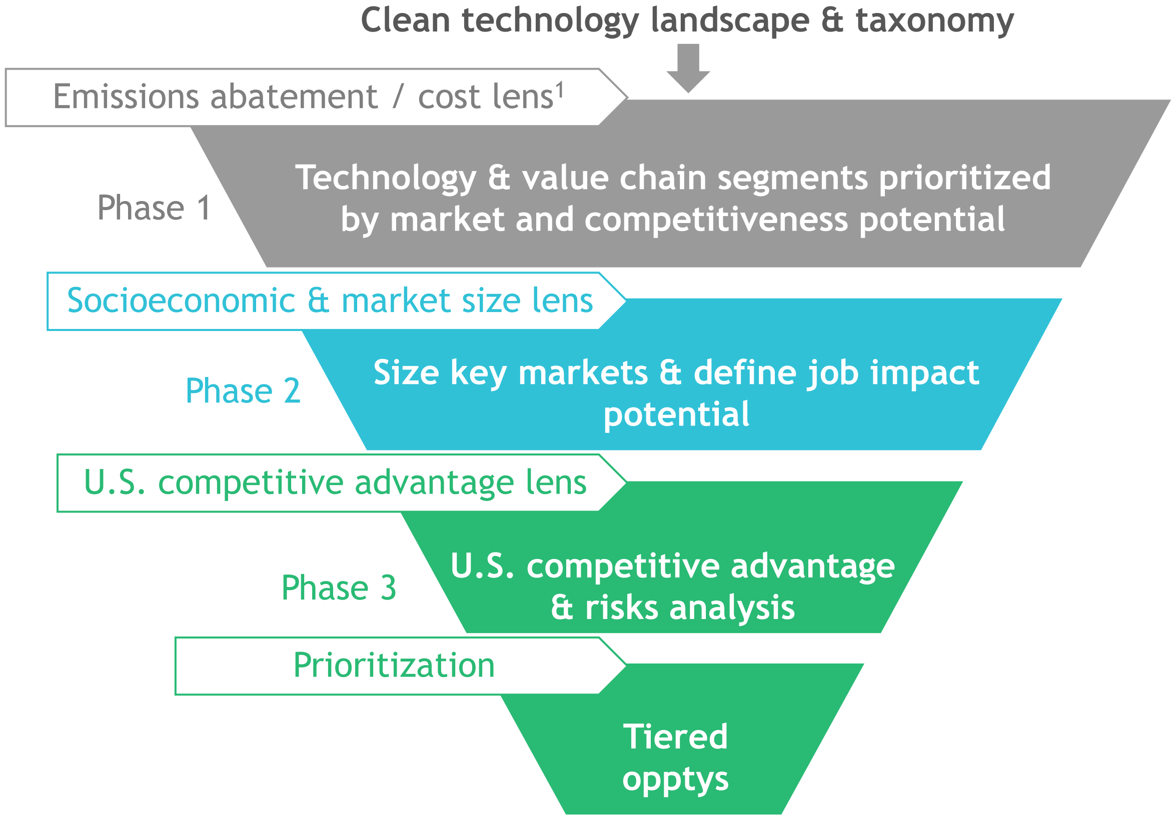
Context and approach

Context | 3-phase approach to prioritize technologies based on abatement potential, socioeconomic factors, and U.S. competitive advantage



Clean technology landscape & taxonomy

Emissions abatement / cost lens[1]

Phase 1

Technology & value chain segments prioritized by market and competitiveness potential

Socioeconomic & market size lens

Phase 2

Size key markets & define job impact potential

U.S. competitive advantage lens

Phase 3

U.S. competitive advantage & risks analysis

Prioritization

Tiered opptys

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1. Assessed per technology spanning the full value chain

Technologies will be split across 9 parts of the value chain for further analysis

Value chains will be adapted as need based on the specifics of the technology

	Raw materials & inputs	OEM	Project Development	Financing	EPC	O&M	Transport & Storage	Offtake	Support Services
Definition per value chain segment	Natural resources used as technology OEM inputs Fuels / inputs for energy generation and product production	Manufacture of critical technology components	Project origination & coordination • Site selection • Permissions & contracting • Secure financing	Providing capital & deal structure • Source, type & amount of funding	Engineering, procurement & construction • Detailed eng. design • Supply chain mgmt • Contractor mgmt. • System testing	Operations & maintenance • Baseline operations • Asset monitoring • Maintenance & repairs	Logistics of product final delivery to customer • Transport logistics • Product storage	Sale of end product to customer • Final offtake contracting • Sales channels / markets	Differentiated offerings to support use after sales E.g.: • Software • Consulting services • Auditing / certification
Example: Offshore wind (illustrative, not exhaustive)	• OEM materials (e.g., steel, fiberglass, iron, copper, etc.)	• Turbine components • Offshore foundations • Electrical infrastructure	• Lease sales • State/federal permitting • Green PPAs • Grid inter-connection	• Debt, equity, grants, etc. • PTCs and ITCs provide incentives	• Supply chain management & transport • Specialized vessels to install turbine	• Preventative & corrective maintenance • Automated condition monitoring	• Included in EPC	• Power produced injected into bulk transmission	• Windfarms to be decommi-ssioned

Analysis completed for each prioritized segment and clean technology across three key metrics

Market

Market dynamics domestically and globally

- **Global Total Addressable Market (TAM)** over time across three scenarios
- **U.S. Serviceable Addressable Market (SAM)** over time across three scenarios, detailed for priority target markets
- **U.S. Serviceable Obtainable Market (SOM)**, or U.S. exports, over time and across scenarios

Competitiveness

Qualitative and quantitative measure of competitiveness

- Access to constrained **raw materials**
- Relative **intellectual property and technical research** leadership
- Relative access to **low-cost labor, energy, and inputs**
- Levels of **regulatory and policy support**
- Comparative **domestic market** outlook
- Robustness of **existing infrastructure**

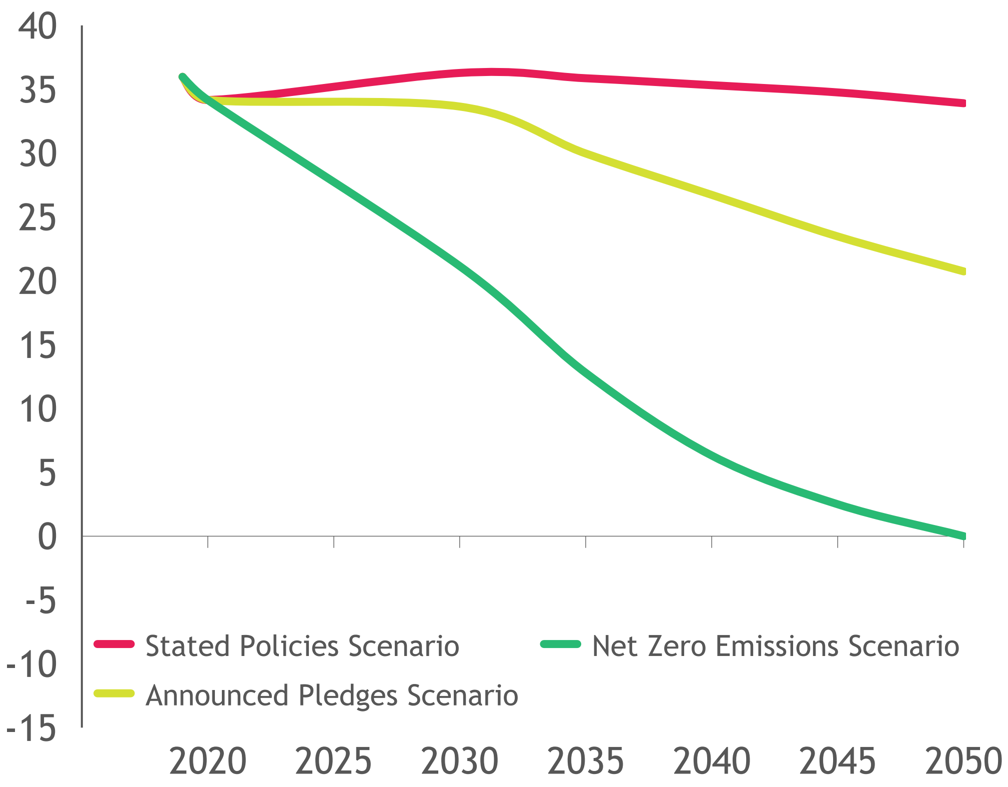
Societal impact

Relevance of value chain segment to global communities

- **Domestic job creation** potential in total positions and cumulative job-years
- Qualitative assessment of **transferable skills and capability gaps**

Market | Scenarios built on data from IEA World Energy Outlook deployment forecasts

Annual CO2 Emissions (GTPA)

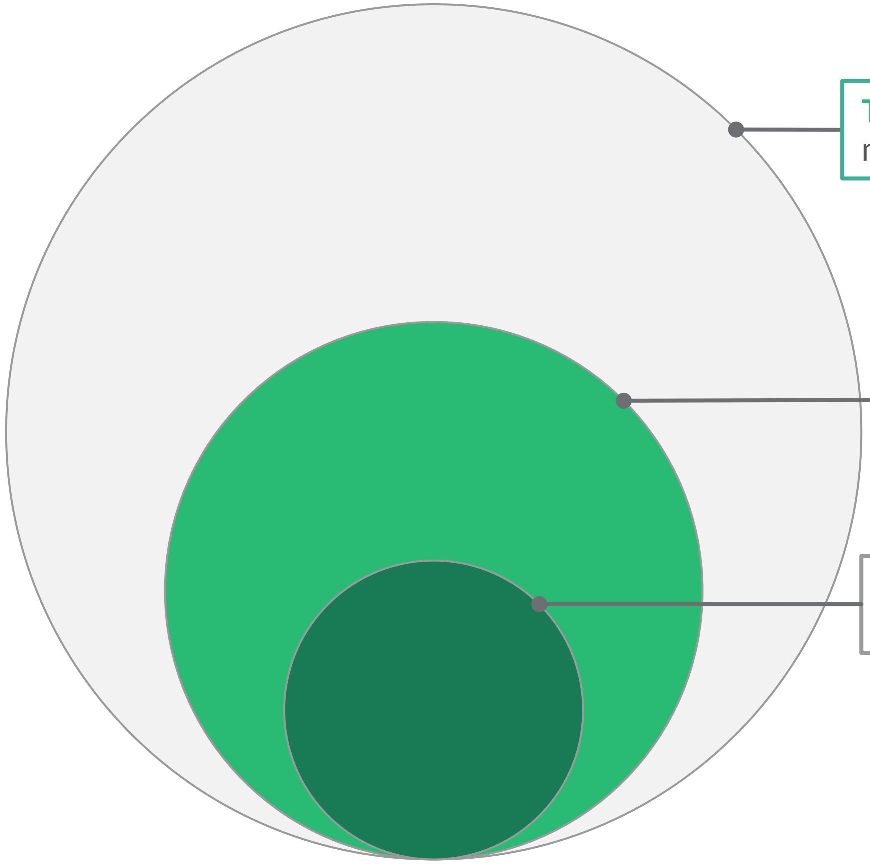


Est. 2050 impact (C°)	Scenario descriptions
1.8 – 2.1° (STEPS)	**Stated Policies Scenario (STEPS):** Reflects specific policies currently in place and that have been announced by governments around the world
1.7 - 2.0° (APS)	**Announced Pledges Scenario (APS):** Assumes all commitments made by governments around the world are met in full and on time[1]
1.4 - 1.7° (NZE)	**Net Zero Emissions by 2050 Scenario (NZE):** Meets energy-related UN Sustainable Development Goals[2] and reaches net zero emissions by 2050

Focus of project

1. Includes Nationally Determined Contributions (NDCs) and longer-term net zero targets 2. Those goals related to universal energy access and major improvements in air quality
Source: IEA World Energy Outlook 2021

Market | Market sizing completed at three levels



Total Addressable Market (TAM): Total market demand for a given product / service

Serviceable Addressable Market (SAM): Portion of TAM which can be feasibly accessed

Serviceable Obtainable Market (SOM): Portion of SAM which is can be captured

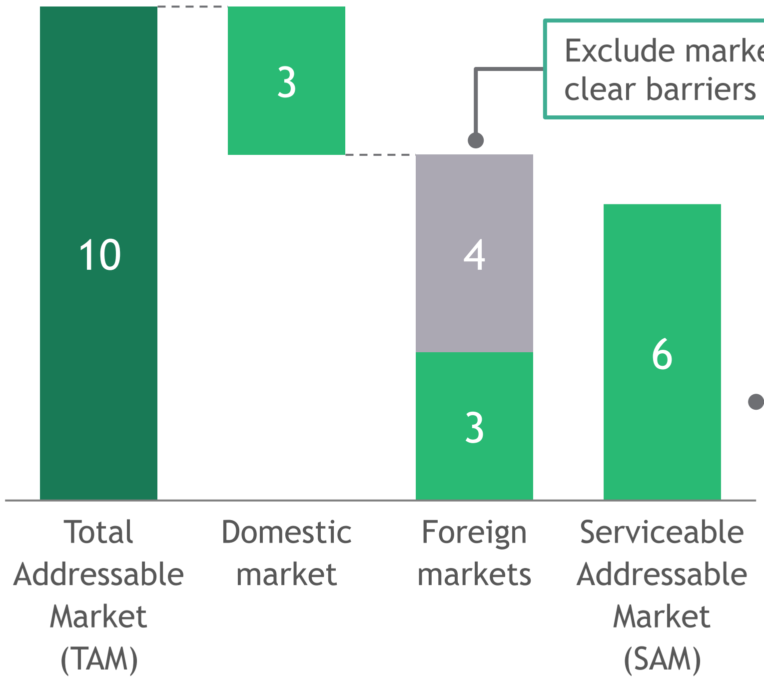
SOM estimates leverage technology specific approaches using analogous examples

More detail on approach included on next slide

Market | The U.S. serviceable addressable market will exclude foreign markets with clear political or economic barriers to entry

Illustration of approach

Est. market size per prioritized segment and scenario ($B)



Exclude markets with clear barriers to entry

Sum of domestic market + open foreign markets becomes serviceable addressable market (SAM)

Illustrative SAM calculation

Total addressable foreign market size

− Markets with clear political/economic barriers to entry

= Subtotal: Serviceable foreign markets

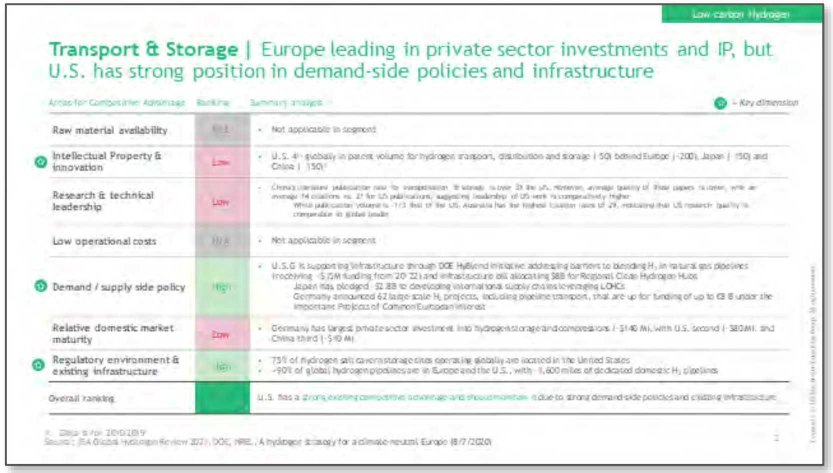
\+ U.S. Domestic market

= **Serviceable Addressable Market (SAM) for the U.S.**

Barriers to entry may be political (e.g., potential import bans or non-market barriers from China) **or economic** (e.g., unlikely to export products with high transportation costs to countries with sufficient domestic supply)

Competitiveness | Fact-based analysis determined where the U.S. has existing advantage or potential to build

Segment-level assessment across 7 competitiveness drivers determined 3 x 3 placement



Low-carbon Hydrogen

Transport & Storage | Europe leading in private sector investments and IP, but U.S. has strong position in demand-side policies and infrastructure

● = Key dimension

Areas for Competitive Advantage	Ranking	Summary analysis
Raw material availability	N/A	Not applicable in segment
● Intellectual Property & innovation	Low	U.S. 4th globally in patent volume for hydrogen transport, distribution and storage (~50) behind Europe (~200), Japan (~150) and China (~150)[1]
Research & technical leadership	Low	China's literature publication rate for transportation & storage is over 3X the US, however, average quality of these papers is lower, with an average 14 citations vs. 27 for US publications, suggesting leadership of US work is comparatively higher While publication volume is ~1/3 that of the US, Australia has the highest citation rate of 29, indicating that US research quality is comparable to global leader
Low operational costs	N/A	Not applicable in segment
● Demand / supply side policy	High	U.S.G is supporting infrastructure through DOE HyBlend initiative addressing barriers to blending H_2 in natural gas pipelines (receiving ~$15M funding from 2022) and infrastructure bill allocating $8B for Regional Clean Hydrogen Hubs Japan has pledged ~$2.8B to developing international supply chains leveraging LOHCs Germany announced 62 large-scale H_2 projects, including pipeline transport, that are up for funding of up to €8 B under the Important Projects of Common European Interest
Relative domestic market maturity	Low	Germany has largest private sector investment into hydrogen storage and compressions (~$140 M), with U.S. second (~$80M), and China third (~$10 M)
● Regulatory environment & existing infrastructure	High	75% of hydrogen salt cavern storage sites operating globally are located in the United States ~90% of global hydrogen pipelines are in Europe and the U.S., with ~1,600 miles of dedicated domestic H_2 pipelines
Overall ranking		U.S. has a strong existing competitive advantage and should maintain it due to strong demand-side policies and existing infrastructure

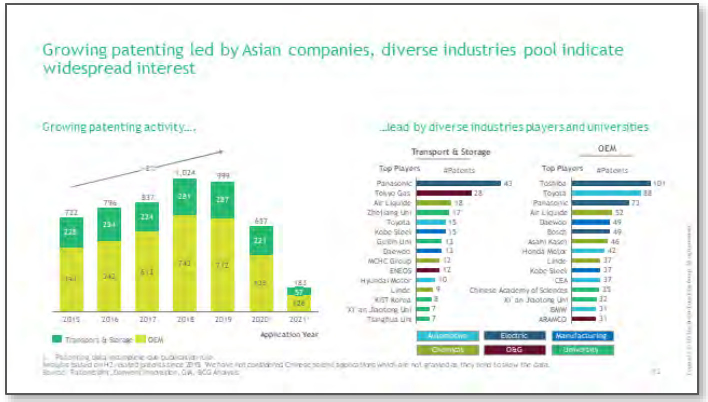
1. Data is for 2010-2019

Source: IEA Global Hydrogen Review 2021, DOE, NREL, A hydrogen strategy for a climate-neutral Europe (8/7/2020)

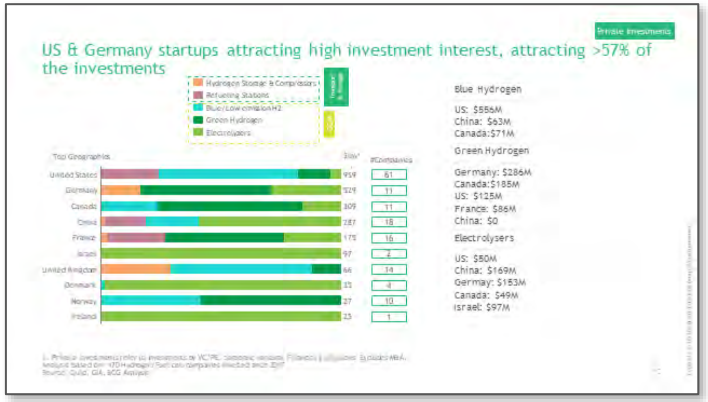
Competitiveness categories:

1. Raw material availability
2. Intellectual property & innovation
3. R&D leadership
4. Low operational costs
5. Demand / supply side policy
6. Relative domestic market maturity
7. Regulatory environment & existing infrastructure

Detailed analysis of global patent, investment, M&A and legislative activity per value chain segment determined High/Low ranking in each of 7 categories



Growing patenting led by Asian companies, diverse industries pool indicate widespread interest



Private investments

US & Germany startups attracting high investment interest, attracting >57% of the investments

Blue Hydrogen

US: $556M
China: $63M
Canada:$71M

Green Hydrogen

Germany: $286M
Canada:$185M
US: $125M
France: $86M
China: $0

Electrolysers

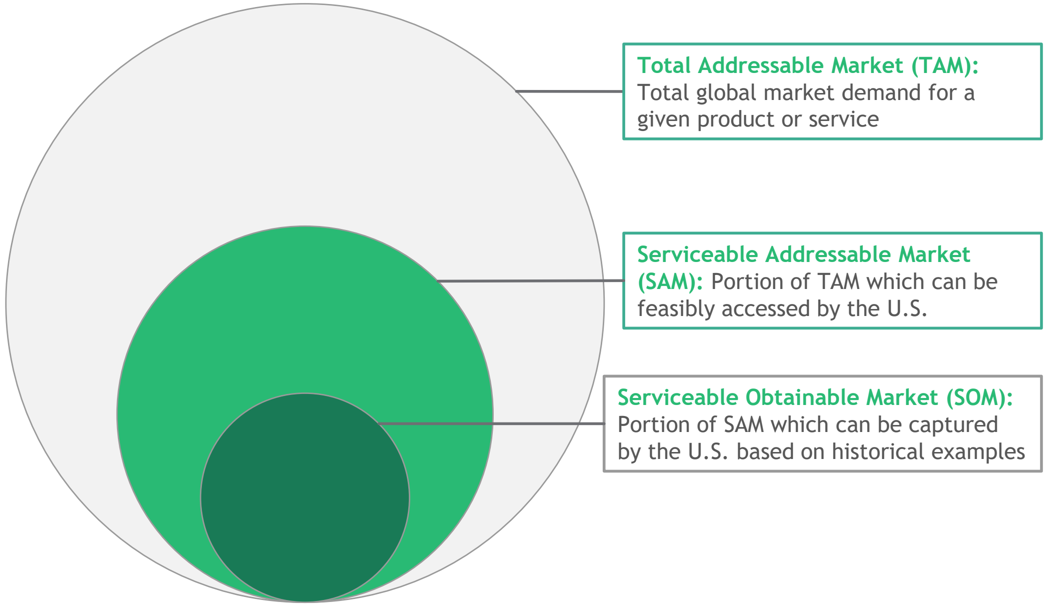
US: $50M
China: $169M
Germay: $153M
Canada: $49M
Israel: $97M

Competitiveness | Deep dive on the seven contributing factors assessed in competitiveness analysis

	Competitive advantage driver	Description
1	**Raw material availability**	**Access (via robust global market or domestic reserves) to critical minerals** required for building and maintaining technology
2	**Intellectual Property & innovation**	Opportunity for innovation leaders to **build defensible IP** with high potential to reduce costs or improve performance of technology
3	**Research & technical leadership**	Potential for research and training from public & private institutions to **build technical leadership position**, driving new innovations with a highly trained workforce
4	**Low operational costs**	Access to **labor, energy, and other inputs at competitive price points** in order to drive cost advantage
5	**Demand / supply side policy**	**Depth and breadth of government policies** (incl. incentives and direct investment) aimed at supporting the technology and driving at-scale deployments
6	**Relative domestic market maturity**	**Size and scale of domestic players** based on market share, investment, M&A activity, and other metrics denoting health and scale of players involved in technology
7	**Regulatory environment & existing infrastructure**	**Maturity and accessibility of existing infrastructure** along with **ease of navigating regulatory environment** to reduce start-up barriers for deploying technology

Societal impact | Job numbers are conservatively based on Serviceable Obtainable Market, the lower bound of potential U.S. global market share

Review of market size definitions used



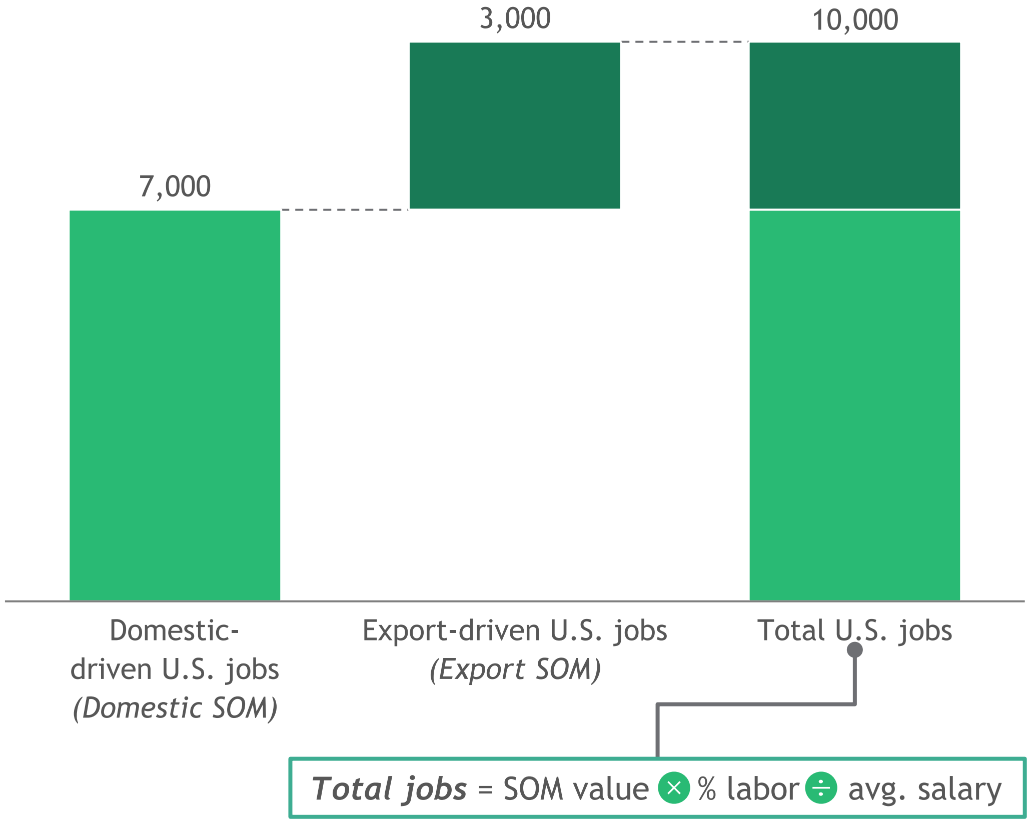
Total Addressable Market (TAM): Total global market demand for a given product or service

Serviceable Addressable Market (SAM): Portion of TAM which can be feasibly accessed by the U.S.

Serviceable Obtainable Market (SOM): Portion of SAM which can be captured by the U.S. based on historical examples

SOM is a conservative view of U.S. market potential which may be further increased with strategic policy support

Approach to jobs quantification



Total jobs = SOM value × % labor ÷ avg. salary

Societal impact | Definition and example of job-years

What are job-years?

- A "job-year" is a measure of employment based on the equivalent of employing a single FTE (full-time equivalent) for one year
- Job-years = # of jobs x duration of jobs

Why use job-years?

- Unlike using the absolute number of jobs, job-years capture both the number of new jobs created as well as how long a given job would be expected to last
- Job-years can be thought of as the total amount of employment a given segment would create over time

Illustrative example of job years vs number of jobs:

Construction: 15 new construction jobs which last 2 years each

- 15 jobs x 2 years per job = **30 job-years**

O&M: 3 new maintenance jobs which last 10 years each

- 3 jobs x 10 years per job = **30 job-years**

Despite construction seeming to have more **jobs**, it is equivalent to O&M in terms of total **job-years**

Societal impact | Definition and example of cumulative jobs

What are cumulative jobs?

- Cumulative jobs count the ongoing positions created over time, rather than individual jobs
- They are calculated as the net growth between the job-years in each year, representing the total growth in the number of positions over time

Illustrative example of job years vs number of jobs:

Construction: A temporary 1-year construction job that opens in 2025 and is repeated continuously through 2050
  - This counts as **1 cumulative job**

O&M: An operations job that opens in 2025 and is filled by the same person for 10 years until 2035
  - This counts as **1 cumulative job**

Project development: A 5-year project development job that opens in 2025 and lasts through 2030, and re-opens in 2035
  - This counts as **2 cumulative jobs**

Regardless of who fills the **jobs** or how long they hold their position, cumulative job years show total growth in the number of positions over time

Technology selection

Six criteria were assessed to inform prioritization based on mitigation impact, economic growth, and national security / strategic interests

Criteria	Description
Abatement potential	Describes the **total abatement potential per technology in 2050** as Mt CO_2e / year, primarily based on IEA's Net Zero by 2050 Roadmap
Expected abatement cost	Describes the **expected abatement cost** of each technology on a $ / ton of CO_2 abated basis. Figures are primarily pulled from EDF MACC 2.0, with additional triangulation from IEA and proprietary BCG research
Feasible export types	Summarizes preliminary view on most likely form of export, including: • **OEM**: Physical assets or plant equipment which enables the associated technology • **IP**: Ability to license a technology or process without necessarily exporting the physical assets • **O&M**: Provision of core operations and maintenance services/tools required for the technology • **Product**: Physical output products for the associated technology • **Services**: Provision of non-core ancillary services to support a technology or associated market • **Software**: Provision of software products or services to directly or indirectly support a technology
Ease of export	Summarizes preliminary view on how feasible exports for the export types shown may be, classified as: • **High**: Currently traded in international markets • **Medium**: Similar products are currently traded internationally • **Low**: International trading is expected, but no similar examples exist today • **N/A**: No trade exist due to clear barriers exist to international trade
Near-term deployment potential	Defines the time scale at which each technology is expected to be deployed at based on IEA projections, defined as: • **High**: Achieves >30% of abatement potential by 2030 • **Medium**: Achieves >30% of abatement potential by 2035 • **Low**: Achieves >30% of abatement potential by 2040 • **N/A**: Achieves >30% of abatement potential after 2040
National security and strategic interest	Classifies the potential level of national security implications per technology, based on implications across several topics: • **High**: Has direct potential military applications • **Medium**: Provides liquid fuels • **Low**: Supports grid resiliency • **N/A**: Does not have any clear national security implications

Long list of technologies evaluated for potential analysis

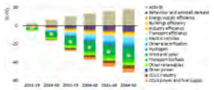
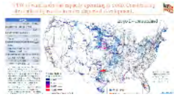
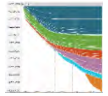
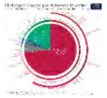
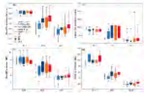
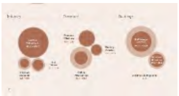
■ High	▨ Medium	▢ Low	░ N/A

★ *Selected in part 2* ☆ *Selected in part 1*

		Abatement potential *(2050 Mt CO_2e)*	Feasible export types	Expected cost *(2050 \$/ton CO_2e)*	Ease of export	Near-term deployment	Nat'l security interest
	Tier 1: Criteria-based priorities						
☆	Grid-Scale LDES (electro-chemical)[4]	*Critical enabler*	Product, IP, Software	*Critical enabler*	▨	■	▢
	Grid-Scale LDES (other)[4]		Product, Software		▨	■	▢
★	Utility-scale Solar[4]	■ 6,500	Product	$30	■	■	▢
☆	Electric Vehicles[4]	■ 6,500	Product, IP, Software	$20-60	■	■	▢
★	CCUS[4]	■ 6,000 - 7,000	Product, IP	$20 - 100	■	■	▢
	Onshore Wind[4,10]	■ 4,200 - 8,000	Product	$10-40	■	■	▢
☆	Hydrogen[4]	■ 4,100	Product, IP, Services	$100-150	▨	▨	▨
★	Offshore Wind[4,10]	▢ 1,100 - 2,000	Product	$30-40	■	■	▢
	Grid-Scale Li-ion[4]	*Critical enabler*	Product, IP, Software	*Critical enabler*	■	■	▢
☆	Advanced Nuclear (SMRs)[2,4]	▢ 300 - 500	Product, IP	$110	▨	▢	■
	Smart Grid/Grid Infrastructure	*Critical enabler*	Product, IP, Software	*Critical enabler*	▨	▨	■
	Tier 2: Additional potential priorities						
☆	DAC[4,5]	▢ 700 - 1,800	Product, IP	$220	▢	░	░
	Clean Cement[4,9]	▢ 1,500	Product, IP	$60	░	░	░
	Sustainable Aviation Fuel (PtL)[4,7,11]	▢ 800 - 1,400	Product, IP	$170	▨	▢	▨
	DG solar[4,5,12]	▢ 800	Product, IP	$90 - $150	■	▨	▢
☆	Clean Iron/Steel/Aluminum (EAF)[4,8,9]	▢ 900	Product, IP	$60	■	▢	■
	Tier 3: Deprioritized						
	Tech Solutions for Ag[1,4]	▨ 2,300	Product, Services	-$230 - 130	▨	▢	░
	Energy Efficiency & Climate Services[4]	▨ 2,100	Services	-$10 - 70	▨	■	░
★	Geothermal[4]	▨ 2,000	Product, Services	$50 - 150	▨	▨	▢
	NBS in Agriculture[4]	▢ 1,600	Services	$100	░	▢	░
	Residential Electrification[4]	▢ 1,600	Product	$100 - 140	■	■	░
	Biofuels[4]	■ 3,100 - 4,300	Product, IP	$30-160	▨	▨	▨
	Electric Charging Infrastructure	*Critical enabler*	Product, IP, Services	*Critical enabler*	■	■	░

1. Includes zero-emissions farm equipment, emissions-reducing feed, modern animal & crop mgmt. practices 2. EDF MACC 2.0 Average costs
3. Drawdown Report, 4. IEA NZE 2050, 5. Princeton CMI, 6. World Resources Institute, 7. IATA, 8. Excludes CCUS-enabled abatement, 9. Impact extrapolated using current % of emissions where not included in explicit projections, WRI, 10. Cornell University MDPI, 11. Rocky Mountain Institute 12. DG solar cost extrapolated using LCOE premium relative to utility-scale solar

Backup | Sources for Carbon Abatement Potential

Key sources	Description
 **IEA (Net Zero Energy 2050 Report & others)**	Key emissions milestones required by sector, including carbon abatement targets
 **Princeton CMI**	Reviews technologies & scale required to achieve Net Zero emissions
 **EDF MACC 2.0**	Carbon abatement impact by clean technology through 2050, including abatement costs
 **World Resources Institute**	Historical view of carbon emissions by sector
 **IPCC**	Reviews technologies & scale required to achieve <1.5 degrees warming
 **Drawdown Report**	Granular view of carbon abatement impact of highly specific initiatives across industries and emissions sectors
Others sources include: IATA, NREL, Cornell MDPI, SEIA, RMI, LDES Society, International Geothermal Ass.	Industry group reports or technology-specific research studies

Backup | Descriptions of potential export types

Export types	Description	Examples
OEM	The physical assets or plant equipment which enables the associated technology	• Li-ion battery pack • Wind turbines / solar panels
Intellectual Property (IP)	The ability to license a technology or process without necessarily exporting the physical associated assets	• Direct Air Capture (DAC) technology • Hydrogen electrolysis technology • Clean cement production processes
Operations & Maintenance (O&M)	The provision of core operations and maintenance services or tools required to deploy the associated technology	• Contracting specialized vessels to maintain offshore wind farms • Contracting to operate and maintain large CCUS plants
Product	The physical output products for the associated technology	• Clean steel products • Clean hydrogen / ammonia • Barrels of sustainable aviation fuel
Services	The provision of non-core ancillary services to support a specific technology or associated market	• Geothermal seismic studies to assess resource potential for future projects
Software	The provision of software products or services to support the operations of a technology, either directly or indirectly	• Battery operations software which help maximize project economics • EV charging software to optimize charging and provide load-balancing grid services

Summary findings

The four technologies assessed in part 2 offer significant economic and strategic benefits to the U.S.

	U.S. addressable market value *($B, 2020-50[1])*	**U.S. job creation** *(Total # jobs created[2])*	**Key strategic benefits**
Solar	$4.0 – 4.5T	550K	• Key for U.S. decarbonization and long-term energy security goals • Expected to provide ~20-25% of U.S. electricity by 2050
CCUS	$1.3 - 1.7T	105K	• Required for hard-to-decarbonize industries for U.S. to hit emissions goals • Supports just transition for O&G workers given overlap in skills & regions
Geothermal	$1.2 – 1.6T	40K	• Offers clean and dispatchable energy, a key enabler for increased penetration of variable renewable resources • Unlocks export opportunities in southeast Asia, Africa, and Latin America
Offshore wind	$0.8 – 1.2T	90K	• Key for U.S. decarbonization targets with high complementarity with solar • Domestic supply chain independence offsets need for expensive imports

Across all four technologies…

$7.5-9T
Cumulative U.S. addressable market

700-850k
Cumulative U.S. jobs created

16-18Gtpa
Decarbonization impact in 2050

45-50%
of U.S. 2050 power generation

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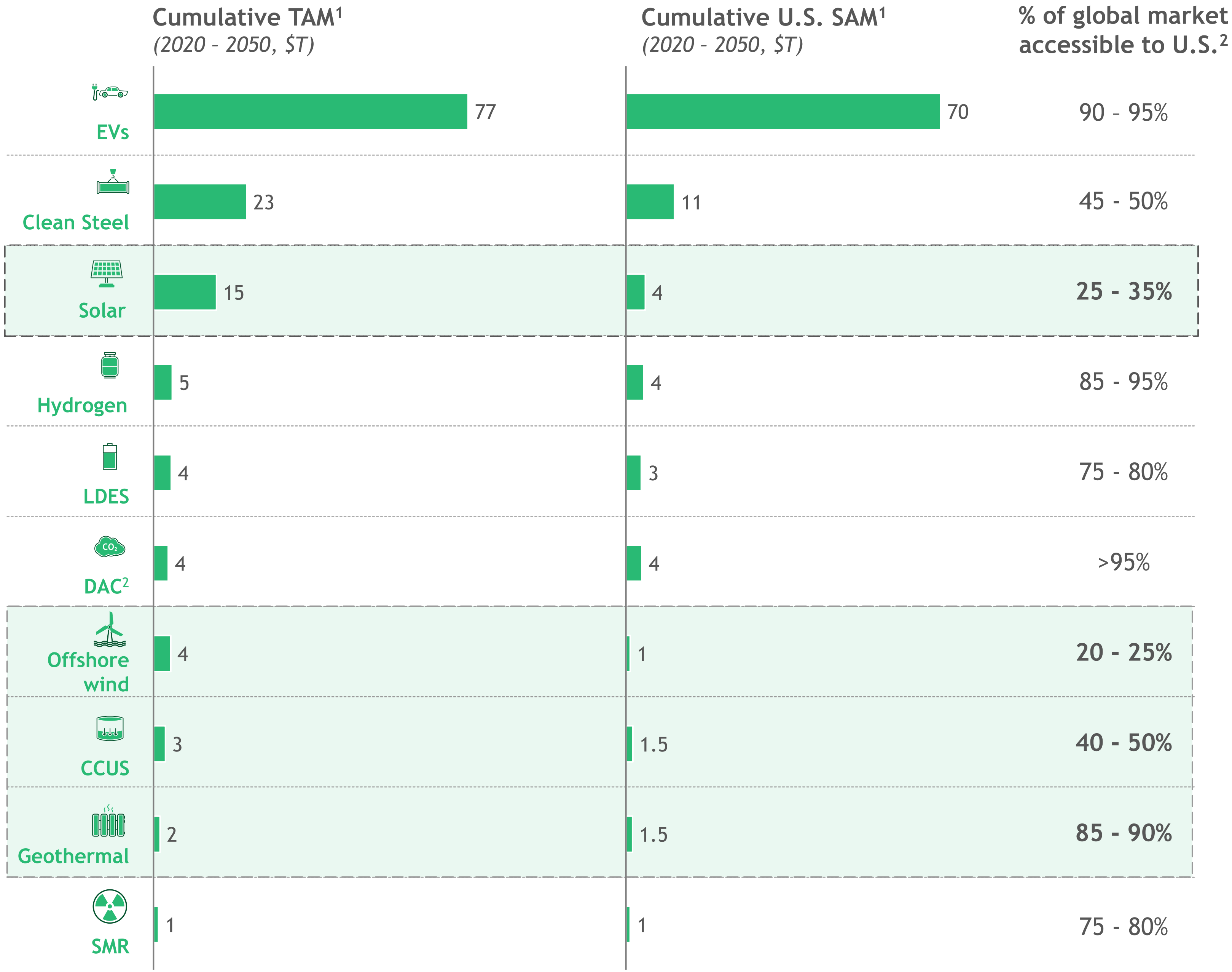
1. Cumulative size of serviceable addressable market for the U.S. from 2020-50 in the IEA's 2022 APS scenario, 2. Job creation calculated as the cumulative sum of net positive job-years (e.g., 2021 job-years minus 2020 job-years gives 2021 new jobs)
Source: BCG analysis

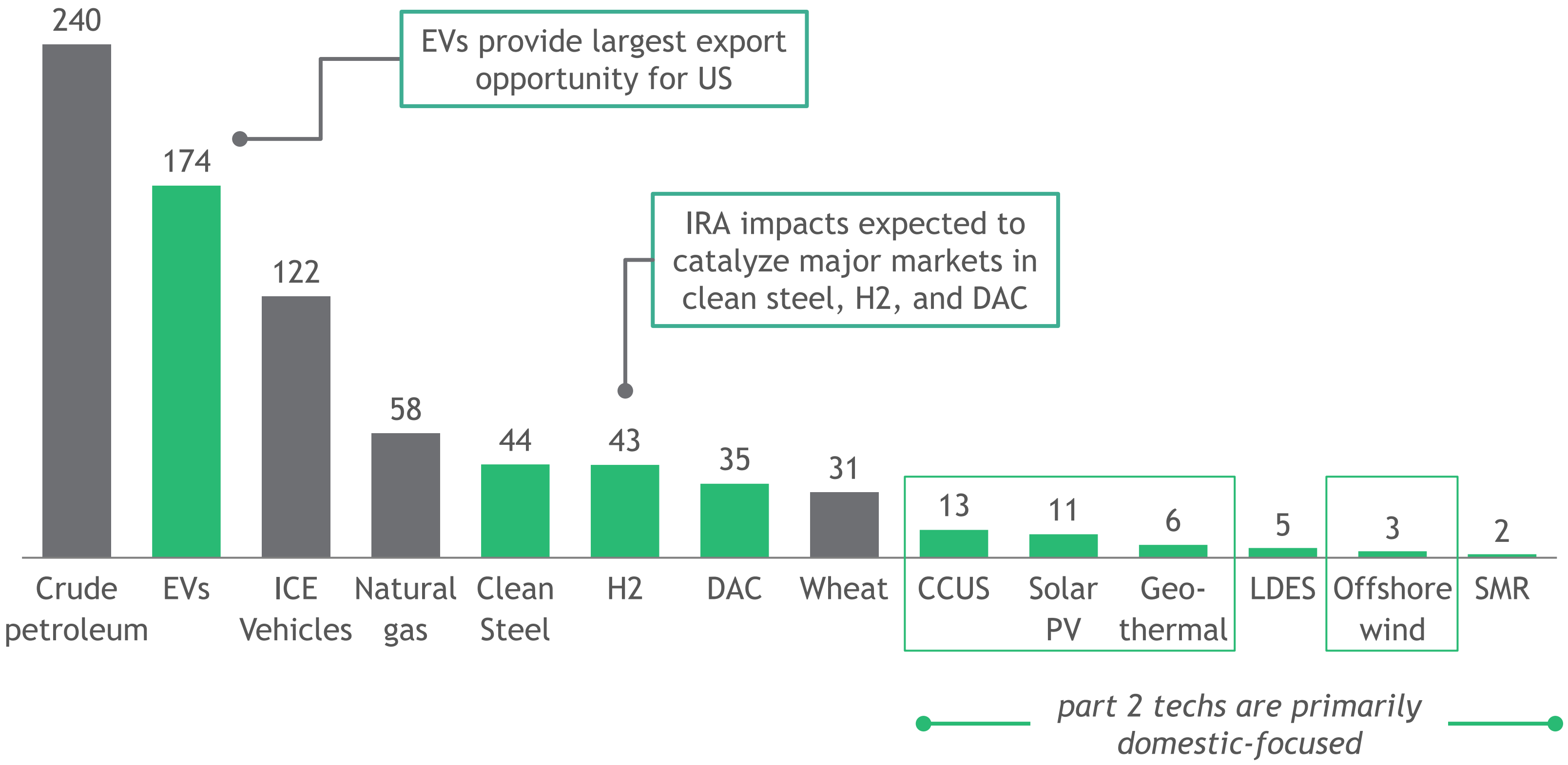
However, U.S. opportunity is primarily driven by the domestic market with limited export potential, unlike previous part 1 technologies



1. Values reflect sum of all value chain segments under the IEA APS scenario; TAM is the total market demand while SAM is the portion of the market that can be feasibly accessed by the U.S. 2. SAM divided by TAM gives a % of accessible market to the U.S.
Source: IEA, BCG analysis

Despite relatively limited export potential of part 2 technologies, growth in clean technology export portfolio can help offset existing U.S. O&G exports

Comparison of legacy U.S. exports *($B, 2021)* to potential clean U.S. exports *($B, 2050)*



EVs provide largest export opportunity for US

IRA impacts expected to catalyze major markets in clean steel, H2, and DAC

part 2 techs are primarily domestic-focused

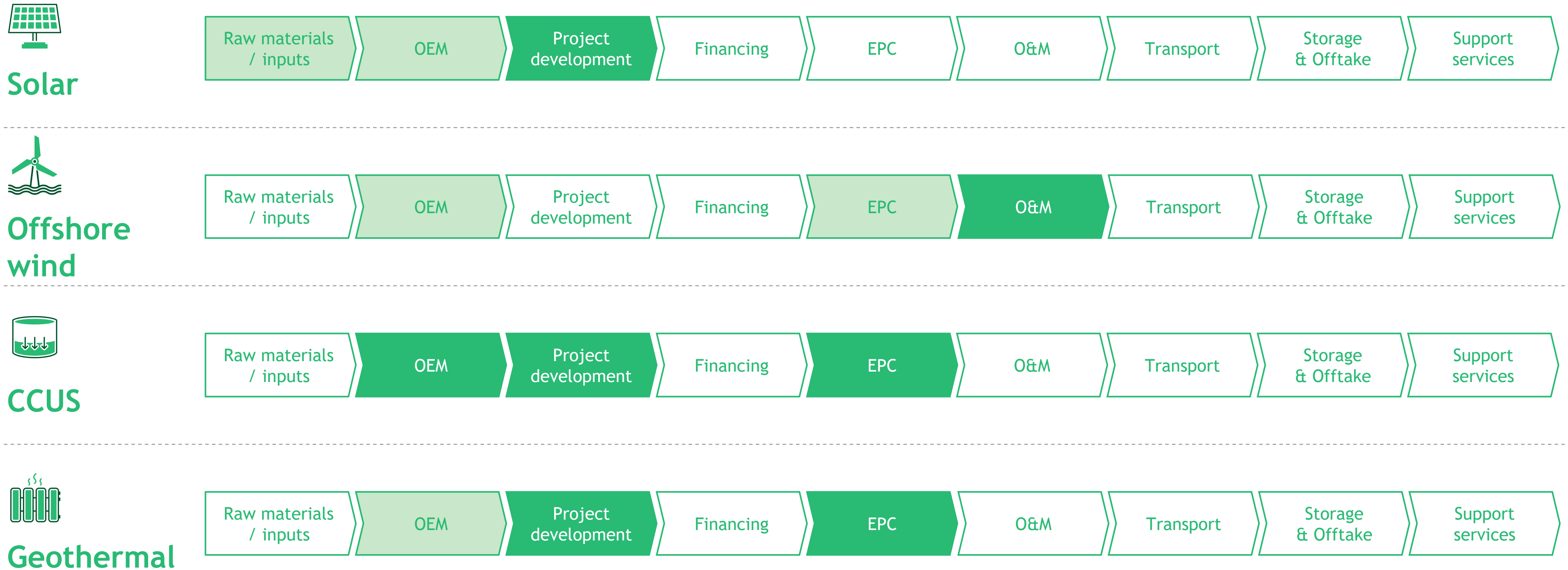
$400-450B U.S. 2021 O&G exports[1]

$300-350B U.S. 2050 clean tech export potential

1. Includes petroleum, ICE vehicles, and natural gas
Source: Trading Economics

Prioritized segments for each technology were the focus of our analysis on U.S. competitive positioning

Prioritized value chain segments



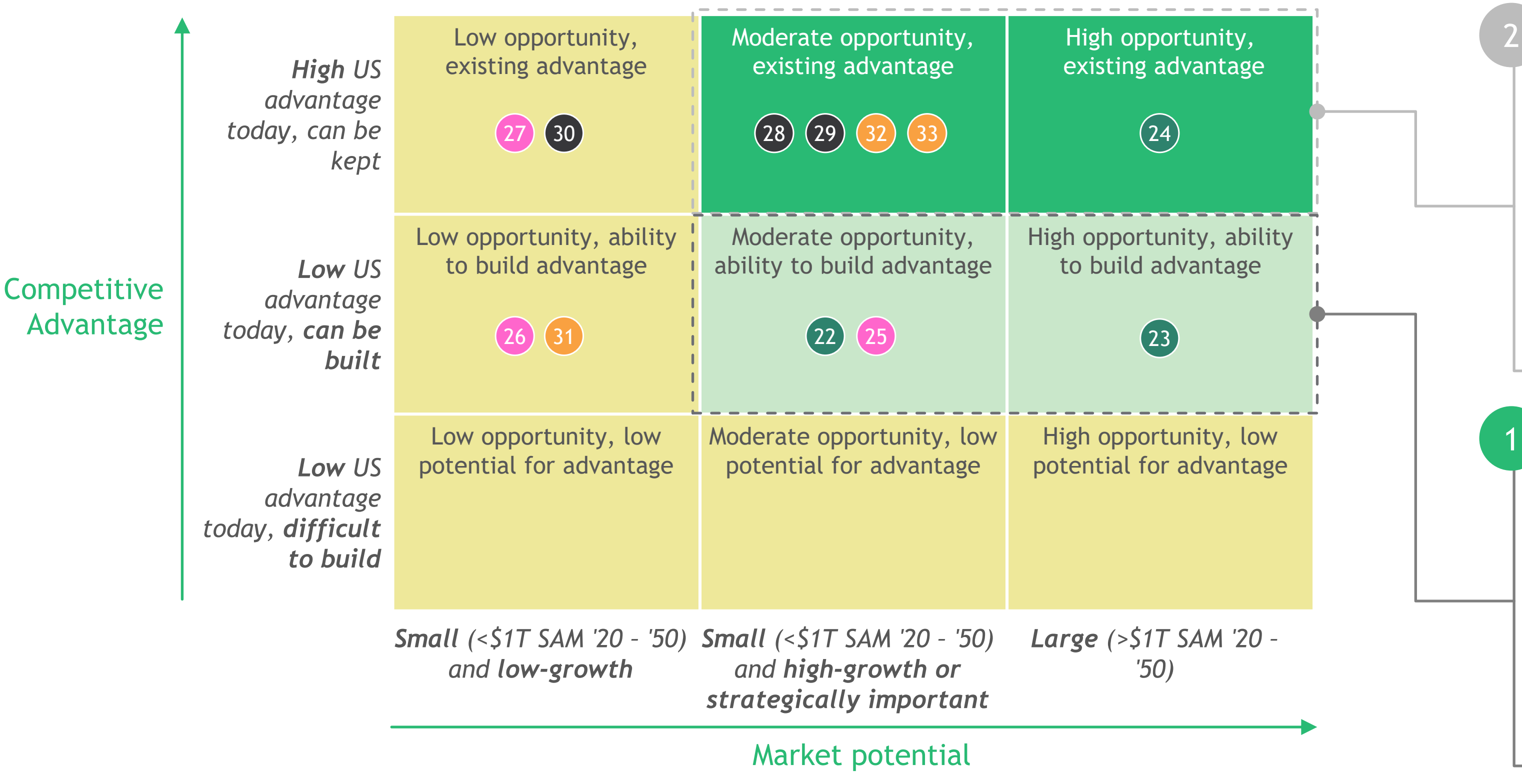
	Raw materials / inputs	OEM	Project development	Financing	EPC	O&M	Transport	Storage & Offtake	Support services
Solar	▨	▨	🟩						
Offshore wind		▨			▨	🟩			
CCUS		🟩	🟩		🟩				
Geothermal		▨	🟩		🟩				

🟩 *U.S. has a strong existing competitive advantage and should maintain it*

▨ *U.S. has a potential to build a durable competitive advantage*

🟨 *U.S. should maintain status quo*

Solar and OSW must recapture domestic manufacturing market, while CCUS and geothermal are well-positioned to lead global deployments



Competitive Advantage

	Small (<$1T SAM '20 - '50) and *low-growth*	*Small* (<$1T SAM '20 - '50) and *high-growth or strategically important*	*Large* (>$1T SAM '20 - '50)
High *US advantage today, can be kept*	Low opportunity, existing advantage 27 30	Moderate opportunity, existing advantage 28 29 32 33	High opportunity, existing advantage 24
Low *US advantage today,* ***can be built***	Low opportunity, ability to build advantage 26 31	Moderate opportunity, ability to build advantage 22 25	High opportunity, ability to build advantage 23
Low *US advantage today,* ***difficult to build***	Low opportunity, low potential for advantage	Moderate opportunity, low potential for advantage	High opportunity, low potential for advantage

Market potential

② CCUS and geothermal

- U.S. is the current global leader in both CCUS and geothermal deployments with significant expertise in sub-surface technology due to a robust O&G industry
- Continued policy support should be focused on driving down costs and accelerating deployments to ensure U.S. maintains leading position as markets grow

① Solar PV and offshore wind

- U.S. has ceded leadership in solar PV and OSW technologies to European and Chinese incumbents who have scaled manufacturing and driven down costs
- Primary opportunity is in reclaiming domestic markets by onshoring manufacturing and supply chains to limit dependence on imports

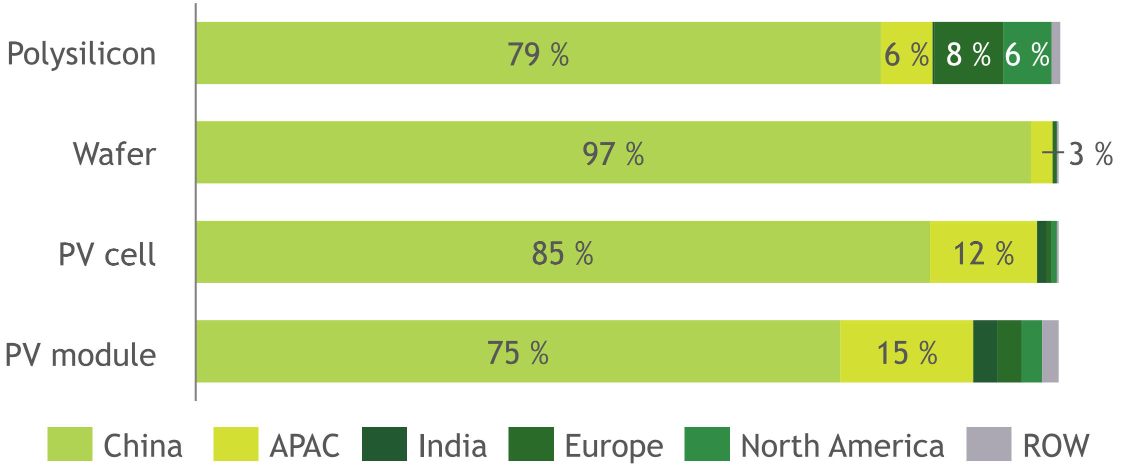
22	Solar - Raw Material & inputs	25	Offshore Wind - OEM	28	CCUS - OEM	31	Geothermal - OEM
23	Solar - OEM	26	Offshore Wind - EPC	29	CCUS - Project Development	32	Geothermal - Project Development
24	Solar - Project Development	27	Offshore Wind - O&M	30	CCUS - EPC	33	Geothermal - EPC

Note: Market potential placement based on APS scenario; Positioning within sectors is not relative

The U.S. has ceded leadership in both solar PV and offshore wind, particularly within manufacturing and development

China and APAC own >85% of solar manufacturing capacity across solar manufacturing activities

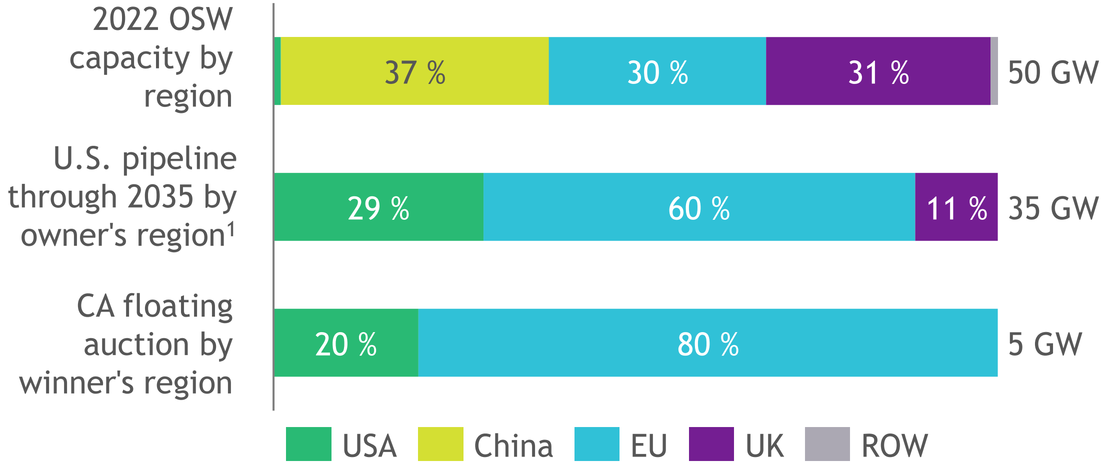
% of global manufacturing capacity, 2021



- China dominates solar manufacturing, leading to high dependence on a single source for solar supply chain
- Tariffs against imports from China due to forced labor and from SEA due to circumvention present U.S. supply chain risks

China and Europe dominate offshore wind deployments today and are expanding into the U.S.

% of offshore wind capacity



- U.S. lags Europe and China in both total deployed OSW and in share of domestic development market
- Experienced European players are rapidly expanding into the U.S. market for both fixed and floating technologies

1. This only includes wind sites where owner is known. Many projects are in early planning stages and might not come to fruition.
Source: IEA, 4C Offshore Wind Database, DOE, BCG Analysis

IRA and IIJA provide support across the value chain, giving U.S. opportunity to recapture domestic market share

Solar PV

Solar PV incentives create opportunity to build a secure domestic supply chain

Polysilicon production

- Advanced manufacturing production credits for polysilicon **helps U.S. polysilicon to be more cost-competitive** to Chinese polysilicon

Wafer, cell, and module mfg.

- **IRA domestic manufacturing tax incentives** for each step of the upstream value chain - wafer, cell, and module - **provide support to onshore manufacturing in the U.S.**
- **U.S.-produced modules can potentially be ~25% cheaper for domestic projects than imports** from SEA/China due to the incentives

Deployment

- **U.S. solar deployment may expand by ~75% by 2050** due to extended ITC and PTC credits for electricity producing clean energy

Offshore wind

IRA credits reduce OSW costs and position the U.S. to serve a rapidly growing domestic market

Permitting & devt.

- **Expansion of lease areas** accelerates wind area auctions

Turbine and foundation mfg.

- **Manufacturing credits** support domestic supply chain and **position U.S. for regional exports**
- **$50M into floating RD&D** and goals to reduce costs by 70% accelerate floating deployment

Construction

- **Infrastructure expansion is facilitated** through $600M for port upgrades and a '10% of sales price' tax credit for building installation vessels

Generation

- **ITCs / PTCs guarantee long-term revenue streams** during electricity generation, helping to de-risk project financing

Recapturing domestic solar and offshore wind markets requires offsetting U.S. cost disadvantages to reclaim manufacturing market share

Challenges to address	Potential solutions to boost competitiveness
High labor costs (i.e., U.S. manufacturing labor is 2-5x more expensive than SEA and China) make it difficult for U.S. manufacturing to be competitive with imports	Rapidly capture **economies of scale** and **accelerate research into manufacturing innovation and modularity** to reduce costs of manufacturing labor-intensive components (i.e., blades and foundations for OSW, modules and cells for solar)
Lack of skilled labor, particularly in areas with technical expertise (e.g., engineers, technicians, factory workers), inhibits rapid scale-up of domestic industries	Implement localized **workforce training programs,** support favorable immigration policies, and **reskill legacy workforce** to proactively address potential shortfalls
Near-term uncertainty around offtake demand, supply chain disruption, and infrastructure development, dissuades manufacturers from investing in U.S. mfg.	**Clear supply chain issues by clarifying regulatory trade policies for solar PV** for near-term deployment, and **facilitate infrastructure building** through transmission planning to encourage local supply chain activity
Loss of IP leadership to foreign players (e.g., floating platforms for OSW and cell technology for solar) hinders innovation and diminishes U.S. export potential	**Reclaim IP lead by** incentivizing domestic R&D, setting up higher-level academic programs and demonstration centers, and commercializing novel techs by reducing their costs

Deep dive | Solar
Manufacturing and development enablers make the U.S. competitive with low-cost imports

Example high-potential enablers

Enable vertically-integrated manufacturing at scale: De-risk investment (e.g., loan guarantees, cost sharing agreements) to build integrated wafer, cell, and module facilities at scale and fund innovation in both technology and manufacturing processes, reducing production costs

Reform interconnection processes: Improve transmission planning and interconnection processes to reduce grid connection delays and enable equitable cost allocation to developers for utility-scale solar projects

Expand and upgrade transmission grid: Invest in rapid expansion and upgrades of grid infrastructure to accommodate the increased load and added variable capacity due to solar deployment, increasing confidence in domestic manufacturing

Formulate workforce development programs: Establish solar-focused apprenticeship and technical programs in collaboration with manufacturers, governments, and educational institutions to create a diverse talent pipeline

Trends to monitor

Expansion of Chinese manufacturing capacity: Continuing expansion of manufacturing facilities in China across each value chain segment may lead to further concentration of solar manufacturing, increasing supply chain risks

Impact of circumvention case and forced labor policy: Further deployment delays may occur due to the circumvention case outcome and unclear guidance on the UFLPA[1] in the U.S. and possible forced labor policy in the E.U.

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[1] Uyghur Forced Labor Prevention Act

Source: BCG Analysis

Deep dive | Offshore wind

Addressing transmission issues enables clear demand pipeline to justify local supply chains, boosting U.S. competitiveness

1

Example high-potential enablers

Support permitting reform: Reduce regulatory barriers across state and federal levels, increase permitting certainty, and create timeline clarity to de-risk project development and help developers secure access to financing

Reform transmission grid planning: Plan and build an interstate high-voltage transmission system for OSW to replace generator lead line approach that puts cost burden on developers and is unsustainable for interconnection volume

Scale manufacturing of components and equipment: Accelerate research into manufacturing automation and modularity and support industry-wide standardization efforts to reduce mfg. / infrastructure costs and secure supply of high-risk components

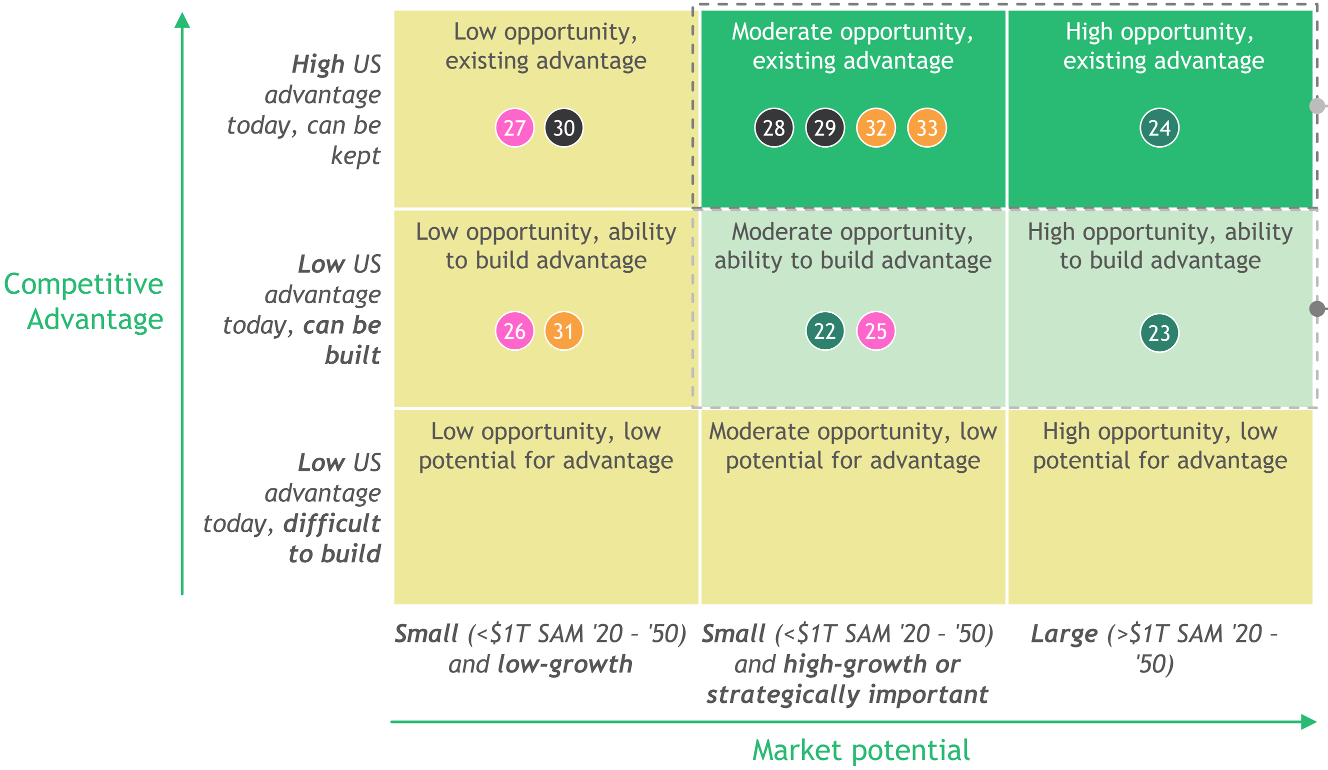
Deploy nascent floating tech at scale: Accelerate demonstration projects and reduce floating costs through increased deployment and standardization to take advantage of deep-water wind areas and capture export potential

Trends to monitor

Projected future shortages of key materials: Dependency on China for rare earth magnets for generators might lead to future supply chain disruptions

Foreign players' floating OSW progress: European and Chinese players lead floating demonstration and patenting activity and are expanding abroad. U.S. must accelerate floating deployment to secure exports before competitors do

Recall | Solar and OSW must recapture domestic manufacturing market, while geothermal and CCUS are well-positioned to lead global deployments



Competitive Advantage	Small (<$1T SAM '20 - '50) and low-growth	Small (<$1T SAM '20 - '50) and high-growth or strategically important	Large (>$1T SAM '20 - '50)
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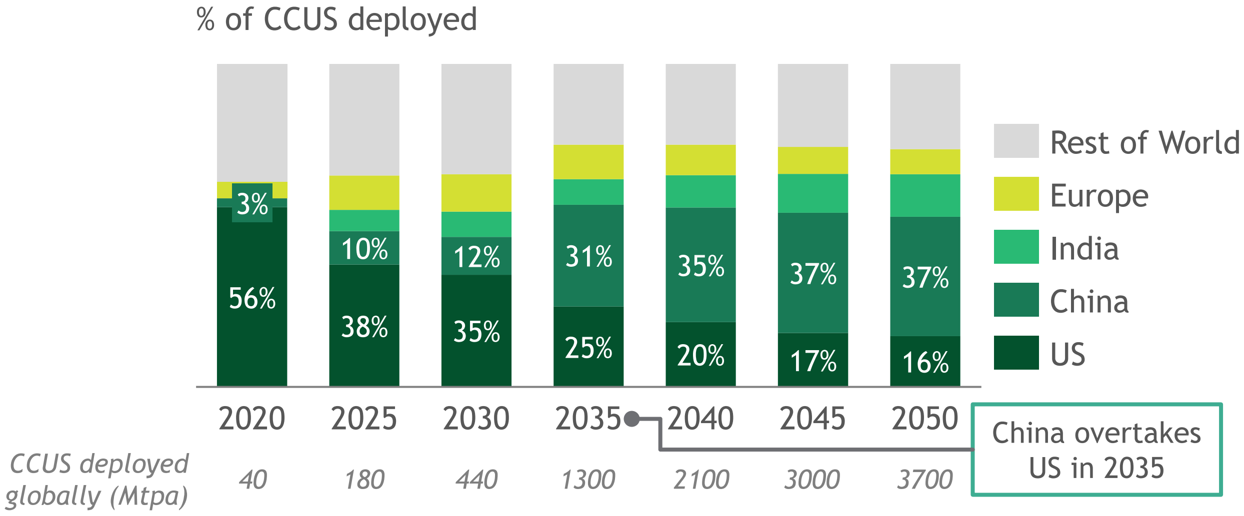
Note: Market potential placement based on APS scenario; Positioning within sectors is not relative

The U.S. is currently a global leader in both CCUS and geothermal, but other players may displace the U.S. without active policy support

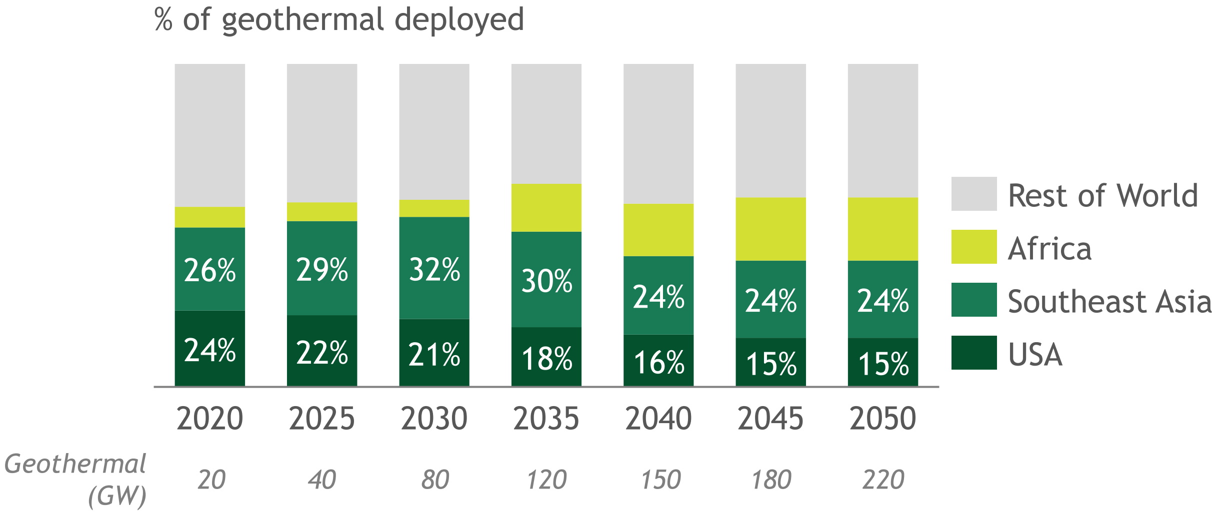
U.S. currently leads in CCUS deployments but is projected to be overtaken by China in 2035



China overtakes US in 2035

- China is expected to overtake U.S. as largest CCUS market by 2035 and will comprise ~40% of global market by 2050
- Non-Chinese and non-U.S. markets account for <50% of global market capacity by 2050

U.S. leads in geothermal but will be overtaken without further investment



- U.S. leads the world in capacity and has durable advantages in drilling and exploration, but market is relatively small unless innovations unlock upside
- Strategic export opportunities exist in concentrated regions like SEA, Africa, and Latin America

Source: IEA, BCG analysis

IRA and IIJA accelerate domestic CCUS and geothermal market growth, potentially positioning U.S. players to build early-mover advantage

CCUS

Expanded CCUS credits accelerate U.S. deployment potential and potential first mover advantage

OEM

- **RD&D funding for novel & modular techs** to drive down costs

Project development

- $3.5B in **direct funding for commercial-scale CCUS projects**

Financing

- **Expanded 45Q tax credit** increased ~70% to $60-85 / tCO2e

Permitting for transport & storage

- ~$100M in **direct funding for states to establish well permitting programs**
- ~$5B in loans and other financing for **CO_2 pipelines & other large-scale carbon sequestration** projects

Geothermal

Geothermal provisions are limited, though may boost deployment by improving project economics

Lack of support across VC, and project dev. received a fraction of the overall support needed

Permitting

- N/A

Project Dev.

- (AGILE) Act authorized **regional coordinating offices and four additional early-stage tech demonstration** projects (not funded)
- $80M for **Enhanced Geothermal Systems (EGS) commercialization projects**

Mfg.

- N/A

Generation

- **Extended ITC/PTC drive down cost** by ~$15/MWh and ensure geothermal remains cost competitive as a baseload option

U.S. must continue to leverage strengths and capitalize on existing lead to maintain position globally for CCUS and geothermal

Challenges to address	Potential solutions to boost competitiveness
High costs today as both technologies need to come down the learning curve to be cost competitive. Commercial scale deployments needed to support manufacturing scale-up and drive down costs	**Provide support and funding for in-field research and early commercial deployments** of innovative technologies (e.g., EGS, supercritical drilling for geothermal; metal organic frameworks, electroswing absorption for CCUS) with funding for initial manufacturing hubs to de-risk private investment
Long permitting timelines (esp. for sub-surface components) take up to 6 years, inhibiting ability to rapidly scale-up deployments and adding additional risk to project financing which dissuade investment	**Reform permitting to shorten timelines** and standardize processes under a single agency's jurisdiction. Align on federal rules for assuming long term subsurface liabilities and extend favorable O&G provisions (e.g., categorical exclusions, caps on BLM reviews, more frequent auctions)
Lack of demand-side signals and corresponding lack of monetization opportunities make it difficult to incentivize project and R&D investment	**Create clear demand signals and monetization opportunities** (e.g., through RPS commitments for geothermal and regulations on CO_2 emissions)
Limited high-quality data characterizing the subsurface makes exploration and development more expensive and uncertain for both technologies	**Enhance data sharing and collection** on existing hydrothermal and O&G reservoirs, hydrothermal conductivity, and other geologic characteristics (incl. sink to source matching for CO_2)

Deep dive | CCUS

Establishing long term monetization opportunities and supporting CO_2 infrastructure will enable the U.S. to further build on its lead in global CCUS deployments

Example high-potential enablers

Create CO_2 regulations and / or long-term monetization opportunities: Establish permanent monetization opportunities for CCUS either through regulations mandating CO_2 reductions (e.g., emissions limits for gov't procured steel) or pricing carbon emissions within certain industries[1] (e.g., LCFS in CA)

Continue to support near-term commercial deployments (e.g., U.S. carbon capture hubs) to further drive down costs of CCUS, leveraging US gov't procurement and other levers. Focus on next gen CCUS tech which can decarbonize applications with low CO_2 concentration in emission stacks

Establish processes for transport & long-term storage / monitoring of CO_2: Define federal-level regulations and provide funding for transport, storage, and monitoring of CO_2 (e.g., length of liability for private companies, permanence) and define clear & efficient permitting processes

Accelerate the transition of O&G workers to CCUS in order to meet labor needs by establishing training programs and incentives for workers to begin developing the necessary skills

Trends to monitor

Net-zero targets and policies: More aggressive net-zero targets & policies will increase demand for CCUS to address hard-to-abate emissions, increasing US export opportunities

Global regulations & standards for CCUS: Several nations (esp. in the EU) remain opposed to CCUS, given its enablement of continued O&G and inability to capture 100% of emissions; universal standards for CCUS will be needed to drive widespread global deployments

---

1. Power, cement, and steel make up nearly 50% of CO2 applications and could be strong fits for emissions limits

Deep dive | Geothermal
U.S. poised to build on leadership position but needs to address non-economic barriers that stifle rapid deployment and support early commercialization efforts for emerging technologies

Example high-potential enablers

Expedite permitting and streamline regulation: Remove barriers to deployment that drive up cost and increase risk for developers (e.g., categorical exceptions, caps on BLM reviews, and target lease approvals)

Enhance demand-side signals: Increase demand to encourage private investment in exploration, development, and innovation (e.g., govt. procurements, firm zero-carbon power incentives)

De-risk investment in emerging technologies: Enhance demonstration grant funding for technologies that will drive durable competitive advantages and can be exported (e.g., lithium extraction, EGS, and supercritical drilling)

Enable rapid scale up: De-risk private investment in new development and enable domestic players to accelerate learning curve on new technologies and achieve economies of scale (e.g., loan guarantees, risk insurance, tax credits)

Trends to monitor

Viability of lithium extraction at scale: The pilot at the Salton Sea, which contains nearly as much lithium as Chile and Bolivia combined, is the largest in the world and could prove the viability of a domestic lithium supply chain

Progress of state-backed competitors: Large state-backed geothermal companies in Indonesia, Kenya, and Turkey are investing in new capacity and technologies, potentially surpassing the U.S. as the global leader and capturing the massive upside of geothermal

Summary enablers to unlock competitive advantage

Demand side enablers

Boost competitiveness by increasing capacity deployed to drive costs down the learning curve

Decrease green premiums

Increase demand by either reducing the cost of the technology or increasing the cost of emitting alternatives

Increase volumes deployed

Increase total technology deployment through direct procurements or deployment targets

Ensure access to export markets

Facilitate domestic companies' exports by clearing non-tariff barriers

Supply side enablers

Boost competitiveness by building economies of scale in manufacturing and maintain lead in IP

Streamline deployment

Reduce barriers to deployment and streamline permitting processes to de-risk investment in projects, increasing capacity deployed

De-risk infrastructure investment

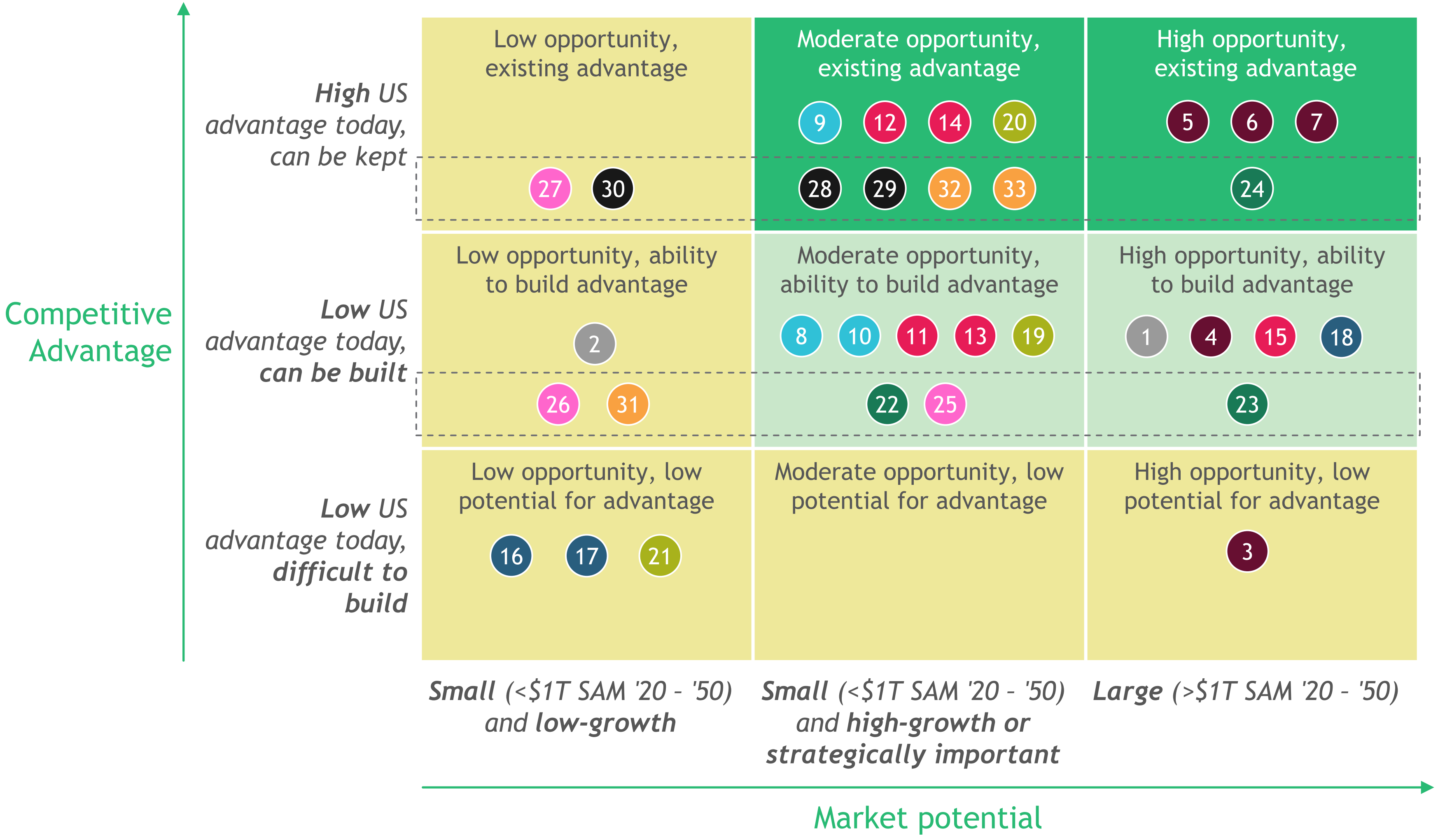
Increase access to capital for relevant projects and facilitate infrastructure building, decreasing cost burden on developers

Maintain lead in innovation

Promote RD&D to maintain technological competitiveness in quality/cost and translate research leadership to commercial success

Draft - to be refined

Backup | Prioritization of Part I and Part II segments for U.S. to build competitive advantage



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Low** US advantage today, **can be built	Low opportunity, ability to build advantage 2 26 31	Moderate opportunity, ability to build advantage 8 10 11 13 19 22 25	High opportunity, ability to build advantage 1 4 15 18 23
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Market potential

Note: Market potential placement based on APS scenario; Positioning within sectors is not relative

1	LDES - OEM
2	LDES - O&M software
3	EV - Raw Materials
4	EV - Battery & Powertrain Manu.
5	EV - OEM
6	EV - Software Development
7	EV - Aftersales Services
8	H_2 - OEM
9	H_2 - Transport & Storage
10	H_2 - Project Development
11	DAC - OEM
12	DAC - Project Development
13	DAC - EPC
14	DAC - Transport & storage
15	DAC - Offtake
16	Clean Steel - OEM
17	Clean Steel - EPC
18	Clean Steel - Offtake
19	SMR - Raw Materials
20	SMR - OEM
21	SMR - EPC
22	Solar - Raw Material & inputs
23	Solar - OEM
24	Solar - Project Development
25	Offshore Wind - OEM
26	Offshore Wind - EPC
27	Offshore Wind - O&M
28	CCUS - OEM
29	CCUS - Project Development
30	CCUS - EPC
31	Geothermal - OEM
32	Geothermal - Project Development
33	Geothermal - EPC

Part 2 four new technologies

Technology-specific findings

Solar PV

Solar | Definition of each segment across value chain

	Raw materials & inputs	OEM	Project Development	Financing	EPC	Operations/ Maintenance	Offtake	Support services
Utility-scale	**Mining and refining of raw materials for:** **Solar cell** (silicon, cadmium, tellurium, copper, gallium, etc.) **Balance of System** (copper wiring, silver, aluminum, steel, glass, etc.)	**R&D:** Significant R&D is ongoing (e.g., CdTe, thin film) to refine solar PV technology **PV module:** Manufacturing of wafer, thin-film module, etc. and assembling into a PV module **Balance of system (BOS) equipment:** Manufacturing and assembly of wiring, switches, inverters, battery bank, charge controller and electric grid	**Development includes:** • Origination • Site selection • Land acquisition • Interconnection • Permitting and studies • Insurance • Power Purchase Agreement (PPA) May be developed in tandem with storage or standalone	Developer typically arranges project financing Financing is available through • Private banks • Bank loans • Third party solar PPA **Tax equity partnerships** can help to take advantage of incentives such as Investment tax credits (ITC) etc.	EPC includes: • Final site design and engineering • Procurement • PV module transport and storage • On-site solar panel installation • Final assembly & connection to electric grid • Testing EPC process may be done in tandem with storage or can be done standalone	**Operations:** • Manage budget • Monitor solar plant real-time • Optimize operations **Maintenance:** • Preventative (routine inspection) • Corrective (repairs and replacement due to panel cracking, inverter failure, etc.) • Condition-based (predict breakdowns using real-time data)	Acts as **'front of the meter'** system as power is injected directly into the bulk transmission grid	**Renegotiate** lease and offtake once PPA term is up **Recycle** salvaged modules and manage hazardous materials (e.g., CdTe, lead)
C&I and Residential	*Same as above*	*Same as above* • Racking equipment is different for distributed system compared to utility-scale	**Development includes:** • Origination / customer acquisition • Site visit • System size and design evaluation	Owner of the business or residence arranges project financing, often via developer May take advantage of Investment tax credits (ITC)	Installer does: • Final site design and engineering • Panel and BOS installation and connection • Testing	**Owner usually operates and monitors** the solar installation and may use a contractor for regular maintenance	Act as **'behind the meter'** system as power generated can offset customer usage or be injected into distribution grid	*Same as above*

Solar | Opportunity to win domestic market by focusing on raw materials, OEM, and project development segments

Priority segments for deep dive

High	Medium	Low	N/A

	Raw materials & inputs	OEM	Project Development	Financing	EPC	Operations/ Maintenance	Offtake	Support Services
APS market *(cumulative U.S. SAM 2020 - 2050, $B)*	$150 - 200B	$700 - 800B	$2,000 -2,500B	$100 - 150B	$400 - 500B	$300 - 400B	N/A	$100 - 120B
Competitive Advantage	Building scale to economically produce polysilicon (silicon is available abundantly) will help U.S. to offset China's monopoly (~80% of global polysilicon production), and diversify its raw material supply chain and input into OEM	Economies of scale benefits, and IP advantage in a fast tech lifecycle create opportunities to build a competitive advantage in new innovative solar technologies if sufficient manufacturing scale and IP generation can be reached	Project developers can build competitive advantage because of availability of wide range of technical expertise (e.g., regulatory, resource analysis etc.), optimal sites (abundance of solar resource in US) and knowledge of complex processes (e.g., permitting, etc.)	As an established technology, solar financing is typically readily available, limiting potential for competitive advantage	While solar EPC requires technical knowledge, necessary skills (e.g., construction, electrical wiring, etc.) are typically widely available, reducing potential for competitive advantage	Solar O&M is mostly regional or local and, while logistically challenging, necessary expertise is widely available. This limits potential for competitive advantage outside local markets	Offtake is highly regulated and local or regional in nature, with power offtakers being either regional electricity grids or local communities / industrial /commercial users. Little potential for competitive advantage exists	As plants reach end-of-life, recycling solar components (especially critical elements such as aluminum, silver, silicon etc.) can create a large potential industry. Nascent stage of the industry creates potential to build early competitive advantage via scale

Solar | Raw materials & inputs

DESCRIPTION OF TECHNOLOGY

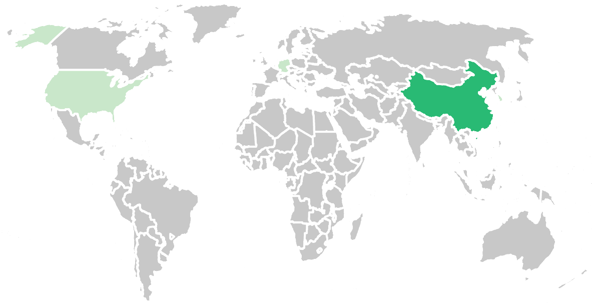
Raw materials & inputs for solar PV includes materials for the PV module (polysilicon, aluminum, glass, resin), and additional components which make up the balance of system (e.g., plastic, copper, steel, wiring, etc.). Most inputs are widely available and relatively low-cost, except polysilicon which needs to be produced using a technical process of purifying silicon.

$150 - 200B
Cumulative APS
U.S. SAM
($B, '20-50)

MARKET DYNAMICS

	2020	2030	2040	2050
SAM ($B, APS)	$2 - 4	$5 - 10	$4 - 6	$2 - 4
Annual global additions (GW)	130-140	530-540	410-420	350-360
Avg. margin (%)	25 – 75%			

GLOBAL PLAYERS - COUNTRIES



🟩 China (80% of global polysilicon)

▨ U.S., Germany, South Korea (rest 20%)

COMPANIES

Polysilicon

TW SOLAR

GCL

DAQO

WACKER

新特能源
XINTE ENERGY CO., LTD.

HSC

VALUE PROPOSITION

U.S. can offset China's monopoly (~80% share) in polysilicon manufacturing and diversify its raw material supply chain by building sufficient polysilicon production capacity to achieve economies of scale, and utilizing low-energy cost-effective process technology (e.g., FBR over Siemens process)

COMPETITIVE ADVANTAGE

Raw material availability	Most of the inputs such as aluminum, glass, copper etc. are commoditized and easily available across the globe. China produces 80% of global polysilicon, but since silicon is abundantly available in the earth's crust, U.S. can build competitive advantage by diversifying its polysilicon supply by building domestic capacity at scale	M
Demand / supply side policy	IRA incentivizes domestic production of polysilicon by providing investment tax credits and manufacturing credits including an adder tax incentive called 'domestic content'	H
Regulatory environment & existing infrastructure	Domestic manufacturers are restarting and upgrading their existing inactive polysilicon plants (tariff war with China led to their closure) while concurrently planning to build new plants near cheap energy source with latest process technology to produce polysilicon cost-effectively	M

High	Medium	Low	N/A

Source: BCG Analysis

Solar | OEM

DESCRIPTION OF TECHNOLOGY

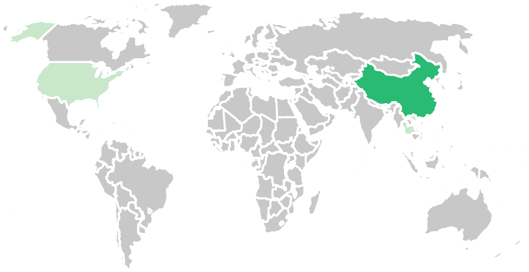
OEM includes manufacturing of solar PV modules and Balance of System equipment. Solar PV panel production includes conversion of polysilicon to ingot, ingot to wafer, wafer to cells and cells to module. Very few manufacturers are vertically integrated. BOS equipment manufacturers produce inverters, racking, cables, fuse, switches, etc. US leads in manufacturing other solar technologies such as thin film (CdTe) which require a completely different set of OEMs.

$700 - 800B
Cumulative APS
U.S. SAM
($B, '20-50)

MARKET DYNAMICS

	2020	2030	2040	2050
SAM ($B, APS)	$10 - 15	$35 - 40	$15 - 20	$10 - 15
Annual global additions (GW)	130-140	530-540	410-420	350-360
Avg. margin (%)	5 - 25%			

GLOBAL PLAYERS - COUNTRIES



🟩 Country with the largest solar PV module production (~80%)

🟩 Rest of the countries with major solar PV module production

COMPANIES

Module	Inverters	Trackers
CanadianSolar	HUAWEI	nextracker
First Solar	SUNGROW	Soltec
LONGi	SMA	ARCTECH
JA SOLAR	solaredge	ARRAY TECHNOLOGIES

VALUE PROPOSITION

Economies of scale benefits and IP advantage in a fast tech lifecycle create opportunities to build a competitive advantage in new innovative solar technologies if sufficient manufacturing scale and IP generation can be reached

COMPETITIVE ADVANTAGE

Intellectual Property & innovation	Even though China currently produces more than 80% of modules with significant R&D and IP ownership, their plants mostly use PERC technology. Therefore, U.S. can build competitive advantage by utilizing newer technologies whose patents have expired (e.g., Heterjunction, TOPCon) in new plants to produce higher-efficiency and lower-cost modules	M
Research & technical leadership	U.S. can build competitive advantage by creating a highly-skilled workforce through trade programs and advanced academic research through existing research institutions to further innovate higher-efficiency and lower-cost process technologies	M
Demand / supply side policy	U.S. manufacturers can build price competitive advantage by using IRA manufacturing credits to build new plants for solar module or BOS equipment. Incentives cover a wide range of tax credits including manufacturing of polysilicon, ingot, wafer, cell, inverters, and are priced such that manufacturers can outprice imported modules. Eventually by building plants at scale, they can bring costs down and become self-sufficient without the need of subsidy	H

High	Medium	Low	N/A

Source: BCG Analysis

Solar | Project Development

DESCRIPTION OF TECHNOLOGY

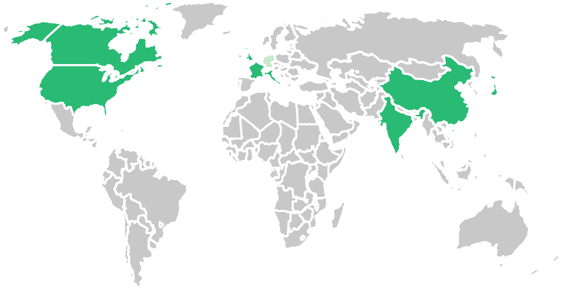
Project Development includes activities such as site acquisition, solar resource analysis, permitting, interconnection, PPA and financing, environmental review, minimizing risk, construction, and operations planning. Solar developers may become owners and operators of the solar farm but often sell the plant to independent power producers or infrastructure funds. Project development activities differs minorly across utility-scale, C&I and residential developers.

$2000 - 2500B
Cumulative APS
U.S. SAM
($B, '20-50)

MARKET DYNAMICS

	2020	2030	2040	2050
SAM ($B, APS)	$45 – 55	$90 – 100	$60 – 70	$50 - 60
Annual global additions (GW)	130-140	530-540	410-420	350-360
Avg. margin (%)	5 – 25%			

GLOBAL PLAYERS - COUNTRIES



🟩 Countries with top global large-scale solar PV developers

COMPANIES

adani Renewables

GCL NewEnergy

aes

SB Energy

First Solar

enel Green Power

Brookfield Renewable

VALUE PROPOSITION

Project developers can build competitive advantage because of availability of wide range of technical expertise (e.g., regulatory, resource analysis etc.), optimal sites (abundance of solar resource in U.S.) and knowledge of complex processes (e.g., permitting, etc.)

COMPETITIVE ADVANTAGE

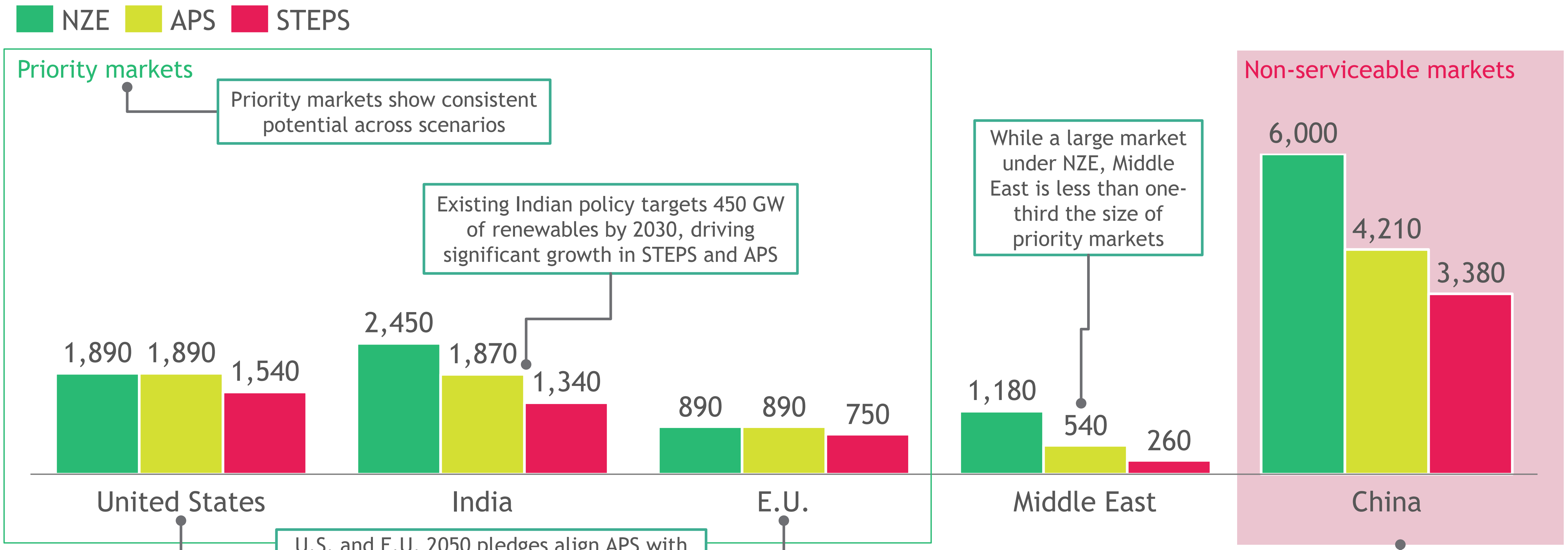
Research & technical leadership	Availability of technical skilled labor for activities such as solar resource analysis, interconnection etc. provides competitive advantage to existing domestic project developers	M
Demand / supply side policy	In the short-term, U.S. project developers can build a cost competitive advantage by taking maximum advantage of IRA incentives and existing relationships with local stakeholders but in the long-term, scale and innovation will help to build durable advantage	M
Relative domestic market maturity	Local nature of project development creates a competitive advantage for domestic players compared to the few international players as diseconomies of scale start to affect the cost of bigger players	M
Regulatory environment & existing infrastructure	Knowledge of domestic regulations, processes and challenges (e.g., interconnection) can help project developers differentiate themselves from others with no or limited knowledge of the solar landscape in the U.S. New interconnection reforms proposed by Federal Energy Regulatory Commission (FERC) would further enable clearance of interconnection backlogs and speed up solar deployment. Abundant presence of solar resource in the U.S. acts as a natural advantage.	M

High	Medium	Low	N/A

Source: BCG Analysis

Solar | India and E.U. markets are dependable opportunities across scenarios, while the U.S. domestic market presents large potential

Installed solar capacity through 2050 by market and scenario (GW)



Priority markets show consistent potential across scenarios

Existing Indian policy targets 450 GW of renewables by 2030, driving significant growth in STEPS and APS

While a large market under NZE, Middle East is less than one-third the size of priority markets

U.S. and E.U. 2050 pledges align APS with NZE, though policy gap to STEPS creates large downside potential

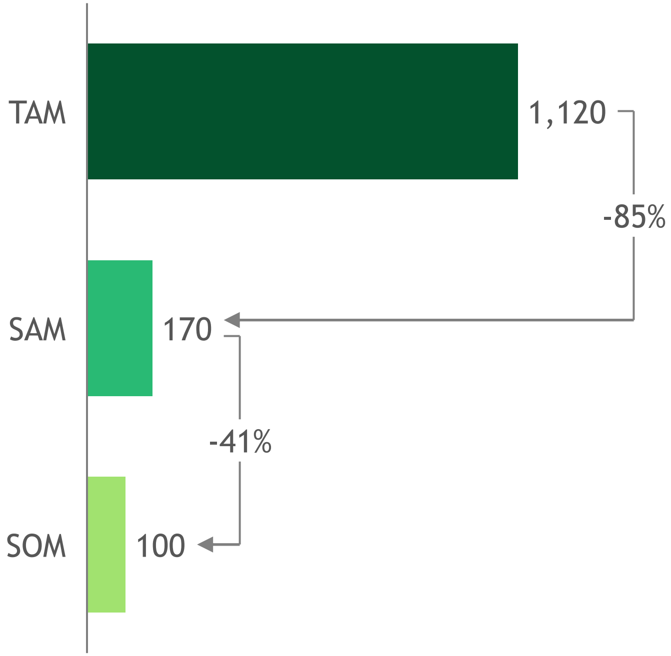
While a very large market, exporting to China is unlikely due to China's dominance and geopolitical issues

Source: IEA World Energy Outlook 2022; BCG analysis

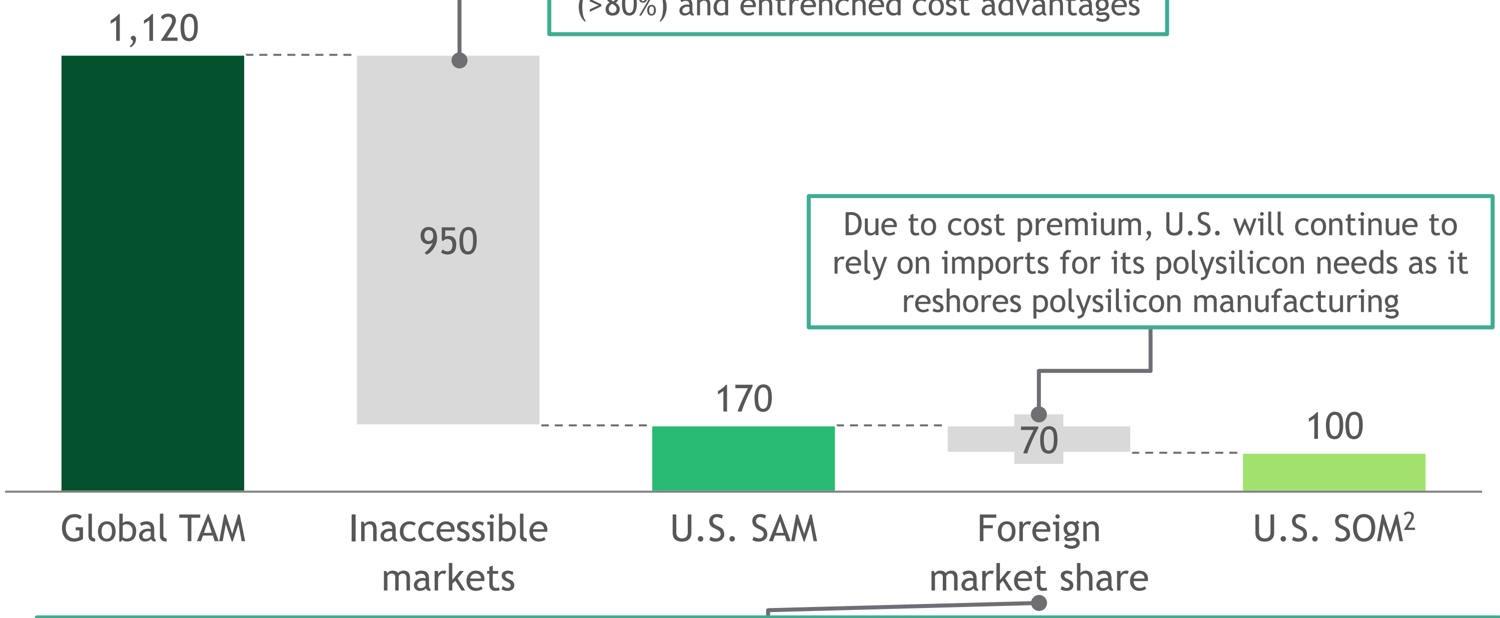
Raw Material | U.S. share of polysilicon manufacturing of ~10% of global TAM implies a conservative potential U.S. SOM of ~$50 - 150B through 2050 for solar raw material & inputs

APS market sizing metrics

Cumulative market value, 2020 – 2050 *($B)*



Walk from TAM to SOM[1] under APS scenario



U.S. SAM excludes all foreign markets due to Chinese upstream dominance (>80%) and entrenched cost advantages

Due to cost premium, U.S. will continue to rely on imports for its polysilicon needs as it reshores polysilicon manufacturing

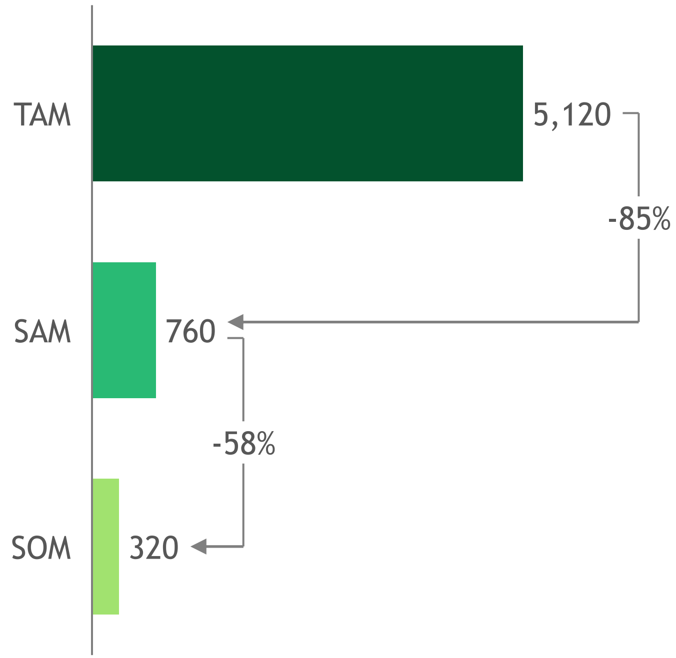
Based on U.S. share of polysilicon manufacturing capacity to deployment capacity in the U.S. in 2021 (40%) and same SOM % as OEM (80%) assuming U.S. will build end-to-end supply chain

1. Average of lower and upper bounds. 2. LB: 40% of domestic SAM (Share of U.S. capacity for polysilicon production to U.S. solar deployment in 2021); UB: 80% of domestic SAM (Same as OEM assuming U.S. will build end-to-end supply chain from polysilicon to module due to IRA incentives)
Source: IEA World Energy Outlook 2022; BCG analysis

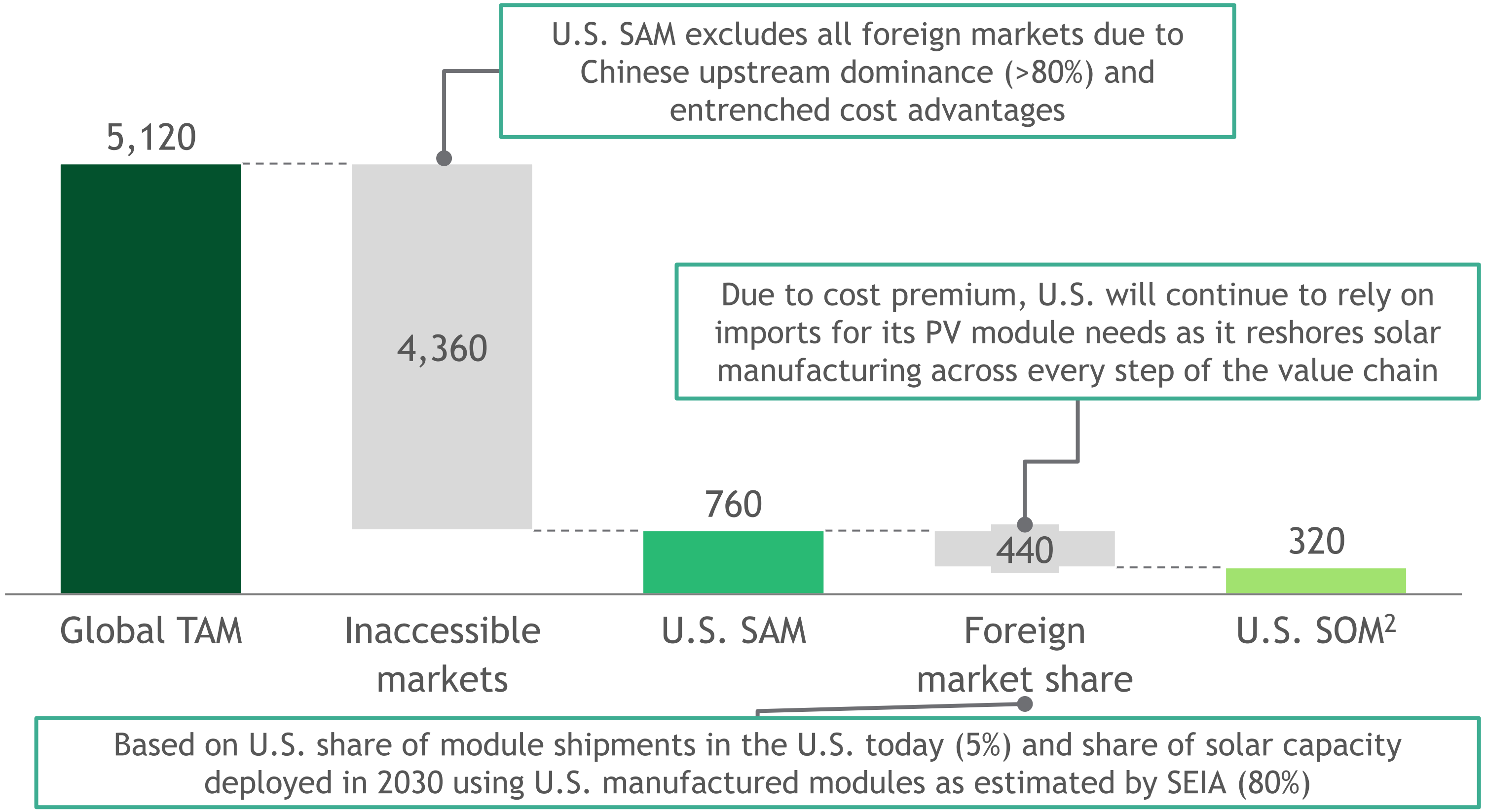
OEM | U.S. share of OEM manufacturing of ~5 – 10% of global TAM implies a conservative potential U.S. SOM of ~$300 - 400B through 2050 for solar OEM

APS market sizing metrics

Cumulative market value, 2020 – 2050 *($B)*



Walk from TAM to SOM[1] under APS scenario



U.S. SAM excludes all foreign markets due to Chinese upstream dominance (>80%) and entrenched cost advantages

Due to cost premium, U.S. will continue to rely on imports for its PV module needs as it reshores solar manufacturing across every step of the value chain

Based on U.S. share of module shipments in the U.S. today (5%) and share of solar capacity deployed in 2030 using U.S. manufactured modules as estimated by SEIA (80%)

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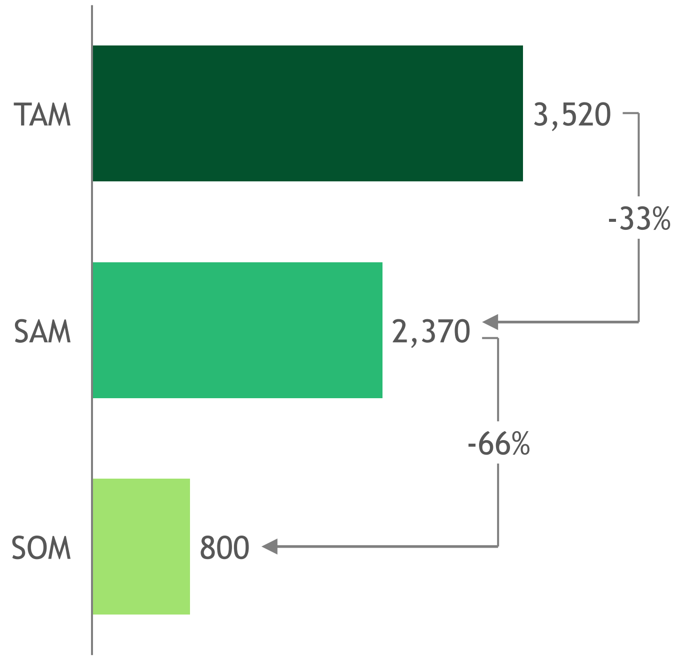
1. Average of lower and upper bounds. 2. LB: 5% of domestic SAM (Share of domestic module manufacturing within total PV module shipments in the U.S. in 2022 to date); UB: 80% of domestic SAM (SEIA predicts U.S. can build up to 50GW of solar manufacturing by 2030 and we estimate U.S. will build 64GW capacity in 2030).
Source: IEA World Energy Outlook 2022; BCG analysis

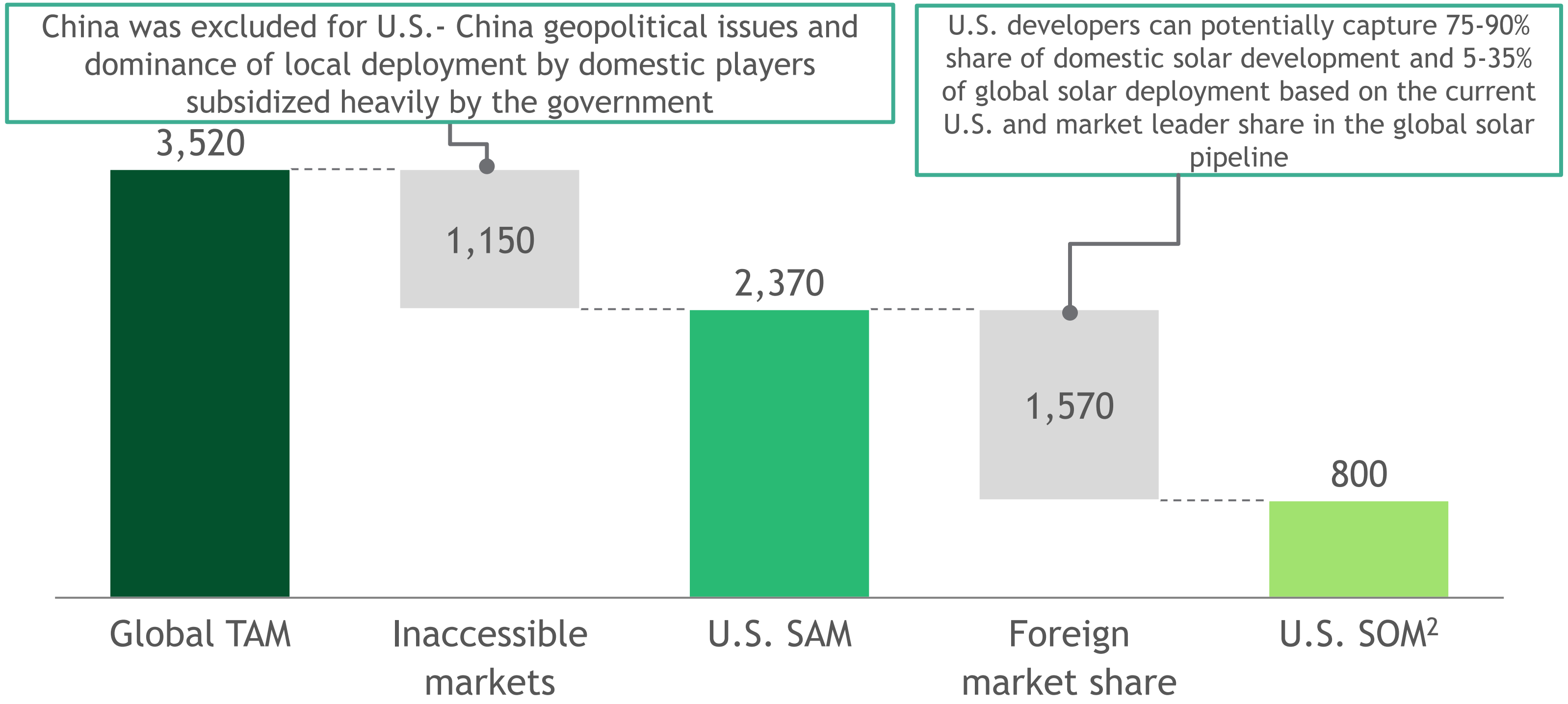
Project Development | U.S. share of project development of ~20 - 25% of global TAM implies a potential U.S. SOM of ~$650 - 750B through 2050 for solar developers

APS market sizing metrics

Cumulative market value, 2020 – 2050 *($B)*



Walk from TAM to SOM[1] under APS scenario



China was excluded for U.S.- China geopolitical issues and dominance of local deployment by domestic players subsidized heavily by the government

U.S. developers can potentially capture 75-90% share of domestic solar development and 5-35% of global solar deployment based on the current U.S. and market leader share in the global solar pipeline

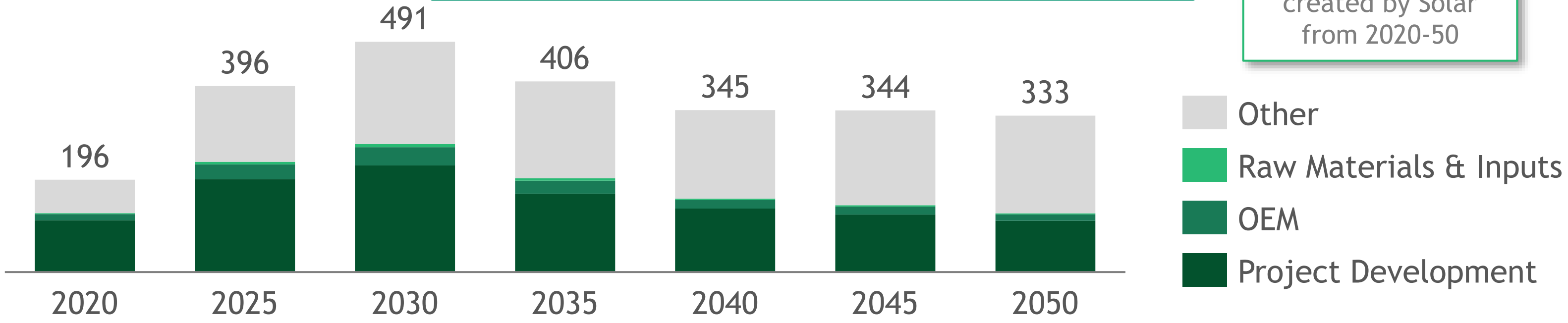
1. Average of lower and upper bounds. 2. LB: 75% of domestic SAM (Share of projects in U.S. pipeline (2021-2025) owned by U.S. headquartered developers) + 5% of export SAM (Share of U.S. project developers amongst top 10 developers in global solar pipeline); UB: 90% of domestic SAM (Share of Chinese developers is ~95-100% within China (market leader) for deployed solar plants but U.S. can possibly achieve a similar domestic share) + 35% of export SAM (Share of Canadian (market leader) project developers amongst top 10 developers in global solar pipeline).
Source: IEA World Energy Outlook 2022; BCG analysis

Solar | ~550K jobs expected to be created by 2050 with Raw Materials, OEM, and Project Development driving ~50% of total jobs created

Strong jobs growth seen in upstream segments (PD, EPC) as more solar farms are deployed before tapering off as downstream jobs (O&M) pick up

Total Solar jobs in each year
Thousands of jobs

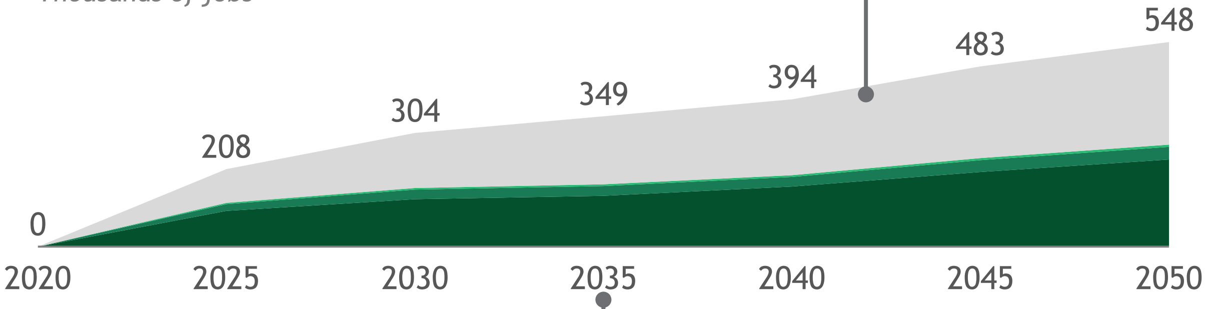
Jobs market driven by O&M of deployed solar farms as Project Development and EPC slow down



~11.5-12.5M
Total job-years created by Solar from 2020-50

New jobs created (cumulative)[1]
Thousands of jobs

Other jobs initially driven by EPC and then O&M as deployment slows down



Job creation slows down as annual deployments decline but continue to grow as O&M jobs increase

Jobs created in RM[2] segment
~6K
~$75K/yr
Avg. annual salary

Jobs created in OEM segment
~34K
~$85K/yr
Avg. annual salary

Jobs created in PD[3] segment
~235K
~$110K/yr
Avg. annual salary

~550K
Total jobs created by Solar

Note: Even though raw materials and OEM are critical for U.S. to win in domestically for energy security, primary job drivers are project development (~40%), EPC (~25%) and O&M (~25%)

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1. In APS scenario; incremental new jobs calculated as the sum of all non-negative one-year differences in # job-years (e.g., 2021 job-years minus 2020 job-years gives 2021 new jobs); incremental new jobs added to sum from prior period for cumulative calculation 2. Raw Materials & inputs 3. Project Development
Source: IEA, BCG analysis

Raw materials & inputs | Lack of integrated supply chain and high operational costs a key challenge in expansion of polysilicon manufacturing

☆ = *Key dimension*

	Areas for Competitive Advantage	Ranking	Summary analysis
	Raw material availability	Low	• China is the leader (70% global production) in the main raw material for polysilicon manufacturing - metallurgical-grade silicon (MGS) - with U.S. having <9% and the rest of the capacity coming from EU, Australia, Brazil, South Africa and Malaysia • Uyghur Forced Labor Prevention Act in the U.S. bans imports of products using MGS produced in Xinjiang due to forced labor, but China is constructing more MGS plants in regions outside Xinjiang now
	Intellectual Property & innovation	Low	• U.S. can lower manufacturing costs by adopting Fluidized Bed Reactor (FBR) technology which is ~80% more energy efficient than the Siemens technology for polysilicon manufacturing; as REC Silicon[1] (FBR patent holder) has started to use FBR in its U.S. plants, U.S. could become a technical leader in low-energy polysilicon (GCL-Poly[2], China also owns some patents in FBR)
	Research & technical leadership	High	• While China leads the research volume, U.S. (in 2nd place) produces higher quality research with 50% more citations per publication • Research activity is led by Chinese universities with U.S. DOE in 2nd place, while Indian and Swiss universities feature in top 10 • Outside China, only the U.S. and Germany have sizeable capacities, hence the U.S. can leverage the technical knowhow of its 3 manufacturers - REC Silicon[1] (Norwegian), Hemlock (American), and Wacker (German) – to rapidly increase production capacity

☆	**Low operational costs**	Low	• With high labor (~10% of total cost) and energy (~40% of total cost) costs, U.S. is cost disadvantaged to China (market leader)
			    • U.S. and EU manufacturing labor is significantly costlier than other markets (~$50/hr in the U.S. & EU vs ~$10/hr in China)
			    • U.S. electricity prices are lower than in EU and Japan but more expensive than China
			• U.S. will take at least few years to scale up and reach similar economies of scale cost benefits as China

☆	**Demand / supply side policy**	High	• Recently announced IRA policy will help lower U.S. polysilicon production cost; manufacturers can choose between the 45X advanced manufacturing tax credit of $3/kg (~$0.8¢/W) or the 48C advanced energy project credit of 30% of investment cost
☆	**Relative domestic market maturity**	Low	• Highly concentrated market with 10 players producing 96% of global polysilicon; U.S. has 3 players with ~5% global capacity whereas China has over 7 major players producing ~80% of the global capacity • Since Chinese duties were placed on U.S. polysilicon in 2014, U.S. plants are operating significantly under capacity (~25% of capacity is operational) because most of the polysilicon produced in the U.S. needs to be exported to China as U.S. has no domestic wafer manufacturing capacity • Global polysilicon production is expected to almost double by 2023 with most of the new capacity based in China; new polysilicon plants are located in Sichuan and Inner Mongolia to avoid forced labor bans for Xinjiang production from U.S. and potentially EU
	Regulatory environment & existing infrastructure	High	• U.S. polysilicon production is further incentivized by the IRA ITC domestic content bonus of 10% which requires at least 40% of total costs attributable to domestic U.S. manufacturing, thereby making downstream manufacturers want to source domestic polysilicon
	Overall ranking		Even though polysilicon capacity is highly concentrated (~80%) and estimated to almost double in China by 2023, U.S. (~5%) can leverage its current technical knowhow to scale its polysilicon capacity to satisfy any rising domestic demands due to supply chain integration

1. Renewable Energy Corporation (REC) Silicon 2. Subsidiary of Golden Concord Group Limited (GCL)

OEM | Rapid operationalization of manufacturing capacity at scale a key U.S. challenge to building an integrated domestic supply chain

☆ = *Key dimension*

	Areas for Competitive Advantage	Ranking	Summary analysis
	Raw material availability	Low	• U.S. has 3 players with ~5% global capacity whereas China has over 7 major players producing ~80% of the global capacity • Since Chinese duties were placed on U.S. polysilicon in 2014, U.S. plants are operating significantly under capacity (~25% of capacity is operational) because most of polysilicon needs to be exported to China as U.S. has no domestic wafer manufacturing capacity • Polysilicon manufacturing is expected to almost double by 2023 with most of the new capacity based in China; new polysilicon plants are located in Sichuan and Inner Mongolia to avoid forced labor bans for Xinjiang production from U.S. and potentially EU
	Intellectual Property & innovation	Low	• Patenting activity within OEM has decreased since 2016 by ~10-15%, possibly indicating maturity of the solar industry • China dominates OEM patenting activity with South Korea in 2nd place and the U.S. in 4th place • In the U.S., SunPower, Tesla, and Rocket Labs lead the patenting activity • U.S. needs to accelerate innovation within OEM to recapture any lead in the segment via IP
☆	**Research & technical leadership**	High	• While China leads the research volume, U.S. (in 2nd place) produces higher quality research with 50% more citations per publication • Research activity is led by Chinese universities with U.S. DOE in 2nd place, while Indian and Swiss universities feature in top 10 • U.S. can use FirstSolar's leadership in thin-film technology and global manufacturing capacity (~20GW by 2025) with plants in U.S., Vietnam, Malaysia, and India, to further R&D and scale manufacturing of thin-film modules

☆	**Low operational costs**	Low	• With high labor (~25% of total cost) and energy (~10% of total cost) costs, U.S. is cost disadvantaged to China (market leader)
			  • U.S. and EU manufacturing labor is significantly costlier than other markets (~$50/hr in the U.S. & EU vs ~$10/hr in China)
			  • U.S. electricity prices are lower than in EU and Japan but more expensive than China
			• U.S. will take at least few years to scale up and reach similar economies of scale cost benefits as China

☆	**Demand / supply side policy**	High	• Recently announced IRA policy will help lower U.S. module delivered price compared to SEA price by ~25%; manufacturers can choose between the 45X advanced manufacturing tax credit for wafers (5¢/W), cells (4¢/W), modules (7¢/W) and the 48C advanced energy project credit of 30% of investment cost
	Relative domestic market maturity	Low	• Currently, with no wafer & cell capacity and limited module capacity (~5%), U.S. OEM is in a nascent stage and large investment is needed to compete on cost with China which has invested >$50B in solar manufacturing to reach high economy of scale benefits • As the 2nd largest market for solar panels through 2050, U.S. demand for panels will only increase as deployment accelerates
	Regulatory environment & existing infrastructure	High	• U.S. OEM production is further incentivized by the IRA ITC domestic content bonus of 10% which requires at least 40% of total costs attributable to domestic U.S. manufacturing, thereby making module manufacturers want to source domestic wafers and cells
	Overall ranking		With <2% OEM manufacturing capacity, loss of IP lead, and high operational costs, the U.S. does not have a competitive advantage in OEM today, but the recent IRA incentives provides the U.S. an opportunity to recapture competitive advantage in OEM if the U.S. can rapidly scale manufacturing to gain economies of scale cost benefits

Project Development | U.S. well-positioned to continue winning development in domestic market with some potential for exports

☆ = *Key dimension*

Areas for Competitive Advantage	Ranking	Summary analysis
☆ **Raw material availability**	High	• Abundant availability of land (entire U.S. could be powered by solar occupying ~0.6% of U.S. land mass) and strong, consistent solar radiation (sunlight) makes U.S. well-positioned to deploy solar at scale with the market expected to grow >1000% from ~130GW today to ~1500GW by 2050 (2nd largest globally)
Intellectual Property & innovation	N/A	• Project developer competitive advantage is not driven by patents
Research & technical leadership	High	• Experience of some of the world's largest developers such as NextEra, with 28GW of operational renewable energy capacity, can be utilized to expand development efforts into fast-growing markets abroad • With ~5% share of the export market, some U.S. developers have expanded operations internationally; like some European developers such as EDF and Enel, U.S. developers have the potential to capture a bigger export share as they possess strong technical knowhow, local knowledge, and strong relationships with OEMs
Low operational costs	Low	• U.S. average wages significantly higher than any other region with average income per month ~$6K while the EU's is ~$4K, Japan's & South Korea's are ~$3K, China's & Russia's are ~$1K, and India's is ~$200
☆ **Demand / supply side policy**	High	• IRA tax credits brings down cost for developers incentivizing further deployment of solar; developers can choose between various incentives: investment tax credit of up to 70% (includes 40% various types of bonuses) or production tax credit of 1.5¢/kWh with added bonuses if eligible
☆ **Relative domestic market maturity**	High	• With the 2nd largest deployed solar capacity in the world, the U.S. has experience in developing utility-scale solar projects with US project developers currently owning ~75% of the domestic market
Regulatory environment & existing infrastructure	High	• Even though some states such as California are adopting permitting reforms and clean energy targets, there is lack of federal support in big permitting reform or clean energy targets apart from limited IRA / IIJA subsidies that will expire by 2032
Overall ranking	🟩	U.S. has high competitive advantage potential today, with significant growth in domestic project development, robust government support, and potential export opportunities for several large players

While recent legislation has addressed many priority issues for solar, additional policy could further boost U.S. competitiveness and accelerate deployment

	Priority issues for solar	Changes from recent legislation (IRA, IIJA, CHIPS, and EA 2020)	Remaining areas to target with future policies
Polysilicon production	**Uncertainty in demand for domestic polysilicon and high production costs**	- Advanced manufacturing production credits for polysilicon ($3/kg)	- Facilitate polysilicon export to international wafer manufacturers and provide low-cost electricity to domestic polysilicon plants
Wafer, cell, and module manufacturing	**Bottlenecks in setting up domestic manufacturing base (e.g., equipment costs)**		☆ Re-assess section 301 tariffs and stringent certifications for PV manufacturing equipment, and provide low-cost land
	U.S. operational cost disadvantage due to high labor and manufacturing costs	- Advanced manufacturing production credits for wafer ($12/m^2), cell (4¢/W), and modules (7¢/W)	☆ De-risk investment to build integrated wafer, cell, and module manufacturing facilities and fund research into manufacturing automation to achieve scale
	Lack of solar-trained skilled workforce (engineers, scientists) for manufacturing facilities		- Fund and establish solar-focused science and engineering training programs, while maintaining a supportive immigration policy
Deployment	**Long interconnection queues and unclear cost-allocation for required grid infrastructure upgrades**		☆ Reform interconnection processes and enable collaboration between governments, transmission providers, and developers
		- Extended ITC and PTC credits for electricity producing clean energy facilities until 2032	

☆ Priority areas

1. Antidumping and Countervailing Duties 2. Uyghur Forced Labor Prevention Act
Source: IRA, IIJA, DOE, IEA, BCG Analysis

Deep dive | Detailed list of potential solar policy actions to support U.S. competitiveness (I/II)

Policy-based Investment-based ☆ Key interventions

	Demand side	Supply side
Technology-wide		☆ Streamline domestic permitting, review, and approval timelines for solar projects ☆ Establish solar-focused apprenticeship and technical programs in collaboration with manufacturers, governments, and educational institutions to create a diverse talent pipeline while maintaining a supportive immigration policy for high-skilled labor • Create and fund research partnerships between local and foreign academic institutions, government agencies, and private sector to further innovation in solar cell technology • Initiate bilateral and multilateral diplomacy and dialogue with friendly countries to expand solar manufacturing capacity across the globe to develop a diversified and resilient supply chain
Raw materials & inputs	☆ Facilitate partnerships with friendly countries with existing or future wafer manufacturing facilities to export domestically produced polysilicon	• Provide electricity at lower prices to energy-intensive polysilicon manufacturing facilities to make U.S. polysilicon more cost-competitive ☆ Localizing other materials such as solar glass, inverters, frames, and polymers will help reduce overall domestic deployment cost • Invest in recycling technology to recycle minerals from solar panels such as silicon, silver, copper etc. to build a circular supply chain • Friend-shore critical raw materials such as copper, which is expected to have supply shortages by 2030

Deep dive | Detailed list of potential solar policy actions to support U.S. competitiveness (II/II)

Policy-based Investment-based ☆ Key interventions

	Demand side	Supply side
OEM	• Enable a minimum module demand guarantee by establishing a consortium of developers • Require higher domestic content provisions for federal solar PV projects to support the domestic manufacturing industry	☆ Grant competitive loans, federal loan guarantees, and cost-sharing agreements to solar manufacturers through DOE Loan Programs Office ☆ Provide low-cost or free land for solar PV manufacturing facilities • Lower import tariffs and tax rates for imported solar PV manufacturing equipment ☆ Increase incentives for building domestic wafer manufacturing facilities to enable vertical integration of upstream supply chain • Develop partnerships with trusted partners such as Malaysia, South Korea for technology transfer to ramp up cell production in the U.S. • Enable long-term power contracts that require developers to build a solar PV manufacturing facilities with successful implementations in India / Turkey
Project Development		☆ Streamline permitting process for domestic solar projects to reduce delays in deployment ☆ Expand and upgrade transmission grid, improve transmission planning, and reform interconnection processes to reduce delays • Ensure tariff policies (e.g., AD/CVD[1] and UFLPA[2]) do not lead to acute module shortages, which will cause further delays in near-term domestic solar deployment • Establish and implement traceability standards to improve global supply chain mapping capabilities to reduce further supply chain bottlenecks due to regulations (e.g., UFLPA[2])

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1. Antidumping and Countervailing Duties 2. Uyghur Forced Labor Prevention Act

Overview of key assumptions

Assumption	Value	Impact on Calculations	Source
Projections of solar capacity	*Varies by year, market, and scenario*	Solar capacity is forecasted using the IEA 2022 WEO data for APS and STEPS scenario and using IEA 2021 WEO data for SDS/NZE scenarios. These capacity predictions form the basis of all other calculations.	IEA 2022 and 2021 World Energy Outlook, BCG Analysis
Split of capacity projections by type of installation	*Varies by year*	Capacity projections calculated above are split using Wood Mackenzie's report and are assumed to be constant post 2026. Residential is <20kW, C&I is >20kW but <5MW, Utility-scale is >5MW. The global split is used for all regions/countries, which may cause conservative or optimistic outlook for certain countries or regions.	Wood Mackenzie Solar Outlook Q2 – 2021, BCG analysis
Cost projections	*Varies by year, type of installation, and scenario*	Cost projections are calculated using Wood Mackenzie's report from 2020 to 2027, with projections from 2027 to 2050 being calculated using NREL's ATB report. Cost projections are split by value chain segments, which help calculate market size per value chain segment.	2022 NREL Annual Technology Baseline, Wood Mackenzie's H1 2022 US Solar PV System Pricing report, BCG analysis
U.S. SAM	*Varies by year, value chain, and scenario*	The addressable market is used to calculate the obtainable market (SOM). The solar U.S. SAM includes countries where the U.S. has a realistic opportunity to expand into given economic and political barriers.	Expert input & BCG analysis
U.S. SOM	*Varies by year, value chain and scenario*	SOM calculations are an average of the lower and upper bound SOM, which are calculated using various assumptions and proxies. SOM calculations have an impact on job numbers and job growth and inform what the opportunity is in the U.S. and abroad.	Expert input & BCG analysis

Offshore Wind

Offshore Wind | Definition of each segment across value chain

Raw materials & inputs	OEM	Project Development	Financing	EPC	Operations & Maintenance	Offtake	Support Services
Turbine materials: • Steel (up to ~80%) • Fiberglass & plastic • Iron/cast iron • Copper & aluminum	**Wind farm components** include: • **Turbine components** - tower, blades, generator, gearbox, hub, etc. • **Offshore foundations** - differ by floating/fixed • **Electrical infrastructure** - onshore & offshore substations, array & export cables, gen-tie cable	**Wind developers** drive projects through: • Winning BOEM designated WEA lease[1] • Site assessment plan • Environmental impact studies • Raising capital • Interconnection studies • Offtake auction bid and PPA signing • Construction and operations plan **Repowering**: • Old turbines are replaced with larger models • Requires full project devt. from sourcing raw materials to O&M • Lease and electrical BOP can be re-used	**Full financing capital stack** required for projects, including: • Equity investing • Debt financing • Tax equity partnerships • Govt. support **Production and investment tax credits** provide incentives for manufacturers and developers	**Engineering & Procurement:** • Supply chain management • Transportation logistics of moving large components (100m+ blades) in one piece **Construction:** • Leveraging specialized construction vessels • Building tower foundation (if fixed) • Installing the wind turbine (turbines often constructed onshore)	Proximity to shore determines whether O&M base of operations is onshore or offshore **Operations:** • Administration - performance monitoring, electricity sales • Logistics - moving people & equipment **Corrective and preventative maintenance:** • Turbine and foundation maintenance • Transmission network and cable repairs & inspections **Automated condition monitoring and software solutions**	**Power produced directly injected** into bulk transmission through gen-tie: • Using negotiated PPAs with utility partners and other off-takers • High-voltage cables needed to deliver power from coast • Potential to move to backbone transmission lines and mesh grids to address single-source transmission challenges	**Decommissioning:** • Assuming avg. lifespan of ~20 years, decommissioning is unlikely to be relevant until 2040 and beyond

1. WEA = wind energy area

Offshore Wind | U.S. has an opportunity to capture the regional market, with a focus on OEM, EPC, and O&M

Prioritized segment for deep dive

High	Medium	Low

	Raw materials & inputs	OEM	Project Development	Financing	EPC	Operations & Maintenance	Offtake	Support Services
APS Global market *(cumulative U.S. SAM 2020 - 2050, $B)*	$110 - 120B	$230 - 250B	$210 - 230B	$80 - 90B	$90 - 100B	$160 - 180B	N/A	$10 - 20B
Competitive Advantage	Most raw materials accessible globally but government subsidies for domestic steel might drive advantage in the commoditized market	National support for R&D within floating platforms, weather-resistant materials, and superconducting generators, unlocks differentiated technologies and is a key driver of advantage Building domestic supply chains through partnerships with experienced EU players avoids high transport costs and creates opportunity	Fewer regulatory barriers and streamlined permitting can shorten project timelines and reduce risk, providing opportunity Ability to leverage both a diverse skillset and highly local expertise (such as ISO/RTO knowledge) to execute projects without delays drives advantage	Improved offshore market maturity, sufficient pipelines, and government subsidies targeting offshore wind lower cost of financing and drive competitive edge	Requires special port infrastructure and regulation-compliant crane and cable-laying vessels with protectionist policies defending domestic advantage Potential crossover with oil & gas for constructing subsea structures and floating foundations benefits markets with strong IOC presence[1]	Opportunity lies in delivering best-in-class global operations with a focus on optimizing workforce trainings, maximizing safety and reducing transit distances Potential for innovation in automated condition monitoring and floating O&M solutions	Offtake is highly local, either to regional utility markets or isolated microgrids, with limited potential for competitive advantage Adjacent storage options (LDES, offshore-wind-to-H_2) provide additional uses for wind power and drive advantage	Windfarm lifespans are likely 20+ years, with limited near-term need for decommissioning services given low deployed capacity

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[1] IOC = international oil company

Offshore Wind | OEM

High	Medium	Low	N/A

DESCRIPTION OF TECHNOLOGY

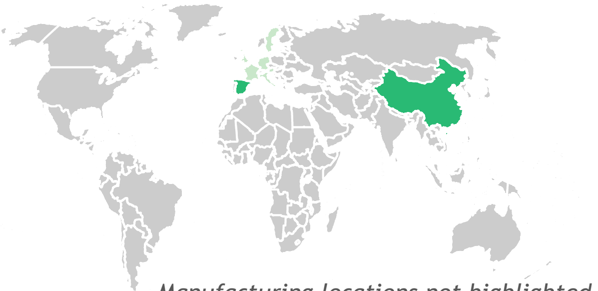
Includes the manufacturing of turbine components (e.g., tower, blades, generator, hub, gearbox) and foundations (monopiles, jackets, nascent floating foundations). Tier 1 vertically integrated companies (such as Siemens Gamesa and Vestas) produce most large components in-house and source the high-precision elements (gearbox, inverter system, brakers, yaw controllers) from specialized tier 2 and 3 suppliers.

$230 - 250B
Cumulative
APS U.S. SAM
($B, '20-50)

MARKET DYNAMICS

	2020	2030	2040	2050
SAM ($B, APS)	-	~$9	~$16	~$6
Incremental capacity (GW)	-	30-35	55-60	25-30
Avg. margin (%)	10 - 20%			

GLOBAL PLAYERS - COUNTRIES


Manufacturing locations not highlighted

🟩 Turbine manufacturer headquarters

🟩 Component manufacturer headquarters

COMPANIES

Component manufacturers

- SIEMENS Gamesa RENEWABLE ENERGY
- Vestas
- GE
- winergy
- ABB
- BOSCH
- SKF
- PRYSMIAN
- Nexans
- nkt cables
- LM WIND POWER
- Mita-Teknik
- bachmann
- VEM

Turbine manufacturers

- Vestas
- SIEMENS Gamesa RENEWABLE ENERGY
- GOLDWIND
- GE
- ENVISION
- DEC 东方电气 DONGFANG ELECTRIC
- MINGYANG WIND POWER 明阳风电

VALUE PROPOSITION

Ability to develop advanced local manufacturing capabilities through joint partnerships with EU players shifts production of large components domestically and decreases high transport costs. Additionally, accelerating R&D into differentiated technologies, such as deploying cost-effective, commercial-scale floating technology, provides IP export potential in the future.

COMPETITIVE ADVANTAGE

Demand / supply side policy	Government financial support, through advanced manufacturing credits and R&D credits, incentivizes building new facilities to support wind supply chains at a globally competitive scale.	H
Intellectual Property & innovation	National support for R&D that unlocks differentiated technologies is key to driving competitive advantage. This includes developing superconducting generators, creating weather-resistant protections for blades and towers, re-designing turbines to reduce weight and materials cost, and deploying floating foundations to capture technical potential in deep waters. Players with ambitious climate goals, floating pilot projects, and oil & gas capabilities (due to synergies in anchoring floating structures) are especially well-positioned to take lead on floating technology, with IP export potential in the future since there are no clearly established floating players yet.	H
Relative domestic market maturity	OEM market today is dominated by EU players Siemens Gamesa and Vestas who control 70% of installed offshore turbines, with plans to expand internationally. Building supply chains domestically, through joint ventures with established EU players, creates local jobs and value and has a potential to shift research centers domestically.	M

Source: BCG Analysis, DOE Offshore Wind Market Report, IEA Wind Energy Outlook

Offshore Wind | EPC

High | Medium | Low | N/A

DESCRIPTION OF TECHNOLOGY

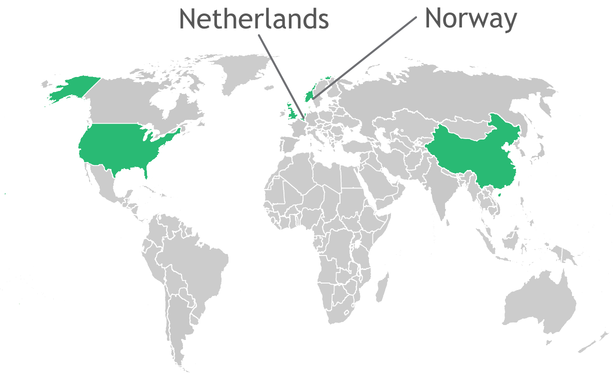
Pre-construction EPC includes supply chain management, marine management services as well as the transportation logistics of moving large components in one piece. Final on-site construction typically requires heavy-lift port capabilities, crane-equipped installation vessels, and diving assets to set the cables, build foundations, and assemble turbines.

$90 - 100B
Cumulative APS U.S. SAM ($B, '20-50)

MARKET DYNAMICS

	2020	2030	2040	2050
SAM ($B, APS)	-	~$3	~$6	~$2
Incremental capacity (GW)	-	30-35	55-60	25-30
Avg. margin (%)	5 – 10%			

GLOBAL PLAYERS - COUNTRIES



🟩 EPC players' headquarters

COMPANIES

EPC & Transport

subsea 7
GREAT LAKES DREDGE & DOCK COMPANY, LLC
H MARINE CONTRACTORS
DEME
FUGRO
seaway7
Van Oord
Jan De Nul GROUP
Boskalis
Fred. Olsen Windcarrier
GeoSea
mpi

VALUE PROPOSITION

Project developers with construction capabilities typically own the high-level engineering and procurement process and hire out individual tasks to specialized EPC contractors. Ability to upgrade port structures, build required equipment, and deliver on the diverse EPC needs of developers drives advantage.

COMPETITIVE ADVANTAGE

Regulatory environment & existing infrastructure	Government support towards port infrastructure upgrades and construction of regulation-compliant, heavy-lift vessels accelerates offshore wind efforts. While country-specific regulations can protect domestic interests, they also contribute to bottlenecks and delays as windfarm timelines are tied to the timely construction of needed installation equipment.	H
Research & technical leadership	Strategic partnerships between diverse engineering companies to deliver the full range of EPC capabilities, from site engineering to specific construction services, is a key driver of advantage. Well-established oil & gas markets can benefit from contracting construction of foundations and subsea structures to oil & gas companies.	H
Relative domestic maturity	Well-developed port infrastructure as well as access to various installation vessels with cable-laying, heavy-lift and crane capabilities is key to the successful completion of OSW projects. There is some export opportunity in re-using installation vessels in neighboring countries where demand is not significant enough to justify constructing domestic vessels; however, installation vessel transport costs are very high.	M

Source: BCG Analysis, DOE Offshore Wind Market Report, IEA Wind Energy Outlook

Offshore Wind | Operations & Maintenance

High	Medium	Low	N/A

DESCRIPTION OF TECHNOLOGY

OEM suppliers typically protect their O&M services during the warranty period (~5 years); afterwards, O&M tends to be performed by the developer. Operations include back-office administration, performance monitoring, and people and equipment transport logistics. Maintenance - for turbines, cables, and foundations - is both preventative and corrective.

VALUE PROPOSITION

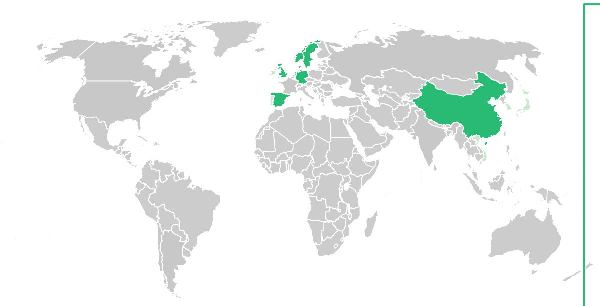
Winning O&M solutions are innovative and flexible, prioritize safety, and reduce costs. Best-in-class global operations with a focus on optimizing workforce trainings and time-in-transit, as well as innovation in automating O&M practices through sensors and drone inspections, drives long-term cost reductions.

$160 - 180B
Cumulative APS U.S. SAM ($T, '20-50)

MARKET DYNAMICS

	2020	2030	2040	2050
TAM ($B, APS)	~$0	~$3	~$9	~$11
Cumulative global capacity (GW)	30-35	290-300	800-820	1,000-1,100
Avg. margin (%)	10 – 15%			

GLOBAL PLAYERS - COUNTRIES



🟩 O&M players' headquarters

COMPANIES

Mix of OEM and PD players

Ørsted
Eneco
RWE
Vestas
Shell
SIEMENS Gamesa RENEWABLE ENERGY
equinor
IBERDROLA
VATTENFALL
Scottish and Southern Energy

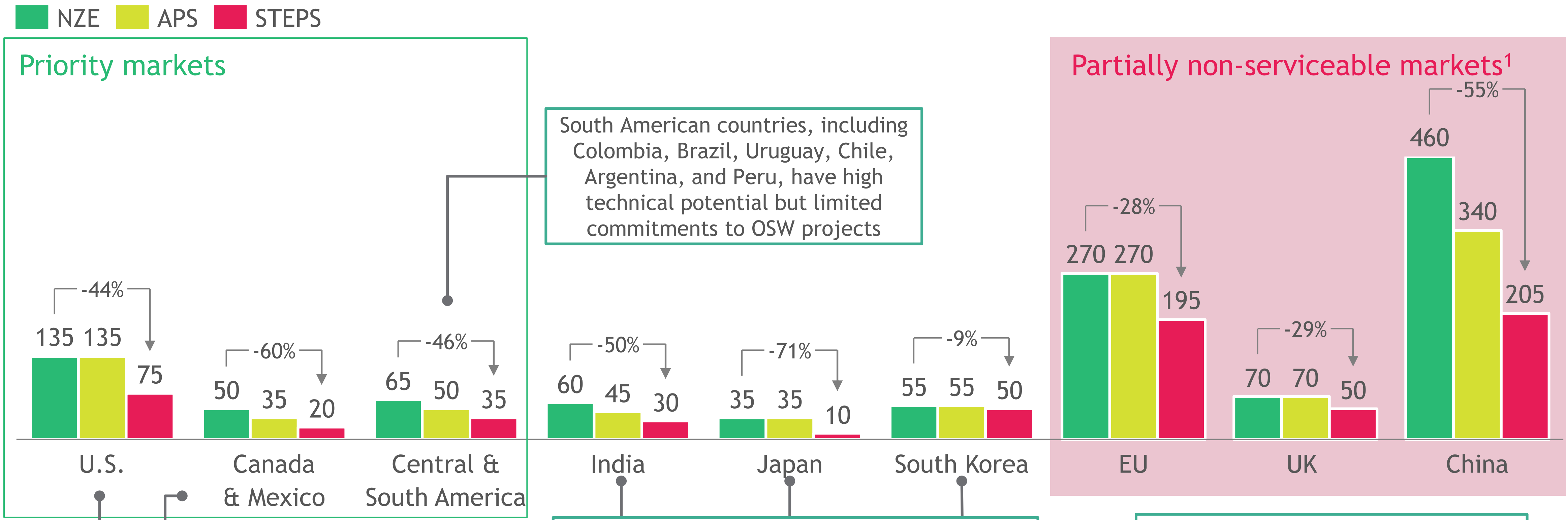
COMPETITIVE ADVANTAGE

Research & technical leadership	Access to skilled, regional labor, with an opportunity to easily train additional technicians, is crucial for successful O&M. Oil & gas players have an established scale advantage and can leverage existing O&M experience to deliver subsea and platform maintenance. Some export potential lies in sending a domestic workforce to foreign countries to train local workers on O&M skills during first years of operation.	H
Intellectual Property & innovation	Innovation in automation through using remotely operated vessels and drones for preventative maintenance and implementing automated condition monitoring (i.e., vibration and temperature sensors with advanced computing systems) presents a significant opportunity to streamline maintenance and reduce long-term labor costs. Research into turbine decoupling to solve O&M challenges of mobile floating turbines can drive competitive advantage.	H
Regulatory environment & existing infrastructure	As projects are built further from shore, increasing transit distances will require safe and cost-effective transport strategies outside of workboats. This might include helicopter support and offshore-based working to minimize workers' time in transit, with significant crossover of safety standards and offshore-based operations with oil & gas.	M

Source: BCG Analysis, DOE Offshore Wind Market Report, IEA Wind Energy Outlook, A Guide to UK Offshore Wind Operations and Maintenance

U.S. regional markets (i.e., the Americas) present largest opportunity given geographical distance is a significant barrier

Installed offshore wind capacity through 2050 by market and scenario (GW)



South American countries, including Colombia, Brazil, Uruguay, Chile, Argentina, and Peru, have high technical potential but limited commitments to OSW projects

U.S. and Canada 2050 net-zero pledges align APS with NZE, with Mexico contributing to higher capacity under NZE

India, Japan, and South Korea have ambitious targets and carbon neutrality policies, but geographic distance limits export opportunity

Europe and China present large opportunities, but high OSW market maturity and domestically-controlled supply chains make export unlikely

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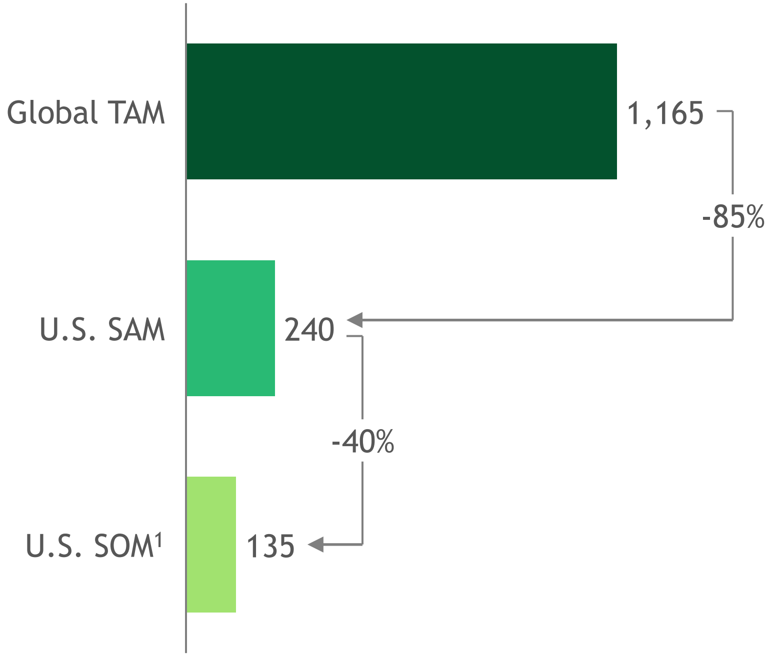
1. Markets where part or all of the value chain would be unserviceable by US companies due to protectionist policies, prohibitive costs, or other reasons. EU and UK excludes Financing.

Source: IEA World Energy Outlook 2022, IEA Offshore Wind Report 2019, BCG Analysis

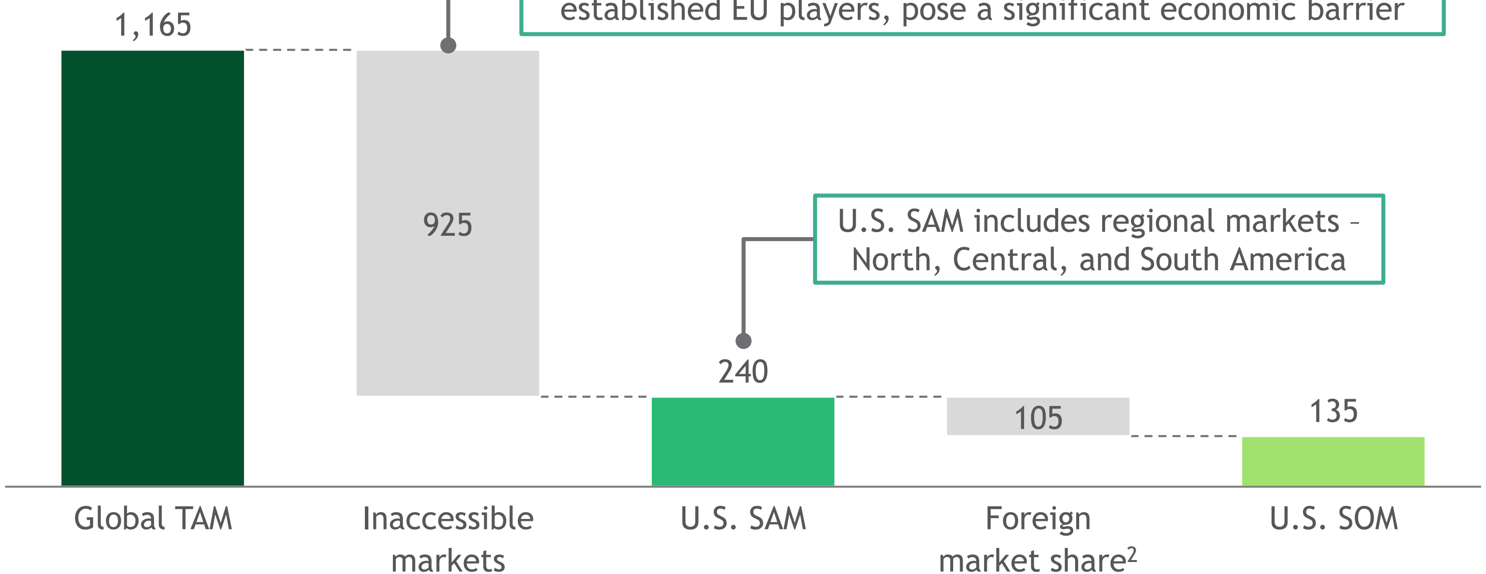
OEM | U.S. expected to own a high share of regional markets given significant economies of scale, with U.S. SOM of ~$100-165B

APS market sizing metrics

Cumulative market value, 2020 – 2050 *($B)*



Walk from TAM to SOM[1] under APS scenario



Excludes all markets besides the Americas since high transport and logistics costs, as well as market dominance of established EU players, pose a significant economic barrier

U.S. SAM includes regional markets - North, Central, and South America

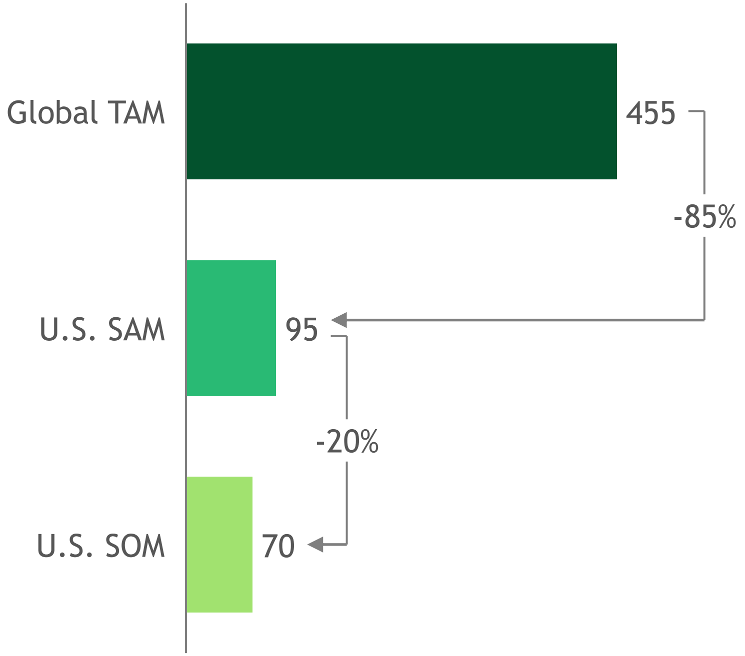
Based on share of onshore wind components manufactured domestically (~70%) and the share of global installed turbine capacity of top OEM players (~25%)

1. Average of lower and upper bounds. 2. LB: 60% of U.S. (onshore wind components manufactured domestically) + 5% of export SAM (share of non-Chinese turbine capacity by U.S. OEM); UB: 80% of U.S (add 20% to LB for domestically-manufactured foundations) + 45% of export SAM (share of non-Chinese turbine capacity by top 2 players). Source: IEA, DOE, BCG analysis

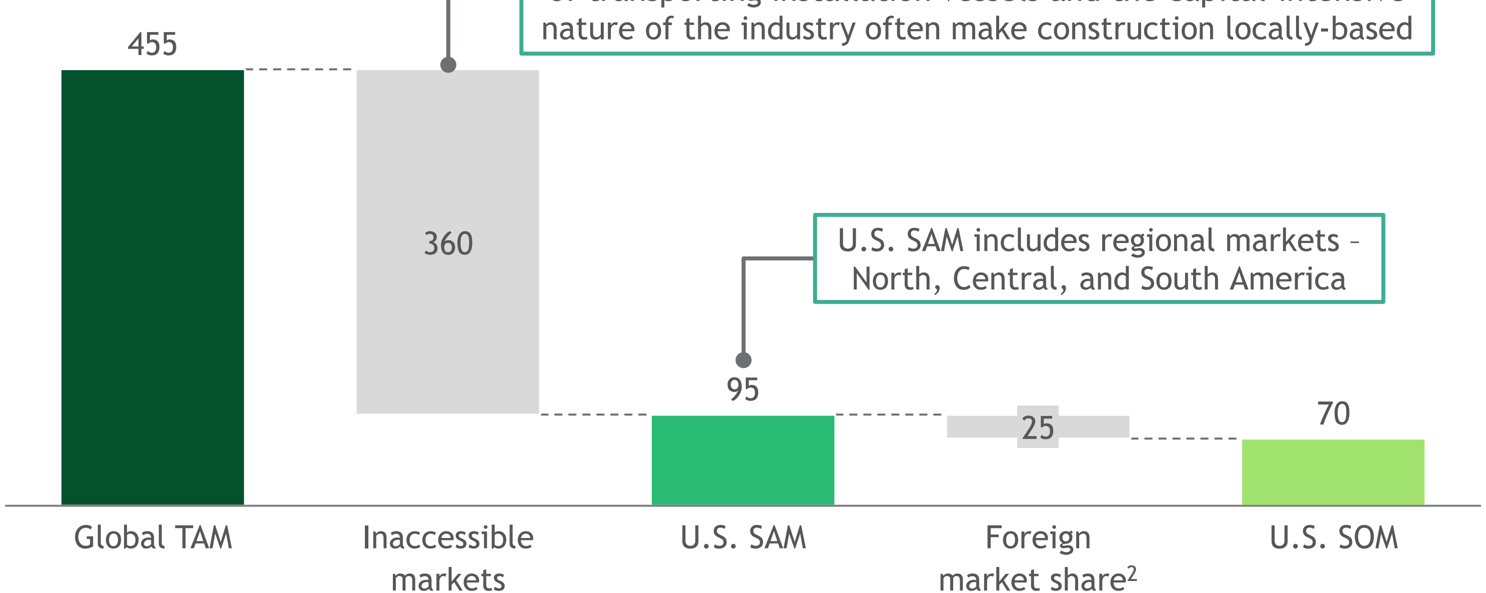
EPC | U.S. projected to own a high share of both domestic and regional construction market, leading to U.S. SOM of ~$60-85B

APS market sizing metrics

Cumulative market value, 2020 – 2050 *($B)*



Walk from TAM to SOM[1] under APS scenario



Excludes all markets besides the Americas since high costs of transporting installation vessels and the capital-intensive nature of the industry often make construction locally-based

U.S. SAM includes regional markets - North, Central, and South America

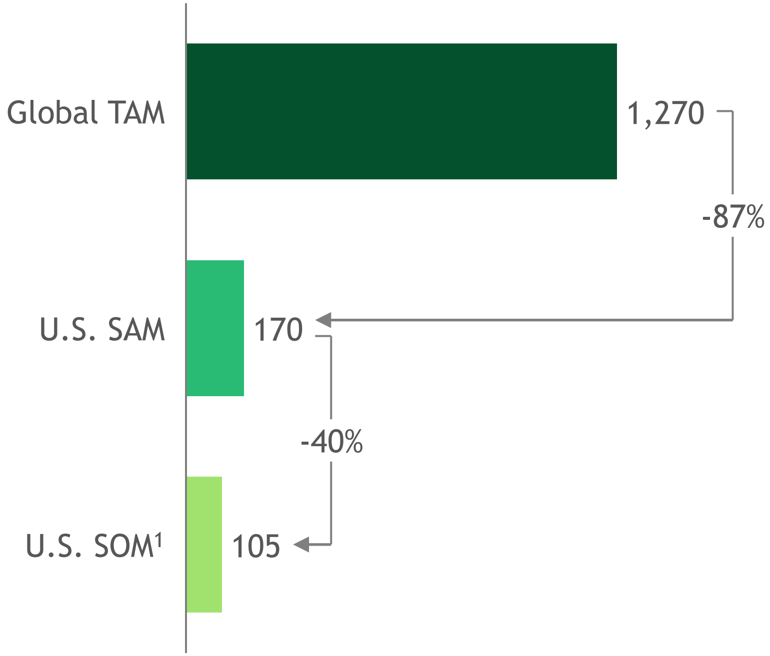
Using '~90% of top solar EPC companies are US-based' as a benchmark for OSW, as well as U.S. share (~90%) of North and South American revenue from top 100 construction companies

1. Average of lower and upper bounds. 2. LB: 90% of U.S. (9 out of top 10 EPC companies in 2019 are U.S.-based as a proxy for OSW) + 10% of export SAM (international sales as 10% of total sales for US firms within top 30 global construction companies); UB: 90% of total SAM (U.S. share of North and South American revenue from top 100 construction companies).
Source: IEA, BCG analysis, Deloitte Global Powers of Construction 2021 report

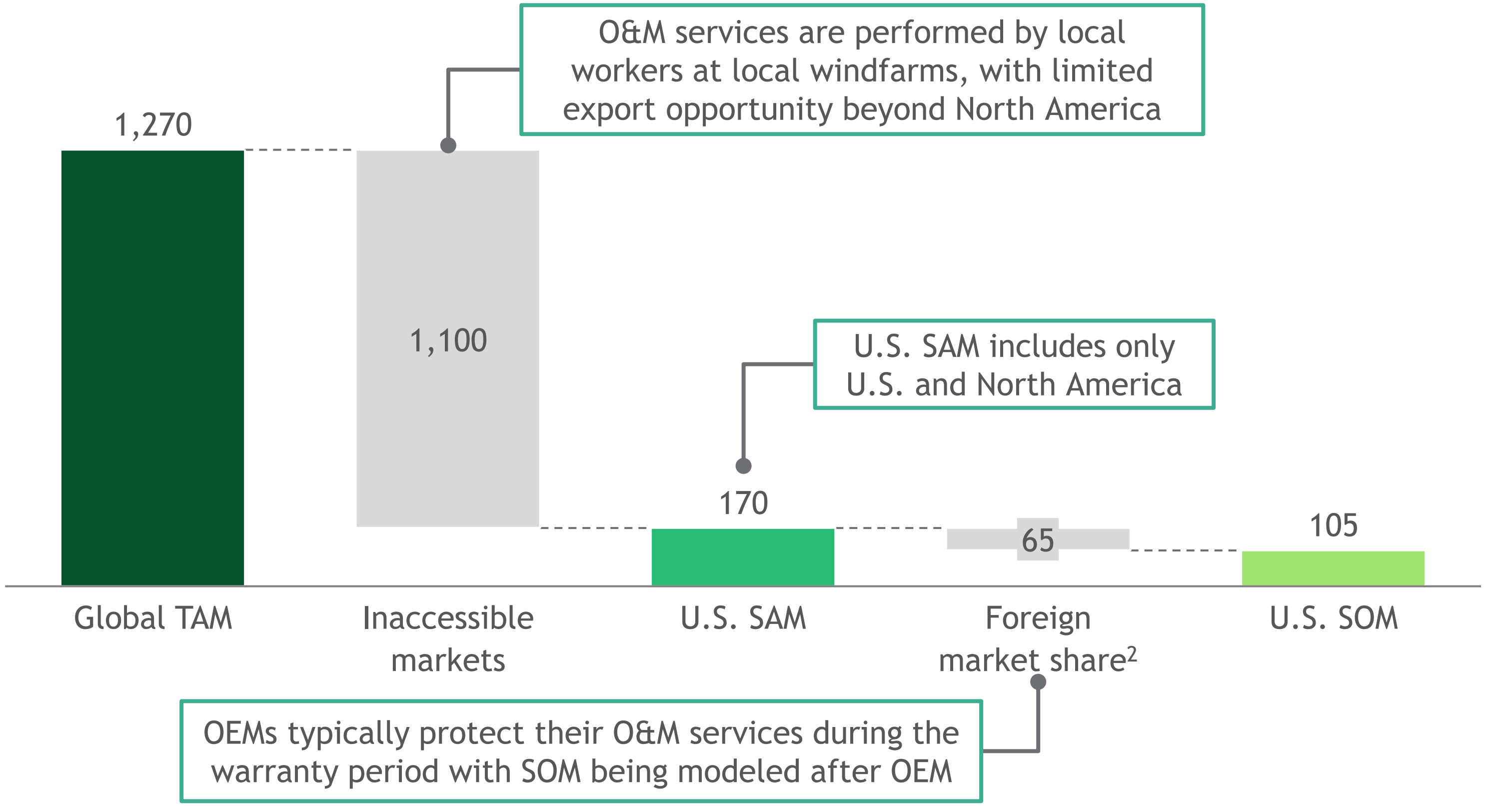
O&M | U.S. exports limited to regional markets given the highly local nature of O&M services, with U.S. SOM of ~$85-125B

APS market sizing metrics

Cumulative market value, 2020 – 2050 *($B)*



Walk from TAM to SOM[1] under APS scenario



O&M services are performed by local workers at local windfarms, with limited export opportunity beyond North America

U.S. SAM includes only U.S. and North America

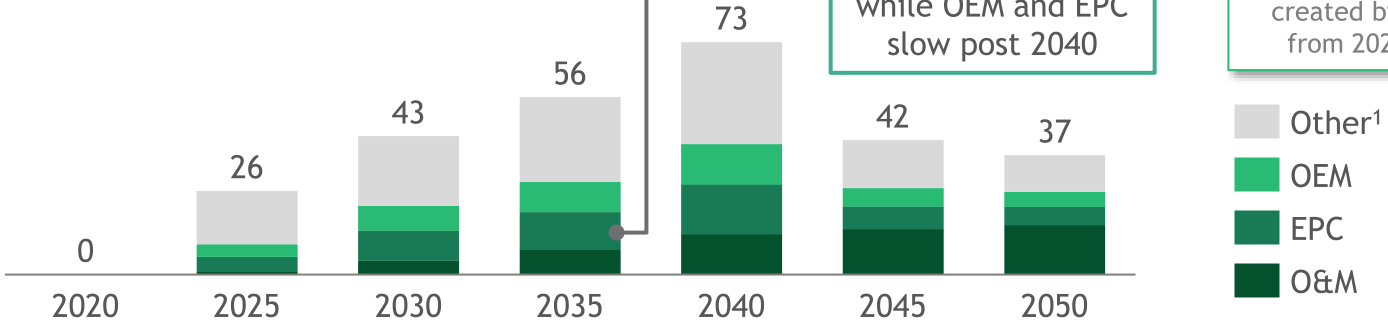
OEMs typically protect their O&M services during the warranty period with SOM being modeled after OEM

1. Average of lower and upper bounds. 2. LB: 60% of U.S. + 5% of export SAM; UB: 80% of U.S. + 45% of export SAM given OEMs often protect O&M services during the warranty period with SOM percentages being the same for O&M and OEM. Source: IEA, DOE, BCG analysis

~90K jobs expected to be created by 2050 with OEM, EPC, and O&M driving ~50% of total jobs created

Strong jobs growth seen from 2020-2040 as U.S. builds up offshore wind capacity before tapering off after 2040 as CAPEX spend declines

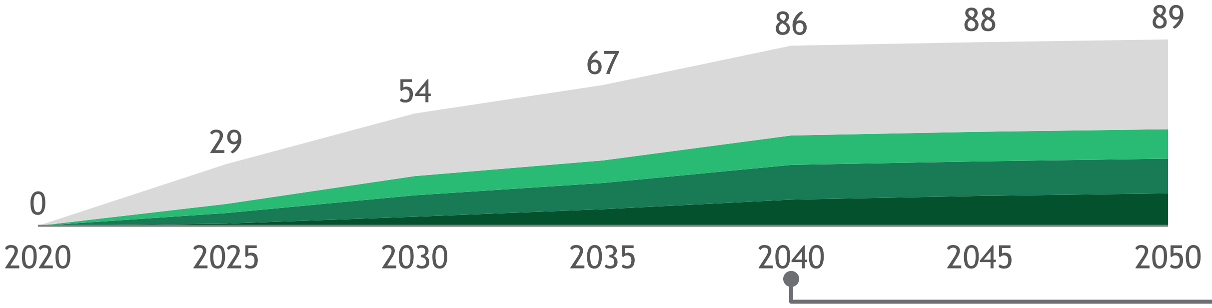
Total OSW jobs in each year
Thousands of jobs



Market driven by long-term O&M, while OEM and EPC slow post 2040

~1.2-1.4M
Total job-years created by OSW from 2020-50

New jobs created (cumulative[2])
Thousands of jobs



Jobs slowdown as U.S. annual deployments decline, given jobs are primarily driven by domestic market

Jobs created in OEM segment
~14K
~$85K/yr
Avg. annual salary

Jobs created in EPC segment
~17K
~$85K/yr
Avg. annual salary

Jobs created in O&M segment
~15K
~$105K/yr
Avg. annual salary

~89K
Total jobs created by OSW

Note: OSW provides opportunities for offshore oil & gas workers to translate their skills to a new industry

1. 65% of 'other' category driven by project development; however, PD was deprioritized since it is highly dependent on regulatory environment with limited opportunity to drive advantage. 2. In APS scenario; incremental new jobs calculated as the sum of all non-negative one-year differences in # job-years (e.g., 2021 job-years minus 2020 job-years gives 2021 new jobs); incremental new jobs added to sum from prior period for cumulative calculation; Source: IEA, BCG analysis

OEM | Limited manufacturing capabilities and gap to China in innovation and research only partially offset by highly favorable policy

☆ = *Key dimension*

Areas for Competitive Advantage	Ranking	Summary analysis
Raw material availability	High	• Raw materials required for turbines are mostly global commodities (e.g., steel, concrete, carbon fiber composites, polymers), except for rare-earth magnets that have been monopolized by China
☆ **Intellectual Property & innovation**	Low	• China is the clear OEM patenting leader, with 2x as many patents as South Korea in 2nd place; the U.S. is in 5th place • SGRE, GE, and Vestas are top 3 players in total patenting activity • Patenting activity in floating has grown rapidly at 15% CAGR since 2016; currently, the U.S. is in 5th place for floating patents and should accelerate development of floating tech before emerging players do
☆ **Research & technical leadership**	Low	• China leads the research volume; the U.S. is in second place with 50% fewer publications but higher quality research • Global research into floating platforms has grown at 30% since 2016; 35% of this research is driven by China and 12% by U.S. • Research into blade design and materials has also grown rapidly with a CAGR of 33%, led by China and the UK
Low operational costs	Low	• U.S. and E.U. manufacturing labor at ~$50/hr is 2-5x more expensive than other markets (~$10/hr in China & Brazil and ~$25/hr in Japan & South Korea), with similar rankings but less extreme differences in labor costs for R&D and engineering roles • U.S. electricity prices are lower than in the E.U. and Japan but more expensive than in China and India
☆ **Demand / supply side policy**	High	• Manufacturers can leverage the 45X Advanced Manufacturing Production Credit for components of $20-50/kW • Additionally, the U.S. DOE has pledged nearly $50M into floating RD&D with a goal to reduce costs of floating wind by 70% and meet 15 GW of floating by 2035
Relative domestic market maturity	Low	• Majority of U.S. OEM facilities are still in early-stage development and are being built by E.U. developers on the East Coast. Currently, only cable and offshore substation facilities are operational, though there are plans for facilities for blades, towers, nacelles, and monopiles. U.S. supply chain is underdeveloped compared to E.U.'s and China's domestic manufacturing base • OEMs are the second largest investment category. The Chinese and U.S. markets are in earlier stage development and are more fragmented than European markets, with funding spread across more players
Regulatory environment & existing infrastructure	High	• Bonus 10% ITC is given to manufacturers who meet 20% domestic content requirements for any manufactured products. The requirement is set to increase to 55% after 2027 and supports domestic manufacturing jobs long-term
Overall ranking	Low	Limited number of dedicated U.S. OEMs and a gap to the leader in innovation and research is only partially offset by favorable policies; offshore wind has low competitive advantage but an opportunity to pursue floating tech and create IP export potential

Source: BCG Analysis, Offshore Wind Report 2022 (DOE), The Demand for a Domestic Offshore Wind Energy Supply Chain (NREL), Offshore Wind Outlook (IEA)

EPC | Construction equipment supply chain bottlenecks and high construction costs are a key challenge within EPC

☆ = *Key dimension*

Areas for Competitive Advantage	Ranking	Summary analysis
Raw material availability	N/A	• Construction materials (e.g., cement, steel) are widely available
Intellectual Property & innovation	Low	• China dominates EPC patenting activity, with 3x as many patents as South Korea in 2nd place; U.S. is in 7th place with E.U. players • Patenting activity within EPC has increased since 2016, driven by China with 40% of EPC patenting compared to the U.S. with 4% • Patenting in EPC is driven by innovation in towing / construction methods and designing crane-equipped vessels
Research & technical leadership	Low	• The U.S. is in third place behind China and the U.K. by EPC research quantity, though it leads with research quality with ~2x as many citations per publication than China • Global research into construction vessels only accounts for 4% of global publications but has accelerated at 34% CAGR since 2016 • Europe particularly prioritizes research into construction vessels with U.K., Germany, and Norway overcoming the U.S.
Low operational costs	Low	• U.S. labor costs are comparable to E.U. costs but ~2-5x higher than in major OSW construction regions in South & East Asia • It costs ~$450[1] and takes 3 years to build a WTIV[2] in the US, compared to ~$330M and 2 years to construct a WTIV in Asia
☆ **Demand / supply side policy**	High	• U.S. installation vessel manufacturers can utilize a credit equal to 10% of the sales price of the vessel which accelerates domestic vessel deployment; additionally, the Port Infrastructure Development Program under IIJA provides $600M to support supply chain resilience and development of OSW support infrastructure
☆ **Relative domestic market maturity**	Low	• Vessel shortages pose a high risk to meeting the 30 GW target given required demand exceeds existing and projected supply of vessels in the U.S. At least 5 installation vessels are required to meet the 2030 target with currently only one vessel under construction; shortage of cable lay, scour protection, and heavy lift vessels pose additional risks • However, the U.S. is highly competitive in engineering services and subsea construction given crossover with offshore oil & gas
☆ **Regulatory environment & existing infrastructure**	High	• The U.S. has a strong regulatory ecosystem that protects domestic interests within EPC, including the Jones Act that requires maintenance and installation vessels to be built within the U.S. and operated by U.S. citizens • While this creates a supply chain bottleneck in the short-term, the Jones Act guarantees long-term domestic job creation
Overall ranking	Low	Supply chain bottlenecks around building Jones Act-compliant construction equipment and a gap to China in research and patenting make the U.S. less competitive within EPC. However, significant policy incentives can help offset the high costs of installation equipment and protect domestic EPC services in the long-term

1. After applying the 10% IRA tax credit 2. Wind turbine installation vessel
Source: BCG Analysis, Offshore Wind Report 2022 (DOE), The Demand for a Domestic Offshore Wind Energy Supply Chain (NREL), Offshore Wind Outlook (IEA)

O&M | U.S. well-positioned to decrease long-term O&M costs by automating maintenance and transferring oil & gas skills and equipment to OSW

☆ = *Key dimension*

	Areas for Competitive Advantage	Ranking	Summary analysis
	Raw material availability	N/A	• Construction materials (e.g., cement, steel) are widely available; raw materials for operations not applicable
	Intellectual Property & innovation	Low	• China is a clear patenting leader in O&M with a more fragmented patenting portfolio; U.S. is in 5th place • The small category of observation and maintenance using drones and UAVs[1] has seen particularly high growth (28% CAGR since 2016). South Korea owns 40% of this patenting activity, followed by China and the U.S. at 10%
☆	**Research & technical leadership**	High	• China leads the research volume in turbine O&M; the U.S. is in second place with 50% fewer papers but higher quality research • Publications around UAVs and drones only account for 2% of total papers but have grown by 36% since 2016; the U.S. is a research leader at 20% of UAVs / drones publications with slightly lower research quality than China in 2nd place
	Low operational costs	Low	• Overall labor costs for OSW are comparable to labor costs in Europe with strict labor policies and safety standards given the high risks of working at sea; O&M skills and labor are transferable from offshore oil & gas where the U.S. has an advantage • U.S. electricity prices are lower than in the E.U. and Japan but more expensive than in China and India
	Demand / supply side policy	N/A	• Not applicable in segment
☆	**Relative domestic market maturity**	High	• The challenge of procuring Jones Act-compliant service operation, survey, support and crew transfer vessels is much lower due to the greater availability of these lower cost vessels and the ability to adapt existing offshore oil & gas vessels to offshore wind • O&M companies receive the most private investment. Investments within ROVs[2] / drones are primarily made into players in the U.S. and the U.K., creating an opportunity for the U.S. to take a lead in automating O&M services • Partnerships in offshore wind jumped 1.5x since 2020, pointing to an increased consolidation of the industry. Top players in the number of partnerships are large successful international developers and oil & gas companies (RWE, Ørsted, Equinor), who also tend to perform O&M services for windfarms. With the first U.S. player in 9th place (Dominion), the U.S. has an opportunity to increase partnerships and leverage the scale advantage created by accessing partners' resources and expertise
	Regulatory environment & existing infrastructure	High	• Jones Act restrictions also apply to maintenance vessels, which must be built domestically and be operated by U.S. crew • Given higher availability of vessels, Jones Act creates an opportunity to own O&M domestically, rather than a bottleneck
	Overall ranking	High	The U.S. is highly competitive within O&M given significant research and private investment into automating O&M services, the relatively high availability of equipment to be used for O&M, and the transferability of O&M skills and workers from offshore oil & gas

1. Unmanned aerial vehicles, 2. Remotely operated vehicles

Source: BCG Analysis, Offshore Wind Report 2022 (DOE), The Demand for a Domestic Offshore Wind Energy Supply Chain (NREL), Offshore Wind Outlook (IEA)

While recent legislation has addressed many priority issues for OSW, additional policy could further boost U.S. competitiveness and accelerate deployment

	Pre-legislation priority issues	Changes from recent legislation (IRA, IIJA, CHIPS, and EA 2020)	Remaining areas to target with future policies
Permitting & development	**Risk burden placed on OSW developers given high upfront costs and no permitting certainty**	• Extended ITC and PTC credits for electricity producing facilities until 2032 increase long-term revenue streams	• De-risk development through increased permitting certainty and direct revenues from lease auctions back into projects
	Long and complex permitting processes with limited clarity on timelines		✪ Reduce regulatory barriers across local, state, and federal levels, and streamline permitting and approval timelines
Design & manufacturing	**U.S. operational cost disadvantage given high labor and manufacturing costs**	• 45X PTC for OSW component production and 48C ITC for manufacturing facility investments	• Secure supply of high-risk components through research into manufacturing automation and modularity to achieve scale
	Gap to leader in innovation for novel technologies	• >$3B in funding under CHIPS and IIJA to clean tech demonstration projects	✪ Prioritize demonstration and commercialization activities for floating
Construction	**Support infrastructure, including ports and vessels, largely undeveloped**	• ~$600M for port infrastructure upgrades • 10% of sales price tax credit for WTIVs	✪ Standardize dimensions to create shared infrastructure and support novel construction methods that decrease WTIV needs
Offtake	**Generator lead line approach places cost burden on individual developers and increases pressure on onshore grid interconnections**	• ~$100M in interregional transmission analysis and planning	✪ Plan and build an interstate high-voltage transmission solution for offshore windfarms

✪ Priority areas

Source: IRA, IIJA, DOE, IEA, BCG Analysis

Deep dive | Detailed list of potential OSW policy actions to support U.S. competitiveness (I/II)

Policy-based   Investment-based   ☆ Key interventions

Technology-wide

Demand side

- ☆ Encourage state legislatures to codify offshore wind targets and create procurement schedules to establish business certainty that incentivizes local supply chain development
- Create legislation that allows BOEM to decide where to direct revenues from federal lease sales to help fund public interests (i.e., transmission planning, supply chain building, fisheries mitigation, environmental protection)

Supply side

- ☆ Streamline domestic permitting, review, and approval timelines by consolidating federal and state processes
- Ensure federal agencies (i.e., BOEM and NOAA) have sufficient staffing and prioritization to manage permitting volume through increasing budget for hiring offshore wind relevant staff
- ☆ Increase permitting certainty for developers and create clarity around permitting timelines, including encouraging BOEM to publish leasing schedules 5-10 years in advance
- Designate a FERC task force to plan and build an interstate offshore transmission system that would replace current generator lead line approach
    - Convene relevant stakeholders from FERC, DOE, BOEM, RTOs / ISOs and other federal agencies
    - Fund research into planned offshore wind transmission solutions, such as mesh and backbone designs
    - Broaden FERC's authority on cost allocation and interstate transmission to resolve connection disputes
    - Allocate funding to production of high-voltage cables and secure supply given low availability
- Use DOL and DOE funding for workforce training and apprenticeship programs to address future labor gaps
    - Accelerate the transition of offshore oil and gas workers to offshore wind by establishing training and relocation assistance programs
- ☆ Allocate budget to map out ocean seascapes and publish the data to help make OSW siting decisions, optimize ocean use across all relevant stakeholders, and remove ocean mapping cost burden from developers
- Facilitate communication across all relevant stakeholders (fishermen, developers, environmental groups, etc.) through BOEM designated resource centers to share information and best practices and resolve conflicts upfront
    - Collaborate with ocean conservancy groups to create guidelines that minimize OSW impact on wildlife, including vessel speed limits to avoid strikes, bird detection software, and minimizing construction noise
    - Support a push to prepare Draft Environmental Impact Statements ahead leasing decisions to help resolve any wildlife concerns upfront
    - Support BOEM in creating a fisheries mitigation strategy to provide guidance on mitigating the impact OSW projects have on fisheries
- Continue efforts to connect LPO with industry and address a financing gap for smaller demonstration projects

Deep dive | Detailed list of potential OSW policy actions to support U.S. competitiveness (II/II)

Policy-based   Investment-based   ☆ Key interventions

	Demand side	Supply side

OEM	- Facilitate partnerships with neighboring markets to export floating technology IP and components	☆ Support research into manufacturing automation and modularity to increase production capacity and secure supply of high-risk components, which includes blades, subsea cables, and base foundations
		☆ Allocate DOE funding to building a dedicated marine energy demonstration center for testing and commercialization of floating technology
		  - Build on existing initiatives (such as the DOE Offshore Wind Shot) to bring down the costs of floating technology through supporting increased deployments and industry-wide standardization
		  - Create opportunities to increase research collaboration among national labs, universities and private sector
		- Support innovation of novel technologies outside of floating, including low-weight turbine designs, superconducting generators, and recyclable materials

EPC	- Continue efforts to connect LPO with ship builders to help finance construction of large WTIVs	☆ Convene relevant stakeholders to create industry-wide standards on dimensions (e.g., component size and weight) to ensure support infrastructure doesn't become obsolete before the end of useful life - Create a regulatory body within BOEM to oversee infrastructure building and usage across projects to prioritize strategic port upgrades and optimize vessel utilization rates given likely supply chain shortages - Allocate RD&D funding into designing innovative vessels and construction methods that reduce WTIV requirements
O&M		- Allocate funding for RD&D into using sensors for condition monitoring and unmanned vehicles for preventative maintenance to help reduce O&M costs - Provide clarity on the regulatory and legal framework for using unmanned maritime and aerial vehicles in oceans

Overview of key assumptions

Assumption	Value	Impact on Calculations	Source
Projections of offshore wind capacity	*Varies by year, market, and scenario*	Offshore wind capacity is predicted by applying 2019 offshore-wind-per-country %'s to the IEA 2022 total wind projections. These capacity predictions form the basis of all other calculations; however, they can be slightly conservative since they might not fully reflect the increased interest of China and U.S. in OSW in the past 3 years.	IEA 2022/2019 World Energy Outlook & IEA 2019 Offshore Wind Outlook
Fixed vs. floating capacity projections	*Varies by year and market*	Once offshore wind capacity is calculated, it is divided into fixed and floating bottom capacity. These inputs help inform the market size modeling since CAPEX and OPEX differ by fixed vs. floating and tend to be higher for floating.	Expert input
Split of CAPEX by value chain	*Varies by fixed vs. floating*	The CAPEX %'s create a split per value chain from the total capital costs, which in turn informs segment prioritization. Since the NREL analysis is made for 8.0-MW turbines, expert input refined the %'s to match larger turbines used today.	2020 Cost of Wind Energy Review & Expert input
Operating expenses	*Varies by year and by fixed vs. floating*	OpEx is used to calculate the market size for O&M and has an impact on total market size numbers as well as value chain segment prioritization.	2022 NREL Annual Technology Baseline
U.S. SAM	*Varies by value chain and is mostly limited to the Americas*	The addressable market is used to calculate the obtainable market (SOM). The offshore wind SAM is conservative and only includes countries where the U.S. has a realistic opportunity to expand into given economic and political barriers.	Expert input & BCG analysis
U.S. SOM	*Varies by value chain and domestic vs. export SAM*	SOM calculations have an impact on jobs numbers and jobs growth and inform what the opportunity is in the U.S. and abroad.	Expert input & BCG analysis

CCUS

CCUS | Definition of each segment across value chain

Capture only

Raw materials & inputs

Natural resources used for initial plant & solvent / sorbent, including

Liquid solvents (amines, alkali metals, alkaline earth metal hydroxides - often potassium or sodium hydroxide)

Solid sorbents (MOFs, zeolites)

Membrane and cryo- separators (e.g., chilled ammonia)

Steel, cement, copper, etc.

OEM

R&D, manufacturing & designing technology

Solid sorbent & liquid solvent
- Initial CAPEX
- Ongoing OPEX for solvent replacement
- R&D (incl. zeolites, MOF)

Custom plant components
- Air filters for pre-cleaning
- Air separation unit (oxy)
- Separation columns
- Compressor

Innovative / modular capture components

Project Development

Project origination & coordination

Greenfield
- Permissions & contracting
- Permitting (incl. land, water usage, etc.)
- Secure financing
- Secure energy inputs

Brownfield (similar but also including site evaluation to determine economic and technical feasibility)

Financing

Financing capital stack for large-scale projects
- Financing from plant owner or project developer
- Additional debt / equity financing from existing capital providers in industry
- Government support, tax credits (e.g., 45Q), etc.

EPC

Engineering, procurement & construction (typically outsourced)

Site-specific engineering considerations
- Greenfield vs brownfield
- CO2 output stream
- Pre-combustion, oxy-fuel combustion, post-combustion
- Industry of CCUS user (power, O&G, industrial)

Process mgmt. (incl. supply chain, contractor mgmt., system testing)

Energy Inputs

Energy inputs required for operation of CCUS facility

Low carbon heat and energy inputs for desorption, compression, transport, storage
- Sourcing of reliable, low carbon energy sources for heat and power
- Buildout of renewables as needed

Operations/ Maintenance

Ongoing OPEX, including operations, maintenance, sorbent / solvent regeneration

Maintenance and replacement
- Sorbent & solvent regeneration
- Baseline operations
- Asset monitoring
- Maintenance & repairs

Transport

Logistics of compressed CO2 delivery

Compression for transport

Local transport logistics
- Pipeline
- Pumps
- Ships
- Other transport mechanisms

Storage & Utilization

Storage or end usage of CO2

Long-term storage
- Saline aquifers
- Depleted oil wells
- Injection machinery

End usage for CO2 gas (e.g., EOR, synfuels)
- Final offtake contracting
- Sales channels / markets

Support Services

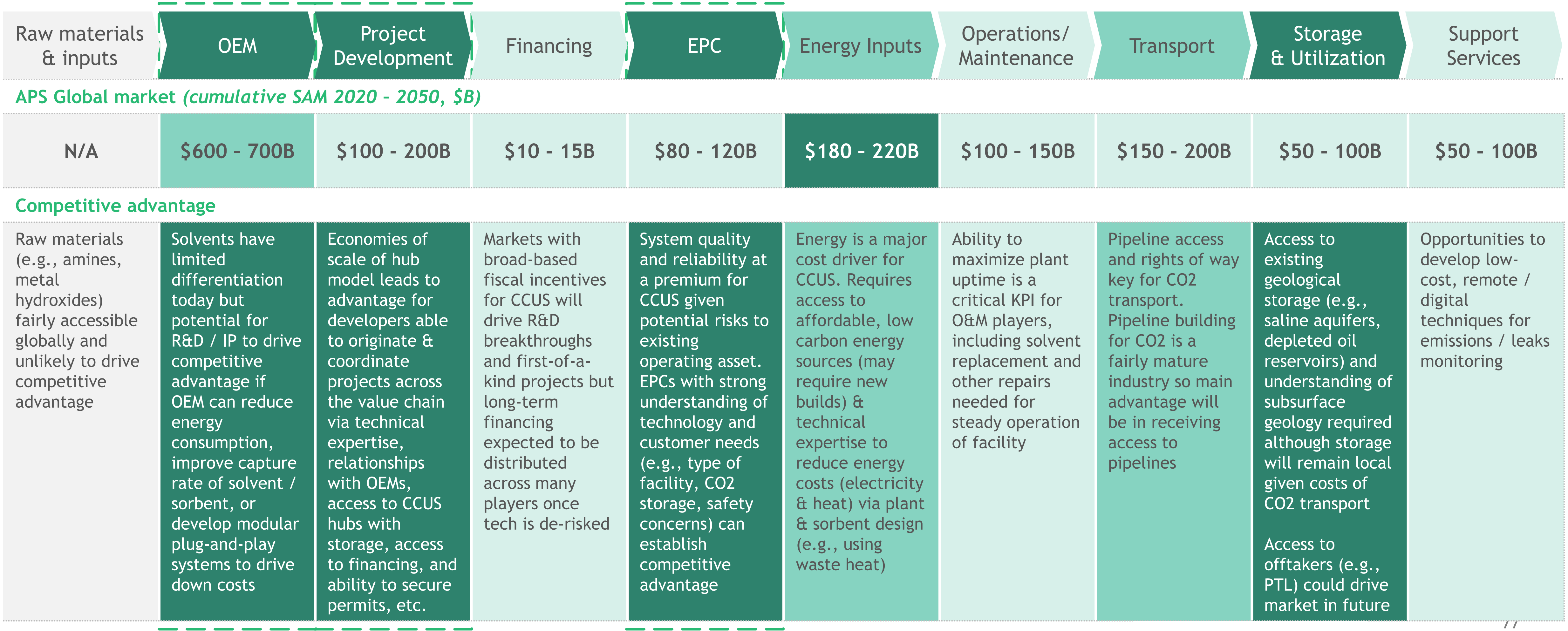
Differentiated offerings to monitor CO2 capture / emissions and expand offering to similar plants E.g.,:
- Auditing / monitoring (for storage)
- Technology licensing

Similar to DAC

CCUS | Significant opportunity exists across the value chain, with OEM, Project Development, and EPC prioritized due to market size & competitive advantage

Prioritized segment for deep dive

High	Medium	Low	N/A



Raw materials & inputs	OEM	Project Development	Financing	EPC	Energy Inputs	Operations/ Maintenance	Transport	Storage & Utilization	Support Services
APS Global market *(cumulative SAM 2020 - 2050, $B)*									
N/A	$600 - 700B	$100 - 200B	$10 - 15B	$80 - 120B	$180 - 220B	$100 - 150B	$150 - 200B	$50 - 100B	$50 - 100B
Competitive advantage									
Raw materials (e.g., amines, metal hydroxides) fairly accessible globally and unlikely to drive competitive advantage	Solvents have limited differentiation today but potential for R&D / IP to drive competitive advantage if OEM can reduce energy consumption, improve capture rate of solvent / sorbent, or develop modular plug-and-play systems to drive down costs	Economies of scale of hub model leads to advantage for developers able to originate & coordinate projects across the value chain via technical expertise, relationships with OEMs, access to CCUS hubs with storage, access to financing, and ability to secure permits, etc.	Markets with broad-based fiscal incentives for CCUS will drive R&D breakthroughs and first-of-a-kind projects but long-term financing expected to be distributed across many players once tech is de-risked	System quality and reliability at a premium for CCUS given potential risks to existing operating asset. EPCs with strong understanding of technology and customer needs (e.g., type of facility, CO2 storage, safety concerns) can establish competitive advantage	Energy is a major cost driver for CCUS. Requires access to affordable, low carbon energy sources (may require new builds) & technical expertise to reduce energy costs (electricity & heat) via plant & sorbent design (e.g., using waste heat)	Ability to maximize plant uptime is a critical KPI for O&M players, including solvent replacement and other repairs needed for steady operation of facility	Pipeline access and rights of way key for CO2 transport. Pipeline building for CO2 is a fairly mature industry so main advantage will be in receiving access to pipelines	Access to existing geological storage (e.g., saline aquifers, depleted oil reservoirs) and understanding of subsurface geology required although storage will remain local given costs of CO2 transport Access to offtakers (e.g., PTL) could drive market in future	Opportunities to develop low-cost, remote / digital techniques for emissions / leaks monitoring

Prioritized in DAC deep dive

Note: OEM, Project dev't, Financing, EPC, Transport, Storage & Utilization, and solvent replacement (part of O&M) included in market size

CCUS | OEM

DESCRIPTION OF TECHNOLOGY

Includes both the manufacture of chemical capture solvents / sorbents AND the additional equipment needed for the capture of CO2 from flue gas.

Sorbent / solvent OEM includes development of capture materials including chemical adsorbents (e.g., amines), membranes, MOFs, and many others

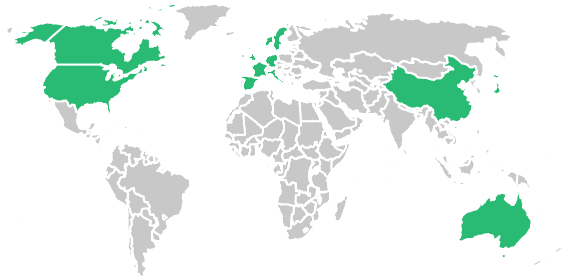
Plant design includes changes to improve heat regeneration and overall energy efficiency

$600-700B
Cumulative APS
US SAM
($B, '20-50)

MARKET DYNAMICS

	2020	2030	2040	2050
US SAM ($B, APS)	-	$8 – 12	$25 – 35	$35 - 45
Annual global additions (Mtpa)	-	50 - 70	150 - 200	140 - 160
Avg. margin (%)	20 - 25%			

GLOBAL PLAYERS - COUNTRIES



🟩 HQs of major OEMs

COMPANIES

Air Liquide
AIR PRODUCTS
AKER CARBON CAPTURE
Axens SOLUTIONS
CO2 CAPSOL
carbon clean
ENTROPY
C-Capture
Shell
Honeywell
SAIPEM
Svante
Leilac Group

VALUE PROPOSITION

Capture solvents / sorbents are produced by a wide range of OEMs today with no clear winner in the space. High costs and energy usage for current materials provide opportunities for players to create defendable, high value IP. Targeted R&D to create capture solvents with reduced energy / heat requirements for desorption and modular plug-and-play systems could drive a durable advantage

COMPETITIVE ADVANTAGE

Raw material availability	Raw materials required for solvents / sorbents are currently global commodities although this may change with future innovations	L
Intellectual Property & innovation	Highly distributed market of OEMs currently with many focused on well-established chemical sorbents utilizing thermal desorption. Innovative technologies (e.g., MOFs, membranes) and modularization of technology could drive competitive advantage	H
Research & technical leadership	Additional R&D necessary for cost declines needed to enable widespread CCUS adoption. Funding to support new technologies such as electro-swing adsorption could enable huge unlocks	H
Demand / supply side policy	Limited market incentives for carbon capture slowing global deployment. Supportive policy could encourage further R&D and development of novel sorbents / solvents	M

High	Medium	Low	N/A

Source: IEA, Global CCS Institute, BCG Analysis

CCUS | Project development

DESCRIPTION OF TECHNOLOGY

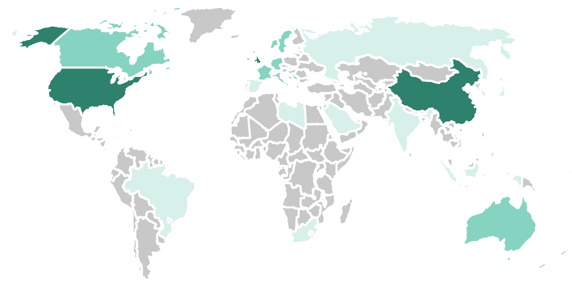
Includes a wide variety of activities around origination, development, and coordination of CCUS projects, including permissions & contracting (e.g., with EPC & operators), initial designing/engineering for facility, securing financing, ensuring access to low carbon energy, securing transport & storage for project, and potentially coordinating with other players involved in carbon hub development

$100-200
Cumulative APS
US SAM
($B, '20-50)

MARKET DYNAMICS

	2020	2030	2040	2050
US SAM ($B, APS)	-	$3 – 5	$5 – 7	$5 - 7
Annual global additions (Mtpa)	-	50 - 70	150 - 200	140 - 160
Avg. margin (%)	15 – 20%			

GLOBAL PLAYERS - COUNTRIES



- 🟩 >10 projects under development or operational
- 🟩 2-10 projects under development or operational
- 🟩 <2 projects under development or operational

COMPANIES

IOCs / NOCs
Chevron, bp, ExxonMobil, equinor, Qatar Petroleum, aramco, ADNOC

E2E Capture
AKER CARBON CAPTURE, MITSUBISHI HEAVY INDUSTRIES

Industrial Gases
Linde, AIR PRODUCTS

New Dev Cos
STOREGGA, CARBONVERT, SUMMIT CARBON SOLUTIONS

Source: IEA, Global CCS Institute, BCG Analysis

VALUE PROPOSITION

Wide range of potential project developers (ranging from asset owners to various external players) with expected first mover advantage given complexity of process and value of underlying assets. Expectation that players with proven track records and relationships required to coordinate across the value chain for CO2 hubs (via JVs) will build competitive moat given complexity of operation

COMPETITIVE ADVANTAGE

Demand / supply side policy	Strong policy support for monetization of carbon capture is crucial to development of CCUS market given high costs today	H
Relative domestic market maturity	Few regions currently have mature CCUS markets or project developers so first movers (likely those with experience in other large infra projects) will be able to build track record of success locally and capture first mover advantage given value of underlying asset and need for experienced developers capable of ensuring high uptime	H
Regulatory environment & existing infrastructure	Streamlined, favorable permitting processes will significantly speed up CCUS deployment (esp. in hubs) while access to renewables and storage infrastructure are similarly crucial for near term deployment	M

High	Medium	Low	N/A

CCUS | EPC

DESCRIPTION OF TECHNOLOGY

Includes all standard EPC processes for construction of large industrial facilities (e.g., site specific engineering considerations, process / supply chain management). Global EPCs likely to maintain position in the CCUS market given complexity of engineering needs and established relationships with key players

$80-120
Cumulative APS
US SAM
($B, '20-50)

MARKET DYNAMICS

	2020	2030	2040	2050
US SAM ($B, APS)	-	$2.0 – 3.0	$3.0 – 5.0	$3.0 – 5.0
Annual global additions (Mtpa)	-	50 - 70	150 - 200	140 - 160
Avg. margin (%)	5 – 15%			

GLOBAL PLAYERS - COUNTRIES

Insufficient data due to nascency of technology

COMPANIES

EPCs

MCDERMOTT
FLUOR
T.EN TECHNIP ENERGIES

Oilfield service companies

HALLIBURTON
Schlumberger

Industrial gas companies

AIR PRODUCTS
Linde
Air Liquide

VALUE PROPOSITION

System quality and reliability at a premium for CCUS given potential risks to operating asset. EPCs with strong understanding of technology and customer needs (e.g., type of facility, CO2 concentrations, safety concerns) and first movers can establish sustainable competitive advantage as the space develops

COMPETITIVE ADVANTAGE

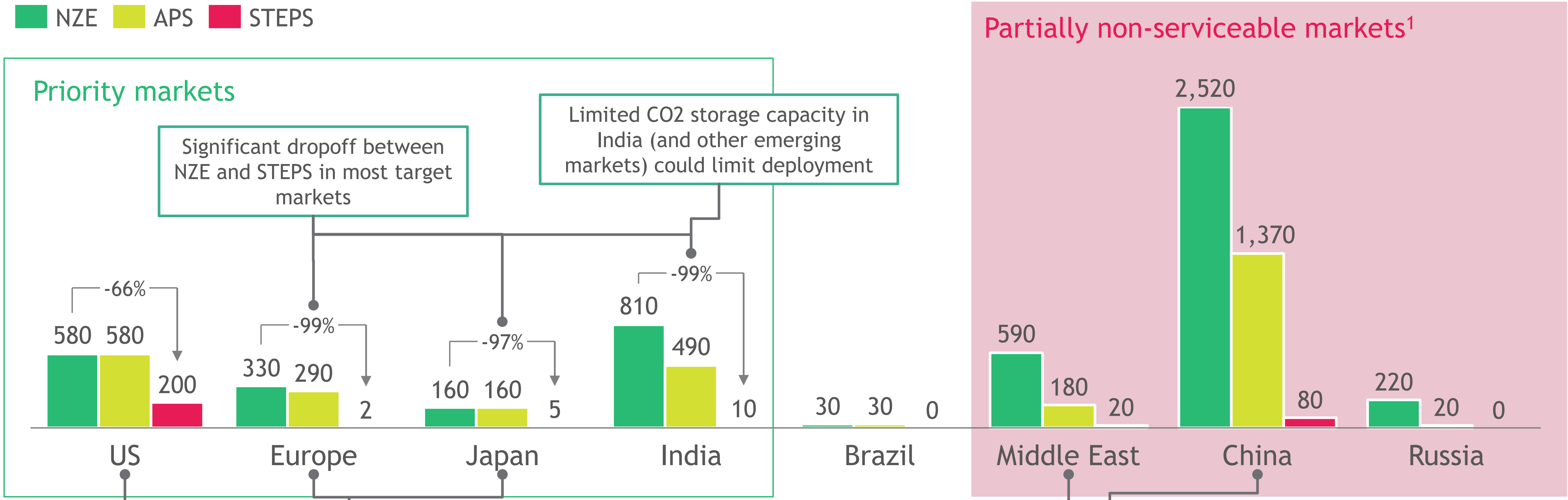
Research & technical leadership	Site engineering design will typically involve OEMs and requires significant technical knowledge for effective connection to infrastructure, especially for modular systems	H
Low operational costs	Ability to reduce costs for bespoke installations is important for eventual widespread adoption of CCUS but unlikely to create durable advantage as others adopt leading techniques	M
Demand / supply side policy	EPCs operating in regions with monetization opportunities for CCUS likely to be first movers and establish track records of success to build competitive moat	L
Relative domestic market maturity	More mature markets similarly likely to support first mover EPCs who can build competitive moats	L
Regulatory environment & existing infrastructure	Supportive regulatory environment for permitting and ability to leverage existing infrastructure accelerates EPC processes and enables development of best practices	M

High	Medium	Low	N/A

Source: IEA, BCG Analysis

U.S. domestic market presents large potential while other markets highly dependent on future policy given differences between NZE & STEPS projections

Installed CCUS capacity through 2050 by market and scenario (Mtpa)



Significant dropoff between NZE and STEPS in most target markets

Limited CO2 storage capacity in India (and other emerging markets) could limit deployment

US, EU, Japan, and India[3] offer largest accessible markets in APS scenario

Middle East offers potentially large opportunity in NZE with ~35% of the market still serviceable by the US

China projected to dominated CCUS market but mostly unserviceable by US, significantly limiting export opportunity[2]

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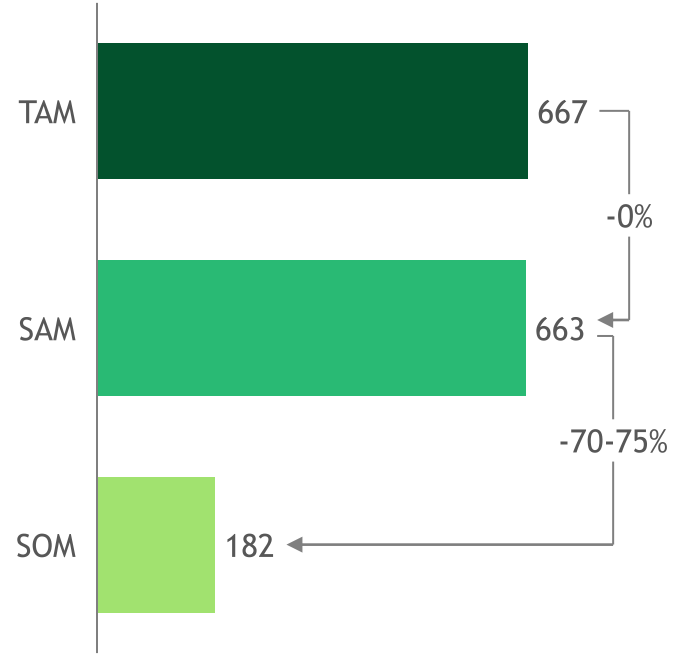
1. Markets where part or all of the value chain would be unserviceable by US companies due to protectionist policies, prohibitive costs, etc. Middle East excludes PD, Fin, T&S, & Support Services; China excludes all VC segments except OEM, and Russia excludes all VC segments 2. Scale may also drive cost advantage for Chinese players limiting US competitiveness 3. Limited storage infrastructure likely also a limiting factor for India's CCUS deployment

Source: IEA World Energy Outlook 2021, BCG Analysis

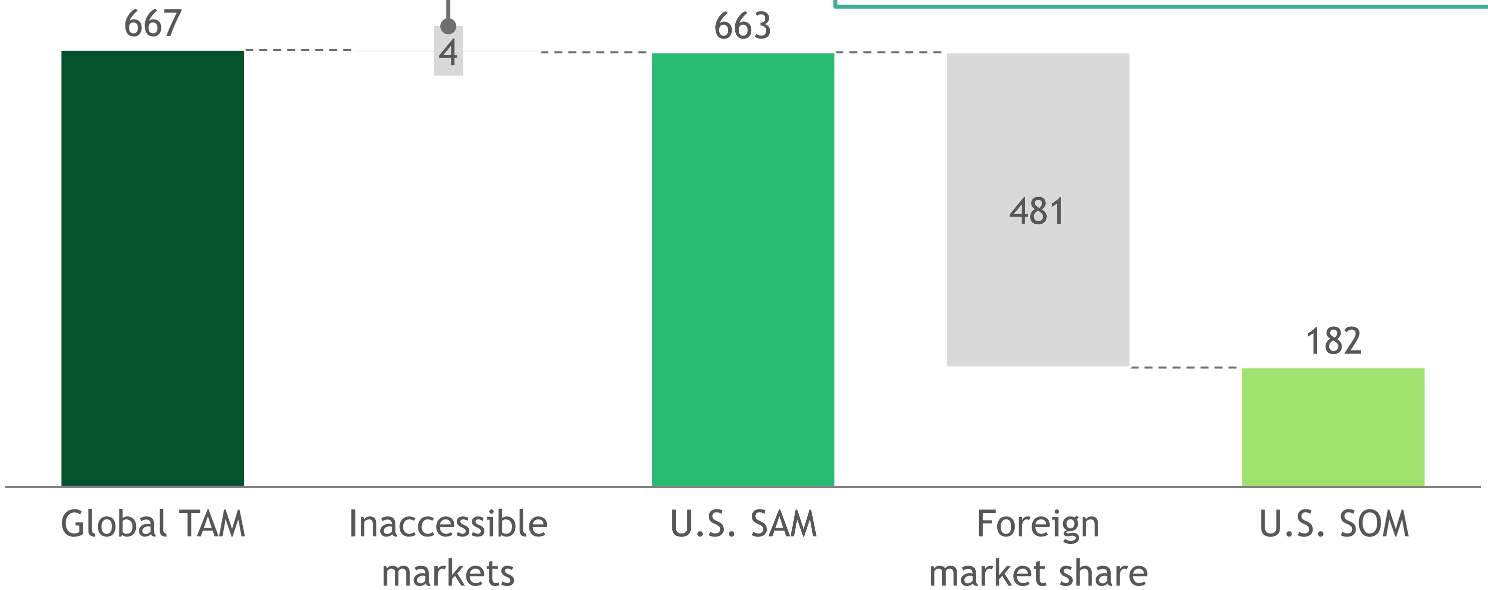
OEM | U.S. current share of CCUS OEM (capture) market of ~20-35% implies a conservative potential U.S. SOM of ~$150 - 200B through 2050 for CCUS OEM

APS market sizing metrics

Cumulative market value, 2020 – 2050 *($B)*



Walk from TAM to SOM under APS scenario



CCUS OEM currently a global market with no major exclusions although some concern around environmental impacts of solvents in EU[1]

Based on share of CCUS capture OEMs currently based in the U.S. vs other countries

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1. CCUS solvents projected to be global market with no major country exclusions but the machinery part of OEM may be excluded from certain regions. Since solvents and solvent replacement make up >60% of OEM market, SAM does not exclude any major regions

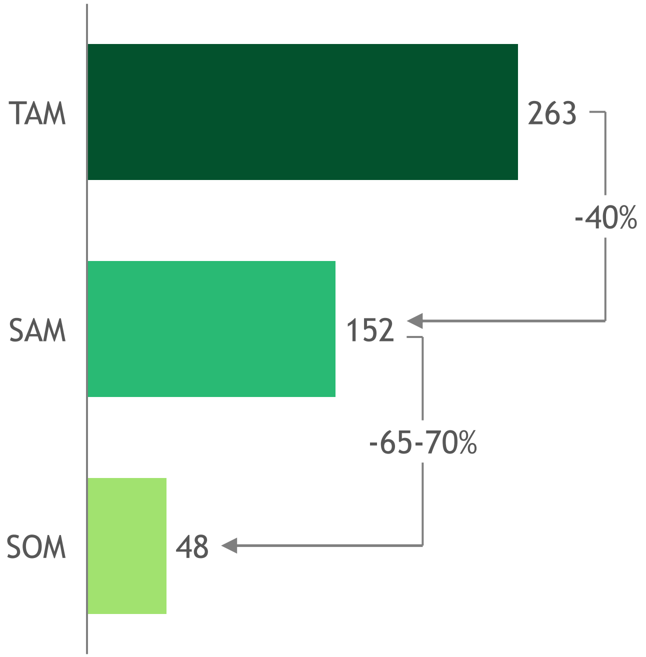
Note: SAM excludes Russia given US sanctions and limited climate commitments. SOM assumed 20-35% capture of market share by US companies based on range of current share of major CCUS OEMs in the US today and the share in Europe which is the current market leader

Source: IEA World Energy Outlook 2021, BCG analysis

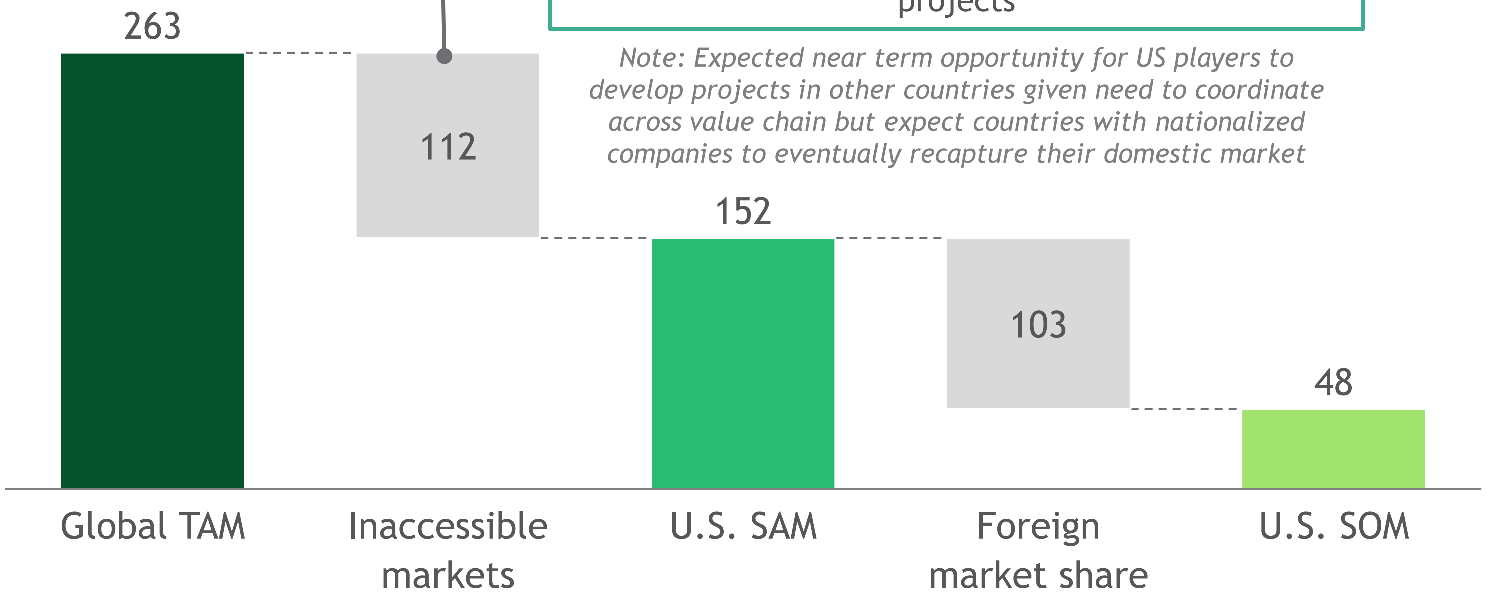
Project Development | U.S. projected to own high share of domestic market (~90%) & low share of export market (~10%) leading to U.S. SOM of ~$50B

APS market sizing metrics

Cumulative market value, 2020 – 2050 *($B)*



Walk from TAM to SOM under APS scenario



Based on markets with trade barriers or protectionist policies / strong nationalized companies driving CCUS projects

Note: Expected near term opportunity for US players to develop projects in other countries given need to coordinate across value chain but expect countries with nationalized companies to eventually recapture their domestic market

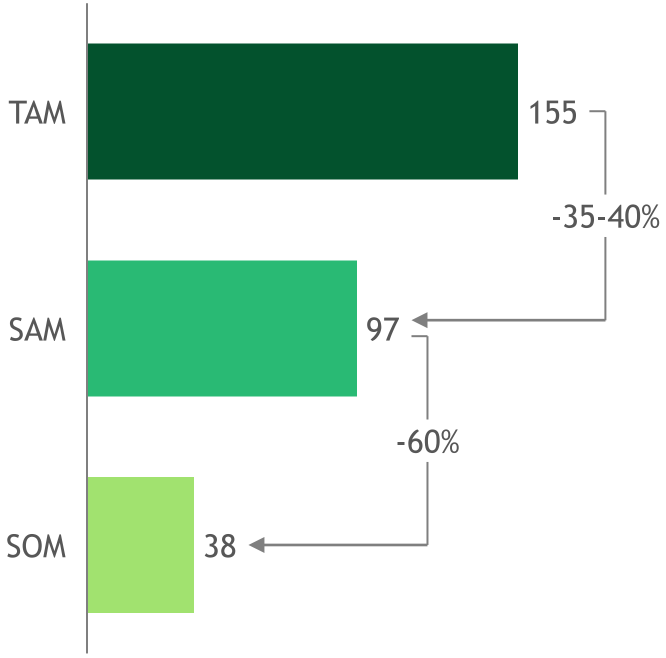
Based on US share of domestic and export renewables project development markets

Note: SAM excludes Russia, China, and the Middle East due to existence of major, nationalized companies handling project development in each. SOM assumed ~90% for domestic market and ~10% of export market based on US share of project development market for renewables both domestically and abroad (upper bound for domestic based on current US ownership of domestic CCUS project developer market)
Source: IEA World Energy Outlook 2021, BCG analysis

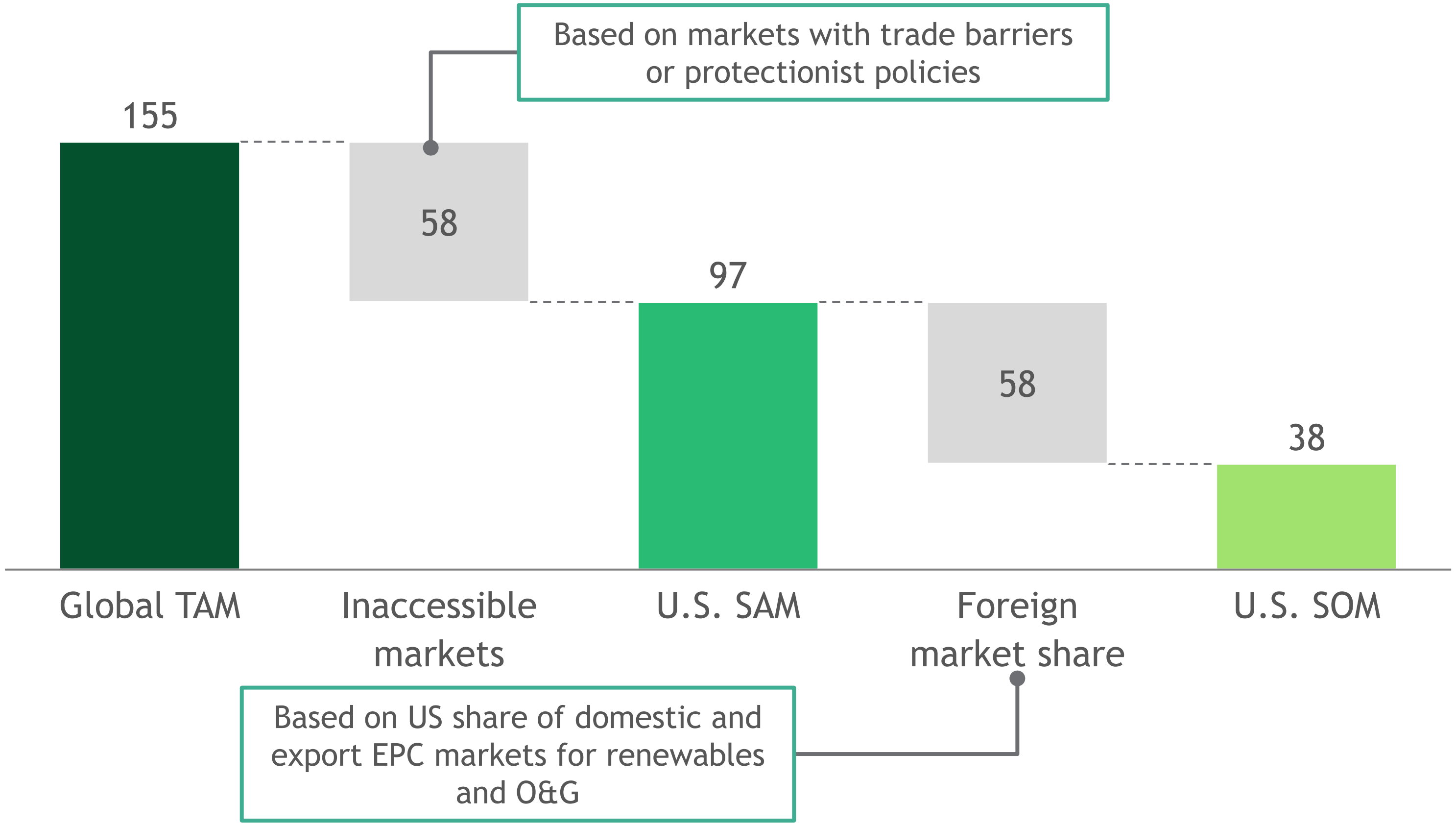
EPC | U.S. projected to own high share of domestic market (~90%) & low share of export market (~20%) leading to U.S. SOM of ~$40B

APS market sizing metrics

Cumulative market value, 2020 – 2050 *($B)*



Walk from TAM to SOM under APS scenario



Based on markets with trade barriers or protectionist policies

Based on US share of domestic and export EPC markets for renewables and O&G

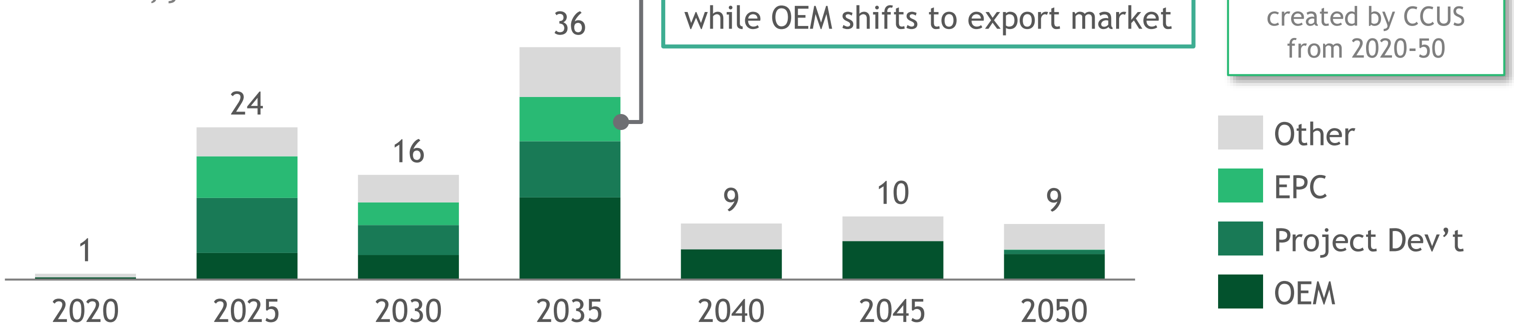
Note: SAM excludes China and Russia due to local regulations and nationalized companies handling EPC. SOM assumed at ~90% for domestic market (based on US company ownership of domestic EPC market for renewables and O&G) and ~25% for export based on US company share of global EPC market
Source: IEA World Energy Outlook 2021, BCG analysis

~100K jobs expected to be created by 2050 with OEM and Project Development the major drivers making up >50% of total jobs created

Strong jobs growth seen from 2022-2035 before tapering off after 2040 as CAPEX spend on new CCUS declines

Total CCUS jobs in each year

Thousands of jobs

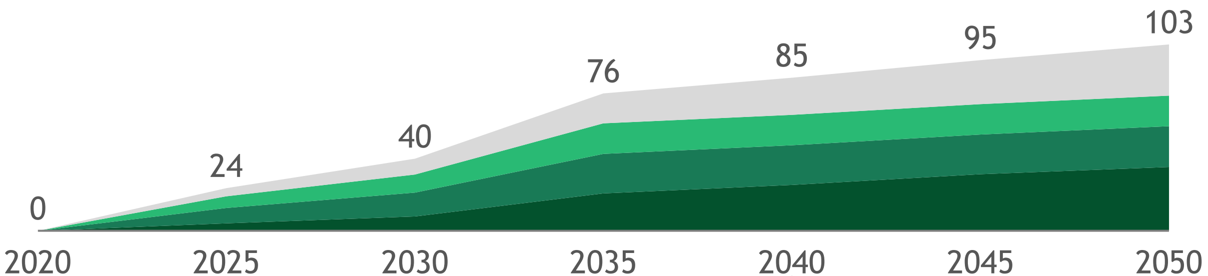


Domestic market slows post-2030, reducing EPC & Project Dev't jobs while OEM shifts to export market

~1.5M
Total job-years created by CCUS from 2020-50

New jobs created (cumulative)[1]

Thousands of jobs



Jobs slowdown as annual deployments decline & export market outpaces domestic

Jobs created in OEM segment
~35K
~$105K/yr
Avg. annual salary

Jobs created in PD[2] segment
~23K
~$95K/yr
Avg. annual salary

Jobs created in EPC segment
~17K
~$85K/yr
Avg. annual salary

~103K
Total jobs created by CCUS

Note: CCUS also supports an equitable transition as job skills from O&G are directly applicable to CCUS

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1. In APS scenario; incremental new jobs calculated as the sum of all non-negative one-year differences in # job-years (e.g., 2021 job-years minus 2020 job-years gives 2021 new jobs); incremental new jobs added to sum from prior period for cumulative calculation 2. Project development

Source: IEA, BCG analysis

OEM | OEM space currently highly fragmented with no dominant players but opportunity for innovators to capture market share

☆ = *Key dimension*

Areas for Competitive Advantage	Ranking	Summary analysis
Raw material availability	High	• Raw materials required for solvents / sorbents are currently global commodities although this may change with future innovation
☆ **Intellectual Property & innovation**	High	• US leads in CCUS patents along with China, with Japan and South Korea in 3rd and 4th and then a big dropoff to the EU & Canada • US O&G and industrial giants (e.g., ExxonMobil, Honeywell, Air Products) are all amongst the top innovators in the space which is currently dominated by international companies given complexity of processes • Limited differentiation between different solvents / systems today with patent filings flat YoY; innovation coming from novel capture technologies such as metal organic frameworks which are one of the few areas demonstrating patent growth • Proprietary nature of solvents is an issue due to inability to study environmental impact, limiting export potential (esp. to EU)
☆ **Research & technical leadership**	High	• US 2nd in publications, distantly behind China but with higher quality papers (based on citations per paper), and then a big dropoff to South Korea and England • US DOE and Chinese Academy of Science are leading players in the space followed by wide range of Chinese and US universities
Low operational costs	Low	• US and EU manufacturing labor is significantly costlier than other markets (~$50/hr in the US & EU vs ~$10/hr in China & Brazil and ~$25/hr in Japan & Korea), with similar rankings but less extreme differences in labor costs for R&D and engineering roles • US electricity prices are lower than in EU and Japan but more expensive than China, India, and Russia while US natural gas prices are amongst the lowest in the world after Russia
☆ **Demand / supply side policy**	High	• >$100M in grants by the US government for R&D in the CCUS space with significant support from national labs and other bodies
Relative domestic market maturity	Low	• Several US-based companies among the major OEMs today but market remains highly dispersed with Europe leading the US in number and scale of major OEMs (although many EU OEMs operate manufacturing plants in the US)
Regulatory environment & existing infrastructure	High	• Several major manufacturers and manufacturing hubs already existing in the US • Concerns from EU regulators around environmental/health impacts of solvents when they break down,
Overall ranking	High	U.S. found to have **high competitive advantage potential** due to early leadership in IP & research and strong domestic policy. Commercialization of domestic technological advances & improved solvent management remain key focus area moving forward with EU & Asian OEMs currently owning most of the market today

Project Development | US has first mover advantage in project development with several IOCs and other international players developing capabilities

☆ = *Key dimension*

Areas for Competitive Advantage	Ranking	Summary analysis
Raw material availability	High	- Significant access to storage (>812 GtCO2e) along with significant emissions from stationary sources near storage sites (2 GtCO2e / yr from ~3300 stationary sources)
Intellectual Property & innovation	High	- US project developers are leaders in managing large complex projects across the full value chain and tend to own the IP when developing international projects involving tech transfers (e.g., in Saudi Arabia)
Research & technical leadership	High	- US O&G players are leaders in CO2 injection into saline aquifers and subsurface management with significant advantages in technical expertise in managing large sub-surface projects
Low operational costs	Low	- US average wages significantly higher than any other region with average income per month ~$6K while the EU's is ~$4K, Japan's & South Korea's are ~$3K, China's & Russia's are ~$1K, and India's is ~$200
☆ Demand / supply side policy	High	- Significant support for CCUS projects from Inflation Reduction Act and infrastructure bill with $60-85/tCO2e tax credit and ~$12B in funding for carbon capture hubs - EU only other region with similar scale of incentives due to carbon price of ~$80/tCO2e but significantly less investment into CCUS specifically
☆ Relative domestic market maturity	High	- US companies have been part of ~40% of all partnerships in CCUS globally with 8 of the top 15 companies with the most partnerships being US-based; most partnerships involve coalition building by project developers to incorporate partners up and down the CCUS value chain - US leads in onshore CO2 storage although Europe leads in offshore storage (and unlikely to do store CO2 onshore in the EU)
☆ Regulatory environment & existing infrastructure	High	- US has invested heavily in developing CO2 pipelines ($2.1B) and permitting programs for CO2 storage infrastructure ($2.5B) with a significant head start over most other regions given extent of O&G pipelines (more miles than China, Canada, Russia combined) - Leader in CO2 storage infrastructure with more projects under development than the rest of the world combined and more storage capacity than any other region except South America and Eurasia - Understanding of local geology and politics is important for project development, potentially limiting export potential
Overall ranking	High	U.S. has **high competitive advantage potential** today, with significant potential for domestic project development, robust government support, and several large players capable of exporting project development capabilities given first mover advantage and ability to coordinate up and down the value chain

EPC | US competitive advantage in EPC space primarily due to first mover advantage driven by early domestic deployments

✪ = *Key dimension*

Areas for Competitive Advantage	Ranking	Summary analysis
Raw material availability	N/A	• Construction materials (e.g., cement, steel) are widely available
Intellectual Property & innovation	Low	• While relationships with OEMs can drive competitive advantage for EPCs, US remains middle of the road amongst EU and China regarding numbers of major EPCs and number of partnerships with major OEMs; this may change in future as US OEMs innovate and seek local partners for initial / validation deployments
Research & technical leadership	High	• Highly trained O&G workforce in the US provides much of the technical expertise required for CCUS projects • Early domestic deployments in the US driving first mover advantage for domestic EPCs which could drive short term export opportunities as US EPCs develop track records of success
Low operational costs	Low	• US average wages significantly higher than any other region with average income per month ~$6K while the EU's is ~$4K, Japan's & South Korea's are ~$3K, China's & Russia's are ~$1K, and India's is ~$200 • Long procurement cycles and difficulty obtaining / retaining talent currently straining projects and expected to worsen as industry expands
Demand / supply side policy	High	• IRA enhanced incentives require prevailing wages and apprenticeship opportunities which are biased towards domestic EPCs supporting US players in develop first mover advantages in CCUS deployments
✪ **Relative domestic market maturity**	High	• US investment in deploying first of a kind commercial CCUS projects should drive first mover advantage for EPCs with US's current pipeline of projects expected to drive >100 Mtpa of CCUS capacity by 2030 (well ahead of EU at ~80 Mtpa and China at ~15 Mtpa)
✪ **Regulatory environment & existing infrastructure**	High	• Similar to project development with significant investment in the US in transport and storage • Limited traction in permitting Class VI wells to date but significant efforts to streamline this process through federal funding and guidelines (e.g., USE IT Act)
Overall ranking	High	U.S. found to have **high competitive advantage** in EPC due to leadership position in global CCUS deployments and ability to develop first mover advantage working on domestic projects despite concerns regarding labor costs and permitting timelines. This first mover advantage could result in export opportunities (particularly in the Middle East where many US EPCs already operate) in the near term but EPC expected to be highly localized in future

While recent legislation has addressed some priority issues for CCUS, additional policy could further boost US competitiveness and accelerate deployment

	Priority issues for CCUS	Changes from recent legislation (IRA, IIJA, CHIPS, and EA 2020)	Remaining areas to target with future policies
OEM	① **High cost / complexity of CCUS applications**	• RD&D funding for novel & modular techs to drive down costs • Direct funding for commercial-scale CCUS projects from IIJA	☆ CCUS cost projections remains too high to support widespread deployment (esp. with bespoke model) and limited support for commercialization of US-developed tech
Project development	② **Limited regulations around CO2 emissions**		☆ Limited demand for developing new CCUS projects and incurring related costs without CO2 emissions mandates or costs (by-sector or economy-wide)
Financing	③ **Lack of long-term monetization mechanisms**	• Expanded $60-85 / tCO2e tax credit from 45Q in IRA	• Tough to incentivize investment given lack of long-term monetization opportunities to de-risk financing
EPC	④ **Long procurement timelines and difficulty obtaining / retaining talent**		☆ Insufficient workforce available to enable rapid deployment of CCUS without additional training programs & incentives for O&G workforce
Transport & Storage	⑤ **Long permitting timelines and limited clarity on CO2 storage liability**	• Direct funding for states to establish well permitting programs in IIJA	☆ Limited clarity on long-term storage & monitoring processes & liabilities at the federal level
	⑥ **Insufficient CO2 transport & storage infrastructure**	• Financing for both CO2 pipelines & large-scale carbon sequestration projects in IIJA	• Need further buildout of CO2 infrastructure to support CCUS hubs which will enable widespread deployment

☆ Priority areas

Source: C2ES, DOE, IIJA, IEA, BCG Analysis

Supply & demand side policies are needed to support CCUS with supply-side driving early growth while demand-side supports CCUS long term (I/II)

Policy-based Investment-based ☆ Key interventions

	Demand side	Supply side
Technology-wide	☆ Increase demand for CCUS via incentives & regulations which create long-term monetization opportunities for CCUS (e.g., emissions regulations for power production, tax credits for CCUS in hard-to-abate sectors) ☆ Establish quality & verification standards for CCUS (e.g., CO2 capture rate, permanence) and align on standards with key export markets to ensure continued policy support and to de-risk projects • Leverage government procurement for low-carbon power & industrial products (e.g., steel, cement) to increase demand for CCUS • Leverage government procurement for synfuels & other products made from captured CO2 to create market for CO2 utilization	☆ Leverage incentives (e.g., tax credits, grants for cost-sharing) and loan guarantees to reduce upfront costs for CCUS deployments and stimulate supply • Invest in low-carbon CO2 utilization technology & provide incentives or low-cost financing for project deployment (e.g., synfuel facility) • Continue investment in renewable and low-carbon energy
OEM		☆ Continue investments in IP R&D for next-generation CCUS technologies with lower costs, higher capture rates, and lower energy consumption (e.g., via DoE Funding Program) ☆ Continue centralized project development (e.g., CCUS hubs at industrial centers) that de-risk projects for OEMs, enable cost sharing, and enable industrial-sized applications of OEM technology (creating demand needed for domestic manufacturing hubs) • Create opportunities and processes to increase research collaboration among national labs, universities and private sector

Source: IEA, BCG analysis

Across project development and EPC, supply-side policies are crucial to developing the infrastructure needed to support widespread CCUS (II/II)

Policy-based Investment-based ☆ Key interventions

	Demand side	Supply side
Project Development[1]	• Create centralized, standardized RFPs for CCUS facilities or OEM inclusion in hub infrastructure to enable competition ☆ De-risk CCUS deployments through government assumption of liability for long-term CO2 storage beyond a required time window • Add industry-specific aspects to 45Q to incentivize CCUS deployments in lower CO2 concentration / higher cost applications	☆ Streamline and prioritize review/approvals process for CO2 storage permits, environmental impact, and zoning under a single regulatory authority which preempts state and regional agencies' jurisdiction and local governments' land-use authority ☆ Align on federal / state rules for assumption of CO2 storage liabilities after a set number of years and clarify CO2 storage monitoring and reporting requirements ☆ Classify pore space for CO2 sequestration as "public use" to resolve uncertainties around pore space ownership ☆ Continue providing necessary infrastructure (e.g., CCUS hubs with access to renewable energy, compression, transport, storage) to enable smaller OEMs with diverse technologies to deploy at scale to accelerate learnings and cost reductions • Develop government resources to help communities understand the impact of CCUS deployments (e.g., air quality improvement, job creation, environmental benefits) to lessen community opposition ☆ Publicly-fund site selection surveys to identify ideal locations for CCUS deployments both in the US and abroad (e.g., identify CO2 storage resources and conduct source-sink matching to optimize transport and storage development) • Provide low-cost financing to de-risk nascent commercial projects • Invest in domestic renewable/low-carbon energy facility development in ideal CCUS locations to enable scaling
EPC	• Incentivize use of domestic EPC players for CCUS facility creation to gain experience and increase competitiveness for exported EPC	• Develop training programs & incentives (e.g., tax credits tied to prevailing wages) to help O&G workers transition to working on CCUS to meet future demand

1. Specific policies for Transportation and Storage/Utilization provided in DAC analysis. Some policies for transport and storage of CO2 included in project development section

Source: IEA, BCG analysis

Geothermal

Geothermal | Definition of each segment across value chain

Raw materials & inputs	OEM	Project Development	Financing	EPC	Operations/ Maintenance	Transport & Storage	Offtake	Support Services
Mining and refining of raw materials for: **Steam and Binary Turbines:** (Iron, Steel, Alloys, Titanium, Aluminum, Epoxy-plastics) **Binary Working Fluids:** (ammonia/water mixtures or hydrocarbons) **Piping:** (Steel, glass fiber casings) **Heat Pumps:** (Polyethylene, steel, aluminum) **Mineral Extraction:** sorbent and energy inputs for extracting lithium	**R&D:** closed-loop, enhanced geothermal systems (e.g., reservoir stimulation and fracturing), dispatchable geothermal, deep-drilling or supercritical **Turbine manufacturing:** turbines, separators, condensers, cooling towers, generators, and piping **Direct heat use:** **Mineral extraction:** primarily lithium using low-temperature sorbents	**Development includes:** • Origination • Exploration • Feasibility reports • Drilling and testing of wells • Environmental assessment and permitting • PPA structuring • Inter-connection queue Customers may be utilities, developers, corporate clients, or industrial users	Developer typically arranges project financing Upfront capital costs are significant. Full capital stack: • Equity • Debt • Government support (tax credits and loans)	EPC includes: • Final site design and engineering • Turbine and generator installation • System connection and testing • Supply-chain management EPC process often works closely with project developer transitioning from the exploration and feasibility phase to construction.	**Operations:** • Resource management and optimization • Reservoir modeling and monitoring • General admin and engineering **Maintenance:** • Turbine and generator maintenance • Piping erosion	Steam or other working fluid is piped through primarily steel casings Transport of electrons is provided by new / existing transmission lines (likely to site in areas with transmission access) Mineral extraction (namely lithium) would need to be shipped	Generated power is injected into the bulk electric system or local microgrid Geothermal can provide multiple sources of value in electricity markets, however current market mechanisms do not fully recognize and compensate geothermal for all potential services Extracted minerals such as lithium can provide supplementary revenue streams	Most materials are non-toxic, simple to decommission, and many of the parts can be recycled and used in other applications Lithium extraction and servicing

Similar to other generating resources

Geothermal | U.S. can drive market and lead in OEM, Project Development, and EPC both domestically and in select foreign markets

Prioritized segment for deep dive

High	Medium	Low	N/A

Raw materials & inputs	OEM	Project Development	Financing	EPC	Operations/ Maintenance	Transport & Storage	Offtake	Support Services
U.S. Serviceable Addressable Market, APS *(cumulative 2020 - 2050, $B)*								
$10 - 15B	**$130 - 175B**	**$340 - 460B**	**$280 - 380B**	**$170 - 230B**	**$310 - 420B**	**N/A**	**N/A**	**N/A**
Competitive Advantage								
Most raw materials (e.g., water, ammonia, hydrocarbons, steel, iron, and aluminum) are accessible globally. Government incentives for domestic materials might drive advantage in the commoditized markets.	Dry and flash steam turbines are mature technologies - advantages driven by scale and manufacturing efficiencies. New technologies such as EGS, AGS, binary plants, and hybrid plants (district heating, lithium extraction) present opportunity to differentiate.	Technical expertise (exploration/drilling), ability to secure permits, coordination across value chain, and access to financing drive advantage. Potential to utilize O&G technology and expertise. EGS changes exploration and de-risks development.	Market maturity and demand-side signals, government subsidies, and government risk reduction programs (e.g., project insurance and low-interest loans) lower cost of financing and drive competitive edge	Capital costs, technical difficulty, custom sites and design, integration with operators and developers, regulation, and environmental risk create barriers to entry. New technologies such as district heating and lithium extractors will require new expertise in EPC.	Dispatchability drives demand for energy management software to optimize deployment and enhance availability and reliability. Sensors and reservoir simulation preserve materials integrity and sustainability of reservoirs.	Transport of electrons is provided by new / existing transmission lines. Mineral extraction (e.g., lithium) would need to be shipped but does not require special technology or expertise.	Offtake of electrons is limited to regional wholesale, retail, and PPA markets. Minerals extracted from brine has potential for competitive advantage, driven by technological development and scale.	Ability to offer support services is non-differentiated and localized. One area for differentiation is add on facilities particularly in lithium extraction.

Geothermal | OEM

DESCRIPTION OF TECHNOLOGY

Geothermal OEM consists of the manufacturing and assembly of turbines (steam and binary), drilling equipment, piping, mineral extraction rigs, and heat-resistant downhole equipment

VALUE PROPOSITION

OEM presents a clear opportunity to build durable competitive advantage in a high-value area, particularly around IP for new and emerging technologies. As IP is developed and refined, supportive policies to scale production and capture economies of scale can provide an early advantage for domestic players as well

$130-175B
Cumulative APS
US SAM
($B, '20-50)

MARKET DYNAMICS

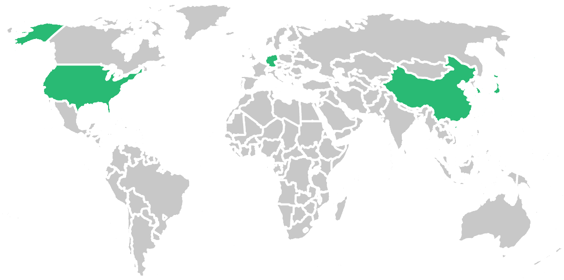
	2020	2030	2040	2050
US SAM ($B, APS)	-	$5 – 10	$4 – 7	$4 - 7
Incremental capacity (GW)	-	8-12	6-10	6-10
Avg. margin (%)	20 - 25%			

COMPETITIVE ADVANTAGE

Intellectual Property & innovation	Highly concentrated market of OEMs currently with many focused on well-established mature turbine technologies (flash and binary). Innovative technologies (e.g., plasma drills, heat-resistant downhole equipment) and modularization of technology could drive competitive advantage.	L
Research & technical leadership	R&D funding to support technology breakthroughs important to develop initial IP and build moats around next-generation technologies.	H

High	Medium	Low	N/A

GLOBAL PLAYERS - COUNTRIES



🟩 HQs of major OEMs

COMPANIES

MITSUBISHI HEAVY INDUSTRIES
Our Technologies, Your Tomorrow

Eavor

GG TECH
www.ggtech.com.pl

ORMAT

SINOPEC

JAPAN RENEWABLE ENERGY

Fuji Electric

TOSHIBA

SIEMENS

Source: IEA, Global CCS Institute, BCG Analysis

Geothermal | Project development

DESCRIPTION OF TECHNOLOGY

Project development drives most of the value in geothermal and integrates with EPC and occasionally OEM players; it includes permitting, exploration, drilling, testing, subsurface mapping, and reservoir simulation.

VALUE PROPOSITION

Highly concentrated, vertically integrated project developers. Exploration and drilling is the most challenging and expensive part of the project, similar to O&G in requisite capabilities and technology. Given the complexity, risk, and capital costs, developers with proven track records and economies of scale tend to dominate.

$340-460B
Cumulative APS
US SAM
($B, '20-50)

MARKET DYNAMICS

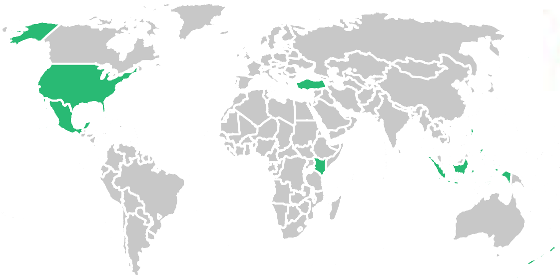
	2020	2030	2040	2050
US SAM ($B, APS)	-	$20 – 30	$10 – 15	$12 - 18
Incremental capacity (GW)	-	8-12	6-10	6-10
Avg. margin (%)	15 – 20%			

COMPETITIVE ADVANTAGE

Intellectual Property & innovation	IP and innovation in exploration (seismic, geochemical, data algorithms) and drilling separate successful developers. Strong O&G players an advantage given crossover of expertise and technology.	H
Relative domestic market maturity	Exploration and drilling benefit from field experience. Given low levels of deployment in most of the world, mature markets give advantages to domestic players as they gain valuable learning experience.	H
Regulatory environment & existing infrastructure	Permitting and regulations can add years to project timelines, which increases risks and financing costs. Streamlined, favorable permitting processes will significantly speed up deployment and drive down costs, giving domestic developers more opportunities to scale and learn.	L

High	Medium	Low	N/A

GLOBAL PLAYERS - COUNTRIES



🟩 Top countries by geothermal capacity

COMPANIES

ORKA
ORMAT
energy DEVELOPMENT CORPORATION
CALPINE®
enel Green Power
Marubeni
MITSUBISHI HEAVY INDUSTRIES
Chevron
HALLIBURTON
ALFA LAVAL
Schlumberger
TOSHIBA
Atlas Copco
Fuji Electric
VERKÍS

Source: IEA, Global CCS Institute, BCG Analysis

Geothermal | EPC

DESCRIPTION OF TECHNOLOGY

Includes all standard EPC processes for construction of large industrial facilities (e.g., site specific engineering considerations, process / supply chain management) and includes connection of electrical systems (e.g. turbines and generators).

VALUE PROPOSITION

Sites depend on the geologic and system characteristics, so efficient and quality designs are at a premium. Understanding of hybrid technologies (e.g., lithium extraction with power generation) and brownfield plants will be a source of competitive advantage going forward.

$170-230
Cumulative APS
US SAM
($B, '20-50)

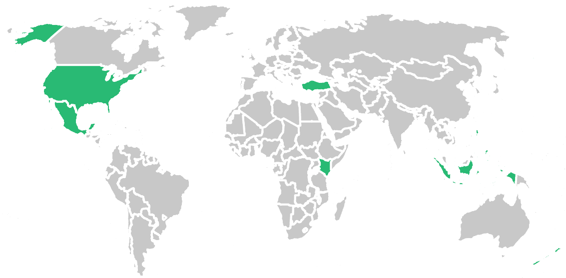
MARKET DYNAMICS

	2020	2030	2040	2050
US SAM ($B, APS)	-	$10 – 15	$5 – 10	$5 – 10
Incremental capacity (GW)	-	8-12	6-10	6-10
Avg. margin (%)	5 – 15%			

COMPETITIVE ADVANTAGE

Research & technical leadership	Site engineering design will typically involve developers and OEMs and requires significant technical knowledge for effective connection to infrastructure. This becomes even more important as complex hybrid plants (e.g., lithium extraction, district heating) become more common.	H
Low operational costs	Ability to reduce costs for custom designs and installations is important for learning and scale to create durable advantage as others adopt leading techniques.	M
Relative domestic market maturity	More mature markets similarly likely to support first mover EPCs who can build competitive moats.	L

GLOBAL PLAYERS - COUNTRIES



🟩 Top countries by geothermal capacity

COMPANIES

ORMAT

Marubeni

EIFFAGE CLEMESSY

VERKÍS

Schlumberger

HALLIBURTON

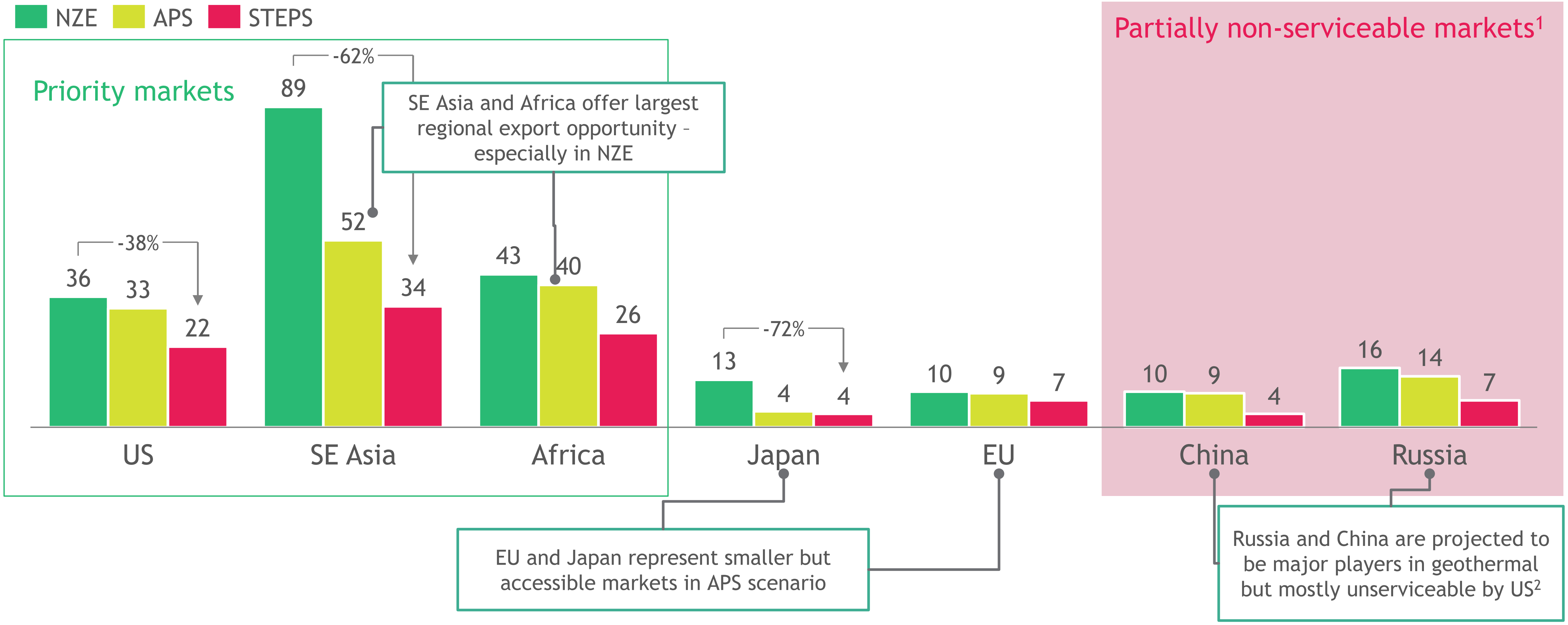
Fuji Electric

High	Medium	Low	N/A

Source: IEA, BCG Analysis

U.S. domestic market presents large potential along with export opportunities in SE Asia and Africa

Installed geothermal capacity through 2050 by market and scenario (GW)



SE Asia and Africa offer largest regional export opportunity – especially in NZE

EU and Japan represent smaller but accessible markets in APS scenario

Russia and China are projected to be major players in geothermal but mostly unserviceable by US[2]

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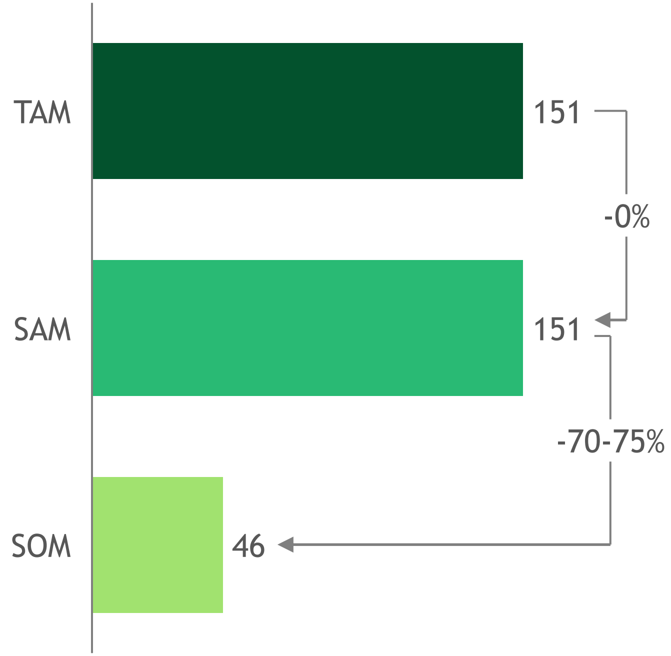
[1] Markets where part or all of the value chain would be unserviceable by US companies due to protectionist policies, prohibitive costs, etc. [2] Scale may also drive cost advantage for Chinese players limiting US competitiveness

Source: IEA World Energy Outlook 2021, BCG Analysis

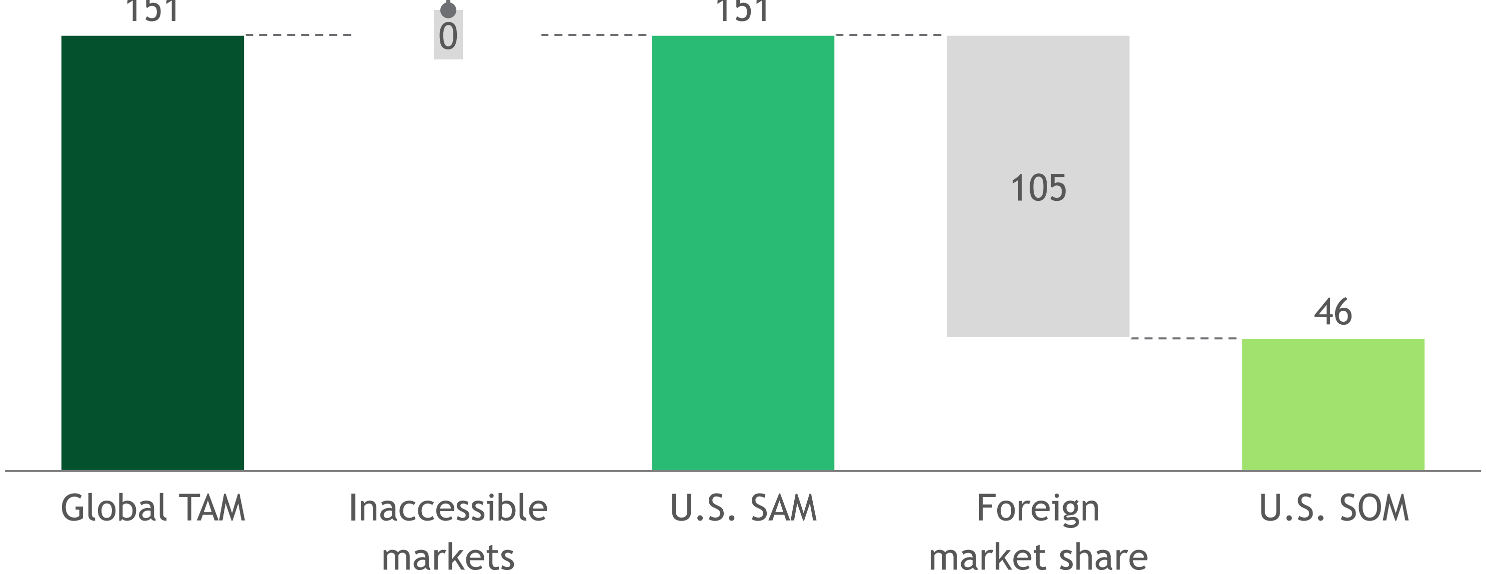
OEM | U.S. current share of Geothermal OEM (capture) market of ~20-35% implies a conservative potential U.S. SOM of ~$40 - 65B through 2050

APS market sizing metrics

Cumulative market value, 2020 – 2050 *($B)*



Walk from TAM to SOM under APS scenario



Geothermal OEM currently a global market with no major exclusions

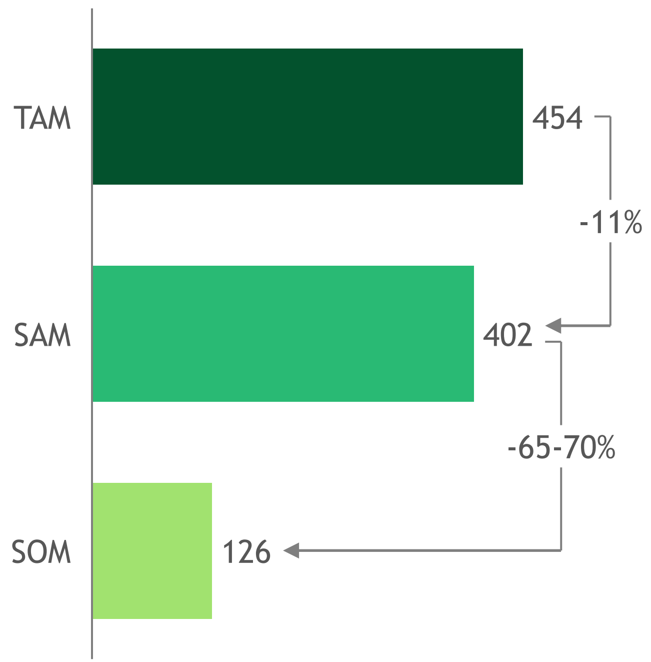
Based on share of geothermal capture OEMs currently based in the U.S. vs other countries

Source: IEA World Energy Outlook 2022, CEP, BCG analysis

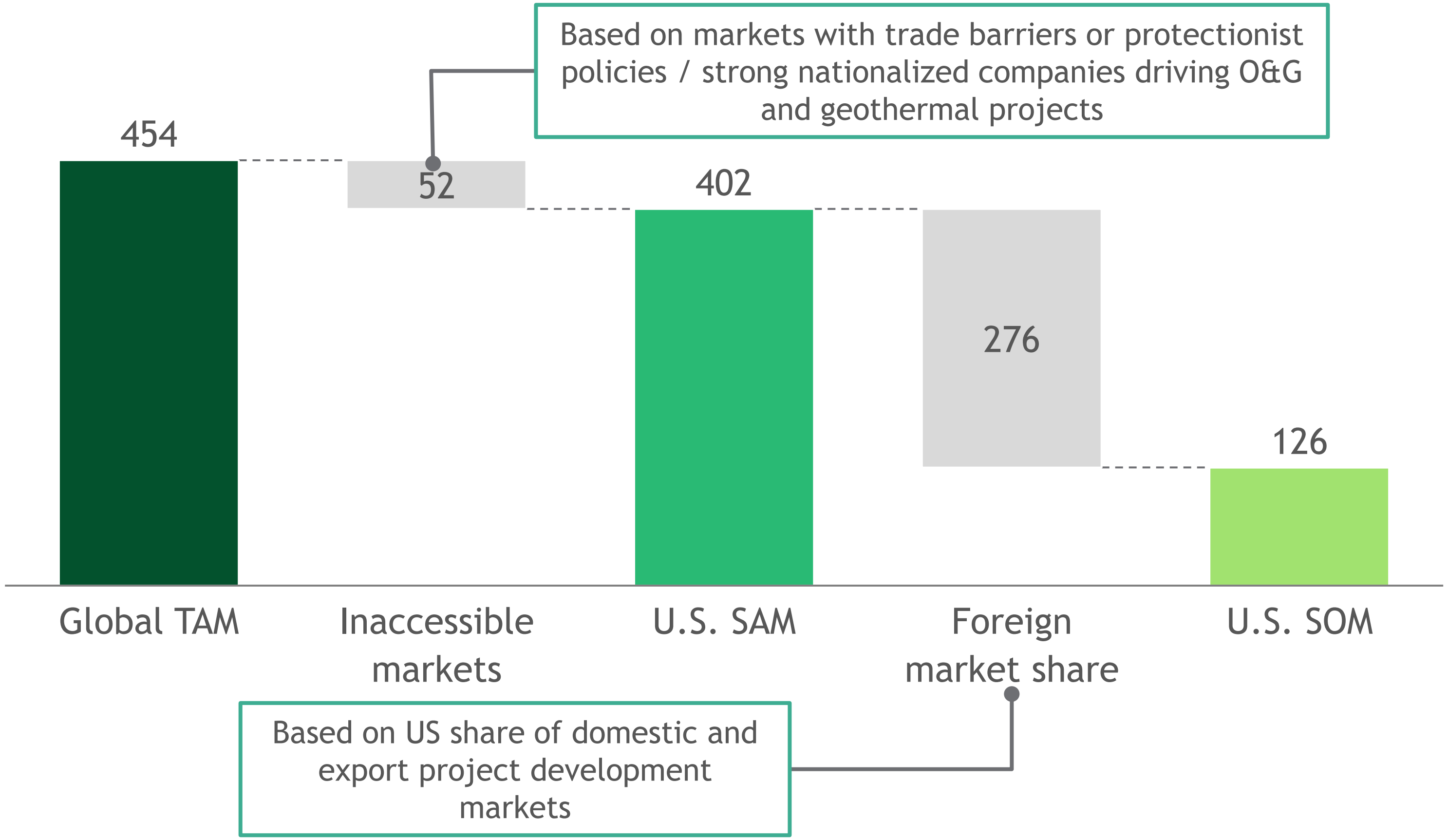
Project Development | U.S. projected to own high share of domestic market (~90%) & low share of export market (~20%) leading to U.S. SOM of ~$125B

APS market sizing metrics

Cumulative market value, 2020 – 2050 *($B)*



Walk from TAM to SOM under APS scenario



Based on markets with trade barriers or protectionist policies / strong nationalized companies driving O&G and geothermal projects

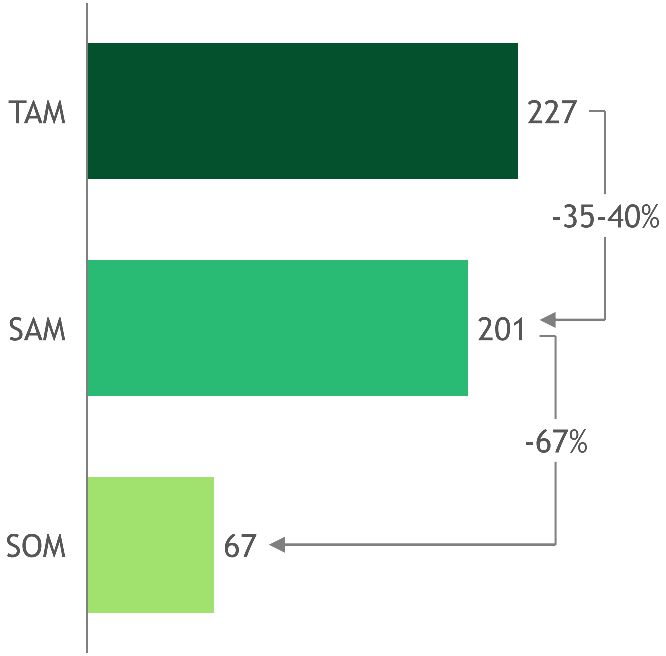
Based on US share of domestic and export project development markets

Note: SAM excludes Russia and China due to existence of major, nationalized companies handling project development in each. SOM assumed ~90% for domestic market and ~20% of export market based on US share of project development market for geothermal both domestically and abroad
Source: IEA World Energy Outlook 2022, CEP, BCG analysis

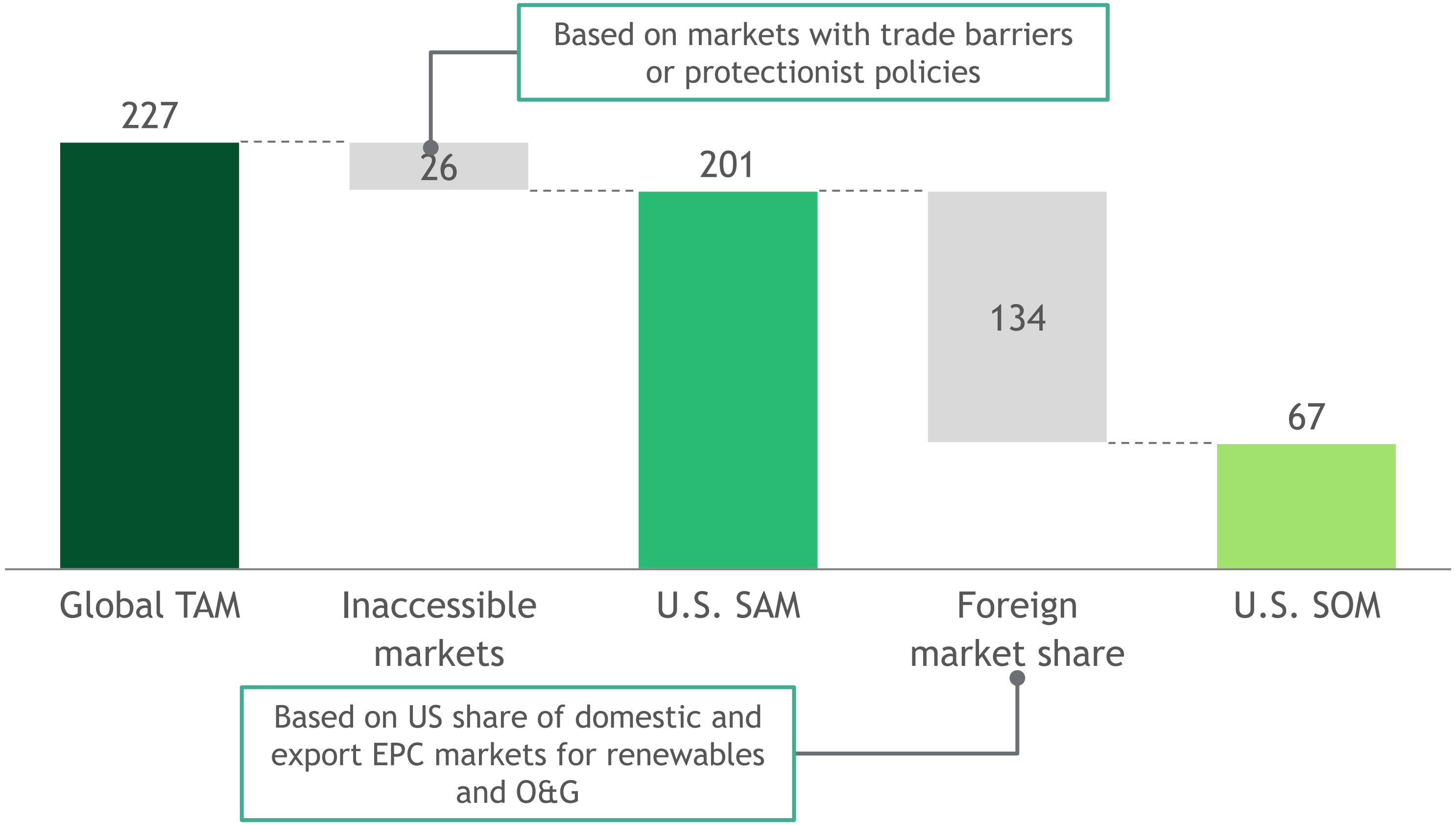
EPC | U.S. projected to own high share of domestic market (~90%) & low share of export market (~20%) leading to U.S. SOM of ~$70B

APS market sizing metrics

Cumulative market value, 2020 – 2050 *($B)*



Walk from TAM to SOM under APS scenario



Based on markets with trade barriers or protectionist policies

Based on US share of domestic and export EPC markets for renewables and O&G

Note: SAM excludes Russia and China due to existence of major, nationalized companies handling project development in each. SOM assumed ~90% for domestic market and ~20% of export market based on US share of project development market for geothermal both domestically and abroad

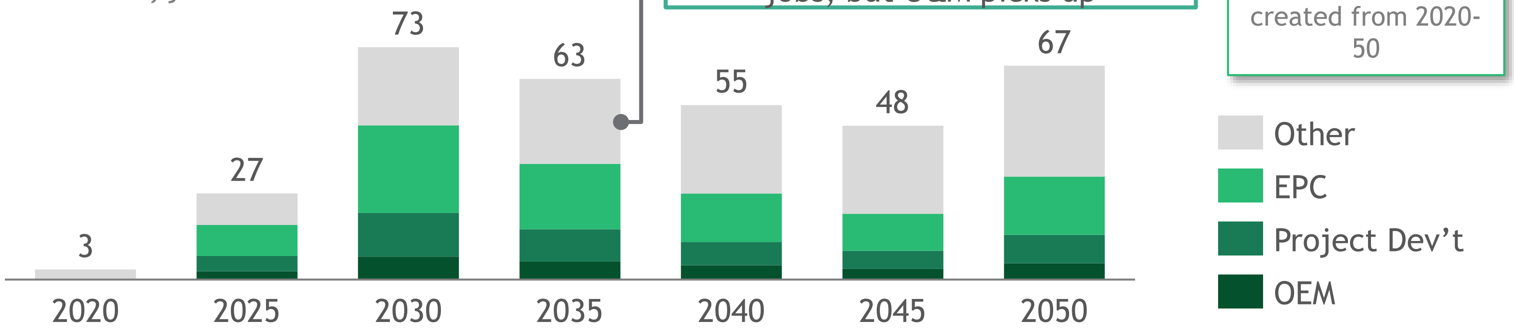
Source: IEA World Energy Outlook 2022, BCG analysis

~100K jobs expected to be created by 2050 with EPC and O&M the major drivers making up >55% of total jobs created

Strong jobs growth seen from 2022-2035 before tapering off after 2040 as CAPEX spend on new geothermal declines

Total geothermal jobs in each year

Thousands of jobs

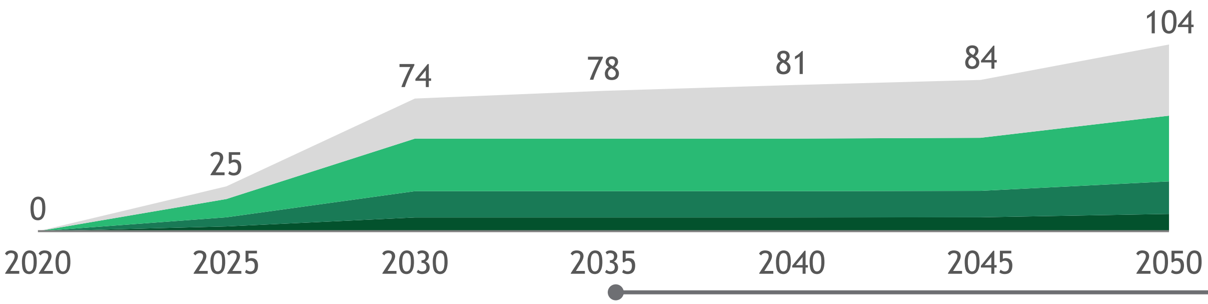


Deployment slows post-2030, reducing EPC & Project Dev't jobs, but O&M picks up

~1.5-2.0M
Total job-years created from 2020-50

New jobs created (cumulative)[1]

Thousands of jobs



Jobs slowdown as annual deployments decline & export market outpaces domestic

Jobs created in OEM segment
~10K
~$95K/yr
Avg. annual salary

Jobs created in PD[2] segment
~18K
~$100K/yr
Avg. annual salary

Jobs created in EPC segment
~40K
~$85K/yr
Avg. annual salary

~100K
Total jobs created by geothermal

Note: Geothermal also supports an equitable transition as job skills from O&G are directly applicable to geothermal

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1. In APS scenario; incremental new jobs calculated as the sum of all non-negative one-year differences in # job-years (e.g., 2021 job-years minus 2020 job-years gives 2021 new jobs); incremental new jobs added to sum from prior period for cumulative calculation 2. Project development

Source: IEA, BCG analysis

Project Development | U.S. can leverage advantages in O&G tech and expertise and nascent startup industry to lead in project development

☆ = *Key dimension*

Areas for Competitive Advantage	Ranking	Summary analysis
Raw material availability	High	• Most materials (e.g., steel, iron, aluminum) are readily available • US has some of the richest geothermal resources in the world, estimated by the DOE to be over 500 GW with <5 GW developed today
☆ **Intellectual Property & innovation**	High	• O&G industry leads in exploration and drilling patents - three US companies (Haliburton, Schlumberger, and Baker) represent nearly 40% of the patents held by the top 10 firms globally • New technologies like enhanced geothermal systems (EGS), seismic advances (e.g., full wavefield inversion, wireless micro electro-mechanical systems, and vertical seismic profiling), and downhole sensors improve exploration and reduce cost
Research & technical leadership	High	• While China leads the research volume, US (in 2nd place) produces higher quality research with 33% more citations per publication • Research activity in the US is led by the DOE in (4th globally) and U. of California - all campuses (13th globally) • US has strong existing developers, led by Ormat, and can leverage O&G developers like Haliburton and Schlumberger
Low operational costs	Low	• US and EU manufacturing labor is significantly costlier than other markets (~$50/hr in the US & EU vs ~$10/hr in China & Brazil and ~$25/hr in Japan & Korea), with similar rankings but less extreme differences in labor costs for R&D and engineering roles • Due to favorable geological characteristics, heat is often closer to the surface in the US, reducing project costs and increasing efficiency of the system
Demand / supply side policy	High	• IRA/IIJA extended the ITC/PTC for geothermal and gave a longer runway for development (2035), providing much needed long-term clarity for developers • 48C advanced energy project credit of 30% of investment cost; IRA credits can decrease US LCOE by up to 30% • Other sources of funding is limited, even when compared to smaller energy industries like nuclear
☆ **Relative domestic market maturity**	High	• US has deployed 3.7 GW of geothermal - more than any other country - and represents 20% of the global capacity • A strong legacy O&G industry contributes to the maturity of the technology, supply chains, and labor force domestically • CA has set a target for an additional 1 GW by 2030 and already contributes 6% of the state's overall production
☆ **Regulatory environment & existing infrastructure**	Low	• Regulation and permitting cause delays and increase costs, slowing domestic deployment which is critical for developers to climb the learning curve and achieve scale • It takes an average of 7-10 years to develop a geothermal plant in the US. Of that, 4-6 years is permitting due to a poor regulatory environment that makes it significantly easier to get a permit for an O&G project.
Overall ranking		The US is already a leader in both geothermal and O&D development and can build on its position by improving the policy and regulatory environment

OEM | US has fallen behind OEMs in Asia but has opportunity to lead in new technologies like closed-loop, binary, and lithium extraction

✪ = *Key dimension*

Areas for Competitive Advantage	Ranking	Summary analysis
Raw material availability	N/A	• Most materials (e.g., steel, iron, aluminum) are readily available
✪ **Intellectual Property & innovation**	Low	• Innovation concentrated in Asia, with China leading and the US a distant 4th • US patent activity has been growing at a modest 3% since 2016 • Ormat leads the US and ranks 5th globally • Opportunity exists in next-gen technologies like mining (lithium extraction), closed-loop systems, and more efficient binary plants
✪ **Research & technical leadership**	High	• While China leads the research volume, US (in 2nd place) produces higher quality research with 33% more citations per publication • Research activity in the US is led by the DOE in (4th globally) and U. of California (13th globally)
Low operational costs	Low	• US and EU manufacturing labor is significantly costlier than other markets (~$50/hr in the US & EU vs ~$10/hr in China & Brazil and ~$25/hr in Japan & Korea), with similar rankings but less extreme differences in labor costs for R&D and engineering roles • US electricity prices are lower than in EU and Japan but more expensive than China, India, and Russia while US natural gas prices are amongst the lowest in the world after Russia
Demand / supply side policy	Low	• Clean energy manufacturing tax credits were limited to other technologies and do not apply to geothermal • Bonus 10% ITC credit is given to developers who meet the domestic content requirements (DCR) of at least 40% of total costs must be attributable to domestic US manufacturing; this is at par with many other countries such as UK, India having 40-60% DCR
Relative domestic market maturity	High	• Outside of Ormat, which manufactures its own equipment, the US does not have many strong OEMs • US has deployed 3.7 GW of geothermal - more than any other country - and represents 20% of the global capacity • CA has set a target for an additional 1 GW by 2030. It already contributes 6% of the state's overall production • Salton Sea project is the largest lithium extraction geothermal hybrid plant in the world
Regulatory environment & existing infrastructure	High	• Bonus 10% credit is given to manufacturers who meet the domestic content requirements (DCR) of at least 40% of total costs must be attributable to domestic US manufacturing; this is at par with many other countries such as UK, India having 40-60% DCR
Overall ranking	🟨	Current OEM market is dominated by Asia, making it unlikely the US will be able to capture market share in mature technologies. However, it has an opportunity to lead in new technologies and leverage its domestic market and research foundation.

EPC | U.S. in strong position to continue winning in domestic market with potential for exports

☆ = *Key dimension*

Areas for Competitive Advantage	Ranking	Summary analysis
Raw material availability	N/A	• EPC competitive advantage is not driven by raw materials
Intellectual Property & innovation	N/A	• EPC competitive advantage is not driven by patents
☆ **Research & technical leadership**	High	• Highly integrated with project development • US has abundance of project developers and EPCs in geothermal and O&G with technical leadership and expertise • While China leads the research volume, US (in 2nd place) produces higher quality research with 33% more citations per publication • Geothermal projects are custom designed due to the changing qualities of the geology, reservoir, and style of plant • The emergence of hybrid plants (e.g., power generation with district heating, lithium extraction, or other output) adds complexity to the design and build
Low operational costs	Low	• US average wages significantly higher than any other region with average income per month ~$6K while the EU's is ~$4K, Japan's & South Korea's are ~$3K, China's & Russia's are ~$1K, and India's is ~$200
Demand / supply side policy	N/A	• EPC competitive advantage is not driven by demand or supply side policy
☆ **Relative domestic market maturity**	High	• Outside of Ormat, which manufactures its own equipment, the US does not have many strong OEMs • US has deployed 3.7 GW of geothermal - more than any other country - and represents 20% of the global capacity • CA has set a target for an additional 1 GW by 2030. It already contributes 6% of the state's overall production
Regulatory environment & existing infrastructure	Low	• It takes an average of 7-10 years to develop a geothermal plant in the US • Extended timelines leads to less projects being built in the US, less scaling, and slower learning
Overall ranking	🟩	U.S. has high competitive advantage domestically today, but in order to open export opportunities, it will need to focus on developing a competitive edge in new hybrid plants and efficient designs. The fastest way to accomplish this is to remove regulatory barriers, taking advantage of a larger domestic market and rich geothermal resources, and expedite deployment - leading to greater scale and faster learning.

IRA/IIJA tax credits reduce cost of geothermal but did not address several important policy gaps

	Priority issues for geothermal	Changes from recent legislation (IRA, IIJA, CHIPS, and EA 2020)	Remaining areas to target with future policies
OEM	**Shortage of funding for commercialization-focused programs**	• Energy Act of 2020 – Advanced Geothermal Innovation Leadership (AGILE) Act • IIJA included $80 M in funding for EGS	☆ Continued shortage of funding for commercialization-focused programs
Project development	**Lack of quality data characterizing the subsurface**		☆ Continued lack of data and characterization of subsurface
	Obstructive permitting and regulations		☆ Permitting and regulations problems remain unaddressed
Financing	**High financing costs due to long timelines and increased risk**	• Extension ITC at 30% ITC and 10% bonus if requirements are met. Applies to facilities after 2024 and phases down in 2035	• Expired government financing, cost-sharing, and risk insurance programs
EPC	**Lack of procurement targets for hybrid plants**		☆ Continued lack of procurement targets for hybrid plants at the federal level, opportunities to develop large direct heat and power generation projects
Offtake	**Limited baseload or firm generation requirements in RPS**	• IRA starts to treat geothermal more like clean tech	☆ Outside of CA, limited baseload or firm generation requirements in RPS to incentivize dispatchable resources
	Lack of consistent subsidies compared to other clean resources	• PTC extension for electricity for geothermal. Up to 1.5 cents/kWh Phases down in 2032, giving more long-term clarity	• Concern the credits won't be permanent • Subsidies for other resources are more generous, reducing competitiveness

Source: NREL, DOE, IIJA, IEA, CTVC IRA Tracker, BakerHostetler, RMI, Energy Act of 2020, BCG Analysis

☆ Priority areas

Deep dive | Detailed list of potential advanced geothermal policy actions to support U.S. competitiveness

Policy-based Investment-based ☆ Key interventions

	Demand side	Supply side
Technology-wide	☆ Incentivize zero-carbon firm power and capacity • Create a designated geothermal agency to raise awareness and harmonize regulations and permitting requirements • Include heating and cooling in emission standards • Set government procurement targets for district heating and direct use	• Continue demonstration projects in lithium extraction ☆ Launch commercialization-focused cost-sharing programs to prioritize technologies like supercritical wells and enhanced geothermal systems ☆ Streamline domestic permitting, review, and approval timelines for geothermal projects • Extend lifetime for tax credits to provide long-term certainty for developers
Project Development	☆ Set target for new geothermal leases on federal land and require BLM to hold auctions more frequently than every two years	• De-risk private investment in new development via loan guarantees, risk insurance, and/or tax credits • Facilitate partnerships with O&G companies to attract capital and transfer expertise
OEM		• Continue to facilitate research collaboration among National Labs, universities, and the private sector • De-risk private investment in geothermal manufacturing facilities through manufacturing tax credits
EPC	• Procure geothermal projects for relevant govt. facilities (e.g., national labs, military bases) to incentivize private investment in geothermal	☆ Streamline permitting process for geothermal projects to give domestic EPC firms geothermal experience

Overview of key assumptions

Assumption	Value	Impact on Calculations	Source
Projections of geothermal capacity	*Varies by year, market, and scenario*	Geothermal capacity is predicted by applying 2019 geothermal-per-country %'s to the IEA 2022 total geothermal projections. These capacity predictions form the basis of all other calculations; however, they can be slightly conservative since they do not capture the potential of new technologies (EGS and deep drilling) to expand what is technically and economically possible for geothermal.	IEA 2022/2019 World Energy Outlook
Power generation vs. district heating	*Varies by year and market*	Current ratios of district heating to power generation by country and the 2011 IEA report were used to determine the appropriate capacity ratio to apply to the IEA power generation forecasts.	IEA Geothermal Roadmap and current country data
Split of CAPEX by value chain	*Varies by fixed vs. floating*	The CAPEX %'s create a split per value chain from the total capital costs, which in turn informs segment prioritization. Since the NREL analysis is made for 8.0-MW turbines, expert input refined the %'s to match larger turbines used today.	2022 NREL Annual Technology Baseline
Operating expenses	*Varies by year and by fixed vs. floating*	OpEx is used to calculate the market size for O&M and have an impact on total market size numbers as well as value chain prioritization.	2022 NREL Annual Technology Baseline
U.S. SAM	*Varies by value chain and mostly is limited to the Americas*	The addressable market is used to calculate the obtainable market (SOM). The offshore wind SAM is conservative and only includes countries where the U.S. has a realistic opportunity to expand into given economic and political barriers.	Expert input & BCG analysis
U.S. SOM	*Varies by value chain and domestic vs. export SAM*	SOM calculations have an impact on jobs numbers and jobs growth and inform what the opportunity is in the U.S. and abroad.	Expert input & BCG analysis

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