Two Paths to US Competitiveness in Clean Technologies

March 2023

By Karan Mistry, Nico deLuna, Tina Zuzek-Arden, Thomas Baker

Commissioned by

1 Executive Summary

Historic opportunities: The need for technical solutions to address climate change and move toward a new, decarbonized reality presents one of the greatest challenges and opportunities of our time. As the world's largest economy, global innovation leader, and financial powerhouse, the United States has an opportunity to accelerate the global race to net zero and help avert the worst effects of the climate crisis. Building early U.S. leadership will speed decarbonization globally and bolster domestic energy security, economic growth, and job creation.

Continuing previous work: This report builds on a previous Boston Consulting Group study[1] that assessed where along the value chain the U.S. can build competitiveness in six clean technologies.[2] This time, we expand our focus to solar photovoltaics (PV); offshore wind; carbon capture, utilization and storage (CCUS); and geothermal technologies. Unlike the previous six technologies assessed, these four additional technologies are relatively mature and directly benefit from the Inflation Reduction Act (IRA) and Infrastructure Investment and Jobs Act (IIJA), particularly solar PV and offshore wind.

Collectively, the 10 assessed technologies are forecast to drive global market opportunities of ~$130–140 trillion through 2050, and can unlock ~30 Gtpa in emissions reductions, which is nearly ~60% of annual global emissions.[3] Beyond these economic and abatement benefits, boosting U.S. competitiveness in high-priority activities along the value chain will also support a clean and secure domestic energy supply, spur the revitalization of atrophied U.S. manufacturing capabilities, and facilitate reduced dependence on critical imports from countries of concern. While recent legislation provides policy foundations needed to commercialize these technologies domestically, additional action is required to fully realize the economic and climate benefits at home and abroad.

Significant domestic benefits: The U.S. has an opportunity to bolster energy security, accelerate decarbonization, and enhance both economic and job growth by boosting competitiveness in solar, offshore wind, CCUS, and geothermal.

These four technologies hold a key role in supporting carbon-free U.S. energy security, with a combined projected share of ~45-50% of 2050 domestic power generation.[4] Solar PV alone is expected to account for ~35-40%, increasing the importance of a diverse and resilient U.S. supply chain. Beyond energy security, these technologies are projected to drive significant domestic economic benefits; combined, they are projected to

---

[1] How the US Can Win in Six Key Clean Technologies

[2] The prior report focused on the following six technologies: electric vehicles (EVs), clean steel, low-carbon hydrogen (H_2), electrochemical long-duration energy storage (LDES), direct air capture (DAC), and advanced nuclear small modular reactors (SMRs)

[3] Bill Gates, "How to Avoid a Climate Disaster"

[4] International Energy Agency 2022 World Energy Outlook

comprise a U.S. addressable market of $7-9 trillion through 2050, with potential to drive ~$25-30 billion in annual exports through 2050, roughly equal to 2020 U.S. grain exports.[5] Together, this increased economic activity is estimated to create 750,000-800,000 new domestic jobs through 2050, roughly the size of the current U.S. chemical manufacturing industry.[6]

A tale of two markets: The U.S. faces starkly different paths to competitiveness across the four technologies assessed, based largely on the presence of entrenched foreign incumbents. The U.S. has ceded leadership in the most mature technologies like solar PV and offshore wind, leaving a narrow path to recapturing the domestic market based on provisions in recent legislation. However, technologies like geothermal and CCUS, which have not yet seen the explosive growth of wind and solar, present an opportunity for early U.S. leadership to catalyze global growth of these industries, driving both domestic and export market growth.

Recapturing the lost domestic market*:* Enhanced U.S. competitiveness can drive a recapture of solar PV and offshore wind domestic market share from entrenched incumbents, enabling a push into select regional export markets that benefit from proximity and favorable trade regimes. The U.S. has ceded leadership in solar and offshore wind to established competitors, with 85-95% of solar manufacturing concentrated in China and Southeast Asia and >95% of offshore wind deployments and manufacturing concentrated in Europe and China. However, recent IRA and IIJA legislation provides significant incentives for U.S. investment across the solar PV and offshore wind value chains. For example, solar PV provisions in the IRA are estimated to make domestically manufactured modules ~30% cheaper than imports, incentivizing investment in domestic supply to offset imports and serve growing domestic demand. Additionally, offshore wind provisions in the IRA support domestic manufacturing and infrastructure, positioning the U.S. to serve not only growing domestic demand but potentially regional demand, as well.

Despite substantial IRA and IIJA support, the U.S. must overcome significant challenges to gain and expand long-term competitiveness in the domestic market. These obstacles include:

- **High domestic manufacturing costs** (e.g., labor, energy, etc.), which can be partially offset by rapidly capturing economies of scale and deploying innovations and automation in legacy manufacturing processes.
- **A shortage of skilled labor and expertise** that must be addressed via workforce training programs, supportive immigration policies, and reskilling legacy workers.
- **Near-term trade, infrastructure, and regulatory uncertainty** that chills investment and can be resolved via transparent policy reforms.

---

[5] Trading Economics: United States Exports By Category

[6] Employment and output by industry: U.S. Bureau of Labor Statistics (bls.gov)

- **Loss of IP and innovation leadership,** which can be addressed with targeted research, demonstration, and commercialization support, as well as rebuilding domestic manufacturing capabilities and ecosystems.
- **Insufficient transmission infrastructure,** which prevents new solar PV and offshore wind from being interconnected in a timely manner, and can be addressed with expedient interconnection reform and streamlined transmission permitting and cost allocation.

Catalyzing global growth through leadership*:* The U.S. is a global leader in CCUS and geothermal technologies and is positioned to both catalyze and capture growing global demand. The U.S. is the world's largest geothermal and CCUS market, with ~25% and ~65% of global geothermal and CCUS capacity, respectively. U.S. players are well positioned to leverage U.S. intellectual property (IP) and expertise in the legacy oil & gas (O&G) space to lead in project development and engineering, procurement, and construction (EPC) activities, which have significant overlap with innovative geothermal technologies (e.g., Enhanced Geothermal Systems, EGS) and large-scale CCUS infrastructure. While both technologies have limited global deployment today, continued technical innovations and policy developments present opportunity for significant growth, especially in high-potential markets like South Africa and Indonesia.

The U.S. can capitalize and build on its current leading position in CCUS and geothermal to capture first-mover advantages and catalyze growth of global markets by utilizing the following strategies:

- **Commercializing and demonstrating innovations**, such as EGS, to build durable competitive advantage and increase demand by improving project economics.
- **Clearing inhibitors to domestic deployments** like burdensome permitting processes to accelerate early learnings and capture economies of scale, such as with large-scale CCUS hubs and infrastructure and greenfield geothermal developments.
- **Sending strong demand-side signals** to incentivize firms to adopt low-carbon energy and increase economic potential of both technologies.
- **Data-sharing of subsurface geologic formations** to build on U.S. advantages and legacy oil & gas experience.

A clear path to leadership: While the specifics for each technology vary, the U.S. can build on a history of innovation and become a leader across all four technologies by accelerating domestic deployment and rebuilding U.S. manufacturing expertise. Achieving scale in both installed capacity and manufacturing drives these technologies down the cost curve and supports U.S. research and technical leadership through increased iteration and innovation.

Contents

2 Brief overview of analysis and approach

2.1 Assessment objectives

Similar to the prior study, *How the US Can Win in Six Key Clean Technologies*, this assessment aims to boost U.S. competitiveness in four clean energy technologies – solar, offshore wind, CCUS, and geothermal – in support of economic growth while accelerating the transition to a net zero economy at home and abroad.

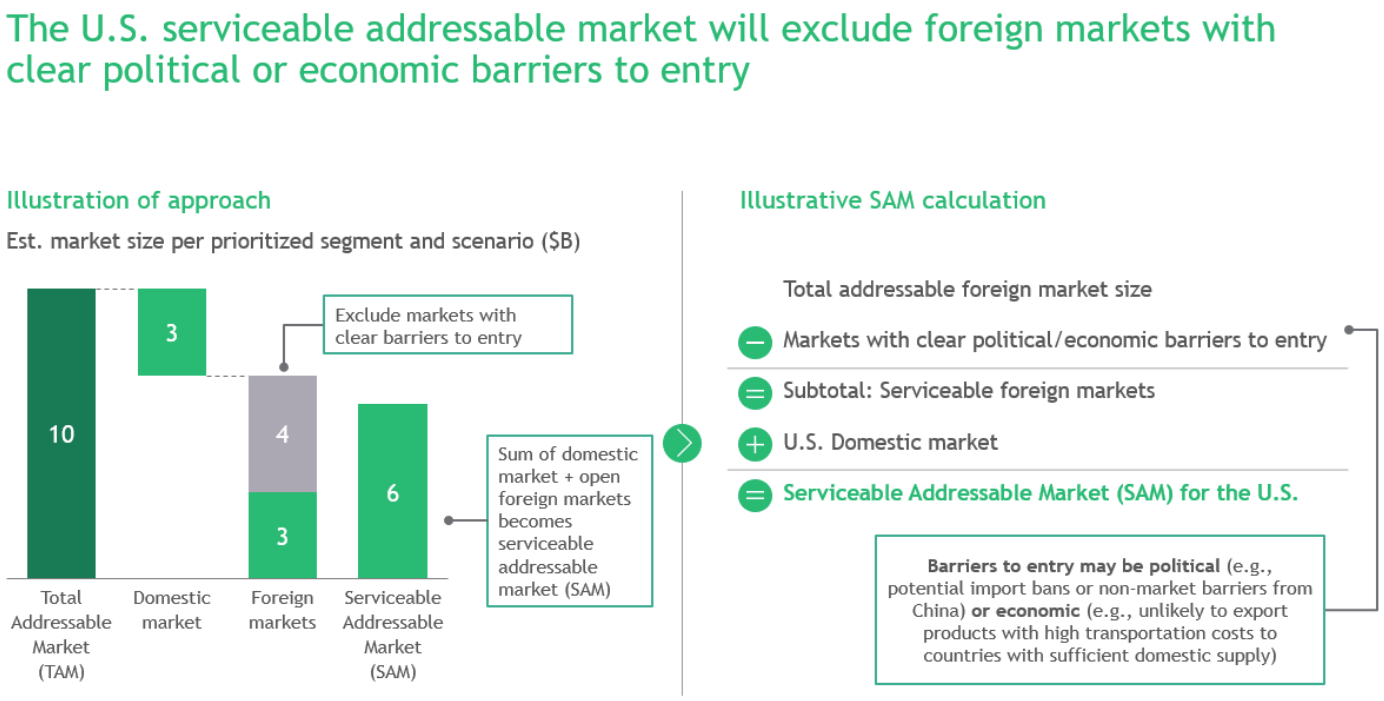
2.2 Metrics assessed

2.2.1 Total Market Value

By leveraging a diverse set of sources, including the International Energy Agency (IEA), National Renewable Energy Laboratory (NREL), International Renewable Energy Agency (IRENA), and Energy Information Administration (EIA), we calculated market sizes through 2050, using 2022 U.S. dollar value. We assessed the market opportunity for the U.S. by value chain segment in three ways:

- Total addressable market (TAM) – the total global market size
- Serviceable addressable market (SAM) – the total global market excluding countries where U.S. exports are unlikely, with detailed outlook on priority target markets (see Figure 2.1 below)
- Serviceable obtainable market (SOM) – the fraction of the addressable market the U.S. could feasibly capture.

The serviceable obtainable market metric is meant to give a range of plausible U.S. domestic and export values and can be impacted by how the U.S. acts today to build competitive advantage in the future.



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

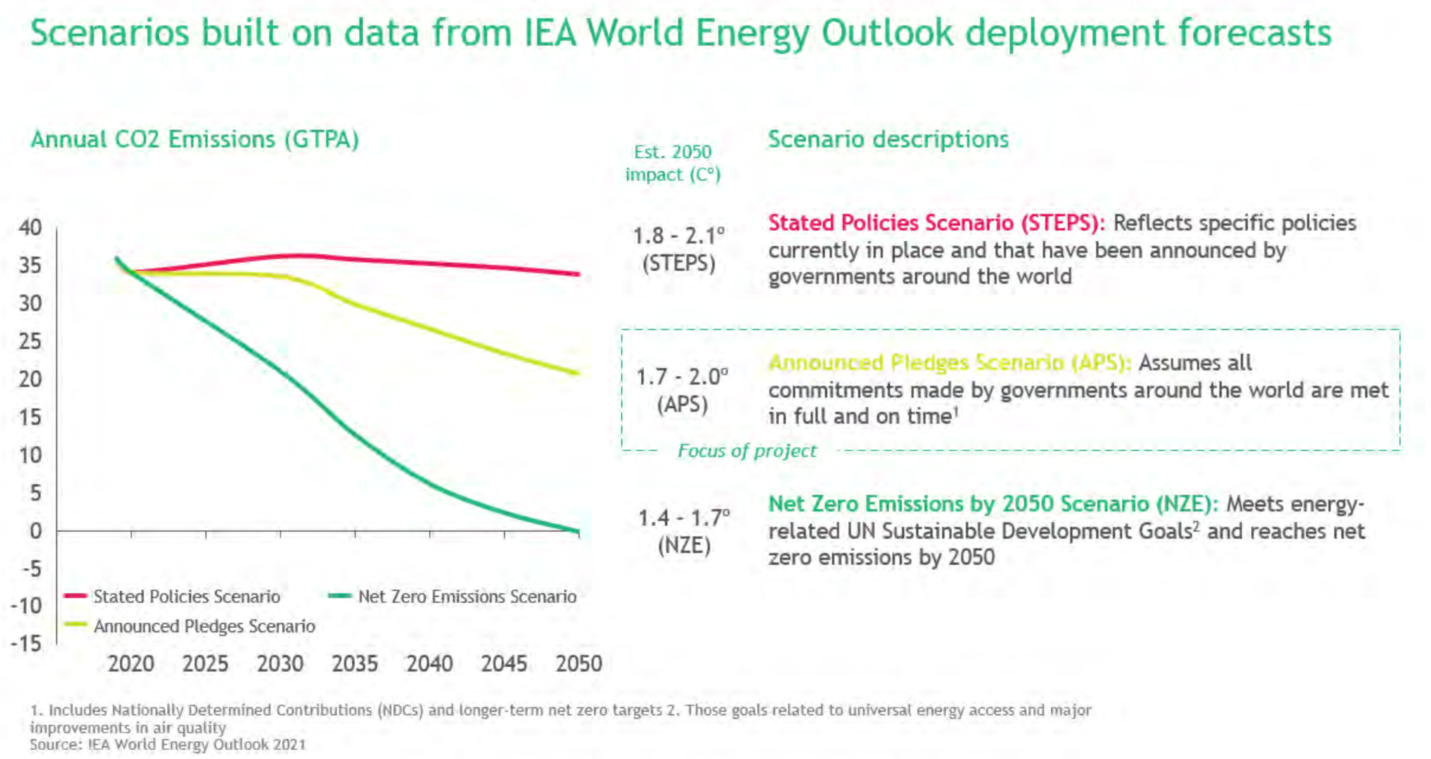
+ U.S. Domestic market

= 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)

Figure 2.12: Illustration of serviceable addressable market (SAM) approach

To account for the potential variability in technology deployment and emissions reductions over the next 30 years, we considered three scenarios directly tied to global emissions reductions:



Scenarios built on data from IEA World Energy Outlook deployment forecasts

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]

Focus of project

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

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

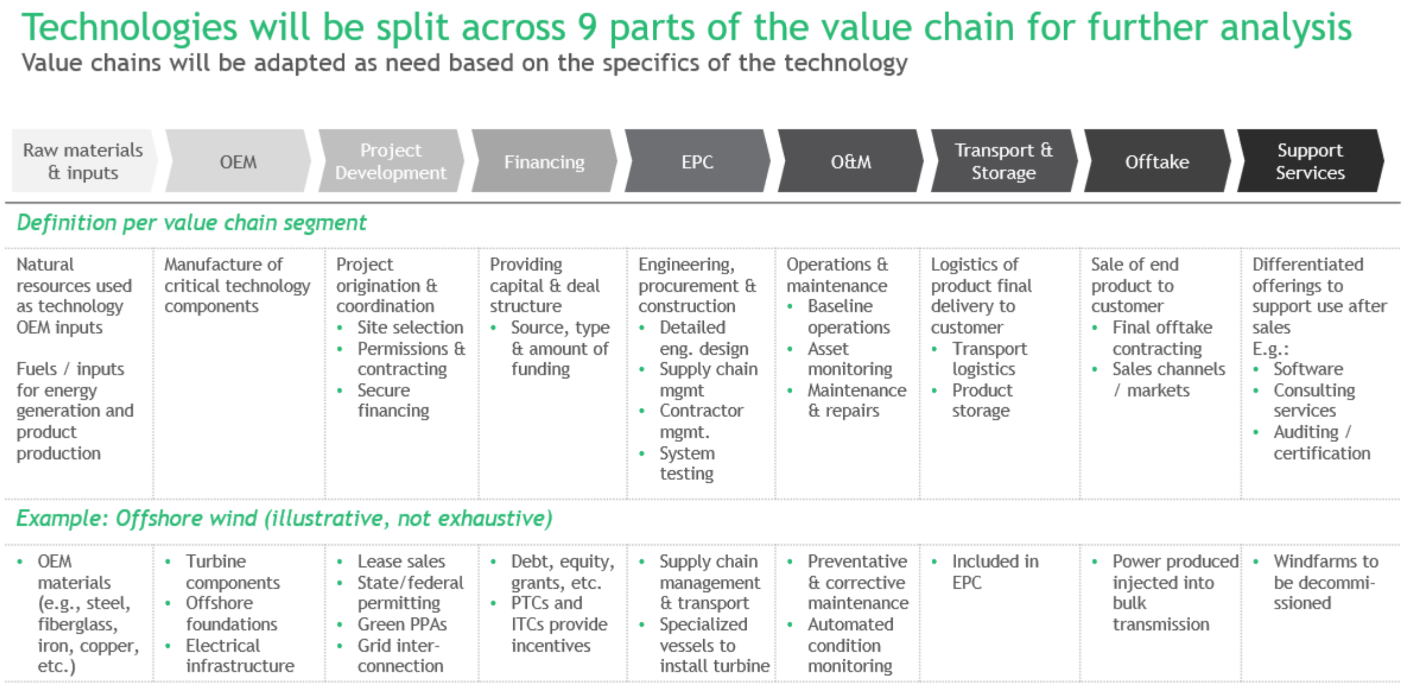
Figure 2.2: Overview of market scenarios modeled

This study conducted modeling for each scenario. Ultimately, comparisons and final determinations for prioritization were determined using the IEA's Announced Pledges Scenario (APS), which represents an ambitious middle target for emissions reduction and can therefore be viewed as cautiously optimistic.

Market sizes estimated in this work are highly sensitive to a given scenario, so it is imperative to note which scenario is being used to inform market sizes, competitive environments, and recommendations.

2.2.2 Opportunity for U.S. competitive advantage

The four technologies above were broken down into specific value chain segments to enable more granular market analyses, jobs impact projections, and assessments of the U.S. competitive advantage. Value chain segments for analysis reflected the following standardized list of critical segments in Figure 2.3, with some modifications across technologies:



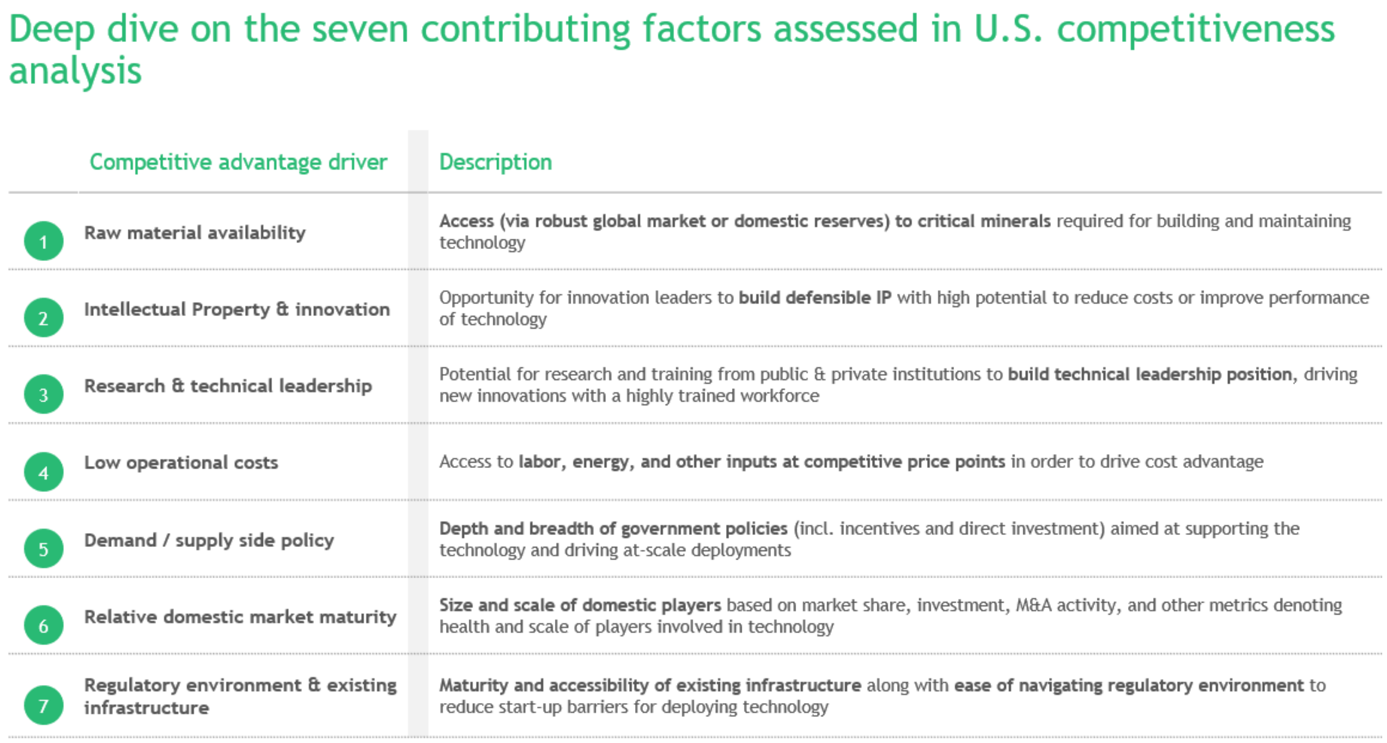
Technologies will be split across 9 parts of the value chain for further analysis

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

Figure 2.3: Illustrative value chain breakdown

Next, we prioritized a subset of value chain segments with strong market potential and capacity for the U.S. to develop a durable competitive advantage. For each of these prioritized segments, we performed a detailed qualitative and quantitative evaluation of competitiveness that spanned the following seven dimensions:



Deep dive on the seven contributing factors assessed in U.S. 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

Figure 2.4: Competitive drivers assessed

As a result of the analysis, we assigned competitive advantage factors a ranking of “high” or “low”. A factor was considered a “key dimension” within a given value chain segment if it was a critical unlock, in that it enabled a country’s competitive participation in the segment.

Based on the relative market potential and U.S. current competitive positioning, the prioritized value chain segments were placed in a matrix to guide where relevant policies should focus time and effort, shown in Figure 2.5 below:

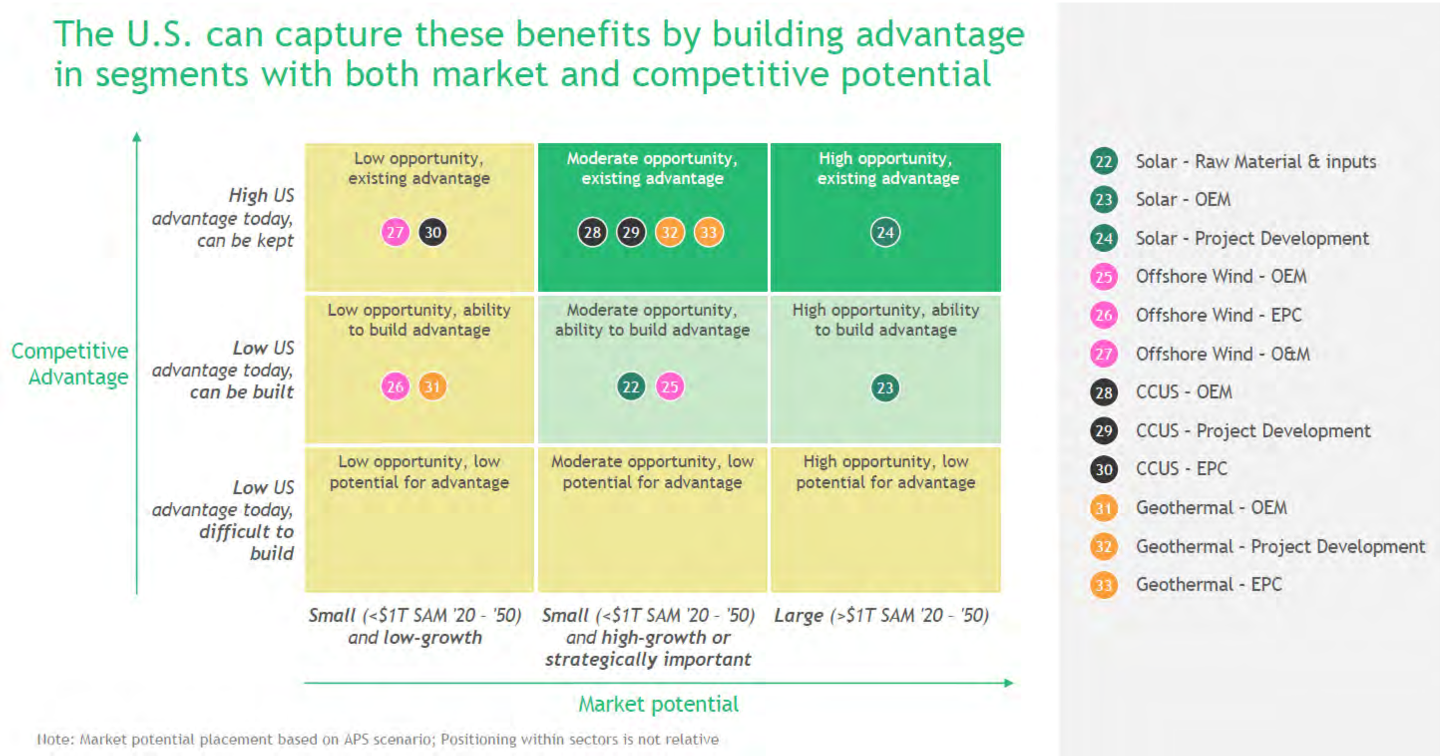


Figure 2.5: Matrix of technology value chain segment prioritization results

2.2.3 Analysis of job creation

The third level of analysis focused on U.S. socioeconomic impact measured through domestic job creation. For each technology value chain segment, we estimated the total employment (in number of job-years) and total number of new positions created, including domestic and export-driven jobs, using the following process:

After estimating labor expense as a percentage of total spend for each value chain segment, we applied this number to U.S. SOM, estimating the total labor spend driven by domestic and export market sales. NAICS data from the Bureau of Labor Statistics (BLS) was then to estimate the average salary per individual for relevant types of work in the associated value chain segment activities. We then divided total labor spend by average annual salary to estimate the total annual employment in job-years. Figure 2.6 below illustrates this approach:

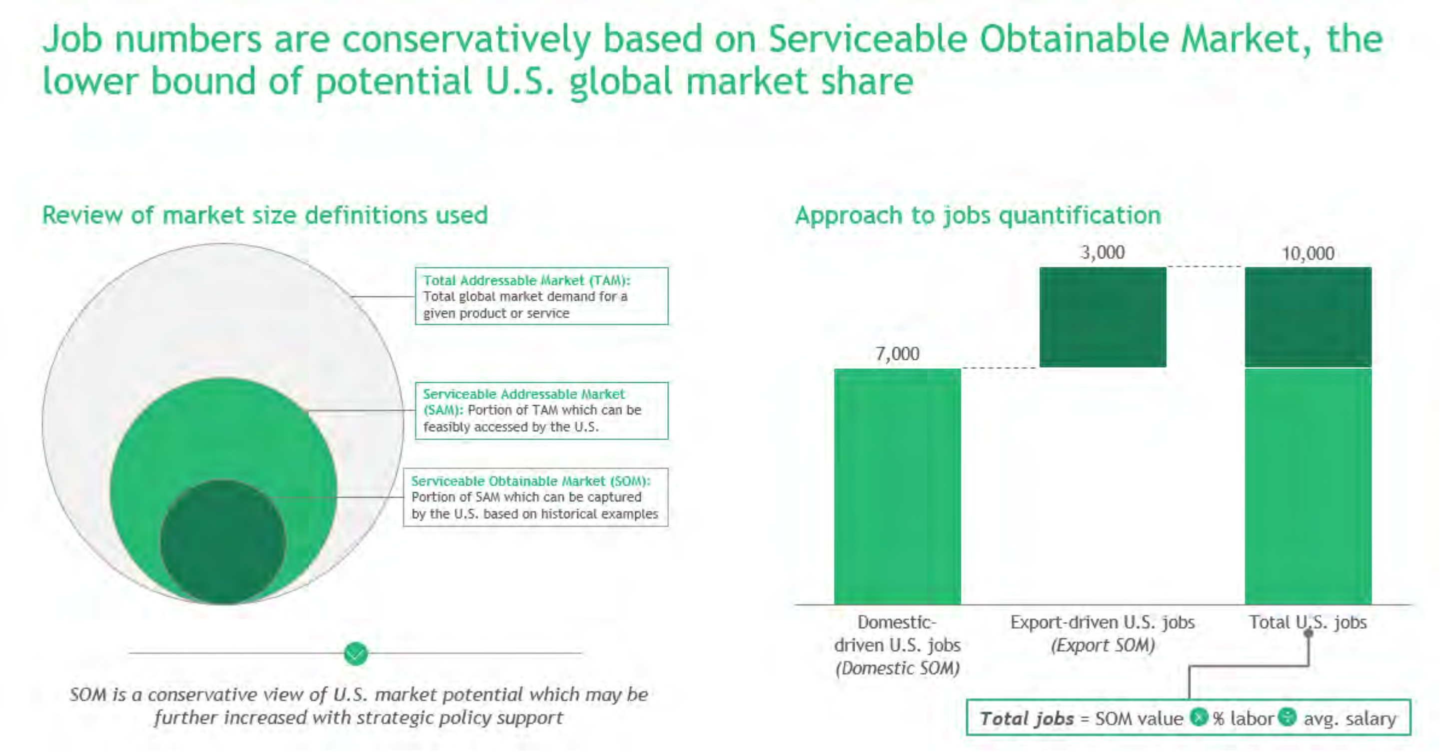


Figure 2.6: Job calculation approach

3 Solar PV

3.1 Solar PV executive summary

The significant role solar PV will play in the U.S. energy transition creates an economic and strategic opportunity to reclaim domestic market share in the solar manufacturing space. IRA/IIJA incentives make it economically attractive for developers use U.S.-manufactured panels in domestic solar projects, reducing reliance on imports and opening a path for the U.S. to regain IP and innovation leadership in the solar space.

Solar will be one of the largest sources of energy globally (~11,000 GW installed by 2050[7]) and account for 35-40% of U.S. power generation, compared to 3% today. With an abatement potential of ~7,300 Mtpa and a global market size of $15-16 trillion from 2020-2050, solar will be crucial to achieve global decarbonization goals and economic growth. Of this significant global potential, the U.S. has an opportunity to capture a portion of the $4.0-4.5 trillion addressable market from 2020-2050. For the U.S., building a resilient and diverse supply chain, with increased domestic activity, will be critical for energy security and competitive leadership. Boosting U.S. solar manufacturing and deployment may also create over 550,000 domestic jobs from 2020-2050, with project development, EPC, and operations and maintenance (O&M) driving most of the job growth.

The U.S. has ceded leadership in solar manufacturing to China and Southeast Asia, which combined hold 75-97% market share across main upstream manufacturing activities, due to entrenched cost disadvantages. This has led to a staggering >90% of modules for U.S. domestic solar projects being imported from Southeast Asia in 2019. However, recent legislation such as IRA/IIJA provide significant supply- and demand-side support for rebuilding domestic solar manufacturing and incentivizing new project deployment, particularly using U.S.-produced components. These policies will help decrease the U.S. solar levelized cost of energy (LCOE) by

---

[7] IEA World Energy Outlook 2022 (APS scenario)

~40%[8], increase solar deployment by ~75% through 2050, and make U.S.-produced modules ~30-40% cheaper than imported modules.

For long-term competitiveness, the U.S. needs to address major challenges such as high capital requirements to set up manufacturing facilities, high module production costs, high import costs of manufacturing equipment, the lack of a skilled solar-trained workforce, and delays in project deployment due to long interconnection queues. The U.S. can accelerate manufacturing and deployment by building on IRA/IIJA provisions through the following actions:

- Investing in vertically integrated manufacturing, automation, and R&D at scale, which may help offset more costly U.S. labor, overhead, and capital expenditures.
- Enabling maximum upside of the IRA incentives by implementing new policies providing loan guarantees and cost-sharing agreements to de-risk investment in capital-intensive manufacturing facilities, as well as re-assessing tariffs and stringent certifications for solar PV manufacturing equipment.
- Facilitating maximum solar deployment by improving transmission planning and interconnection processes, and investing in grid expansion to reduce connection delays.
- Addressing the shortage of solar-skilled manufacturing labor by expanding and establishing solar-focused apprenticeship and technical training (e.g., programs for factory technicians, engineers, etc.) in collaboration with manufacturers, governments, and educational institutions.

The U.S. must also continue monitoring and managing risks that threaten long-term competitiveness, such as:

- Increased cost pressure from incumbents such as China, as the scale of production and state financial and regulatory support continue.
- The lack of access to key supply chain chokepoints (e.g., wafer manufacturing facilities, alternatives to Chinese manufacturing equipment, etc.) that are needed to build an end-to-end domestic module manufacturing base.
- Continued regulatory uncertainty (e.g., tariffs on imports and anti-circumvention investigations), which stifle domestic investment in manufacturing and raw material processing facilities, and delay domestic deployments due to shortage of module supply.
- Significant supply chain disruptions due to external factors (e.g., geopolitics, pandemic, etc.) upending highly concentrated global supply chains.

3.2 Size of the opportunity both in domestic market and exports

The overall U.S. serviceable addressable market for solar is projected to hit ~$4.0-4.5 trillion through 2050. The market peaks in the mid-2030s and starts tapering down toward 2050 as the U.S. and other countries expand deployment of other technologies to reach their decarbonization goals.

---

[8] BCG Executive Perspectives: U.S. Inflation Reduction Act

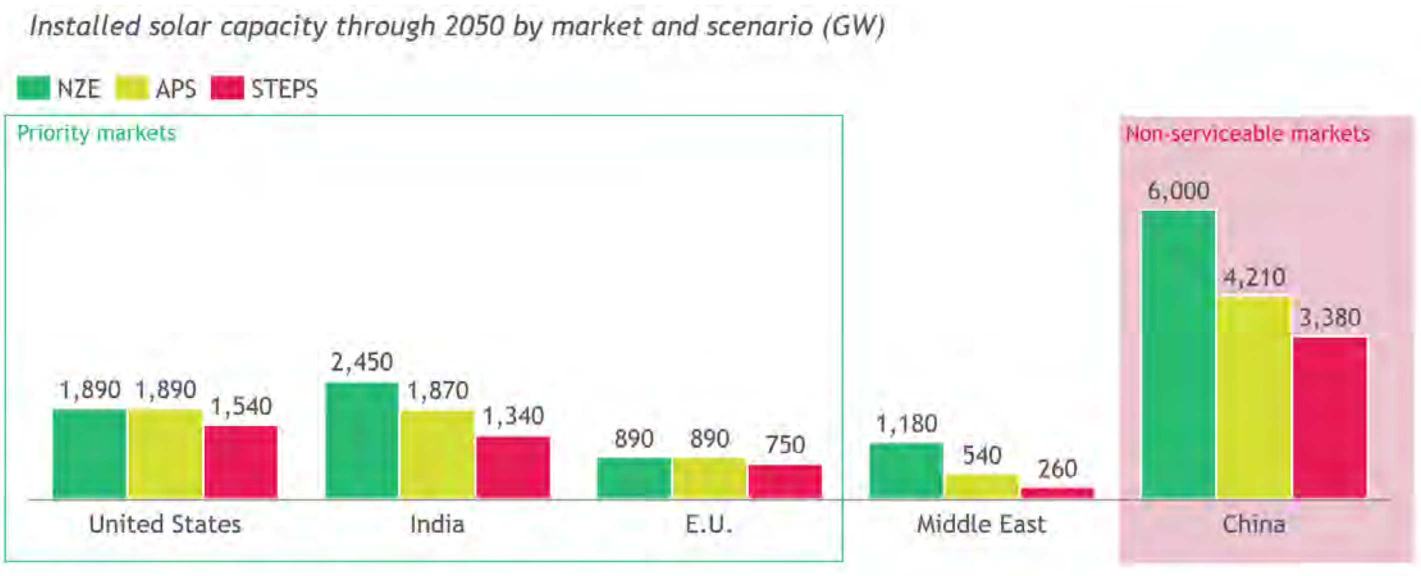


Figure 3.1: Solar PV market assessment

Professional services, such as project development and financing, present the most likely route to U.S. export growth. The ability of large U.S. players to leverage synergies and expertise gained from the domestic market can play a role in developing projects abroad in high-growth markets like India, the EU, and South America. The potential of Middle Eastern markets could increase under a net zero scenario, but IEA projections based on current policies in the region mean demand and U.S. export potential are uncertain, as shown in Figure 3.1 above. EPC and O&M present limited opportunity for U.S. export of engineering and maintenance services, as the relative simplicity of solar plant construction and operations provides limited potential for competitive advantage. Raw materials and original equipment manufacturing (OEM) also present limited export opportunity as U.S. domestic demand is expected to exceed domestic supply of modules. However, if the U.S. can rapidly scale and automate to become cost competitive, it could export solar modules to countries looking to diversify their solar supply chain, such as the EU, India, and others.

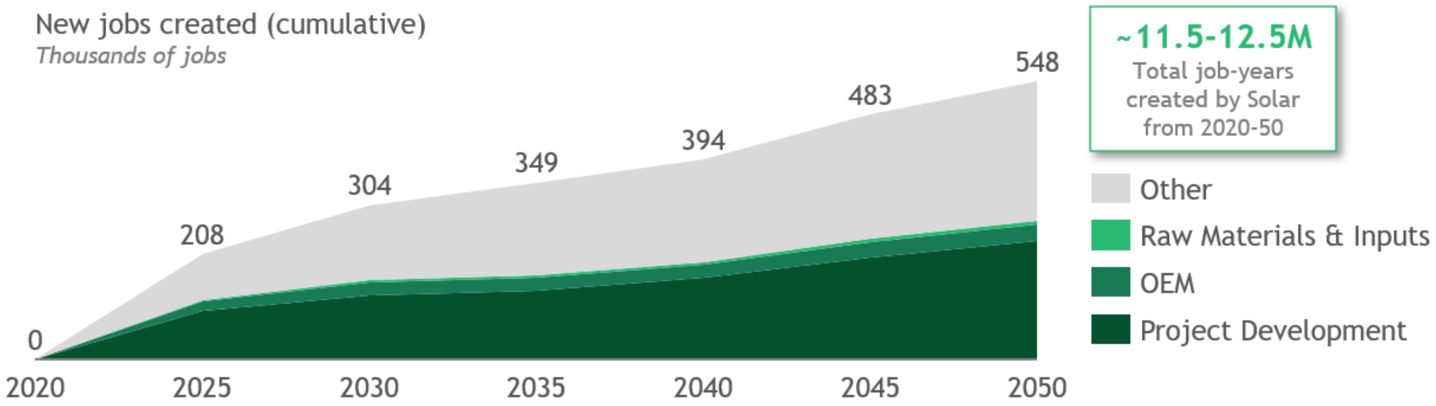
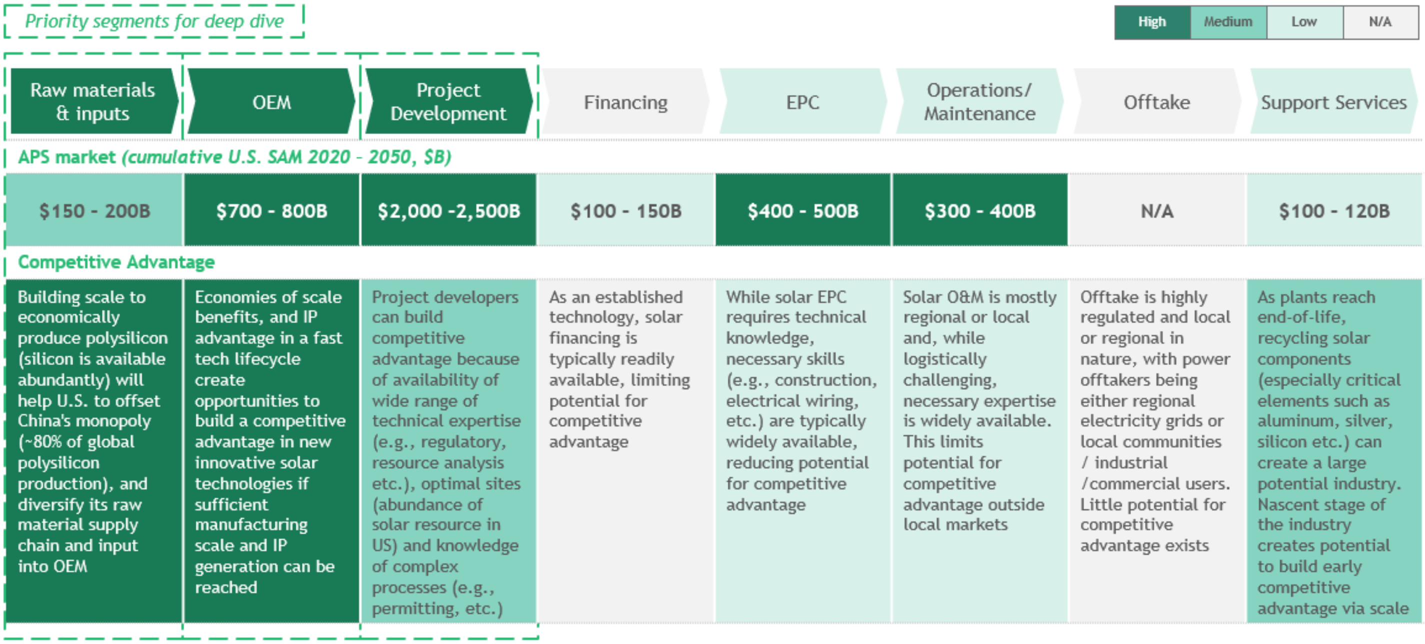


Figure 3.2: Solar PV job growth forecast

Accelerating solar project deployments and building a domestic manufacturing base are expected to create ~550,000 jobs through 2050 across all value chain segments, with the prioritized segments of raw materials, OEM, and project development driving ~50% of the total job creation. Even though raw materials and OEM are critical for the U.S. to win in the domestic market for energy security, the primary job drivers are project development (~35%), EPC (~30%), and O&M (~30%).

3.3 Overview of key areas of opportunity for the U.S.

With an abatement potential of ~7300 Mtpa, ~35-40% share of U.S. power generation by 2050, and a $4.0-4.5 trillion addressable market, solar is vital for meeting U.S. decarbonization goals, enhancing energy security, and increasing economic growth. Investment in the upstream value chain segments of raw materials, OEM, and project development is the most critical factor in accelerating domestic solar project deployment and building a resilient, domestic supply chain. The IRA and IIJA provisions can help the U.S. develop a robust domestic supply chain by subsidizing component manufacturing across each step – polysilicon, wafers, cells, modules – along with providing tax incentives for developers, tied to key domestic content requirements, to spur domestic manufacturing.



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

Figure 3.3: Solar PV value chain prioritization

Raw materials and inputs: To build a diverse, resilient, and end-to-end domestic supply chain of solar panels and to capture the $150-200 billion serviceable addressable market for polysilicon, the U.S. must both restart inactive polysilicon plants and build new capacity. Currently, China dominates polysilicon production with ~80%[9] of global capacity, and its tariffs on U.S. polysilicon shut down U.S. plants that previously fed into the Chinese supply chain; as a result, these U.S. plant operate at ~25%[10] capacity today and produce only <5% of global polysilicon. As the U.S. gradually reshores wafer and cell manufacturing capabilities, demand for domestic polysilicon will grow rapidly, creating an opportunity for mothballed U.S. polysilicon players to revive and expand production capacity to feed into the IRA-supported U.S. supply chain. The recent IRA incentive of $3/kg for polysilicon manufacturing may enable U.S. players to become cost competitive with China, with the 10% domestic content bonus for investment and production tax credits helping boost demand for domestic polysilicon. The U.S. could also export polysilicon to countries looking to diversify beyond Chinese supply. Compared to China, the U.S. has ~3-5x higher labor costs (~10% of polysilicon production costs) and higher energy costs (~40% of polysilicon production costs), but rapid scale, automation, manufacturing innovation, and siting its plants in cheaper, clean energy locations can help the U.S. can become cost competitive.

---

[9] IEA Special Report on Solar PV Global Supply Chains

[10] U.S. Department of Energy Report on Solar Photovoltaics: Supply Chain Deep Dive Assessment

OEM: Currently, OEM manufacturing is highly concentrated in China, with global production capacity of ~97% of wafers, ~85% of PV cells, and ~75% of PV modules[11]. Despite the U.S. being at a significant cost disadvantage to low-cost incumbents, diversifying the U.S. solar panel supply chain is critical to avoid significant disruption in the event that highly concentrated supply chains were to experience a sudden shock. This provides the U.S. with a timely opportunity to capture a portion of the $700-800 billion OEM serviceable addressable market and reshore wafer, cell, and module manufacturing. IRA provisions, such as the advanced manufacturing tax credit for wafers (5¢/W), cells (4¢/W), and modules (7¢/W) and the investment tax credit of 30% with an additional 10% domestic content bonus, may help lower the delivered price of U.S.-produced modules by ~30-40% compared to imported Southeast Asia modules. The domestic content bonus of 10%, which requires at least 40% of total investment costs attributable to domestic U.S. manufacturing, will spur module manufacturers to source U.S.-produced wafers and cells, and lead project developers to buy U.S.-produced modules. Despite the near-term economic support from IRA/IIJA provisions, the U.S. has lost its IP and technical leadership due to limited investment in OEM R&D. China leads patenting activity with ~5x the patents of the U.S., which ranks fourth overall in patenting activity behind China, South Korea, and Japan. Compared to China, the U.S. has ~3-5x higher labor costs (~25%[12] of OEM production costs), and higher energy costs (~10% of OEM production costs), along with a lack of skilled workers (e.g., factory technicians, engineers, etc.). Therefore, investing in workforce development programs and supporting manufacturing and technology innovation to enable automation, scale, and vertical integration of upstream manufacturing is crucial for U.S. competitiveness.

Project development: The U.S. has a large opportunity to capture a portion of the ~$2.0-2.5 trillion serviceable addressable market for project development, including both domestic and export markets. The abundance of open, flat, and sunny land, combined with supportive federal policies, drives demand that gives U.S. players significant development expertise. The U.S. has the second-largest deployed solar capacity in the world and ample experience in developing utility-scale solar projects, with U.S. project developers currently owning ~75% of the domestic market. The insights and knowledge of some of the world's largest developers such as NextEra, which has ~28GW of operational renewable energy capacity, can be utilized to expand development efforts into fast-growing markets such as India, the EU, and South America. Some U.S. developers have expanded operations internationally, owning ~5% of the export solar development market. But U.S. developers, like their European counterparts such as EDF and Enel, have the potential to capture a larger global export share given their technical expertise, ability to navigate complex permitting and regulatory processes, and strong relationships with OEMs, which can be translated to foreign markets. Despite U.S. players' significant domestic experience, however, other valuable sources of competitive advantage (e.g., local knowledge) are required to win in new export markets.

3.4 Primary challenges to address

To reshore manufacturing and facilitate the rapid deployment of solar, the U.S. must address several structural challenges. Although recent federal policies such as the IRA provide support to manufacturers and developers, additional action is needed to enable maximum uptake of the IRA provisions and boost long-term competitiveness.

Challenge A: Lack of solar-trained workforce may hinder rapid build-out of manufacturing at scale. A dearth of skilled labor may lead to slow growth in the expansion of domestic manufacturing facilities, necessitating continued reliance on imports for solar modules. Selection of potential actions:

- Fund and establish solar-focused engineering and technical apprenticeship and research programs.
- Maintain a supportive immigration policy to attract a highly skilled manufacturing labor force.

---

[11] IEA Special Report on Solar PV Global Supply Chains

[12] U.S. Department of Energy Report on Solar Photovoltaics: Supply Chain Deep Dive Assessment

Challenge B: High cost of energy discourages domestic polysilicon production. The high cost of energy in the U.S. compared to Asian competitors drives up the cost of domestic polysilicon production, which is very energy intensive. Selection of potential actions:

- Site plants in locations with low-cost green energy.
- Create and fund research programs to support manufacturing innovation and process efficiencies
- Increase manufacturing incentives (IRA provides ~0.8¢/W) for polysilicon manufacturing to completely offset the U.S. manufacturing cost premium (~3-4¢/W).

Challenge C: Potential supply chain disruption of critical minerals may lead to delays in solar deployment. Global shortages of critical minerals, such as copper, can result in supply chain disruptions, prompting delays and stagnation of solar deployment. Selection of potential actions:

- Friendshore critical raw materials for mining and processing capacity with trusted partners.
- Enable further build-out of raw material mining, refining, and production capacity for critical minerals such as copper, both domestically and in collaboration with friendly countries.

Challenge D: High capital expenditure for domestic manufacturing facilities disincentivizes investment. The U.S. faces 2-3x higher CapEx to set up solar manufacturing plants, compared to Southeast Asia, due to domestic tariffs and stringent certification requirements on imported manufacturing equipment. Selection of potential actions:

- Reassess import tariffs (Section 301 of the Trade Act of 1974) and stringent safety certifications for imported solar PV manufacturing equipment to reduce manufacturing costs.
- De-risk investment by providing low-cost loans, loan guarantees, and cost-sharing agreements to solar manufacturers through the Department of Energy (DOE) Loan Programs Office or federal procurement.
- Enable a minimum module demand guarantee by a consortium of developers to de-risk large investments by manufacturers.

Challenge E: Lack of domestic expertise to set up manufacturing equipment incurs additional costs. With limited to no manufacturing facilities for certain steps of module manufacturing, the U.S. lacks the technical expertise to set up and operate equipment at new facilities. The need to hire international expertise increases costs for manufacturers. Selection of potential actions:

- Develop partnerships with trusted counterparties such as Malaysia and South Korea to bring in foreign expertise with the requisite technical know-how to oversee equipment set up and technology transfer, helping to ramp up wafer, cell, and module production in the U.S.

Challenge F: High cost of labor discourages domestic module manufacturing. U.S. manufacturing faces ~3-5x higher cost of labor, which makes manufacturing modules in the U.S. more expensive than Asian counterparts. Selection of potential actions:

- Create and fund research partnerships between local and foreign academic institutions, government agencies, and the private sector to support manufacturing automation to offset the high labor costs in the U.S.

Challenge G: Complex permitting requirements delay solar deployment. Complex permitting processes, including stringent environmental standards, delay deployment timelines and add additional cost to developers. This lack of domestic demand can add risk to reshoring manufacturing facilities and disincentivize investment. Selection of potential actions:

- Streamline permitting processes and engage relevant stakeholders early for domestic solar projects to reduce delays in deployment.

Challenge H: Long interconnection queues[13] and insufficient transmission infrastructure delay solar deployment. Long interconnection queues for solar projects and unclear cost allocations for required grid infrastructure upgrades increase cost for developers, delay solar deployment, and reduce the confidence necessary to produce a consistent domestic demand. Selection of potential actions:

- Expand and upgrade the transmission grid, improve transmission planning, and reform interconnection processes to reduce costs and speed up deployment.

3.5 Summary actions to support U.S. competitiveness

The U.S. should pursue four primary actions to boost competitiveness in solar PV:

- Enable vertically integrated manufacturing at scale: De-risk investment (e.g., loan guarantees, cost sharing agreements) to build integrated wafer, cell, and module manufacturing facilities at scale and fund innovation in technology and manufacturing processes, reducing domestic production costs.
- Reform interconnection processes: Improve transmission planning and interconnection processes to reduce grid connection delays and enable equitable cost allocation to solar 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, thereby boosting confidence in domestic manufacturing offtake.
- Expand relevant workforce and formulate workforce development programs: Create a diverse talent pipeline by expanding and establishing solar-focused apprenticeship and technical programs in collaboration with manufacturers, governments, and educational institutions.

Beyond these actions, the U.S. should also remain aware of two major trends which could hinder U.S. competitiveness in solar PV:

- **Impacts of circumvention case and forced labor policy:** Further deployment delays may occur due to the recent circumvention case outcome and unclear guidance on the forced labor policy in the U.S. and, possibly, the EU, leading to a short-term shortage of solar module supply.
- **Expansion of Chinese manufacturing capacity:** Continuing expansion of manufacturing facilities in China across all manufacturing steps may lead to further concentration of solar manufacturing, increasing global supply chain risks and leading to the further proliferation of cheaper solar module imports, which would add cost pressure to U.S. manufacturing.

4 Offshore Wind

4.1 Offshore wind executive summary

Offshore wind will play a key role in the U.S. energy transition and enjoys the advantages of higher capacity factors, minimal land footprint, and physical proximity to coastal population centers over its onshore counterpart. While the U.S. has fallen behind Europe and China in offshore wind manufacturing and deployment, the sector has seen unprecedented growth in 2022, with the Biden administration setting an ambitious target of 30 GW offshore wind deployed by 2030. The U.S. now has a promising opportunity to accelerate domestic deployments and regional exports by building a robust manufacturing base and leading innovation in nascent floating technologies.

---

[13] Berkeley Lab Interconnection Queue Report

Currently, the EU, U.K., and China dominate >95% of global installations and associated supply chains with ~50 GW of combined capacity deployed, compared to <0.1 GW deployed in the U.S.[14] Despite the early experience of foreign competitors, the U.S. can access a sizable market opportunity of ~$1 trillion through 2050 by transferring expertise from a well-developed offshore oil & gas industry and rebuilding domestic supply chain capabilities to avoid the high cost of shipping large components. The U.S. can further leverage favorable policy incentives to leapfrog legacy production processes and build an innovative advanced manufacturing base.

Innovation in nascent floating technology creates a promising opportunity for the U.S. to build a differentiated niche and capture regional export potential. The U.S. has plentiful offshore wind technical potential in deep waters, highly transferable skills from offshore oil & gas, and ambitious state and federal floating targets, making it well placed to capture this early lead**.** Additionally, recent legislation dramatically reduces offshore wind cost position and encourages domestic manufacturing and infrastructure expansion, potentially enabling the U.S. to serve growing domestic demand while also satisfying emerging regional needs. This primarily includes markets in the Americas with high floating technical potential but no currently installed capacity, such as Canada, Mexico, Chile, Brazil, and Argentina.[15]

Achieving the ambitious goal of deploying 30 GW by 2030 is expected to create ~90,000 domestic jobs, with the added benefit of promoting an equitable job transition for offshore oil & gas workers. To meet this target, the U.S. must translate its research leadership into commercial success by further driving offshore wind down the cost curve, resolving inefficiencies around transmission planning and permitting processes, and building a local manufacturing base. To ensure a durable competitive advantage, the U.S. should build on IRA/IIJA provisions with the following actions:

- **Accelerate research, demonstration, and deployment of floating technology** to biold a competitive niche and capture full domestic and export potential.
- **Streamline permitting processes to de-risk project development** and increase access to financing.
- **Scale manufacturing of components and equipment** through increased automation to improve domestic manufacturing competeiveness.
- **Invest in a more centralized transmission planning approach** when building key supporting infrastructure to lessen the cost burden on developers.

4.2 Size of the opportunity both in domestic market and exports

As the U.S. accelerates deployments to meet its 30 GW target, domestic deployment is projected to peak between 2030 and 2040 for most value chain segments. O&M is the only value chain segment that continues to grow through 2050, as operating windfarms must now be maintained for the duration of their useful 20-plus year life. Offshore wind offers a smaller yet strategically important market opportunity for the U.S., with the serviceable addressable market projected to reach ~$0.9-1 trillion from 2020-2050.

---

[14] DOE: Offshore Wind Market Report 2022

[15] BCG Executive Perspectives: U.S. Inflation Reduction Act

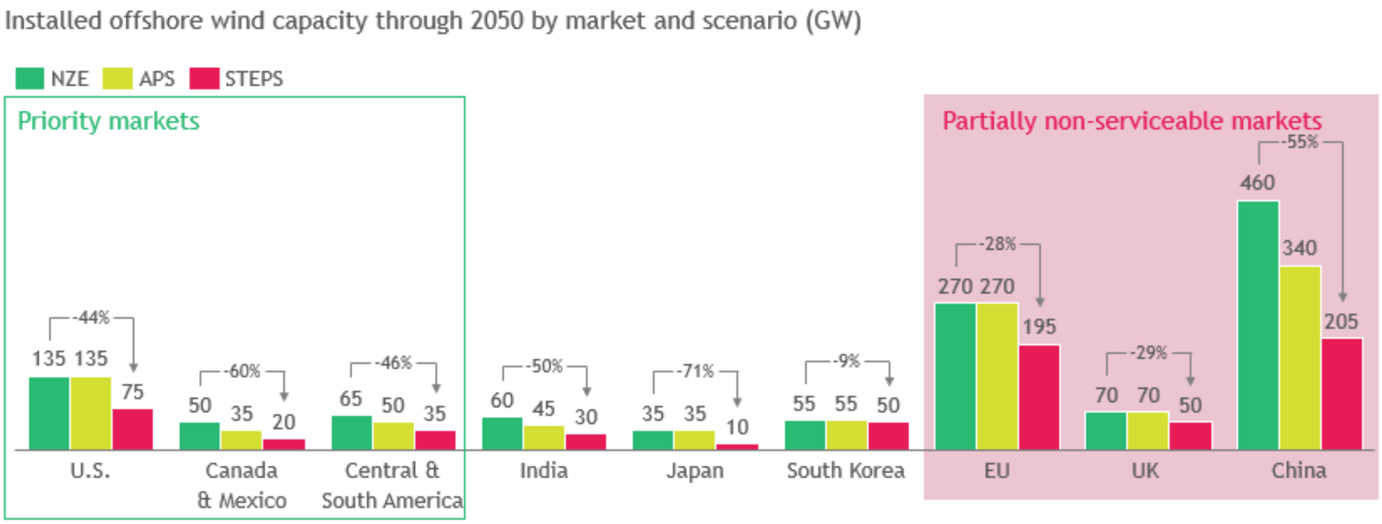


Figure 4.1: Offshore wind market assessment

Offshore wind economic activity is highly localized around windfarm areas given the high costs of shipping components and moving construction equipment and the fact that support infrastructure like ports and transmission must be built locally. These high logistics and transport costs present both an opportunity and a hindrance; they create an automatic cost advantage for U.S. domestic production over imports, but they also restrict direct U.S. export opportunity to the Western hemisphere. Financing and project development are the only value chain segments for which the U.S. can also capture more distant markets, such as Europe and Asia-Pacific, since financial capital, knowledge, and expertise are all exportable regardless of distance. Domestic deployments drive ~75% of total U.S. SAM opportunity, with the remaining market size expected to come primarily from exports into regional markets in North, Central, and South America. As a result, the U.S. is expected to defend much of its serviceable market opportunity and capture up to $400-500 billion, which is a sizable ~50% of the addressable market.[16]

Of all regional markets, Canada and Mexico are most likely to share offshore wind supply chains with the U.S. given their geographical proximity, friendly trade relations, and insufficient domestic demand to justify fully developed local supply chain activity. The U.S. is also expected to be the closest offshore wind industrial base to South and Central America and is well positioned to share skills, expertise, equipment, and components with countries that have high technical potential but are in early-stage development, such as Brazil. However, the U.S. advantage relies in large part on whether the it can commercialize floating technology in time to meet regional demand, since ~85% of technical offshore wind potential in Central and South America lies in deep waters.[17] To capture full export potential, the U.S. also must scale up production capacity to exceed domestic needs before markets with large industrial bases and prior onshore wind experience (i.e., Brazil) build their own supply chains.[18] Unfortunately, exports of components, equipment, and workers to more distant markets are unlikely since Europe and China have fully developed domestic supply chain capabilities, and hold proximity advantages over the U.S. when expanding into neighboring markets.[19] Beyond financing and project development skills, IP exports such as licensing floating technology are the most likely exports beyond regional markets.

---

[16] IEA: World Energy Outlook 2022 (APS scenario)
[17] IEA: Offshore Wind Outlook 2019
[18] IEA: Offshore Wind Outlook 2019
[19] DOE: Offshore Wind Market Report 2022

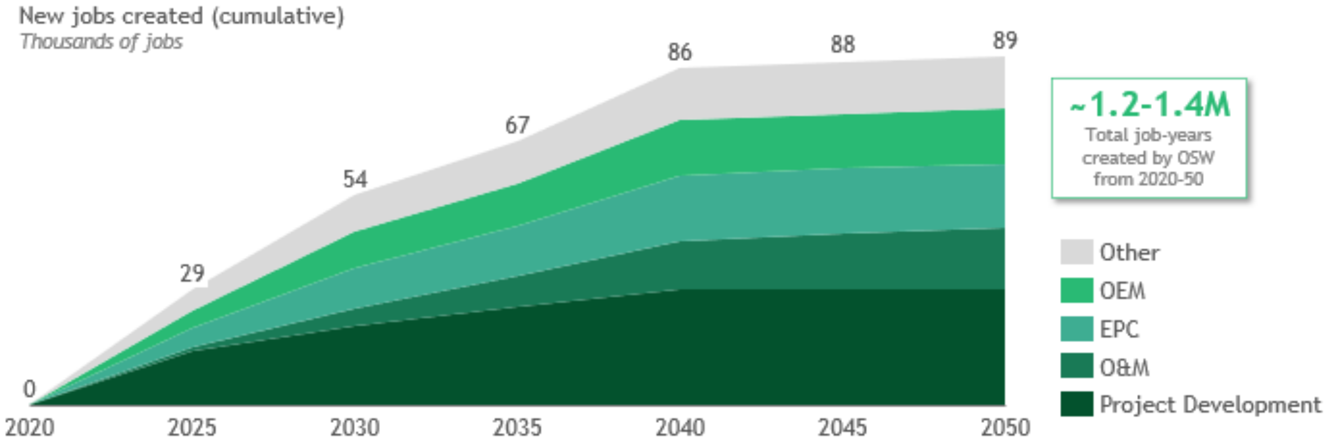


Figure 4.2: Offshore wind job growth forecast

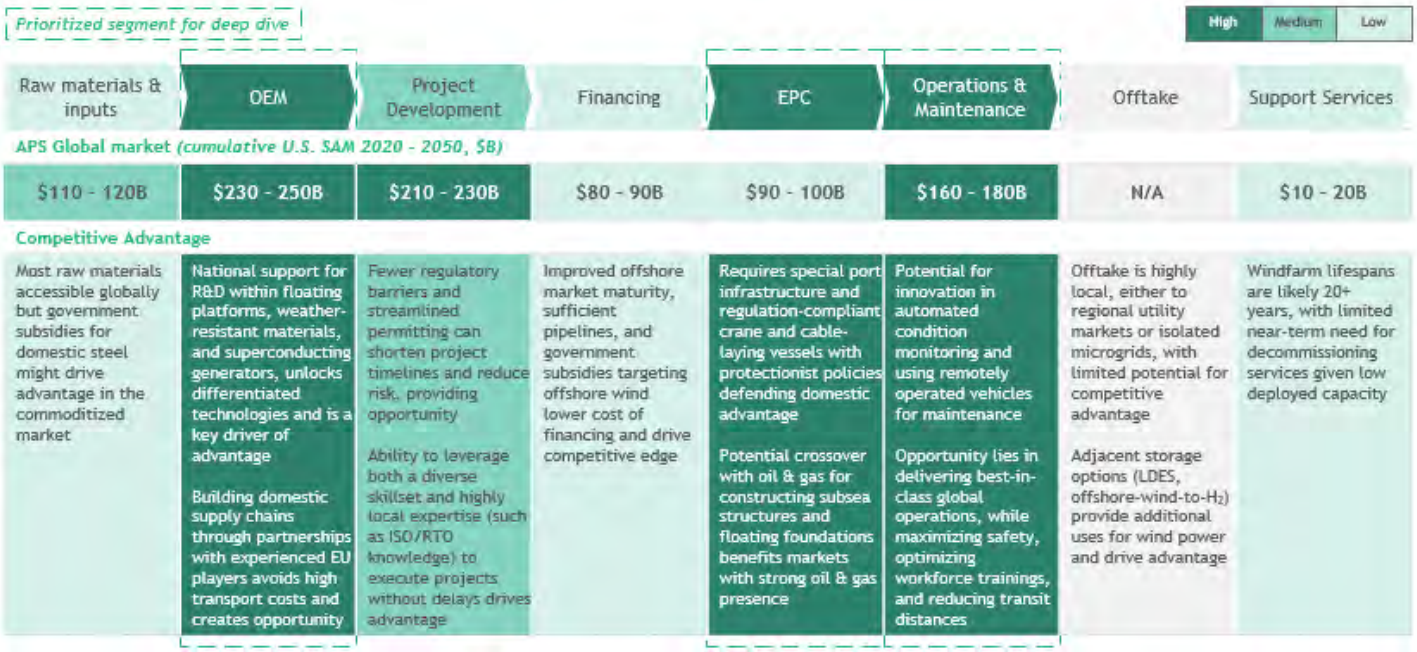
Accelerating offshore wind deployments in both domestic and regional export markets is also projected to lead to the creation of ~90,000 new jobs, driven by project development, OEM, EPC, and O&M. The domestic market drives >70% of total job growth and supports an equitable transition for offshore O&G workers who can translate their skills and expertise to offshore wind. Project development creates close to 35% of total jobs in this highly labor-intensive value chain segment, and up to 40% of project development jobs may be driven by exports, given the broad export potential to Asian markets.

4.3 Overview of key areas of opportunity for the U.S.

Meeting offshore wind targets is key in helping the U.S. reach net zero emissions goals and increase reliability in a decarbonized grid. Offshore wind has higher capacity factors than other renewables, complimentary production profiles with solar, and physical proximity to coastal metropolitan areas. Recently passed legislation further enables the U.S. to meet its goals by incentivizing offshore wind supply chain activity and thus accelerating offshore wind deployments, which can globally abate 1,100-2,000 million tons of CO_2 per annum in 2050.[20] The IRA expands technology-neutral investment tax credits to a maximum of 50%, which can reduce U.S. offshore wind LCOE by up to ~35%. Cost reductions increase domestic demand and create more business activity, which can in turn improve access to long-term financing and spur local supply chain development.[21] Additionally, manufacturing credits of $20-50/kW for high-demand components, $600 million for port infrastructure upgrades, and a tax credit for manufacturing installation vessels can help the U.S. build a robust supply chain and create a defendable advantage. Finally, opportunities for researchers to apply for over $3 billion in grants for development and demonstration projects for clean technologies continues to demonstrate U.S. leadership in RD&D funding.

---

[20] Cornell University: MDPI, IEA: NZE 2050 scenario
[21] BCG Executive Perspectives: U.S. Inflation Reduction Act



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 oil & gas presence	Potential for innovation in automated condition monitoring and using remotely operated vehicles for maintenance Opportunity lies in delivering best-in-class global operations, while maximizing safety, optimizing workforce trainings, and reducing transit distances	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

Figure 4.3: Offshore wind value chain prioritization

While the U.S. must develop domestic capabilities across all segments, it should prioritize those that provide a sizeable market opportunity and a durable competitive advantage. The prioritized segments include OEM, EPC, and O&M, which are expected to contribute $230-250 billion, $90-100 billion, and $160-180 billion, respectively, in addressable market opportunity through 2050.

OEM: Building domestic manufacturing activities is key to driving a defendable advantage that offsets import reliance and avoids high costs of transporting components; additionally, the U.S. has an opportunity to accelerate deployment of nascent floating technology and secure regional export potential. Today, the U.S. ranks fifth in offshore wind manufacturing-related patenting activity and lags Chinese and European players in innovation. There are also no offshore wind component facilities currently operational in the U.S. because of limited offtake demand and high operational costs (e.g., manufacturing labor is 3-5x more expensive in the U.S. than in China).[22] Despite these disadvantages, the regional nature of offshore wind supply chains encourages U.S. domestic manufacturing of many components. Thus, provisions in the IRA that subsidize component manufacturing and allocate federal funding into RD&D provide a path toward reclaiming U.S. manufacturing leadership by partially offsetting high domestic manufacturing costs and incentivizing supply chain activity. Additionally, since the U.S. has high technical potential in deep waters and ambitious goals to lower floating offshore wind costs by 70% by 2035, it can take a lead in deploying commercial-scale floating technology that creates both IP and component export potential.[23]

EPC: With its large set of engineering and offshore O&G skills, the U.S. is well positioned to deliver on the diverse EPC needs of developers. Additionally, the U.S. can become locally competitive in exporting EPC capabilities and equipment given a regional first-mover advantage in building specialized large assets. U.S. offshore oil & gas players have extensive experience in mapping oceans, laying subsea cables, and constructing underwater structures, a key competitive advantage in transferring skills, jobs, expertise, and equipment from offshore oil & gas. Additionally, IRA and IIJA provisions facilitate infrastructure building through funding port upgrades and allocating tax credits for Jones Act-compliant installation vessels, although the latter takes ~3 years and costs ~$500 million to build. The U.S. must thus accelerate manufacturing rapidly to build the five-

---

[22] Economist Intelligence Unit: Manufacturing labor costs per hour (US$); DOE | Offshore Wind Market Report 2022

[23] The White House: Biden-Harris Administration Announces New Actions to Expand U.S. Offshore Wind Energy

plus vessels that are required to enable 2030 installation targets.[24] Additionally, the U.S. should continue to research innovative construction methods to close the gaps to China and Europe in EPC-related research and patenting.

O&M: While the U.S. has an existing advantage in domestic O&M by transferring skills and equipment from offshore oil & gas to wind, export potential relies on establishing technology that automates O&M needs, such as remote condition monitoring, advanced software analytics, and remotely operated vehicles. Traditional O&M services tend to be highly regional in nature, which limits U.S. market opportunity in O&M to North America. Access to skilled regional labor and transferability of O&M skills, workers, and equipment from offshore O&G supports local workforce development, increases the availability of Jones Act-compliant maintenance vessels, and creates a key advantage for the U.S. in traditional O&M services. The U.S. can also seize IP export potential through further innovation in advanced O&M software and equipment and translate its research leadership into novel strategies to automate preventative maintenance, making O&M services safer and more cost-effective.

4.4 Primary challenges to address

Since the U.S. has only installed <0.1 GW compared to the >50 GW of offshore wind capacity currently operational in Europe and China, offshore wind continues to be more expensive than other clean technologies and faces uncertain demand.[25] Accelerating deployments in the U.S. would help drive down costs and incentivize local supply chain activity, which in turn positions the U.S. to become a regional manufacturing base. To boost U.S. competitiveness, the following challenges should be resolved.

Challenge A: Lack of interstate transmission planning adds burden to project developers and delays projects. Power grid infrastructure projects are complex and lengthy in both permitting and construction, which has resulted in exploding interconnection queues for grid access.[26] The current generator lead-line approach, in which developers fund and build individual transmission lines themselves and link up windfarms one by one to an onshore network, is unsustainable for the needed volume of offshore wind projects. Selection of potential actions:

- Plan and build an interstate high-voltage transmission system (such as using mesh and backbone designs) for offshore wind by convening relevant stakeholders from the DOE, Federal Energy Regulatory Commission (FERC), Bureau of Ocean Energy Management (BOEM), Regional Transmission Organizations/Independent System Operators (RTOs/ISOs), and other federal agencies.
- Broaden FERC’s authority on cost allocation and interstate transmission to resolve disputes around connections.
- Allocate funding to production of high-voltage cables and secure supply.

Challenge B: Developers bear large risk and cost burden, which disincentivizes many players from entering the industry. Owners must pay large amounts upfront for wind areas leases (>$100 million for ~1 GW of capacity) but have no permitting certainty, which further reduces profits on projects that already struggle with low margins.[27] Potential actions include:

- Create legislation that allows BOEM to decide where to direct revenues from federal lease sales to help fund public interests; this can include transmission planning, supply chain building, fisheries mitigation, environmental protection, etc.

---

[24] NREL: The Demand for a Domestic Offshore Wind Energy Supply Chain: 2022

[25] DOE: Offshore Wind Market Report 2022

[26] DOE: Offshore Wind Market Report 2022

[27] BOEM: California Activities 2022

- Allocate funds to map out ocean seascapes and publish the data to help make offshore wind siting decisions, optimize ocean use across relevant stakeholders, and remove the cost burden from developers.

Challenge C: Long permitting processes and lack of clarity around timelines make access to financing difficult. Permitting processes span federal, state, and local jurisdictions and are lengthy (10-plus years) and complex, while limited clarity around timelines introduces risk to the project and makes access to financing difficult. Selection of potential actions:

- Streamline domestic permitting, review, and approval timelines by consolidating federal and state processes.
- Ensure federal agencies such as the National Oceanic and Atmospheric Administration (NOAA) and BOEM have sufficient staffing and prioritization to manage permitting volume by increasing the budget for hiring relevant staff.

Challenge D: Stakeholder opposition can delay projects from being deployed. Interests of all relevant stakeholders, including ocean conservancies, fisheries, maritime groups, and coastal residents, can result in prolonged review processes and expose projects to continuous litigation. Additionally, provisions in the IRA that have tied offshore wind leasing to offshore O&G leasing requirements have put an additional strain on future deployments as environmental groups might grow reluctant to build more offshore wind if it means supporting new drill sites. Selection of potential actions:

- Facilitate communication across all relevant stakeholders through BOEM-designated resource centers.
- Collaborate with ocean conservancy groups to create guidelines (e.g., vessel speed limits, bird detection software, and construction noise reduction) that minimize offshore wind impact on wildlife and support a push to prepare environmental impact statements ahead of leasing decisions to help resolve wildlife concerns during siting.
- Support BOEM in creating a fisheries mitigation strategy that limits the impact of offshore wind projects.

Challenge E: Undeveloped support infrastructure, including ports and vessels, cannot handle projected offshore wind deployments. The high costs of building installation vessels (~$500 million) and limited U.S. vessel manufacturing capacity poses risks to building the required Jones-Act compliant installation vessels, while remaining port upgrades require significant investments.[28] Selection of potential actions:

- 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, using input from industry groups, BOEM, and the American National Standards Institute.
- Create a regulatory body within BOEM to oversee infrastructure building and usage to prioritize the most pressing needs and optimize utilization rates.

The final two challenges are relevant for U.S. competitiveness within both domestic and export markets and must be resolved if the U.S. wants to capture full export potential to local regions.

Challenge F: High labor and manufacturing costs might slow down progress toward 2030 goals and diminish export ambitions. Some critical components, such as blades, foundations, subsea cables, and installation vessels, pose a high risk of supply chain disruptions for the U.S. given high U.S. labor costs, potential future shortages of skilled labor, and undeveloped U.S. manufacturing capabilities. Selection of potential actions:

- Rapidly capture economies of scale and support research into manufacturing automation and modularity to increase production capacity and reduce manufacturing labor costs.

---

[28] NREL: The Demand for a Domestic Offshore Wind Energy Supply Chain 2022

- Implement local workforce training and apprenticeship programs, and reskill legacy O&G workforce to proactively address potential future labor gaps.

Challenge G: Gap to leadership in innovation for novel technologies diminishes U.S. export potential. The U.S. has lost IP and research leadership to foreign players, which prevents the U.S. from taking advantage of deep-water wind areas using nascent floating technologies and capturing the full export potential to local markets. Selection of potential actions:

- Accelerate research into floating technology, build demonstration projects, and reduce floating technology costs through increased deployment and standardization.
- Encourage domestic manufacturing of floating offshore wind components to rebuild domestic expertise and encourage long-term innovation and IP generation.

4.5 Summary actions to support U.S. competitiveness

The U.S. should pursue four primary actions to boost competitiveness:

- **Plan and build an interstate high-voltage transmission system for offshore wind:** This would replace the individual generator lead-line approach and resolve high interconnection volume requests.
- **Streamline domestic permitting, review, and approval timelines:** This involves consolidating federal, state, and local permitting processes, ensuring federal agencies have sufficient staffing and prioritization, increasing permitting certainty, and creating clarity around timelines to de-risk project development.
- **Secure supply of high-risk components:** The U.S. should accelerate research into manufacturing automation and modularity and support industrywide standardization efforts.
- **Accelerate demonstration projects and reduce floating technology costs:** Increased deployment and standardization can take advantage of deep-water wind areas and capture export potential to local markets.

Beyond these actions, the U.S. should also monitor two key trends which might prevent it from meeting its offshore wind goals:

- **Foreign players' floating technology progress threatens U.S.'s ability to secure export potential.** Regional export markets have high technical potential in deep waters, so the U.S. must accelerate floating technology commercialization to secure export markets before competitors do. Currently, European and Chinese players have deployed ~125 MW of floating capacity and lead floating patenting activity, with the U.S. lagging in fifth place.[29]
- **Dependency on China for rare earth magnets for generators** might lead to future supply chain disruptions of offshore wind components.[30] Researching and commercializing superconducting generators that do not require rare earth magnets can help decrease reliance on imports.

5 Carbon Capture, Utilization, and Storage (CCUS)

5.1 CCUS executive summary

Carbon capture, utilization, and storage (CCUS) provides a promising route for decarbonizing hard-to-abate sectors, particularly as many countries continue to build new, carbon-intensive industrial and power facilities

---

[29] DOE: Offshore Wind Market Report 2022

[30] NREL: Wind Energy Supply Chain Deep Dive Assessment 2022

that are expected to drive emissions for decades to come. The U.S. is the current leader in CCUS with >50% of global deployments and significant capabilities overlap with a robust domestic oil & gas sector.[31] This leadership position provides the opportunity for the U.S. to capture a sizable market through targeted R&D and scale-up as economies turn to improved CCUS technologies to reach decarbonization targets. However, other large economies are expected to grow their CCUS capabilities rapidly and may overtake the U.S. in the 2030s unless the U.S. builds on its first-mover advantage to firmly secure exports.

The U.S. CCUS sector receives an early boost from IRA/IIJA[32] support which will accelerate deployments by making ~40% of potential U.S. CCUS use cases economic for the first time, through generous tax credits[33] and significant funding for demonstration projects. This will position the U.S. to build an early first-mover advantage in the project development and EPC spaces, where most CCUS costs are concentrated, while continuing to push forward new innovations in manufacturing and design activities within OEM. This market expansion is further projected to create ~100,000 new jobs for the U.S., with the majority expected to be in regions with significant fossil fuel deployment, supporting the transition of displaced O&G workers to the CCUS industry.

However, the market is projected to increase nearly 100x by 2050, a total capacity equivalent to ~10% of today's global emissions. This will allow other nations to catch up to the U.S., with China projected to surpass the U.S. in the 2030s and comprise ~40% of global deployments by 2050. To build a first-mover advantage and capture growing export markets, the U.S. will have to act in this limited window and invest in next-generation capture technologies, including both novel solvents and non-solvent innovations such as electro-swing absorption. Specifically, the U.S. can build on IRA/IIJA provisions through the following actions:

- Create CO_2 regulations and/or long-term monetization opportunities, such as California's low carbon fuel standard (LCFS), to support continued private investment.
- Continue to support near-term commercial deployments (e.g., U.S. carbon capture hubs) to further drive down costs of CCUS.
- Establish processes for transport and long-term storage/monitoring of CO_2 (e.g., length of liability for private companies) to streamline permitting and de-risk project development.
- Accelerate the transition of O&G workers to CCUS to meet labor needs.

5.2 Size of the opportunity both in domestic market and exports

CCUS offers a sizable market opportunity for the U.S. to capture through 2050, with an addressable market of ~$1.6 trillion through 2050. This market is projected to be primarily domestic through 2030 before global deployments take off from 2030-50 and drive long-term growth. The market is also projected to peak in the 2040-50 timeframe before declining, given the global shift away from fossil-powered assets. The 2050-70 timeframe might bring a new wave of CCUS deployments as China and India race to meet their net zero emissions goals in 2060 and 2070, respectively. Long-term growth opportunities are projected to come primarily from hard-to decarbonize sectors (e.g., cement) and new applications (e.g., blue H_2, bioenergy with CCUS) although CO_2 utilization and storage is expected to remain in use for direct air capture (DAC) as CO_2-emitting assets are retired.

---

[31] IEA World Energy Outlook 2022 (APS scenario)
[32] Inflation Reduction Act and Infrastructure Investment and Jobs Act
[33] BCG Executive Perspectives: U.S. Inflation Reduction Act

Across the value chain, OEM, project development, and EPC are three of the key segments where the U.S. has a significant market opportunity and the best chance at developing a durable competitive advantage in both domestic and export markets. The global nature of the OEM market, dominated by large multinational companies selling to projects around the world, means it has the largest export opportunity. Project development and EPC, on the other hand, will focus primarily on the domestic front, with some near-term export opportunities the U.S. can capture as a first mover.[34]

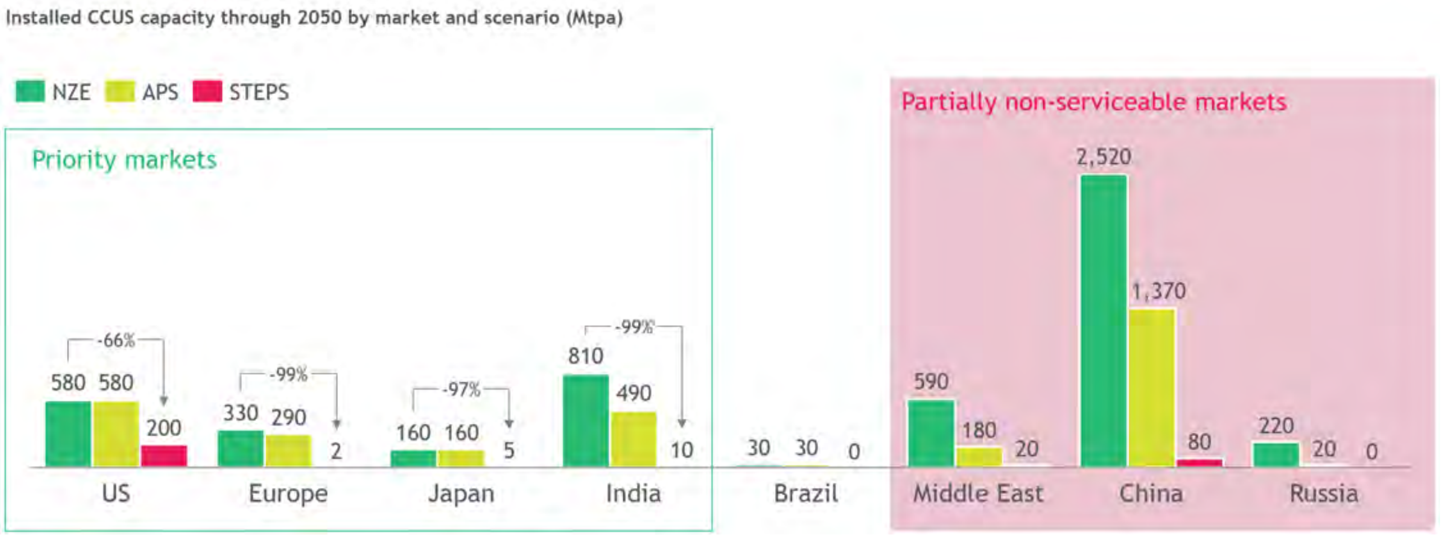


Figure 5.1: CCUS market assessment

Key markets for the U.S. to target include the EU, India, and Japan, given their large economies with significant industrial capacity and decarbonization needs, although there is concern around deployment potential in India and other emerging markets with limited or suboptimal storage resources.[35] Since India's net zero emissions target is shifted out to 2070, India's CCUS market is likely to pick up post-2035, unlike Japan and the EU, which are pressed to meet 2050 goals. Additional opportunities exist for OEMs to export to China and markets such as the Middle East.[36] However, China's projected dominance of the CCUS market post-2035 limits overall export potential and makes it crucial for U.S. OEMs to build leadership positions. Project developers and EPCs will likely focus domestically in the long term, as it will be difficult to maintain a durable advantage in export markets after other players learn best practices.

---

[34] IEA World Energy Outlook 2022 (APS scenario)
[35] IEA "CCUS technology innovation"
[36] Global CCS Institute "State of the Art CCS Technologies 2022"

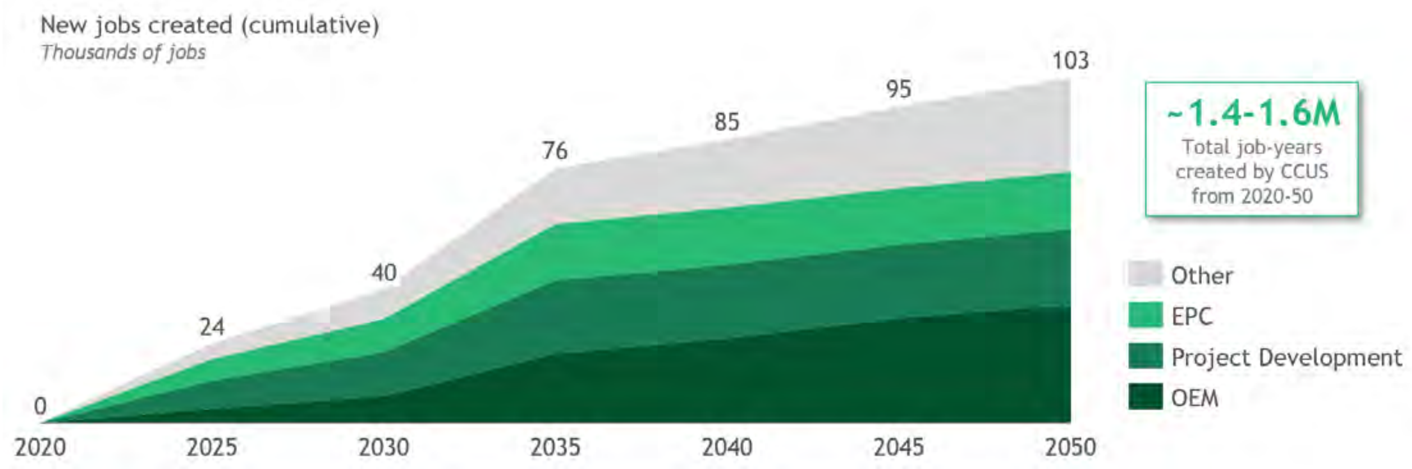


Figure 5.2: CCUS job growth forecast

The acceleration in CCUS deployments is also projected to lead to the creation of ~100,000 new jobs for the U.S., with >75% coming in OEM, project development, and EPC. Domestic deployments will drive ~50% of these jobs, which are expected to be primarily in regions with significant fossil fuel deployments. These may help support a just transition as CCUS jobs are expected to have average annual salaries of ~$100,000, and leverage many of the subsurface and CO_2 management skills of displaced O&G workers.

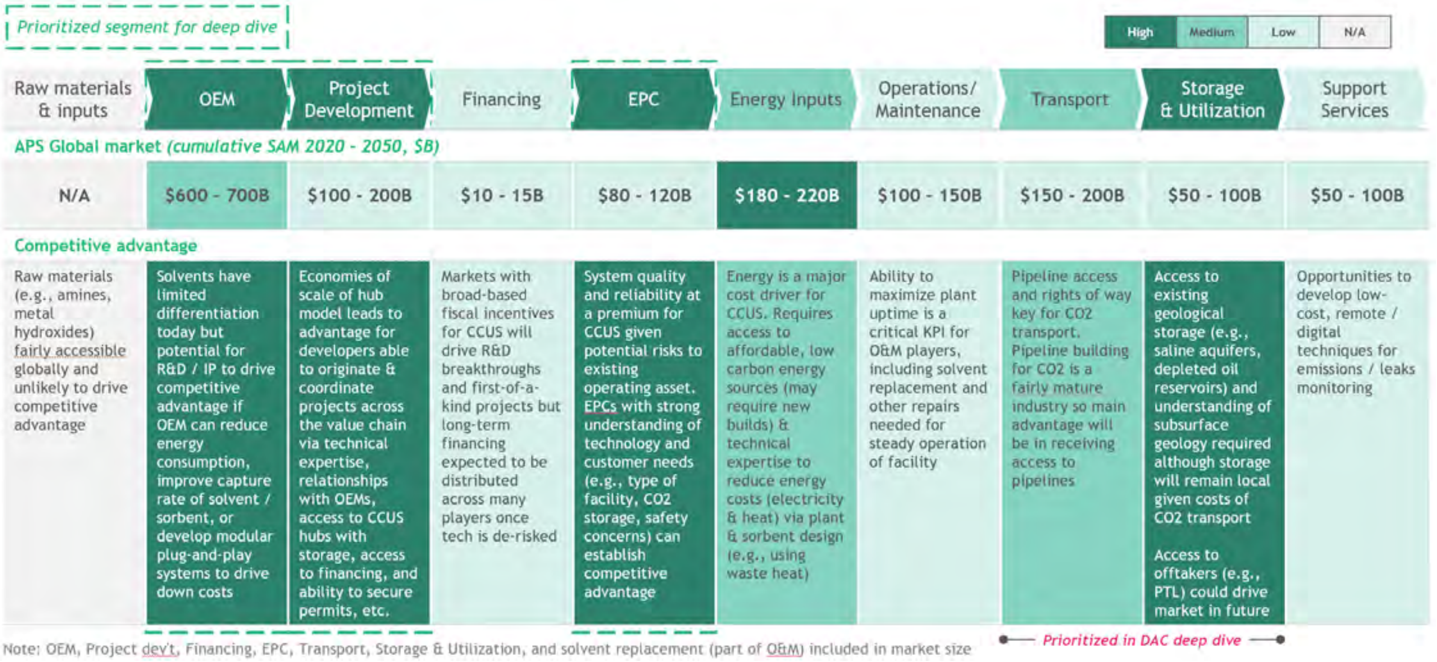
5.3 Overview of key areas of opportunity for the U.S.

CCUS value chain

While the U.S. must develop capabilities across the entire value chain for CCUS, concerted efforts should be made in segments that provide both a large market opportunity and the potential for a durable competitive advantage. The three key value chain segments for the U.S. to focus on are OEM, project development, and EPC. Among these, OEM provides the largest addressable market with a ~$600-700 billion opportunity from 2020-50, given the high component costs and a large export opportunity. Project development and EPC, on the other hand, will primarily be domestic-focused, driving smaller addressable markets of ~$100-150 billion each.[37]

---

[37] IEA World Energy Outlook 2022 (APS scenario)



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

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

Prioritized in DAC deep dive

Figure 5.3: CCUS value chain prioritization

OEM: Currently, there is no clear winner among the wide range of OEMs that produce capture solvents and sorbents, leaving an opportunity for the U.S. to leverage its strong R&D capabilities into a competitive advantage. High costs and energy usage for current materials provide opportunities for players to create defensible, high-value IP and win market share. The U.S.'s existing research ecosystems and leadership across patents and publications in CCUS make this a promising area.

Project Development: Given the complexity of managing processes across the full value chain and the value of the underlying assets, there is no set business model for project developers, which leaves an opportunity for U.S. players to act as first movers.[38] Players who develop proven track records of success and forge the relationships required to coordinate complex operations across the value chain for CO_2 hubs (via joint ventures) may be able to build competitive moats. Because U.S. O&G majors have extensive experience in managing large projects and a strong understanding of subsurface management (for CO_2 storage), they could be well positioned to capture market share as CCUS project developers if properly incentivized. Nevertheless, continued commercialization support and streamlined permitting processes (especially regarding long-term CO_2 liability) are necessary to accelerate domestic deployments and allow U.S. project developers to gain a first-mover advantage.

EPC: System quality and reliability are at a premium for CCUS deployments given the potential risks to the high-value underlying assets (e.g., refineries, industrial facilities, power plants). U.S. EPC players with a strong understanding of the technology and customer needs (e.g., type of facility, CO_2 concentrations, safety concerns) could establish near-term competitive advantages as the space develops. The projected U.S. dominance of the CCUS market through 2030 will help its strong network of O&G-focused EPCs become first movers. Although EPC is likely to be localized in the long term, the U.S. can seize near-term export opportunities in countries looking to construct initial CCUS deployments. Similar to project development, streamlined permitting processes are still necessary.

---

[38] Global CCS Institute "Global Status of CCS Report"

5.4 Primary challenges to address

While the U.S. is expected to be an early leader in CCUS, several challenges remain that need to be addressed with additional policies.

Challenge A: CCUS applications remain too expensive and installations too complex for widespread deployment. CCUS cost projections remain at or above $100/t CO_2e for many applications, significantly limiting widespread deployment,[39] particularly in low-margin industries and emerging markets. Additionally, the current bespoke model, in which each installation is unique, limits cost reduction potential. To catalyze the market, costs much be driven down. Selection of potential actions:

- Engage in focused efforts to fund R&D and commercialization of next-generation technologies with lower energy requirements (e.g., metal organic frameworks, electro-swing absorption).
- Support government procurement or direct financing for modular CCUS deployments, leveraging shared infrastructure and scaling to drive down costs.

Challenge B: Limited regulations around CO_2 **emissions discourage project development**. There are currently very few regulations on CO_2 emissions both within the U.S. and globally. Without economy- or sector-wide CO_2 emissions mandates in place, limited demand exists for developing new CCUS projects and incurring the related costs. Selection of potential actions:

- Leverage government procurement for low-carbon power and industrial products (e.g., steel, cement) with strict emissions limits to increase demand for CCUS.
- Define roadmaps for emissions reductions across specific sectors with incentives and penalties applied for individual players (e.g., LCFS for transportation in CA).

Challenge C: Lack of long-term monetization mechanisms limit ability to finance widespread CCUS deployment. While the expanded 45Q credits provide generous monetization mechanisms in the U.S. in the near term, there are few long-term policies in place that allow monetization of CCUS. It will remain difficult to incentivize widespread investment in new projects without these long-term monetization opportunities to de-risk financing. Selection of potential actions:

- Create incentives to provide permanent (or target-based) monetization opportunities for CCUS, such as enacting CCUS tax credits specifically in harder-to-abate sectors.
- Support regulations on the price and amount of carbon emissions for certain industries to create long-term business security for CCUS companies

Challenge D: Difficulty in obtaining and retaining talent delays projects. Currently, there are not enough workers in the U.S. with the necessary CCUS skillsets to enable rapid deployment in the coming years. While O&G workers possess much of the requisite knowledge and skillsets, re-training programs are required to develop the CCUS workforce. Selection of potential actions:

- Create additional training programs and incentives for O&G workers and those in other industries to begin transitioning to working on CCUS.
- Support programs at universities and technical schools teaching necessary skills for CCUS.

Challenge E: Long permitting timelines and limited clarity on CO_2 **storage liability delays projects and add burdens to project developers**. Permitting timelines for CCUS projects are quite long (e.g., four years for first CO_2 injection permit), slowing down project development. Additionally, there is limited clarity on long-term

---

[39] BCG CCUS cost model

storage and monitoring liability at the federal level, increasing the risks to project developers given potential long-term liabilities.[40] Selection of potential actions:

- Establish a unified, coordinated, predictable, and streamlined permitting and siting process for CCUS projects with a single agency given power to resolve state and regional agencies' disputes.
- Define legal rules on geologic pore-space ownership and rights to provide clarity, and designate pore space as “public use” to eliminate legal hurdles.
- Define post-injection CO_2 storage ownership and long-term liability with liability caps establishing a 10-year post-injection timeframe along with clarified monitoring and reporting requirements.

Challenge F: Insufficient CO_2 transport and storage infrastructure to handle significant CCUS deployment. CCUS is expected to be deployed in a hub model, in which many CCUS facilities share transport and storage infrastructure. However, poor standardization across CO_2 pipelines and insufficient siting of CO_2 storage assets currently limits deployment.[41] Selection of potential actions:

- Continue funding early CCUS hubs with access to necessary infrastructure (e.g., renewable energy, compression, transport, and storage) to support initial build-out.
- Publicly fund site selection surveys to identify ideal locations for CCUS deployments both in the U.S. and abroad (e.g., identify CO_2 storage resources and conduct source–sink matching).
- Provide low-cost financing to de-risk nascent commercial projects serving as “anchors” for future hubs.

5.5 Summary actions to support U.S. competitiveness

The U.S. should pursue four primary actions to boost competitiveness:

- **Create CO_2 regulations and/or long-term monetization opportunities**: The U.S. should establish permanent monetization opportunities for CCUS, either through regulations mandating CO_2 reductions (e.g., emissions limits for government-procured steel) or pricing carbon emissions within certain industries (e.g., LCFS in CA).
- **Continue to support near-term commercial deployments** such as U.S. carbon capture hubs to further drive down costs of CCUS, leveraging government procurement and other levers. The focus should be on next-generation CCUS technologies that can decarbonize applications with low CO_2 concentration in emission stacks.
- **Establish processes for transport and long-term storage and 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 and efficient permitting processes.
- **Accelerate the transition of O&G workers to CCUS to meet labor needs:** Establish training programs and incentives for workers to begin developing the necessary skills.

Beyond these actions, the U.S. should also monitor two key trends which could either accelerate or slow global CCUS deployments:

- **Net zero targets and policies:** More aggressive net zero targets and policies will increase demand for CCUS to address hard-to-abate emissions, increasing U.S. export opportunities.
- **Global regulations and standards for CCUS:** Several nations (especially in the EU) remain opposed to CCUS, given its enablement of continued O&G and inability to capture 100% of emissions. Universal CCUS standards will be crucial in driving widespread global deployments.[42]

---

[40] IEA “Energy Technology Perspectives” (2020)
[41] Global CCS Institute 2022 Status Report
[42] IEA CO_2 Transport and Storage

6 Geothermal

6.1 Geothermal executive summary

Geothermal is potentially at an inflection point similar to the oil & gas industry in 2008, when new technologies radically changed the landscape. Exploration, fracking, and drilling technologies, like those utilized for the past decade in O&G, could alter previous assumptions about the potential of geothermal, shifting it from a niche resource to a more central decarbonization solution. As the current global leader in geothermal deployment, the U.S. is well positioned to build on its advantages – a legacy O&G industry, established domestic developers, and leadership in key technologies – to catalyze global growth and capture significant export market upside.

As a decarbonization resource, geothermal can play a vital role with applications in the power, building, industrial, and transportation sectors. Geothermal power plants supply firm and dispatchable generation to enable increased growth of variable resources such as solar and wind – at a price point that is already cheaper than the leading alternative clean grid balancing solution, solar with storage.[43] For other sectors, it provides strategic benefits such as a potential domestic lithium supply chain and direct heat applications. Further, up to 60% of global lithium production by 2025 could come from geothermal brine, and the Salton Sea in California alone could produce 600,000 metric tons annually – or 6x the current global consumption rate (~$6-12 billion annually).[44] Direct heat could also play a large role in residential applications and achieves temperatures high enough to meet up to 50% of global industrial heat demand.[45]

Geothermal also opens up export market opportunities with defendable competitive advantages. Expertise in drilling, exploration, and innovation in new technologies is extremely complex and highly exportable – especially to geopolitically important markets in Southeast Asia, Africa, and Latin America.

The global market addressable by the U.S. is conservatively estimated to be $1.5 trillion through 2050, creating ~100,000 net U.S. jobs. However, the upside could be much larger, with the DOE estimating the U.S. could see a up to a 20x increase in domestic deployment by 2050.[46] The keys to unlocking this massive potential are new technologies that make geothermal possible in a broad range of locations – namely, enhanced geothermal systems (EGS), deep drilling, and heat-resistant well casing and downhole tools. Although each technology requires adaptations specific to geothermal, they overlap considerably with the O&G industry. In most cases, O&G players are more sophisticated and advanced than their geothermal counterparts, presenting the opportunity for knowledge transfer and accelerated learning. Given strong domestic oil & gas players and the DOE's recent announcement of a targeted "moonshot" in geothermal, the U.S. is well situated to lead in advanced geothermal technologies, though competitors in Asia and Europe could surpass the U.S. if it does not capitalize on its advantages.

The IRA and IIJA mark a shift in policy treatment of geothermal, moving it into the same category as other clean power and decarbonization solutions. Beyond the economic benefits, this shift could impact future policy treatment and change its trajectory. In the near term, the extended tax credits are projected to lower the LCOE from ~$55/MWh to ~$40/MWh. Despite the step forward with IRA and IIJA, significant gaps and challenges remain – including obstructive permitting, lack of long-term clarity, and shortage of funding for research and commercialization.

---

[43] Lazard, NREL, and EIA
[44] Forbes and U.S. Geological Survey, Mineral Commodity Summaries, January 2022
[45] 2021 U.S. Geothermal Power Production and District Heating Market Report
[46] DOE Revision Report 2019

Indeed, to capture the economic and strategic benefits of geothermal, the U.S. must address several political and technical challenges that prevent rapid learning and scaling of crucial technologies. In particular, policymakers should focus on four central challenges:

- Obstructive permitting and regulatory processes
- Shortage of funding for research and innovation
- Lack of demand-side signals and awareness
- Insufficient and inaccessible data characterizing the subsurface.

Solving these four blockers will accelerate domestic learning, develop exportable competencies, and drive down the cost of geothermal.

6.2 Size of the opportunity both in domestic market and exports

Geothermal represents a smaller but strategically important market with an estimated global market of $1.5 trillion through 2050 – roughly 10% of the market size expected for solar. The total U.S. addressable export market opportunity is $1.2 trillion through 2050 and the U.S. can be expected to capture ~$250 billion, or ~20%. This could create 100,000 net jobs through 2050, many of which could be filled by existing O&G workers. However, the U.S. can catalyze new market potential and export opportunities through innovation and policy changes (e.g., IRENA analyses indicate a ~5x market upside, DOE estimates U.S. deployment could be ~20x current capacity, and upper bound for export market share is 30-45%).

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

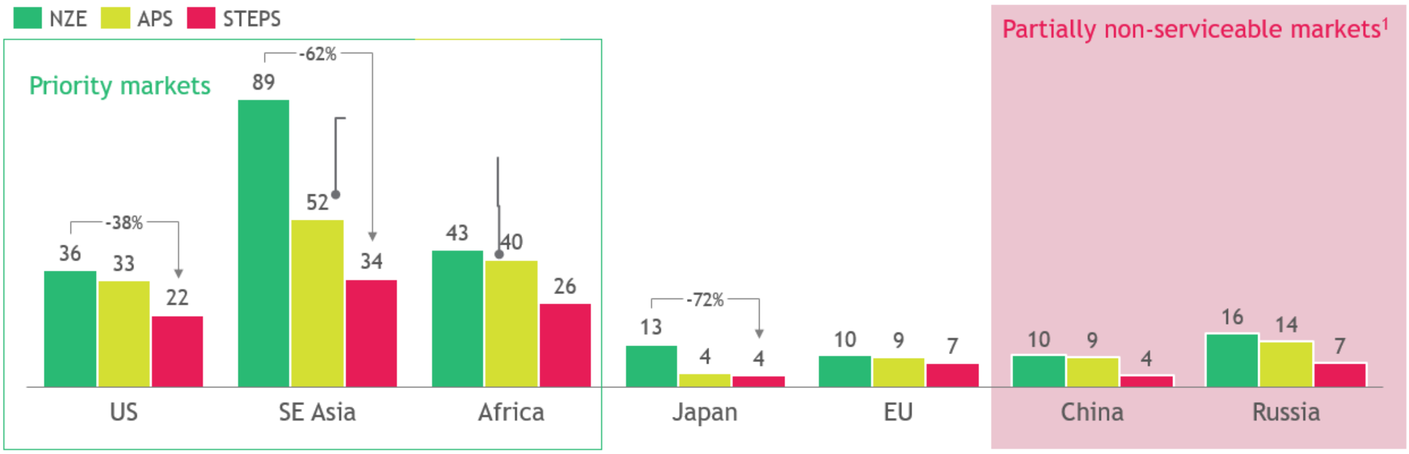


Figure 6.1: Geothermal market assessment

Beyond the financial and economic benefits, geothermal has several desirable traits. It produces zero-carbon firm and dispatchable power to enable higher penetration levels of solar and wind. Direct heat use can also be applied to residential and industrial purposes. Lithium extraction from geothermal brine could facilitate a domestic lithium supply, and the Salton Sea holds and estimated 32 million tons, roughly the same as Bolivia and Chile combined. Finally, the expertise developed in exploration and drilling, especially around EGS, is highly exportable, presenting an opportunity for the U.S. to export to emerging and geopolitically relevant markets (e.g., Indonesia, Kenya, and Mexico).

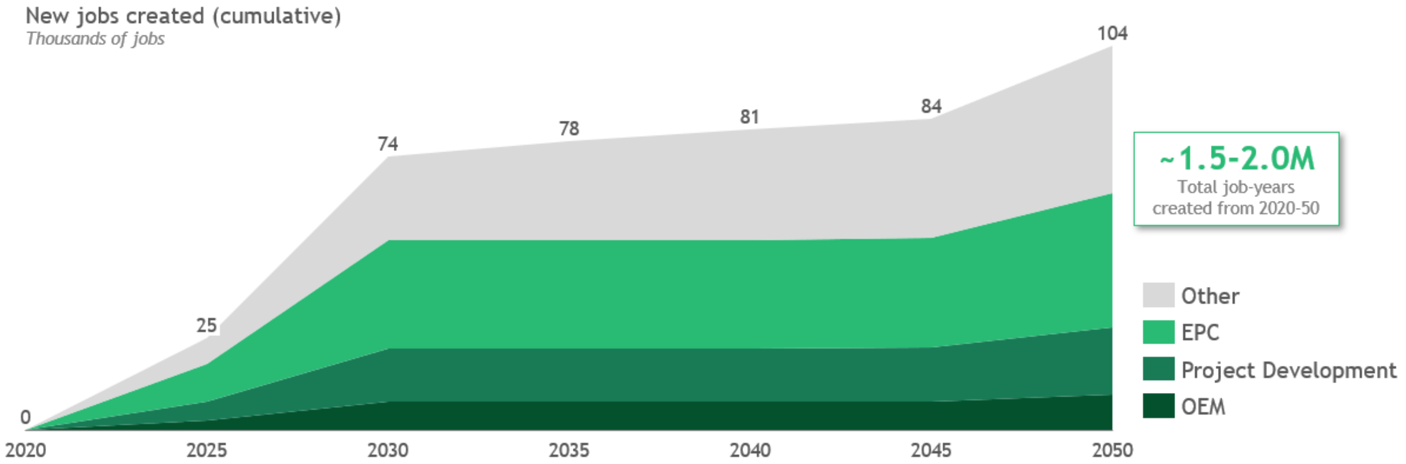
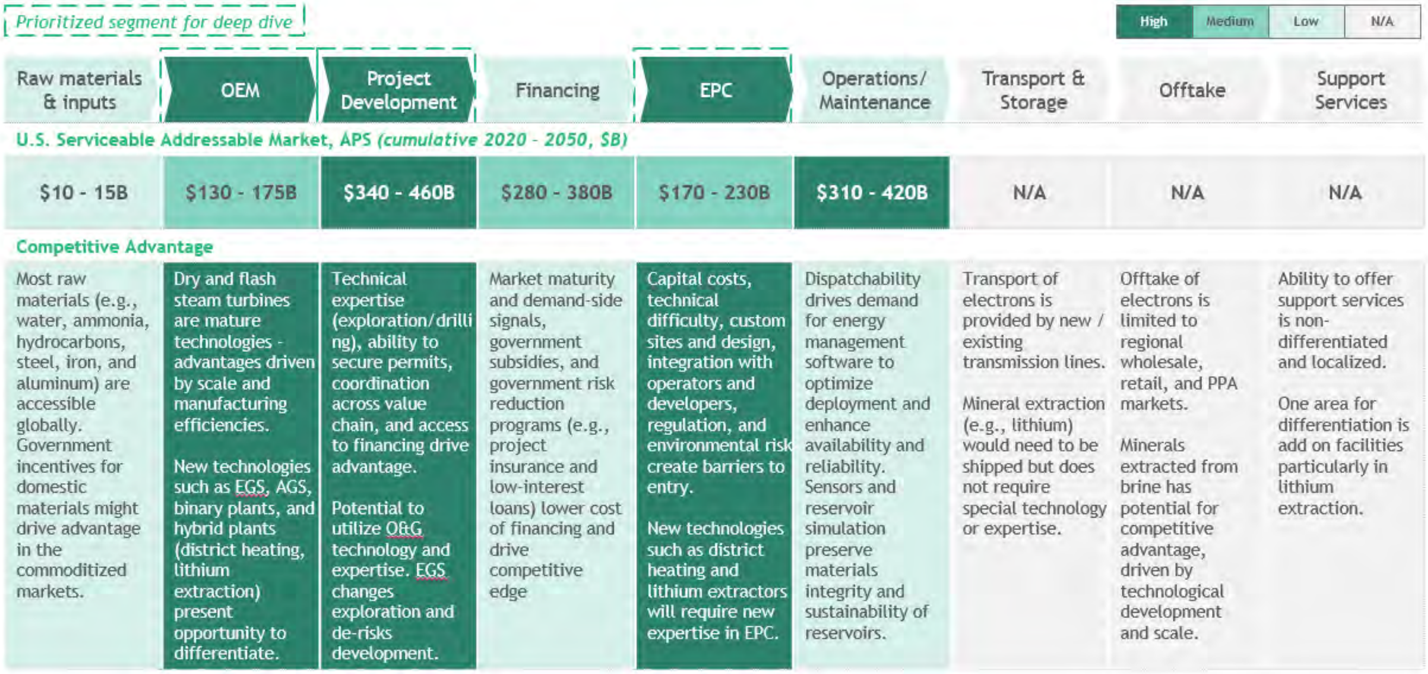


Figure 6.2: Geothermal job growth forecast

6.3 Overview of key areas of opportunity for the U.S.

The geothermal value chain consists of nine segments (see figure 6.3). However, the three segments where the U.S. can develop a competitive advantage and capture economic and strategic benefits are project development, EPC, and OEM.


Prioritized segment for deep dive

High | Medium | Low | N/A

U.S. Serviceable Addressable Market, APS (*cumulative 2020 - 2050, $B*)

Competitive Advantage

Raw materials & inputs	OEM	Project Development	Financing	EPC	Operations/ Maintenance	Transport & Storage	Offtake	Support Services
$10 - 15B	$130 - 175B	$340 - 460B	$280 - 380B	$170 - 230B	$310 - 420B	N/A	N/A	N/A
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.

Figure 6.3: Geothermal value chain prioritization

Project development is the largest segment ($340 - 460 billion) and drives most of the value and differentiation across the industry. Given its experience in drilling and exploration, legacy O&G players, and mature domestic market, the U.S. possesses a durable competitive advantage in project development, which is defendable due to the level of complexity and technical sophistication involved. For these same reasons, however, project development also accounts for the bulk of the risk (50%) and cost (40%). Most of the technology and expertise overlaps with O&G – including reservoir simulation and mapping, fracking, and drilling. Although the U.S. leads in drilling and exploration, it ranks fourth in geothermal patent activity. The key to future success is unlocking enhanced geothermal systems, which utilize the same technology and expertise as fracking and deep drilling.

EPC is highly integrated with project development, and competitive advantages for the U.S. lie in scale and the ability to efficiently design and construct custom sites. Although it's not the largest segment ($170 - 230 billion through 2050), EPC still represents a material economic opportunity, and the U.S. is well positioned to be a leader given its mature domestic market, strong developers, and experience designing next-generation hybrid plants. Because each site is custom-designed to meet the unique geologic and technologic features of the project, quality engineering is highly valued, enabling firms to develop a competitive distinction. The U.S. can leverage its mature domestic market, experience with hybrid plants like the Salton Sea lithium extraction plant, and follow-on advantages of its project developers to differentiate in EPC. Hybrid plants with lithium extraction equipment and direct heat use facilities add a degree of complexity and represent nascent markets with first-mover opportunities. Given the level of integration between segments, the U.S. can cultivate advantages through partnerships with developers.

OEM depends on IP, R&D, and economies of scale. The market size is smaller than some of the other segments ($130 - 175 billion) but emerging technologies in low-enthalpy turbines and deep drilling will unlock new geographies and are critical to expanding the potential of geothermal. The U.S. lags behind China, Japan, and South Korea in patent activity, but is second in research publications and can be a leader in emerging technologies like binary turbines, deep drilling equipment, and heat-resistant downhole materials. As the source of competitiveness in this segment shifts from mature technologies to emerging ones, the U.S. can reclaim lost market share and seize a leadership position.

6.4 Primary challenges to address

Despite its current advantages, several challenges remain which, if left unaddressed, could limit the ability of the U.S. to capture the potential upside.

Challenge A: Obstructive permitting and regulations. Permitting and reviews slow deployment by several years (significantly longer than O&G wells), add risk, and increase costs. This contributes to exceptionally long project timelines (7-10 years) and high financing costs (25%-30% of capital costs), the combination of which stifles investment and prevents domestic players from achieving economies of scale.[47] Selection of potential actions:

- Grant geothermal developers the same treatment as oil & gas for new leases and reviews by extending qualification for categorical exceptions for reviews, lease flexibility for drilling, and 30-day caps on Bureau of Land Management (BLM) reviews.
- Increase frequency and acreage of BLM lease auctions for well sites which are currently only held every two years.

Challenge B: Lack of funding for research and commercialization. Geothermal receives significantly less funding than other clean technologies, resulting in fewer subsidies to drive down costs and constraining vital funding for key emerging technologies. EGS, in particular, depends on these publically funded pilots to de-risk

---

[47] NREL

new technology for private investment, which is pivotal to securing a future leadership position in the market. Selection of potential actions:

- Increase funding for in-field demonstrations for novel technologies like EGS and deep wells – e.g., fully fund AGILE provisions in the Energy Act of 2020 that authorized five more EGS projects like FORGE in Utah.
- Allocate more grant funding for geothermal R&D, with an emphasis on technologies that will develop durable competitive advantages such as EGS, deep drilling, heat-resistant downhole tools, and novel casing materials.

Challenge C: Lack of awareness. A general lack of awareness of geothermal's capabilities, emerging technology, and economics constrains the market and chokes new investment. Further, demand-side policies like the Renewable Portfolio Standard (RPS), which narrowly incentivizes variable resources, and limited utility-rate envelopes do not adequately consider the benefits of clean, firm generation and dispatchable resources. Selection of potential actions:

- Reform demand-side policies such as state RPS to include firm, clean generation and dispatchable resources – e.g., set clean, firm targets and impose grid reliability standards that give utilities license to invest more in balancing resources to support the increased penetration of renewables such as solar and wind.
- Encourage use of clean, firm generation targets in state RPS targets to incentivize early development of technologies such as geothermal, before grid stability from high renewable penetration becomes a limiting factor.
- Set procurement targets for public facilities to acquire direct heat and baseload power to secure crucial public infrastructure and stimulate demand for geothermal.

Challenge D: Risk of dry wells in early development stages. Most of the risk for geothermal is concentrated in the exploration phase – e.g., hitting dry wells or mischaracterizing the subsurface. Combined with the relatively high capital requirements, this early-stage risk can dissuade private investment, limiting learning opportunities for new technologies and domestic developers. Selection of potential actions:

- Reestablish risk insurance and cost sharing programs similar to the programs that were phased out in the 1980s: Program Research Development Announcement (PRDA, 1976), Program Opportunity Notices (PONs, 1977), and User-Coupled Confirmation Drilling Program (UCDP, 1980).
- Provide creative financing that de-risks the venture and stimulates private investment – e.g., loan guarantees like the Geothermal Loan Guarantee Program of 1974 and blended finance options.

Challenge E: Lack of quality data characterizing subsurface. The U.S. has historically underfunded its geologic data collection efforts, rendering much of it inaccessible. Surveys, core information, subsurface imaging, and other information is critical to de-risking development and exploration. Selection of potential actions:

- Improve the United States Geological Survey's (USGS) centralized database of geologic mapping and subsurface characterization, ensuring timely input of data and easy accessibility for developers.
- Increase funding for the USGS and Department of Interior to perform surveys, tests, and catalogues of current wells.

6.5 Summary actions to support U.S. competitiveness

There are four summary recommended actions for policymakers:

- **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., government 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 curves on new technologies to achieve economies of scale

Further, the U.S. should monitor three major trends which could fundamentally alter the competitive landscape for geothermal:

- **Viability of lithium extraction at scale:** Estimated U.S. domestic lithium reserves in geothermal brine is larger than the current global leaders, Chile and Bolivia.
- **Progress of state-backed competitors in emerging markets** like Indonesia, Turkey, and Kenya – who are investing heavily in geothermal.
- **Economic viability of EGS at scale:** Much of the optimism for geothermal rests on the success of EGS at scale, particularly if the DOE can hit the $45/MWh target by 2030.

7 Summary and next steps

An in-depth analysis at the value chain segment level for the four clean technologies has found that the U.S. is well positioned to compete in specific value chain segments for each technology. Using estimated market potential through 2050 and an assessment of the U.S.'s current competitive positioning in a subset of priority segments, we identified policy changes and investments to maintain or build durable competitive advantage.

Two broad themes emerged in our analysis. First, the U.S. can enhance its competitiveness to recapture the domestic market and strengthen domestic supply chains in mature technologies, solar and offshore wind, where it has lost leadership. These technologies are critical for U.S. energy security and decarbonization goals, underscoring the need for U.S. investment in building competitiveness across domestic manufacturing and deployment. Secondly, the U.S. can create and capture markets for technologies, CCUS and geothermal, that it currently leads in. These technologies are impotant for U.S. exports and global leadership, making investment in commercialization of innovations and rapid domestic deployments crucial.

Several key enablers of competitive advantage were identified to support U.S. leadership across all four technologies by accelerating domestic deployment, driving costs down, and providing U.S. players with early learnings.

Examples include both demand- and supply-side policies include:

- ***Demand pull:*** Implement demand-side enablers to boost competitiveness by increasing capacity deployed and driving technology costs down the learning curve. This can be supported by levers such as:
    - **Decreasing green premiums:** Increase demand by providing incentives (e.g., reducing the cost of the clean technology) or disincentives (e.g., increasing the cost of emitting legacy alternatives).
    - **Increasing volumes deployed:** Increase total technology deployment through direct procurements or deployment targets.
    - **Ensuring access to export markets:** Increase demand for domestic companies' exports by clearing non-tariff barriers.

- ***Supply push:*** Implement supply-side enablers to boost competitiveness by building economies of scale through investment in manufacturing and maintaining lead in innovation. This can be supported by levers such as:
    - **Reducing barriers to deployment:** De-risk investment in projects by streamlining permitting, infrastructure expansion, and by expanding and developing relevant workforces.
    - **De-risking project and infrastructure investment:** Increase access to capital for relevant projects and infrastructure, particularly transmission expansion for intermittent renewables.
    - **Reclaiming lead in innovation and commercialization:** Invest in R&D and building IP to maintain innovation lead, and commercialize opportunities to maintain technological competitiveness.

It is important to note that this study was conducted at a single point in time with a snapshot of limited forward-looking data. As new forecasts emerge and both the competitive landscape and technology options shift, it will be necessary to reevaluate the conclusions expressed here.

Next steps: Building U.S. competitive advantage will require translating this analysis into action. That means formulating specific policy proposals and working with relevant stakeholders to build support for implementation. Through well-crafted policy and stakeholder support, the U.S. has an opportunity to reclaim the domestic market in more mature technologies – solar and offshore wind – while maintaining its lead in emerging technologies – CCUS and geothermal – to ensure U.S. energy security and achieve decarbonization goals.

We hope this work can be used as a framework to assess additional clean technologies in the future. This assessment was previously applied to six clean technologies and has now been expanded to four additional technologies. The approach and methodology used to analyze these 10 technologies could be applied to provide a comparative view across a broader set of other potential technologies – which may include clean cement, sustainable aviation fuel, or biofuels.

The implications of this study are clear: The U.S. has the potential to seize and maintain a competitive advantage in several clean energy industries, given the right mixture of government, investment, and industry support.

8 About the authors

Karan Mistry is a Partner in the Los Angeles office with experience across climate and sustainability topics, including a wide range of climate technologies and decarbonization strategies. He focuses on energy and public sector. Karan may be contacted at mistry.karan@bcg.com.

Nico deLuna is a Project Leader in the San Diego office. He is a core member of both BCG‘s climate and sustainability practice and energy practice, with experience working with energy and public sector clients on topics including renewables, grid operations, innovation, and long-term strategic planning. Nico may be contacted at deluna.nico@bcg.com.

Tina Zuzek-Arden is a Managing Director and Partner in the Washington, D.C. office and is BCG’s Global Leader for climate action in the public sector. She advises clients on climate and a just energy transition within the power and public sectors. Tina may be contacted at Zuzek-arden.tina@bcg.com.

Thomas Baker is a Managing Director and Partner in the San Francisco office and is BCG's Global Leader of the Low Carbon Energy & Infrastructure Sector. He's also a core member of BCG's climate and sustainability practice. He can be reached at baker.thomas@bcg.com.

9 Acknowledgements

This paper was commissioned by Breakthrough Energy and Third Way. The authors would like to thank Breakthrough Energy and Third Way for their input and guidance in developing this perspective.

The authors would like to thank Ian Naccarella, Sara Kopunova, Abhishek Saraf, and Jordan Conger for their contributions to preparing and evaluating the research discussed in this report. The authors would also like to thank Matt Palmquist for his writing assistance, as well as Anja Vinter and Inma Lujan for their contributions to the design, editing, and production of this report.

The contents of this paper are the sole viewpoints and perspectives of the authors. The organizations consulted were not asked to review content prior to publication. The following organizations informed our perspectives and findings for this project: AC Strategies, Brightline Defense, Capture6, CEA Consulting, Clean Air Task Force, Clean Energy Business Network, Cozairo, Cyrq Energy, Fervo Energy, ClearPath, General Electric (GE) Renewable Energy, Special Initiative on Offshore Wind, National Renewable Energy Laboratory (NREL), Oceankind, University of North Carolina Wilmington (Center for Marine Science), U.S. Department of Commerce (International Trade Association), and U.S. Department of Energy (Office of Clean Energy Demonstrations, Loan Programs Office).

10 Acronyms / glossary

AI	Artificial Intelligence
APS	Announced pledges scenario
BLM	Bureau of Land Management
BLS	Bureau of Labor Statistics
BOEM	Bureau of Ocean Energy Management
CapEx	Capital expenses
CCUS	Carbon capture, utilization, and storage
CO_2	Carbon dioxide
DAC	Direct air capture
DOD	Department of Defense
DOE	Department of Energy
EIA	Energy Information Administration
EGS	Enhanced geothermal systems
EPC	Engineering, procurement, and construction
EU	European Union
EV	Electric vehicle
FERC	Federal Energy Regulatory Commission
Gt	Gigaton
Gtpa	Gigaton per annum
GW	Gigawatt
H_2	Hydrogen
IEA	International Energy Agency
IIJA	Infrastructure Investment and Jobs Act
ISO	Independent system operators
IP	Intellectual property
IRA	Inflation Reduction Act
IRENA	International Renewable Energy Agency
kW	Kilowatt
LCFS	Low carbon fuel standard
LCOE	Levelized cost of energy
LDES	Long duration energy storage
Mtpa	Megatons per annum
MW	Megawatt
NAICS	North American Industry Classification System
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
O&G	Oil & gas
O&M	Operations and maintenance
OEM	Original equipment manufacturer
PON	Program opportunity notices
PRDA	Program research development announcement
PV	Photovoltaics
R&D	Research and development
RD&D	Research, demonstration, and development
RPS	Renewable Portfolio Standard
RTO	Regional transmission organizations
SAM	Serviceable addressable market
SOM	Serviceable obtainable market
TAM	Total addressable market
UCDP	User-Controlled Confirmation Drilling Program
USGS	United States Geological Survey