US State and Regional Energy Innovation Index

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Vibrant regional energy innovation ecosystems are important for any national net-zero strategy. But to understand the potential contributions they can make to the price and performance of clean energy technologies, we must first benchmark the resources they bring to bear.

KEY TAKEAWAYS

- A diverse array of new and improved energy technologies that emit far fewer greenhouse gases, while matching (or nearly so) the price and performance of incumbent technologies, are needed to reduce the harms of climate change.
- State and regional energy innovation ecosystems in the United States can and should make significant contributions to the development and improvement of these technologies.
- Recent legislation has established federal policies to strengthen these ecosystems. Many states and regions are responding to this opportunity by adopting clean energy-based economic development strategies.
- The ITIF U.S. State and Regional Innovation Index provides a baseline against which to measure the future impact of this legislation at the state and regional level. It covers 9 categories of innovation system functions and 14 areas of technological specialization.
- The federal government should continue to support state and regional capacity-building for clean energy innovation so that bottom-up strategies stand a better chance of success. Federal programs should strengthen coordination with one another.

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INTRODUCTION

The United States, along with the rest of the world, has embarked on a transition to clean energy. The transition's ultimate endpoint is net-zero greenhouse gas (GHG) emissions to limit the impact of climate change. Energy security, human health, local environmental protection, and economic opportunity also motivate the global community to pursue this important objective. But the path to net zero is strewn with obstacles. Many of the technologies the world needs to stay on it are too expensive, perform too poorly, or are simply unavailable right now. Innovation should therefore be a major focus of any net-zero strategy.[1]

Regional energy innovation ecosystems have great potential to contribute to such strategies. Geographically concentrated networks of technology and service firms, research institutions, and nonprofit and public sector entities could drive price and performance improvements in a diverse array of clean energy sources and uses. This report assesses the potential of energy innovation ecosystems across the United States to contribute to this important mission, drawing on a wide range of data, such as federal and private funding, publications and patents, and state and regional policies and public opinion, covering nine categories of innovation system functions, to compile an index of this potential. Fourteen technology-specific indices, which draw on subsets of the main database, complement the main index and highlight regional diversity.

The index, while inevitably imperfect, provides a baseline against which to measure the future impact of recent federal legislation. Landmark bills passed by Congress in 2021 and 2022 support states and regions that seek to strengthen their energy innovation ecosystems. Quite a few states and regions had already begun to do so before the new federal programs were created, and many more are now responding to these opportunities. The report concludes by offering broad suggestions for sustaining this momentum and improving the odds that the new policies will succeed.

REGIONAL INNOVATION ECOSYSTEMS: ENGINES OF THE ENERGY TRANSITION

Abundant, affordable, reliable energy is a fundamental requirement of a high standard of living. A small handful of individuals, following Thoreau, may choose a life of voluntary simplicity, but the vast majority of the world's population seeks the comforts and opportunities that are widely available in high-income countries. While these need not be supplied as wastefully as they are now, especially in the United States, they intrinsically demand substantial energy inputs.

The Industrial Revolution, which brought for the first time a measure of comfort and opportunity to a large proportion of the population in the places it swept through, rested on energy from fossil fuels. That pattern continues today, with these same fuels providing about 80 percent of global primary energy. They remain abundant and reasonably affordable and reliable, but the social costs of burning them have mounted. Most notably, fossil fuel combustion accounts for about 75 percent of the GHG emissions that are driving catastrophic storms, wildfires, and other symptoms of global climate change.[2]

The challenge facing human civilization, then, is to enable all those who desire to live at a high standard to have the quantity and quality of energy they need to do so, while simultaneously and dramatically reducing the harm that would cause. As Gaster, Atkinson, and Righter argue, new and improved energy technologies that emit far fewer GHGs, while matching (or nearly so) the price and performance of the incumbents, lie at the core of any strategy with any chance of surmounting this monumental challenge.[3]

A diverse array of such innovations are needed. Some, such as solar panels and heat pumps, are well advanced, though still capable of significant improvement. Many others, such as green steel and carbon dioxide (CO_2) removal, are early in their development. Many of these new technologies are complex systems themselves, and nearly all must be further integrated with even more complex systems, such as the power grid.[4]

Energy innovation is a subject of discussion in international climate talks and figures into many national policies. Some national governments are making important contributions by funding clean energy research, development, and demonstration, fostering climate-tech venture investments, and the like. But the innovation rubber really hits the energy transition road at the regional level. That's because innovation, especially innovation in complex systems, accelerates most quickly when dense networks of firms and supporting institutions, clustered in relatively compact geographic areas, pursue it.[5]

The concept of regional innovation ecosystems is an old one, dating back to the 19th century economist Alfred Marshall, who noted "something in the air" in places such as Sheffield, where Britain's pioneering cutlery makers were concentrated. Modern research has revealed that "something" to have many elements: When working effectively, regional innovation ecosystems foster knowledge exchange, attract specialized labor, facilitate infrastructure investment, and encourage entrepreneurship, among other things. Regions diverge economically in large part because of these ecosystems. Some are home to innovative industries that serve growing markets beyond the regions in which they are located, while others rely on stagnant or shrinking sectors. Silicon Valley and Detroit epitomize these extremes in the public mind.[6]

Digitalization might have been expected to undermine these dynamics, but, as many analysts have noted, "the death of distance has been greatly exaggerated." Van der Wouden and Youn, for instance, find that while the geographical distance between research collaborators grew substantially between 1975 and 2015, so had the "learning premium" associated with geographical proximity. Those who collaborated locally were far more likely to enter new fields and build their own capabilities than those who collaborated long distance. The effect was especially strong in STEM (science, technology, engineering, and math) disciplines, such as chemistry, materials science, and engineering, which are particularly important in energy innovation.[7]

The systemic nature of energy innovation heightens the importance of collaboration within regions. Innovative low-carbon power, transportation, and industrial systems typically involve diverse components that must be integrated carefully to optimize performance and minimize cost and emissions. These integration processes, in turn, often require learning-by-doing and learning-by-using across organizational and institutional boundaries. Geographic proximity is likely to ease them by facilitating hands-on and face-to-face interactions.[8]

The importance of regional energy innovation ecosystems in the coming decades will be heightened by the vulnerability to disruption of places dependent today on fossil-fuel-based industries. Wyoming's coal mines, Houston's petrochemical plants, and Detroit's auto factories are among those at risk. Hanson, a co-author of 2016's "The China Shock" paper (a belated recognition of that epochal impact by neoclassical economists) wrote that "the energy transition … is a shock foretold" for such regions.[9]

Whether such "brownfield" regions are willing and able to repurpose their existing assets or build new ones to seize the opportunities presented by the transition will go a long way toward determining their future economic dynamism in a low-carbon world. Wyoming's effort to position itself as a leader in nuclear power and carbon capture, Houston's push to become a hydrogen hub, and Detroit's emerging shift to electric vehicles illustrate these dynamics. Of course, such retooling regions must frequently compete with "greenfield" locations elsewhere, domestically and globally.[10]

That competition has important consequences for the energy transition. If regional innovation ecosystems are able to lower the cost and improve the performance of emissions-reducing technologies, their uptake will expand, feeding ideas and resources back to the regions that make them. This virtuous cycle extending beyond the region will be enhanced and enabled by international agreements and national policies, but ultimately depends on positive feedbacks within the region among laboratories, factories, testbeds, and related facilities, organizations, and institutions.

FROM TBED TO CEBED: THE REGIONAL MOMENT IN U.S. ENERGY AND CLIMATE INNOVATION POLICY

Some regional innovation ecosystems specializing in low-carbon technology have emerged relatively spontaneously. Wind energy innovation revitalized Denmark's central Jutland region, for instance, repurposing older manufacturing assets beginning in the 1970s and later fending off higher-tech competitors elsewhere. Others have been built up more deliberately. The solar power manufacturing cluster in China's Yangtze River Delta was created in the 2000s in large measure by targeted local, provincial, and national policies.[11]

The deliberate approach to building such ecosystems is likely to dominate going forward, as the need for energy innovation, and the extra-regional export opportunities created by the energy transition, are increasingly evident to policymakers worldwide. China's success in solar manufacturing is part of a broader strategy to dominate emerging clean technologies. The European Union is pursuing a "smart specialization strategy" with an increasingly green tilt to diversify its regional economies and move them "up the ladder of higher knowledge complexity and value creation."[12]

Some state and local governments in the United States adopted such strategies in the 2010s. New York has sought to establish its southern tier as a global center for energy storage manufacturing, while Colorado's Front Range region has become a hub for cleantech start-ups. Until recently, however, the U.S. federal government has not kept pace with its global competitors in this regard.[13]

That changed with the passage of major legislation by the 117th Congress (2021–2022). New programs supported regional innovation ecosystems and technology-based economic development (TBED) across all industries, encouraging many states and regions to propose initiatives focusing on clean energy technologies. Five out of 21 regional coalitions that won the Build Back Better Regional Challenge, funded by the Department of Commerce (DOC) under the 2021 American Rescue Plan, focused on energy innovation. So did 7 of DOC's 31 regional tech hubs designees and 7 of its 18 regional strategy development grantees, a program authorized by the 2022 CHIPS and Science Act. (See box 1 for a brief description of this program.) Six of the 10 winners of regional "engine" grants selected by the National Science Foundation (NSF) (also under CHIPS and Science) are seeking to drive sustainable energy or climate-related innovation as well.[14]

In addition, the Bipartisan Infrastructure Law and Inflation Reduction Act established programs and funding streams specifically to catalyze regional energy innovation. The new DOE Office of Clean Energy Demonstrations (OCED), for instance, is implementing an $8 billion program to create regional hubs for clean hydrogen production, distribution, and use. OCED has roughly $20 billion more for large-scale demonstration projects in other technology areas, including $6.3 billion for industrial decarbonization. DOE's Office of Fossil Energy and Carbon Management has received an additional $3.5 billion to fund direct air capture hubs. More broadly, Congress has explicitly tasked DOE with responsibility for fostering regional competitiveness through clean energy innovation, and given preference to fossil-fuel-dependent communities in many of these programs.[15]

The response to these bills indicates that an increasing number of states and regions in the United States are seeking to enhance their competitive advantages in a world striving for net-zero emissions. (Box 2 briefly describes a regional strategy and box 3 a state strategy.) Their efforts fold into a broader discourse around TBED and "place-based" policies. Best practice in these domains rests on a grounded assessment of existing state and regional assets that allows identification of "adjacent possible" sectors. These are sectors with a realistic potential for future export growth rather than fantastic dreams of building the next Silicon Valley.[16]

This report advances the movement toward Clean Energy Based Economic Development (CEBED) by applying insights from the large corpus of analytical work that underpins TBED. We have compiled a wide range of indicators that measure how well a region's energy innovation system is functioning today. We hope the findings will inform strategies to build a more prosperous and cleaner future.

Federal Regional Technology and Innovation Hub Program (Tech Hubs)

The Tech Hubs program, initially proposed by ITIF, was authorized by the 2022 CHIPS and Science Act. It seeks to enable regions (Metropolitan Statistical Areas (MSAs) or closely connected MSAs and nearby micropolitan statistical areas) to become globally competitive in "industries of the future." Such industries lie within the ambit of 10 broad technology areas laid out in the act, including "advanced energy and industrial efficiency" as well as "disaster prevention or mitigation." Congress authorized $10 billion for the program and appropriated $500 million through fiscal year 2023.[17]

Regional consortia seeking Tech Hubs grants from the Economic Development Administration (EDA), a unit of DOC, must include an institution of higher education; state, local, or tribal governments; industry; labor; and economic development organizations. These consortia must set forth a compelling narrative that describes a region's potential to achieve world-class status, the barriers that impede its achievement, and projects that would address those barriers. Projects may advance innovation, strengthen the workforce, develop business and entrepreneurship opportunities, and build infrastructure.[18]

In October 2023, EDA designated 31 consortia as eligible for 5 to 10 grants of $50 million to $75 million. It also awarded 29 strategy development grants of roughly $500,000, 11 to consortia eligible now and 18 to consortia that may become eligible in future phases of the program. In addition to EDA funding, Tech Hubs will receive preferential treatment in a variety of other federal programs, such as those supporting foreign direct investment and providing export assistance.[19]

Seven of the eligible consortia fall within the categories of "Accelerating America's Clean Energy Transition" and "Strengthening Our Critical Minerals Supply Chain":

- Louisiana: offshore wind and renewable energy
- Idaho and Wyoming: small modular reactors (SMR) and advanced nuclear
- South Carolina: exportable electricity technologies
- Florida: sustainable and resilient infrastructure
- New York: batteries
- Nevada: lithium
- Missouri: battery materials

Several others will contribute less directly to energy innovation, such as gallium nitride technology (Vermont), which underpins power system electronics.[20]

The governing statute for the program enumerates 13 considerations for selecting hubs, which EDA has distilled into 7 broad criteria: project quality and ability to execute, impact on economic and national security, investment and policy commitments, workforce, capital, equity and diversity, and governance. A consortium's plan to leverage existing innovation assets is included in the first, fourth, and fifth criteria, while its forecast for the targeted technology's impact and prospects for retaining manufacturing are incorporated into the second.[21]

MEASURING STATE AND REGIONAL ENERGY INNOVATION ECOSYSTEMS

Energy innovation ecosystems are made up of complex networks of actors, institutions, and resources that contribute to the generation, development, diffusion, and use of innovative energy products and services. To be effective, such systems must perform a broad range of functions, including mobilizing resources, developing and diffusing new scientific and technical knowledge, facilitating experimentation by entrepreneurs, facilitating the formation of supply chains and new markets, legitimizing new technologies in society, guiding the search for new knowledge in certain directions, and guiding its spillover into other related industries.[22]

Our index is built from the following four subindices that seek to capture distinct groups of these functions:

- Knowledge development and diffusion
- Entrepreneurial experimentation
- Supply chain and market formation
- Social legitimation

In this section, we briefly review the categories and indicators included in each of the four subindices. Most indicators are available at the county level and are aggregated to the regional and state levels.

In addition to the main index, our work provides insights into regional technological specializations, which vary greatly across the United States. (See figure 1 for a comparison of Massachusetts and South Carolina.) Fourteen technology areas, each of which is covered by an index that draws on a subset of the main database and is constructed in the same fashion, are listed at the end of this section.

A very detailed account of sources and methods can be found in appendix 2.

Subindex: Knowledge Development and Diffusion

Knowledge development and diffusion activities comprise the first subindex. Unless new scientific and technical knowledge is developed and diffused, no new clean energy innovations will emerge, and there will be nothing to scale up. The subindex consists of three categories of indicators.

Category: Research and Development

Mobilization of resources to fund research and development (R&D) activities performed by companies, government laboratories, and academic institutions lies at the base of this subindex. The public sector plays a larger role in energy R&D than in many other sectors, in large part because the transition to clean energy is being driven by the environmental threat of climate change, and markets have not been responsive to it. The category focuses on federal low-carbon energy R&D spending, which far outpaces state and local investments, assessing the ability of states and regions to garner federal awards.

Category: Knowledge

R&D funding contributes to scientific discoveries. The quality of this new knowledge varies considerably. Most discoveries end up having little scientific or commercial value, while highly valued knowledge is ultimately recognized by and diffused through networks of academic and professional peers. We use data on publications as a proxy for new discoveries and data on publication citations to estimate their quality and extent of diffusion.

Category: Invention

R&D funding also to contributes to the development of technical know-how and the generation of new inventions. Like new knowledge, the quality and commercial viability of inventions varies considerably. We use data on patents as a proxy for new inventions and data on patent citations to estimate their quality and extent of diffusion.

Subindex: Entrepreneurial Experimentation

Entrepreneurial experimentation activities comprise the second subindex. These activities largely involve a different set of actors, institutions, and processes than those involved in knowledge development and diffusion, whose aim is to test and demonstrate the commercial viability of new technological innovations in niche markets.

Category: Demonstration

Technology demonstration projects seek to establish the market viability of new clean energy innovations. The public sector plays a larger role in energy demonstration projects than in many other sectors due to the high-risk nature and long development horizons of many emerging energy technologies. We use federal spending data to assess the ability of states and regions to garner federal awards for energy demonstration projects.

Category: Entrepreneurship

Entrepreneurs create new ventures that carry out the high-risk technological, business, and social experiments that must be performed before innovative energy products and services can join the mainstream. These new ventures may receive support from venture capitalists and federal grants and, when successful, scale up by exiting through acquisitions or initial public offerings (IPOs). We use data on federal seed investments, venture capital investments, and successful company exits to assess state and regional contributions to the entrepreneurship function.

Subindex: Supply Chain and Market Formation

Supply chain and market formation activities comprise the third subindex. Successful scale-up of innovations, whether carried out by a new or established business, depends on the availability of inputs at a competitive cost and on a growing array of buyers who find value in deploying these innovations. Some supply chains and markets may lie within the state or region where an innovation is made, although these functions frequently extend beyond these boundaries. Proximity to suppliers and customers can provide valuable feedback as innovations bridge from early adoption to mass markets.

Category: Industry

A central goal of CEBED is to create jobs and steady employment in clean energy industries. We use data on low-carbon energy employment to assess the ability of states and regions to create such jobs and strengthen state and regional supply chains.

Category: Technology Adoption

A long-term CEBED strategy ultimately depends on generating an abundant and reliable supply of low-carbon energy resources to power industrial activities and ensure sustainable economic development. We use data on the supply of low-carbon electricity generation and energy storage resources to assess the ability of states and regions to mobilize resources and facilitate market formation for building clean energy infrastructure.

Subindex: Social Legitimation

Social legitimation activities comprise the fourth subindex. Innovation is an intrinsically social process. Incumbent energy technologies are often buttressed by political, legal, and regulatory mechanisms and embedded in supportive state and regional cultures. The more innovations disrupt legacy systems, the more effort is required for them to break through to widespread adoption.

Category: Public Goals and Strategies

Social legitimation of innovations and CEBED depends on the goals and strategies of policymakers. We use data on published public policy and strategy documents to assess the degree to which states and regions have adopted CEBED strategies.

Category: Social Values

In a democracy, social legitimation and CEBED policies ultimately depend on the values of the general public. We use data on public opinion about clean energy R&D and climate action to assess the extent to which the citizens of states and regions value clean energy innovation and CEBED.

Technological Specialization

A function of energy innovation ecosystems that adds significant depth to the index is guidance on the direction of the search for new technologies, and ultimately, CEBED. The clean energy transition is a deliberate and purposeful attempt to guide the economy away from dependence on unabated fossil fuels and toward a sustainable path of low-carbon energy production and use. Within that overarching framework, energy innovation ecosystems may also be guided toward specific technology areas. The index seeks to capture these technological specializations at the state and regional level. These are measured by subindices covering fourteen technology areas:

1. Advanced energy materials
2. Bioenergy
3. Carbon capture, utilization, and storage (CCUS)
4. Clean energy manufacturing
5. Clean energy transportation
6. Energy efficiency
7. Energy storage
8. Geothermal energy
9. Grid technologies
10. Hydrogen and fuel cells
11. Nuclear energy

12. Solar energy
13. Water energy
14. Wind energy

Limitations

Our measures of state and regional energy innovation ecosystems are imperfect. For instance, private R&D spending is a very important input to these ecosystems, but it is not measured adequately enough to incorporate into the index. Data constraints also limit our visibility into clean energy employment and state and regional clean energy innovation policies in the third and fourth subindices. In the final section of this report, we recommend that federal agencies invest in improved measurement systems so that state and regional economic development strategists can become better informed.

New Energy New York

New York State's Southern Tier, an eight-county region bordering Pennsylvania, was a thriving center of manufacturing in the first half of the 20th century. Major U.S. firms such as IBM and General Electric called the Southern Tier home. While the region's strength in electronics manufacturing cushioned the blow, the Southern Tier suffered a long decline in the second half of the 20th century, which has worsened since then.[23]

New Energy New York (NENY) is a regional initiative led by Binghamton University that seeks to help revive the area by creating a globally competitive battery technology development and manufacturing hub. The NENY coalition includes state and local government agencies along with universities and a variety of community and nonprofit organizations. The initiative's key elements include technology prototyping, supplier identification and certification, workforce development, and start-up incubation, with attention to equity across diverse populations throughout.[24]

The initiative emerged from a longer-term effort by both Binghamton to develop its innovation capacity in the wake of deindustrialization and by the state to target clean energy industries for economic development. A series of grants from federal and state sources, capped by a New York State Energy Research and Development Authority (NYSERDA)-funded clean energy incubator, put Binghamton in position to compete effectively in the new federal grant programs. M. Stanley Whittingham, a Binghamton University distinguished professor who won the Nobel Prize for his contributions to the invention of the lithium-ion battery, played a foundational role in establishing NENY's credibility. A battery "gigafactory" being developed by iM3NY, on a site where IBM manufactured products from 1911 to 2002, is another anchor asset.[25]

With strong support from the state's congressional delegation and significant state investments, NENY has run the table in federal grant competitions. It won $63.7 million In EDA's Build Back Better Regional Challenge to construct a technology and manufacturing development center equipped with state-of-the-art manufacturing lines for the production of full-size battery cells. It was designated as an EDA Tech Hub, enabling it to compete for $50 million to $75 million in the next phase of the program and benefit from preferential treatment in other federal programs. In early 2024, it took home an NSF Regional Engine award worth $15 million over the next two years and up to $160 million in the next decade to carry out R&D, technology translation, and workforce development for the battery industry. NENY and its partners must now execute the challenging commitments they have made to secure these investments.[26]

THE INDEX

This section reports illustrative results from the ITIF State and Regional Energy Innovation Index. The weighting scheme used to compile the index is set forth in appendix 1. The full results and the underlying database, which cover all 50 states and the District of Columbia and up to 935 regions (Core-Based Statistical Areas, as defined by the Office of Management and Budget), can be accessed through the ITIF Center for Clean Energy Innovation website. The website allows users to find scores for the overall index, four subindices, and nine functional categories for user-specified states or regions for the years 2016 to 2021. Users can also find the 14 technology-specific versions of these scores and generate charts displaying a location's functional and technological strengths and weaknesses. The site also features national heat maps of this data.

Table 1 reports the top five and bottom five states in the 2021 Index and their strongest and weakest functional categories and technology areas. States with small populations take the top slots, perhaps because many index categories are scaled by the size of the state population or economy. Nonetheless, the index reveals important strengths and weaknesses. For example, while the Index's top-ranked state, Vermont, ranks well across most categories, it is especially strong in start-ups (measured by federal Small Business Innovation Research (SBIR) grants, private venture capital investments, and successful company exits). The #2 state, South Dakota, by contrast, does well in technology adoption, thanks to the importance of wind power there, but does relatively poorly in generating and diffusing original research through scientific publications. Neighboring North Dakota, which ranks fifth overall, shows an even sharper contrast, capturing a disproportionate share of federal R&D spending for its size but coming in 48th in the social legitimation subindex due to very low public support for low-carbon energy research and climate action. The technology specializations reveal similar divergences. Hawaii, for instance, ranks last in grid technologies but sixth in solar energy.

Table 1: Top and bottom states and their strengths and weaknesses in the 2021 index

State	Rank	Functional Strength	Functional Weakness	Technology Strength	Technology Weakness
Vermont	1	Start-ups	Demonstration projects	Energy storage	Nuclear energy
South Dakota	2	Technology adoption	Publications	Clean energy manufacturing	Nuclear energy
Alaska	3	Economic development goals	Technology adoption	Grid technologies	Clean energy manufacturing
Montana	4	Publications	Patents	Water energy	Nuclear energy
North Dakota	5	Federal R&D spending	Societal values	Energy storage	Clean energy manufacturing
Kentucky	47	Clean energy employment	Societal values	Transportation	Advanced energy materials

State	Rank	Functional Strength	Functional Weakness	Technology Strength	Technology Weakness
New Jersey	48	Societal values	Clean energy employment	Carbon capture	Energy storage
DC	49	Societal values	Economic development goals	Grid technologies	Energy storage
Texas	50	Demonstration projects	Economic development goals	Grid technologies	Water energy
Hawaii	51	Federal R&D spending	Economic development goals	Solar energy	Grid technologies

Table 2 reports the top 5 and bottom 5 out of 382 MSAs in the 2021 Index and their strongest and weakest functional categories and technology areas. Like the state index, the regional index reveals important strengths and weaknesses. The top region, which is in central Virginia, for instance, is at the top of the supply chain and market formation subindex, which includes clean energy employment, but only 123rd in the entrepreneurial experimentation subindex. The bottom region, Rome, Georgia, actually matches the top region in the entrepreneurship ranking, but is pulled down by extreme weakness in all the other subindices. Among larger, better-known metro regions, the San Francisco metropolitan region ranks 79th, Chicago 269th, Atlanta 293rd, and New York City 295th out of the 382 MSAs.

Table 2: Top and bottom regions and their strengths and weaknesses in the 2021 Index

Region	Rank	Functional Strength	Functional Weakness	Technology Strength	Technology Weakness
Staunton-Stuarts Draft, VA	1	Clean energy employment	Societal values	Energy efficiency	Bio-energy
Burlington-South Burlington, VT	2	Start-ups	Demonstration projects	Transportation	Carbon capture
Lynchburg, VA	3	Publications	Economic development goals	Nuclear energy	Energy storage
Sebring, FL	4	Clean energy employment	Societal values	Hydrogen	Energy storage
Blacksburg-Christiansburg-Radford, VA	5	Clean energy employment	Patents	Energy efficiency	Bio-energy

Region	Rank	Functional Strength	Functional Weakness	Technology Strength	Technology Weakness
Sierra Vista-Douglas, AZ	378	Demonstration projects	Clean energy employment	Carbon capture	Bio-energy
Beaumont-Port Arthur, TX	379	Federal R&D spending	Societal values	Solar energy	Energy efficiency
Sherman-Denison, TX	380	Demonstration projects	Societal values	Energy storage	Hydrogen
Gadsden, AL	381	Demonstration projects	Societal values	Energy storage	Transportation
Rome, GA	382	Start-ups	Societal values	Bio-energy	Hydro-power

Table 3 and table 4 report illustrative results for 5 of the 14 technology areas at the state and regional levels, respectively, for 2021. Vermont's top ranking in the overall index is reflected in its high ranks in four of these five areas, while Rhode Island, which ranked 34th overall, leads in wind energy technological innovation. Similarly, among MSA regions, Bangor, Maine, ranks 1st in wind energy technological innovation (and 2nd in water technological innovation, which is not shown), but 25th overall and as low as 221st in hydrogen and 230th in nuclear energy.

Table 3: Top ten states across five technology areas in 2021

State Rank	Clean Energy Manufacturing	Clean Energy Transportation	Energy Storage	Solar Energy	Wind Energy
1	South Dakota	Vermont	Vermont	Vermont	Rhode Island
2	Vermont	Michigan	North Dakota	New Mexico	Maine
3	Illinois	New Mexico	California	Rhode Island	South Dakota
4	New Mexico	New Hampshire	Alaska	New Hampshire	New Hampshire
5	Maine	South Dakota	Oregon	District of Columbia	Colorado
6	Minnesota	Iowa	Massachusetts	Hawaii	North Dakota
7	North Carolina	Virginia	Nevada	Massachusetts	Massachusetts
8	Massachusetts	Wyoming	Colorado	California	Kansas
9	Idaho	Montana	Idaho	Colorado	Iowa
10	New Hampshire	Wisconsin	South Dakota	Alaska	New Mexico

Table 4: Top ten regions across five technology areas in 2021

Region Rank	Clean Energy Manufacturing	Clean Energy Transportation	Energy Storage	Solar Energy	Wind Energy
1	Santa Fe, NM	Burlington-South Burlington, VT	Boulder, CO	Santa Fe, NM	Bangor, ME
2	Lafayette-West Lafayette, IN	Waterloo-Cedar Falls, IA	Burlington-South Burlington, VT	Burlington-South Burlington, VT	Ames, IA
3	Corvallis, OR	Logan, UT-ID	Ann Arbor, MI	Tallahassee, FL	Manchester-Nashua, NH
4	Chattanooga, TN-GA	Boulder, CO	Joplin, MO-KS	Amherst Town-Northampton, MA	Corpus Christi, TX
5	Boulder, CO	Santa Fe, NM	Valdosta, GA	Charlottesville, VA	Davenport-Moline-Rock Island, IA-IL
6	Ames, IA	Columbus, IN	Pocatello, ID	Corvallis, OR	Boulder, CO
7	Buffalo-Cheektowaga, NY	Carson City, NV	Toledo, OH	Bend, OR	Des Moines-West Des Moines, IA
8	Bloomington, IN	Detroit-Warren-Dearborn, MI	Corvallis, OR	Trenton-Princeton, NJ	Enid, OK
9	Huntsville, AL	Bloomington, IN	Midland, MI	Ithaca, NY	Albuquerque, NM
10	Boston-Cambridge-Newton, MA-NH	Mankato, MN	Columbus, IN	Santa Cruz-Watsonville, CA	Bismarck, ND

Finally, figure 1 and figure 2 compare two states in the middle of the rankings, Massachusetts (ranked 25th) and South Carolina (ranked 26th) to illustrate their functional and technological similarities and differences. Massachusetts outshines South Carolina in entrepreneurship and societal values, while South Carolina displays greater strength in clean energy employment (industry) and technology adoption. Across technological areas, Massachusetts ranks in the top 10 states across most, but in the bottom third in transportation and hydrogen. South Carolina's top area is nuclear energy, where it ranks 4th, while its worst showing is in energy efficiency, where it ranks 28th.

Figure 1: Functional comparison of Massachusetts and South Carolina

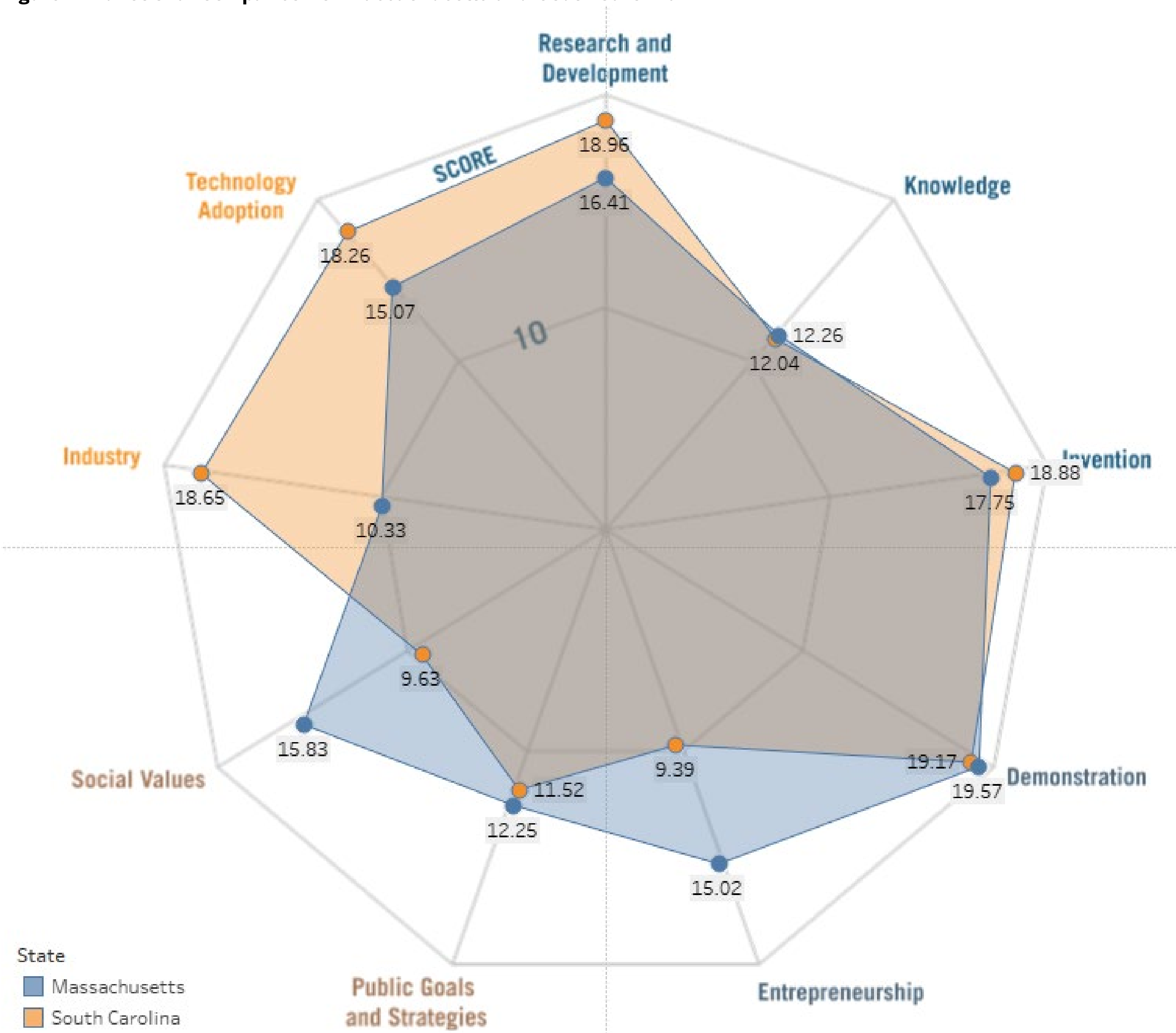
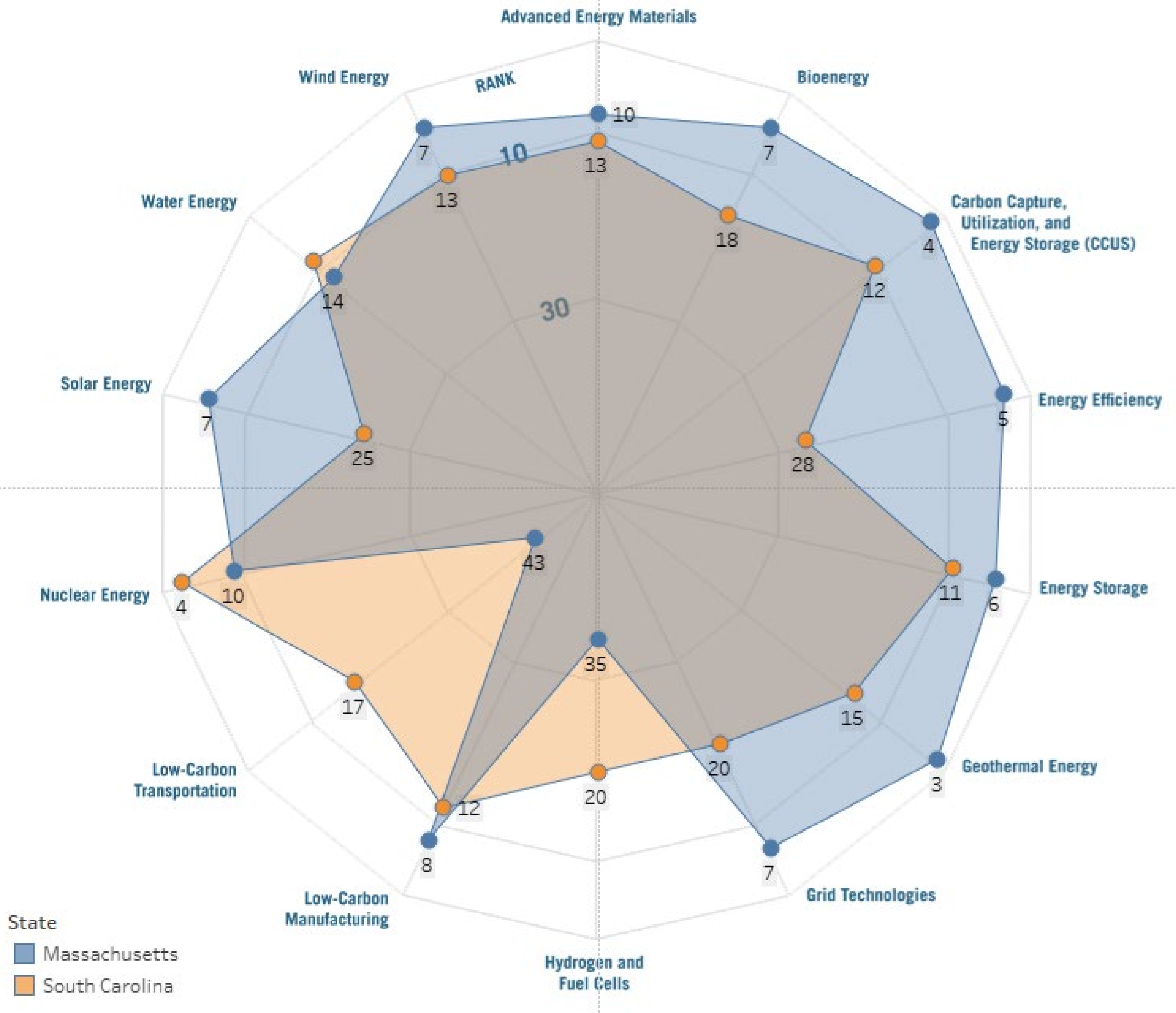


Figure 2: Technological comparison of Massachusetts and South Carolina



South Carolina Nexus for Advanced Resilient Energy

The state of South Carolina entered the modern manufacturing economy in the early 1990s when German automaker BMW sited a new campus there. The auto plant and the industrial ecosystem that grew up around it took the place of a textile industry in decline. A decade later, Boeing began building parts of its 787 Dreamliner in the state, which is now the sole assembly site for the plane. A sprawling network of suppliers grew up around these anchor facilities. Manufacturing production and employment surged as the sector regained its role as a pillar of the state economy.[27]

When the federal Tech Hubs program was announced, the state's economic development agency had completed a roadmapping exercise that identified further diversification of manufacturing as a key strategy. Burgeoning global markets in fields such as electric vehicles, nuclear power, and renewables beckoned. Tech Hub's "advanced energy" key technology focus area aligned with this strategy.[28]

The state assembled a broad cross-sectoral coalition to support its Tech Hub proposal, including manufacturers such as Rolls Royce and Westinghouse, utilities, educational institutions, and DOE's Savannah River National Laboratory, along with numerous state agencies. The South Carolina Nexus for Advanced Resilient Energy (SC Nexus) seeks to create a "globally leading hub driving innovation in core technologies that enable an end-to-end resilient, sustainable energy ecosystem across clean-electricity generation, distribution, and grid-scale storage."[29] The proposal targets manufacturing of components for nuclear, offshore wind, hydrogen, and solar photovoltaic systems; the creation of a battery innovation and testing ecosystem; and power grid re-engineering. It includes a plan to establish an incubator to support the state's advanced energy entrepreneurs.[30]

SC Nexus's designation as a Tech Hub in October 2023 allows it to compete for a phase 2 award of $50 million to $75 million. Its phase 2 application, submitted in February 2024, focuses on manufacturing distributed energy resource systems and enabling their innovative use. It includes testbeds and simulation resources for improving grid operations and security, drawing on DOE and Department of Defense as well as academic capabilities, and a new enegy storage institute that aims to commercialize new technologies for grid-scale use. Whether or not the state wins this award, it plans to continue with the SC Nexus strategy.[31]

CONCLUSIONS AND RECOMMENDATIONS

Regional innovation ecosystems have the potential to become vital engines of the global transition to low-carbon energy. The creation and strengthening of agile, geographically proximate learning networks of research institutions, suppliers, and producers, loosely coordinated by public and nonprofit regional organizations, offers a promising pathway to drive price and performance improvements in many specialized domains of clean-tech production and use.

The United States ought to be home to many of these ecosystems. As the world's largest historic source of emissions, it has an obligation to contribute to climate solutions; as the world's leader in science, technology, and innovation, it has tremendous potential to do so.

The ITIF State and Regional Energy Innovation Index provides a comprehensive map of that potential. This report summarizes indicators that seek to measure a wide range of energy innovation ecosystem functions including knowledge discovery and dissemination, entrepreneurial experimentation, supply chains and market formation, and social legitimation. These indicators are available at multiple geographical levels, including states and metropolitan regions, and cover 14 technological domains.

Economic development organizations in the United States are increasingly cognizant of the potential benefits of clean energy innovation. Recent federal legislation has amplified that awareness and provided resources to act on it. This index provides a baseline against which to measure the impacts of federal programs growing from that legislation in the coming years.

These prospective impacts would be enhanced by sustaining and improving key features of the new programs. We offer several recommendations to this end.

- **The federal government should continue to support the development and implementation of innovation-based state and regional development strategies, including those relying on clean energy innovation.** The economic development programs created by Congress over the last three years are fundamentally sound and long overdue. The CHIPS and Science Act provides the authority to expand several of them substantially. While fiscal conditions may not allow fully authorized levels to be reached for some time, moderate growth is necessary to sustain the institutional momentum that these programs have created at the state and regional levels. The strong bottom-up interest in clean energy innovation ensures that it will have a robust place in state and local strategies as long as federal resources continue to flow.[32]
- **Federal programs supporting state and regional economic development strategies should continue to use evaluation criteria that enable clean energy innovation.** The new programs generally mandate that federal grants address critical national challenges. The Tech Hubs program, for example, includes "advanced energy" as one of its key technology focus areas that may be tackled by applicants. Both the broad requirement to address national challenges and the specific inclusion of clean energy innovation within it are appropriate. Energy security, reliability, and affordability, and limiting the impact of climate change, are long-term, large-scale challenges to which clean energy innovation, rooted in regional industrial clusters, is an essential response.[33]
- **Federal agencies should support data collection and related research that enable state and regional economic development strategists to make better-informed decisions about the growth potential and resource and asset requirements of industries drawing on clean energy innovation.** A major difficulty in devising economic development strategies is that the industries of the future may not look like industries of the past. The infrastructure, skill requirements, supply chains, and technological foundations will evolve and may even transform. The difficulty is particularly acute for clean energy innovation because unabated fossil fuel combustion is so deeply embedded in the core technologies of many legacy sectors. Electric vehicles are very different from conventional cars, and green steelmaking processes look nothing like blast furnaces. While uncertainty about the future cannot be eliminated, a concerted national research program would help reduce it as well as help align expectations across regions about opportunities and threats posed by the energy transition.[34]
- **Federal programs should continue to support state and regional capacity-building for clean energy innovation so that bottom-up strategies stand a better chance of success.** States and

regions vary in their sophistication about economic development and administrative capacity to execute strategies. Congress and federal implementing agencies impose uniform requirements that are challenging for a significant fraction of state and regional applicants to fulfill. For instance, the NSF Regional Engines program requires cross-sectoral partnerships that can translate new research into tangible economic outcomes, which many regions lack. The program recognizes that applicants do not start on a level playing field, and it prioritizes "regions … without well-established innovation ecosystems."[35] For this approach to succeed, the agency will need to be patient, recognize potential as well as achievement in evaluating proposals, and cultivate that potential in the post-award period by encouraging awardees to build capacity.

- **Federal programs supporting state and regional economic development strategies should strengthen coordination among themselves to reduce the administrative burdens on applicants to these programs and to ensure the programs are mutually complementary**. A common theme in the discourse among participants in state and regional economic development policy is application fatigue. Applications for federal funds are lengthy and complex, and are not uniform across agencies. Congressional mandates bind federal agencies to some degree, but agencies have discretion to make the process easier without sacrificing either its legality or effectiveness. Federal program managers are aware of this challenge and have taken steps to address it. NSF and EDA have entered into a formal memorandum of understanding, for instance. They are collaborating to make their place-based grants with overlapping focus areas and regions of service "stackable" and exploring joint reporting, among other things.[36] DOE's technology-specific programs seem to be less engaged in these interagency processes**.**

The U.S. economy's ability to adapt to changing geopolitical, environmental, social, and technological circumstances has been an enduring strength throughout its history. The nation's regional economies, individually and collectively, are a key element of this strength. This strength will be tested again by the energy transition and global climate change. Public policy at all levels of governance can and should foster regional clean energy innovation ecosystems to enable the nation to pass this latest test.

APPENDIX 1: INDICATORS AND WEIGHTS

Table A1.1: Low-carbon energy index indicators and weights

Subindices, Categories, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
Knowledge Development and Diffusion	**35%**			
Research and Development		***30%***		
▪ Federal Investments in Low-Carbon Energy Research and Development			100%	90/10
Knowledge		***30%***		
▪ Generation of Low-Carbon Energy Research Publications			50%	90/10
▪ Diffusion of Low-Carbon Energy Research Publications			50%	90/10
Invention		***40%***		
▪ Generation of Low-Carbon Energy Inventions			50%	40/50/10
▪ Diffusion of Low-Carbon Energy Inventions			50%	40/50/10
Entrepreneurial Experimentation	**25%**			
Demonstration		***15%***		
▪ Federal Investments in Low-Carbon Energy Demonstration Projects			100%	90/10
Entrepreneurship		***85%***		
▪ Federal Seed Investments in Low-Carbon Energy Start-ups and Entrepreneurs			20%	90/10
▪ Private Venture Capital Investments in Low-Carbon Energy Start-ups			60%	90/10
▪ Successful Low-Carbon Energy Company Exits			20%	90/10
Supply Chain and Market Formation	**25%**			
Industry		***70%***		
▪ Employment in Low-Carbon Energy Industries			100%	40/50/10
Technology Adoption		***30%***		
▪ Supply of Low-Carbon Electricity Generation Resources			100%	90/10
Social Legitimation	**15%**			
Public Goals and Strategies		***70%***		

Subindices, Categories, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
▪ State-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			40%	90/10
▪ County-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			60%	90/10
Social Values		***30%***		
▪ Public Support for Low-Carbon Energy Research and Development			50%	90/10
▪ Public Support for Congressional Climate Action			10%	90/10
▪ Public Support for State-Level Climate Action			10%	90/10
▪ Public Support for Local-Level Climate Action			10%	90/10
▪ Public Support for Corporate Climate Action			10%	90/10
▪ Public Support for Citizen Climate Action			10%	90/10

Table A1.2: Advanced energy materials index indicators and weights

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
Knowledge Development and Diffusion	**35%**			
Research and Development		***N/A***		
▪ Federal Investments in Low-Carbon Energy Research and Development			N/A	N/A
Knowledge		***43%***		
▪ Generation of Low-Carbon Energy Research Publications			50%	90/10
▪ Diffusion of Low-Carbon Energy Research Publications			50%	90/10
Invention		***57%***		
▪ Generation of Low-Carbon Energy Inventions			50%	40/50/10
▪ Diffusion of Low-Carbon Energy Inventions			50%	40/50/10
Entrepreneurial Experimentation	**25%**			
Demonstration		***N/A***		

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
▪ Federal Investments in Low-Carbon Energy Demonstration Projects			N/A	N/A
Entrepreneurship		***100%***		
▪ Federal Seed Investments in Low-Carbon Energy Start-ups and Entrepreneurs			N/A	N/A
▪ Private Venture Capital Investments in Low-Carbon Energy Start-ups			75%	90/10
▪ Successful Low-Carbon Energy Company Exits			25%	90/10
Supply Chain and Market Formation	**25%**			
Industry		***70%***		
▪ Employment in Low-Carbon Energy Industries			100%	40/50/10
Technology Adoption		***30%***		
▪ Supply of Low-Carbon Electricity Generation Resources			100%	90/10
Social Legitimation	**15%**			
Public Goals and Strategies		***N/A***		
▪ State-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			N/A	N/A
▪ County-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			N/A	N/A
Social Values		***100%***		
▪ Public Support for Low-Carbon Energy Research and Development			50%	90/10
▪ Public Support for Congressional Climate Action			10%	90/10
▪ Public Support for State-Level Climate Action			10%	90/10
▪ Public Support for Local-Level Climate Action			10%	90/10
▪ Public Support for Corporate Climate Action			10%	90/10
▪ Public Support for Citizen Climate Action			10%	90/10

Table A1.3: Bioenergy index indicators and weights

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
Knowledge Development and Diffusion	**35%**			
Research and Development		***30%***		
▪ Federal Investments in Low-Carbon Energy Research and Development			100%	90/10
Knowledge		***30%***		
▪ Generation of Low-Carbon Energy Research Publications			50%	90/10
▪ Diffusion of Low-Carbon Energy Research Publications			50%	90/10
Invention		***40%***		
▪ Generation of Low-Carbon Energy Inventions			50%	40/50/10
▪ Diffusion of Low-Carbon Energy Inventions			50%	40/50/10
Entrepreneurial Experimentation	**25%**			
Demonstration		***15%***		
▪ Federal Investments in Low-Carbon Energy Demonstration Projects			100%	90/10
Entrepreneurship		***85%***		
▪ Federal Seed Investments in Low-Carbon Energy Start-ups and Entrepreneurs			20%	90/10
▪ Private Venture Capital Investments in Low-Carbon Energy Start-ups			60%	90/10
▪ Successful Low-Carbon Energy Company Exits			20%	90/10
Supply Chain and Market Formation	**25%**			
Industry		***70%***		
▪ Employment in Low-Carbon Energy Industries			100%	40/50/10
Technology Adoption		***30%***		
▪ Supply of Bioenergy Electricity Generation Resources			100%	90/10
Social Legitimation	**15%**			
Public Goals and Strategies		***70%***		

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
▪ State-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			40%	90/10
▪ County-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			60%	90/10
Social Values		***30%***		
▪ Public Support for Low-Carbon Energy Research and Development			50%	90/10
▪ Public Support for Congressional Climate Action			10%	90/10
▪ Public Support for State-Level Climate Action			10%	90/10
▪ Public Support for Local-Level Climate Action			10%	90/10
▪ Public Support for Corporate Climate Action			10%	90/10
▪ Public Support for Citizen Climate Action			10%	90/10

Table A1.4: Carbon capture, utilization, and storage index indicators and weights

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
Knowledge Development and Diffusion	**47%**			
Research and Development		***30%***		
▪ Federal Investments in Low-Carbon Energy Research and Development			100%	90/10
Knowledge		***30%***		
▪ Generation of Low-Carbon Energy Research Publications			50%	90/10
▪ Diffusion of Low-Carbon Energy Research Publications			50%	90/10
Invention		***40%***		
▪ Generation of Low-Carbon Energy Inventions			50%	40/50/10
▪ Diffusion of Low-Carbon Energy Inventions			50%	40/50/10
Entrepreneurial Experimentation	**33%**			
Demonstration		***15%***		

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
▪ Federal Investments in Low-Carbon Energy Demonstration Projects			100%	90/10
Entrepreneurship		***85%***		
▪ Federal Seed Investments in Low-Carbon Energy Start-ups and Entrepreneurs			20%	90/10
▪ Private Venture Capital Investments in Low-Carbon Energy Start-ups			60%	90/10
▪ Successful Low-Carbon Energy Company Exits			20%	90/10
Supply Chain and Market Formation	**N/A**			
Industry		***N/A***		
▪ Employment in Low-Carbon Energy Industries			N/A	N/A
Technology Adoption		***N/A***		
▪ Supply of Low-Carbon Electricity Generation and Storage Resources			N/A	N/A
Social Legitimation	**20%**			
Public Goals and Strategies		***70%***		
▪ State-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			40%	90/10
▪ County-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			60%	90/10
Social Values		***30%***		
▪ Public Support for Low-Carbon Energy Research and Development			50%	90/10
▪ Public Support for Congressional Climate Action			10%	90/10
▪ Public Support for State-Level Climate Action			10%	90/10
▪ Public Support for Local-Level Climate Action			10%	90/10
▪ Public Support for Corporate Climate Action			10%	90/10
▪ Public Support for Citizen Climate Action			10%	90/10

Table A1.5: Low-carbon energy manufacturing index indicators and weights

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
Knowledge Development and Diffusion	**35%**			
Research and Development		***30%***		
▪ Federal Investments in Low-Carbon Energy Research and Development			100%	90/10
Knowledge		***30%***		
▪ Generation of Low-Carbon Energy Research Publications			50%	90/10
▪ Diffusion of Low-Carbon Energy Research Publications			50%	90/10
Invention		***40%***		
▪ Generation of Low-Carbon Energy Inventions			50%	40/50/10
▪ Diffusion of Low-Carbon Energy Inventions			50%	40/50/10
Entrepreneurial Experimentation	**25%**			
Demonstration		***15%***		
▪ Federal Investments in Low-Carbon Energy Demonstration Projects			100%	90/10
Entrepreneurship		***85%***		
▪ Federal Seed Investments in Low-Carbon Energy Start-ups and Entrepreneurs			20%	90/10
▪ Private Venture Capital Investments in Low-Carbon Energy Start-ups			60%	90/10
▪ Successful Low-Carbon Energy Company Exits			20%	90/10
Supply Chain and Market Formation	**25%**			
Industry		***N/A***		
▪ Employment in Low-Carbon Energy Industries			N/A	N/A
Technology Adoption		***100%***		
▪ Supply of Low-Carbon Electricity Generation Resources			100%	90/10
Social Legitimation	**15%**			
Public Goals and Strategies		***70%***		

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
▪ State-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			40%	90/10
▪ County-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			60%	90/10
Social Values		***30%***		
▪ Public Support for Low-Carbon Energy Research and Development			50%	90/10
▪ Public Support for Congressional Climate Action			10%	90/10
▪ Public Support for State-Level Climate Action			10%	90/10
▪ Public Support for Local-Level Climate Action			10%	90/10
▪ Public Support for Corporate Climate Action			10%	90/10
▪ Public Support for Citizen Climate Action			10%	90/10

Table A1.6: Low-carbon energy transportation index indicators and weights

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
Knowledge Development and Diffusion	**35%**			
Research and Development		***30%***		
▪ Federal Investments in Low-Carbon Energy Research and Development			100%	90/10
Knowledge		***30%***		
▪ Generation of Low-Carbon Energy Research Publications			50%	90/10
▪ Diffusion of Low-Carbon Energy Research Publications			50%	90/10
Invention		***40%***		
▪ Generation of Low-Carbon Energy Inventions			50%	40/50/10
▪ Diffusion of Low-Carbon Energy Inventions			50%	40/50/10
Entrepreneurial Experimentation	**25%**			
Demonstration		***15%***		

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
▪ Federal Investments in Low-Carbon Energy Demonstration Projects			100%	90/10
Entrepreneurship		***85%***		
▪ Federal Seed Investments in Low-Carbon Energy Start-ups and Entrepreneurs			20%	90/10
▪ Private Venture Capital Investments in Low-Carbon Energy Start-ups			60%	90/10
▪ Successful Low-Carbon Energy Company Exits			20%	90/10
Supply Chain and Market Formation	**25%**			
Industry		***70%***		
▪ Employment in Low-Carbon Energy Industries			100%	40/50/10
Technology Adoption		***30%***		
▪ Supply of Low-Carbon Electricity Generation Resources			100%	90/10
Social Legitimation	**15%**			
Public Goals and Strategies		***70%***		
▪ State-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			40%	90/10
▪ County-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			60%	90/10
Social Values		***30%***		
▪ Public Support for Low-Carbon Energy Research and Development			50%	90/10
▪ Public Support for Congressional Climate Action			10%	90/10
▪ Public Support for State-Level Climate Action			10%	90/10
▪ Public Support for Local-Level Climate Action			10%	90/10
▪ Public Support for Corporate Climate Action			10%	90/10
▪ Public Support for Citizen Climate Action			10%	90/10

Table A1.7: Energy efficiency index indicators and weights

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
Knowledge Development and Diffusion	**35%**			
Research and Development		***30%***		
▪ Federal Investments in Low-Carbon Energy Research and Development			100%	90/10
Knowledge		***30%***		
▪ Generation of Low-Carbon Energy Research Publications			50%	90/10
▪ Diffusion of Low-Carbon Energy Research Publications			50%	90/10
Invention		***40%***		
▪ Generation of Low-Carbon Energy Inventions			50%	40/50/10
▪ Diffusion of Low-Carbon Energy Inventions			50%	40/50/10
Entrepreneurial Experimentation	**25%**			
Demonstration		***15%***		
▪ Federal Investments in Low-Carbon Energy Demonstration Projects			100%	90/10
Entrepreneurship		***85%***		
▪ Federal Seed Investments in Low-Carbon Energy Start-ups and Entrepreneurs			20%	90/10
▪ Private Venture Capital Investments in Low-Carbon Energy Start-ups			60%	90/10
▪ Successful Low-Carbon Energy Company Exits			20%	90/10
Supply Chain and Market Formation	**25%**			
Industry		***70%***		
▪ Employment in Low-Carbon Energy Industries			100%	40/50/10
Technology Adoption		***30%***		
▪ Supply of Low-Carbon Electricity Generation Resources			100%	90/10
Social Legitimation	**15%**			
Public Goals and Strategies		***70%***		

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
▪ State-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			40%	90/10
▪ County-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			60%	90/10
Social Values		***30%***		
▪ Public Support for Low-Carbon Energy Research and Development			50%	90/10
▪ Public Support for Congressional Climate Action			10%	90/10
▪ Public Support for State-Level Climate Action			10%	90/10
▪ Public Support for Local-Level Climate Action			10%	90/10
▪ Public Support for Corporate Climate Action			10%	90/10
▪ Public Support for Citizen Climate Action			10%	90/10

Table A1.8: Energy storage index indicators and weights

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
Knowledge Development and Diffusion	**35%**			
Research and Development		***30%***		
▪ Federal Investments in Low-Carbon Energy Research and Development			100%	90/10
Knowledge		***30%***		
▪ Generation of Low-Carbon Energy Research Publications			50%	90/10
▪ Diffusion of Low-Carbon Energy Research Publications			50%	90/10
Invention		***40%***		
▪ Generation of Low-Carbon Energy Inventions			50%	40/50/10
▪ Diffusion of Low-Carbon Energy Inventions			50%	40/50/10
Entrepreneurial Experimentation	**25%**			
Demonstration		***15%***		

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
▪ Federal Investments in Low-Carbon Energy Demonstration Projects			100%	90/10
Entrepreneurship		***85%***		
▪ Federal Seed Investments in Low-Carbon Energy Start-ups and Entrepreneurs			20%	90/10
▪ Private Venture Capital Investments in Low-Carbon Energy Start-ups			60%	90/10
▪ Successful Low-Carbon Energy Company Exits			20%	90/10
Supply Chain and Market Formation	**25%**			
Industry		***70%***		
▪ Employment in Low-Carbon Energy Industries			100%	40/50/10
Technology Adoption		***30%***		
▪ Supply of Low-Carbon Electricity Storage Resources			100%	90/10
Social Legitimation	**15%**			
Public Goals and Strategies		***70%***		
▪ State-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			40%	90/10
▪ County-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			60%	90/10
Social Values		***30%***		
▪ Public Support for Low-Carbon Energy Research and Development			50%	90/10
▪ Public Support for Congressional Climate Action			10%	90/10
▪ Public Support for State-Level Climate Action			10%	90/10
▪ Public Support for Local-Level Climate Action			10%	90/10
▪ Public Support for Corporate Climate Action			10%	90/10
▪ Public Support for Citizen Climate Action			10%	90/10

Table A1.9: Geothermal energy index indicators and weights

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
Knowledge Development and Diffusion	**35%**			
Research and Development		***30%***		
▪ Federal Investments in Low-Carbon Energy Research and Development			100%	90/10
Knowledge		***30%***		
▪ Generation of Low-Carbon Energy Research Publications			50%	90/10
▪ Diffusion of Low-Carbon Energy Research Publications			50%	90/10
Invention		***40%***		
▪ Generation of Low-Carbon Energy Inventions			50%	40/50/10
▪ Diffusion of Low-Carbon Energy Inventions			50%	40/50/10
Entrepreneurial Experimentation	**25%**			
Demonstration		***15%***		
▪ Federal Investments in Low-Carbon Energy Demonstration Projects			100%	90/10
Entrepreneurship		***85%***		
▪ Federal Seed Investments in Low-Carbon Energy Start-ups and Entrepreneurs			20%	90/10
▪ Private Venture Capital Investments in Low-Carbon Energy Start-ups			60%	90/10
▪ Successful Low-Carbon Energy Company Exits			20%	90/10
Supply Chain and Market Formation	**25%**			
Industry		***N/A***		
▪ Employment in Low-Carbon Energy Industries			N/A	N/A
Technology Adoption		***100%***		
▪ Supply of Geothermal Electricity Generation Resources			100%	90/10
Social Legitimation	**15%**			
Public Goals and Strategies		***70%***		

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
▪ State-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			40%	90/10
▪ County-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			60%	90/10
Social Values		***30%***		
▪ Public Support for Low-Carbon Energy Research and Development			50%	90/10
▪ Public Support for Congressional Climate Action			10%	90/10
▪ Public Support for State-Level Climate Action			10%	90/10
▪ Public Support for Local-Level Climate Action			10%	90/10
▪ Public Support for Corporate Climate Action			10%	90/10
▪ Public Support for Citizen Climate Action			10%	90/10

Table A1.10: Grid technologies index indicators and weights

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
Knowledge Development and Diffusion	**35%**			
Research and Development		***30%***		
▪ Federal Investments in Low-Carbon Energy Research and Development			100%	90/10
Knowledge		***30%***		
▪ Generation of Low-Carbon Energy Research Publications			50%	90/10
▪ Diffusion of Low-Carbon Energy Research Publications			50%	90/10
Invention		***40%***		
▪ Generation of Low-Carbon Energy Inventions			50%	40/50/10
▪ Diffusion of Low-Carbon Energy Inventions			50%	40/50/10
Entrepreneurial Experimentation	**25%**			
Demonstration		***15%***		

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
▪ Federal Investments in Low-Carbon Energy Demonstration Projects			100%	90/10
Entrepreneurship		***85%***		
▪ Federal Seed Investments in Low-Carbon Energy Start-ups and Entrepreneurs			20%	90/10
▪ Private Venture Capital Investments in Low-Carbon Energy Start-ups			60%	90/10
▪ Successful Low-Carbon Energy Company Exits			20%	90/10
Supply Chain and Market Formation	**25%**			
Industry		***70%***		
▪ Employment in Low-Carbon Energy Industries			100%	40/50/10
Technology Adoption		***30%***		
▪ Supply of Low-Carbon Electricity Generation Resources			100%	90/10
Social Legitimation	**15%**			
Public Goals and Strategies		***70%***		
▪ State-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			40%	90/10
▪ County-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			60%	90/10
Social Values		***30%***		
▪ Public Support for Low-Carbon Energy Research and Development			50%	90/10
▪ Public Support for Congressional Climate Action			10%	90/10
▪ Public Support for State-Level Climate Action			10%	90/10
▪ Public Support for Local-Level Climate Action			10%	90/10
▪ Public Support for Corporate Climate Action			10%	90/10
▪ Public Support for Citizen Climate Action			10%	90/10

Table A1.11: Hydrogen and fuel cells index indicators and weights

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
Knowledge Development and Diffusion	**35%**			
Research and Development		***30%***		
▪ Federal Investments in Low-Carbon Energy Research and Development			100%	90/10
Knowledge		***30%***		
▪ Generation of Low-Carbon Energy Research Publications			50%	90/10
▪ Diffusion of Low-Carbon Energy Research Publications			50%	90/10
Invention		***40%***		
▪ Generation of Low-Carbon Energy Inventions			50%	40/50/10
▪ Diffusion of Low-Carbon Energy Inventions			50%	40/50/10
Entrepreneurial Experimentation	**25%**			
Demonstration		***15%***		
▪ Federal Investments in Low-Carbon Energy Demonstration Projects			100%	90/10
Entrepreneurship		***85%***		
▪ Federal Seed Investments in Low-Carbon Energy Start-ups and Entrepreneurs			20%	90/10
▪ Private Venture Capital Investments in Low-Carbon Energy Start-ups			60%	90/10
▪ Successful Low-Carbon Energy Company Exits			20%	90/10
Supply Chain and Market Formation	**25%**			
Industry		***N/A***		
▪ Employment in Low-Carbon Energy Industries			N/A	N/A
Technology Adoption		***100%***		
▪ Supply of Low-Carbon Electricity Generation Resources			100%	90/10
Social Legitimation	**15%**			
Public Goals and Strategies		***70%***		

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
▪ State-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			40%	90/10
▪ County-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			60%	90/10
Social Values		***30%***		
▪ Public Support for Low-Carbon Energy Research and Development			50%	90/10
▪ Public Support for Congressional Climate Action			10%	90/10
▪ Public Support for State-Level Climate Action			10%	90/10
▪ Public Support for Local-Level Climate Action			10%	90/10
▪ Public Support for Corporate Climate Action			10%	90/10
▪ Public Support for Citizen Climate Action			10%	90/10

Table A1.12: Nuclear energy index indicators and weights

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
Knowledge Development and Diffusion	**35%**			
Research and Development		***30%***		
▪ Federal Investments in Low-Carbon Energy Research and Development			100%	90/10
Knowledge		***30%***		
▪ Generation of Low-Carbon Energy Research Publications			50%	90/10
▪ Diffusion of Low-Carbon Energy Research Publications			50%	90/10
Invention		***40%***		
▪ Generation of Low-Carbon Energy Inventions			50%	40/50/10
▪ Diffusion of Low-Carbon Energy Inventions			50%	40/50/10
Entrepreneurial Experimentation	**25%**			
Demonstration		***15%***		

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
▪ Federal Investments in Low-Carbon Energy Demonstration Projects			100%	90/10
Entrepreneurship		***85%***		
▪ Federal Seed Investments in Low-Carbon Energy Start-ups and Entrepreneurs			20%	90/10
▪ Private Venture Capital Investments in Low-Carbon Energy Start-ups			60%	90/10
▪ Successful Low-Carbon Energy Company Exits			20%	90/10
Supply Chain and Market Formation	**25%**			
Industry		***N/A***		
▪ Employment in Low-Carbon Energy Industries			N/A	N/A
Technology Adoption		***100%***		
▪ Supply of Nuclear Electricity Generation Resources			100%	90/10
Social Legitimation	**15%**			
Public Goals and Strategies		***70%***		
▪ State-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			40%	90/10
▪ County-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			60%	90/10
Social Values		***30%***		
▪ Public Support for Low-Carbon Energy Research and Development			50%	90/10
▪ Public Support for Congressional Climate Action			10%	90/10
▪ Public Support for State-Level Climate Action			10%	90/10
▪ Public Support for Local-Level Climate Action			10%	90/10
▪ Public Support for Corporate Climate Action			10%	90/10
▪ Public Support for Citizen Climate Action			10%	90/10

Table A1.13: Solar energy index indicators and weights

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
Knowledge Development and Diffusion	**35%**			
Research and Development		***30%***		
▪ Federal Investments in Low-Carbon Energy Research and Development			100%	90/10
Knowledge		***30%***		
▪ Generation of Low-Carbon Energy Research Publications			50%	90/10
▪ Diffusion of Low-Carbon Energy Research Publications			50%	90/10
Invention		***40%***		
▪ Generation of Low-Carbon Energy Inventions			50%	40/50/10
▪ Diffusion of Low-Carbon Energy Inventions			50%	40/50/10
Entrepreneurial Experimentation	**25%**			
Demonstration		***15%***		
▪ Federal Investments in Low-Carbon Energy Demonstration Projects			100%	90/10
Entrepreneurship		***85%***		
▪ Federal Seed Investments in Low-Carbon Energy Start-ups and Entrepreneurs			20%	90/10
▪ Private Venture Capital Investments in Low-Carbon Energy Start-ups			60%	90/10
▪ Successful Low-Carbon Energy Company Exits			20%	90/10
Supply Chain and Market Formation	**25%**			
Industry		***70%***		
▪ Employment in Low-Carbon Energy Industries			100%	40/50/10
Technology Adoption		***30%***		
▪ Supply of Solar Electricity Generation Resources			100%	90/10
Social Legitimation	**15%**			
Public Goals and Strategies		***70%***		
▪ State-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			40%	90/10

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
▪ County-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			60%	90/10
Social Values		***30%***		
▪ Public Support for Low-Carbon Energy Research and Development			50%	90/10
▪ Public Support for Congressional Climate Action			10%	90/10
▪ Public Support for State-Level Climate Action			10%	90/10
▪ Public Support for Local-Level Climate Action			10%	90/10
▪ Public Support for Corporate Climate Action			10%	90/10
▪ Public Support for Citizen Climate Action			10%	90/10

Table A1.14: Water energy index indicators and weights

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
Knowledge Development and Diffusion	**35%**			
Research and Development		***30%***		
▪ Federal Investments in Low-Carbon Energy Research and Development			100%	90/10
Knowledge		***30%***		
▪ Generation of Low-Carbon Energy Research Publications			50%	90/10
▪ Diffusion of Low-Carbon Energy Research Publications			50%	90/10
Invention		***40%***		
▪ Generation of Low-Carbon Energy Inventions			50%	40/50/10
▪ Diffusion of Low-Carbon Energy Inventions			50%	40/50/10
Entrepreneurial Experimentation	**25%**			
Demonstration		***15%***		
▪ Federal Investments in Low-Carbon Energy Demonstration Projects			100%	90/10
Entrepreneurship		***85%***		

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
▪ Federal Seed Investments in Low-Carbon Energy Start-ups and Entrepreneurs			20%	90/10
▪ Private Venture Capital Investments in Low-Carbon Energy Start-ups			60%	90/10
▪ Successful Low-Carbon Energy Company Exits			20%	90/10
Supply Chain and Market Formation	**25%**			
Industry		***70%***		
▪ Employment in Low-Carbon Energy Industries			100%	40/50/10
Technology Adoption		***30%***		
▪ Supply of Water Electricity Generation Resources			100%	90/10
Social Legitimation	**15%**			
Public Goals and Strategies		***70%***		
▪ State-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			40%	90/10
▪ County-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			60%	90/10
Social Values		***30%***		
▪ Public Support for Low-Carbon Energy Research and Development			50%	90/10
▪ Public Support for Congressional Climate Action			10%	90/10
▪ Public Support for State-Level Climate Action			10%	90/10
▪ Public Support for Local-Level Climate Action			10%	90/10
▪ Public Support for Corporate Climate Action			10%	90/10
▪ Public Support for Citizen Climate Action			10%	90/10

Table A1.15: Wind energy index indicators and weights

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
Knowledge Development and Diffusion	**35%**			
Research and Development		***30%***		

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
▪ Federal Investments in Low-Carbon Energy Research and Development			100%	90/10
Knowledge		***30%***		
▪ Generation of Low-Carbon Energy Research Publications			50%	90/10
▪ Diffusion of Low-Carbon Energy Research Publications			50%	90/10
Invention		***40%***		
▪ Generation of Low-Carbon Energy Inventions			50%	40/50/10
▪ Diffusion of Low-Carbon Energy Inventions			50%	40/50/10
Entrepreneurial Experimentation	**25%**			
Demonstration		***15%***		
▪ Federal Investments in Low-Carbon Energy Demonstration Projects			100%	90/10
Entrepreneurship		***85%***		
▪ Federal Seed Investments in Low-Carbon Energy Start-ups and Entrepreneurs			20%	90/10
▪ Private Venture Capital Investments in Low-Carbon Energy Start-ups			60%	90/10
▪ Successful Low-Carbon Energy Company Exits			20%	90/10
Supply Chain and Market Formation	**25%**			
Industry		***70%***		
▪ Employment in Low-Carbon Energy Industries			100%	40/50/10
Technology Adoption		***30%***		
▪ Supply of Wind Electricity Generation Resources			100%	90/10
Social Legitimation	**15%**			
Public Goals and Strategies		***70%***		
▪ State-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			40%	90/10
▪ County-Level Low-Carbon Energy-Based Economic Development Goals and Strategies			60%	90/10

Subindices, Categories, Indicators, and Metrics	Subindex Weight	Category Weight	Indicator Weight	Metric Weight
Social Values		***30%***		
▪ Public Support for Low-Carbon Energy Research and Development			50%	90/10
▪ Public Support for Congressional Climate Action			10%	90/10
▪ Public Support for State-Level Climate Action			10%	90/10
▪ Public Support for Local-Level Climate Action			10%	90/10
▪ Public Support for Corporate Climate Action			10%	90/10
▪ Public Support for Citizen Climate Action			10%	90/10

APPENDIX 2: METHODOLOGY AND SOURCES

The State and Regional Energy Innovation Index rests at its base on 19 indicators. In all cases, the indicators measure combinations of two or more different dimensions of state and regional contributions, including share, intensity, specialization, and change. These 41 lower-level metrics are then weighted and aggregated into composite indicator scores. The 19 indicators are, in turn, organized into 9 functional categories, which then contribute to the 4 subindices built around the functional groupings described in the main report. This appendix describes the sources of these indicators and the methodologies used to construct them.

As we aggregate indicators from one level to the next, we standardize them and apply weights that reflect our judgments about the importance of each measurement and the quality and availability of the data. We convert the share, intensity, specialization, and change measures of state and regional contributions for the 19 indicators into z-scores, with the mean set to 10 and standard deviation set to 4. The scores are capped at 0 and 20 (2.5 standard deviations from the mean in either direction) so that outliers do not carry too much weight. A state or region making an average contribution to the U.S. energy innovation system on a given indicator would receive a score of 10, while the maximum score would be 20. The z-scores are then combined and aggregated up to create the indicator, category, subindex, and index scores using the weights laid out in table A1.

Base Indicator: Population

Data Sources:

- U.S. Census Bureau's Annual Estimates of the Resident Population for Counties tables[37]
- U.S. Census Bureau's Annual County and Puerto Rico Municipio Resident Population Estimates by Selected Age Groups and Sex tables[38]

Metrics:

- Average Population: The average total population over the previous three-year period
- Adult Population: Total population age 18 years and over

Base Indicator: Real Gross Domestic Product (GDP)

Data Sources:

- U.S. Bureau of Economic Analysis (BEA) Gross Domestic Product by County, 2021 dataset[39]

Metrics:

- Average Real GDP: The average total dollar amount of real GDP over the previous three-year period

SUBINDEX 1: KNOWLEDGE DEVELOPMENT AND DIFFUSION

Categories/Weightings:

- Research and Development (30%)
- Knowledge (30%)
- Invention (40%)

Category 1: Research and Development

Indicators/Weightings:

- Federal investments in low-carbon energy research and Development (100%)

Indicator 1: Federal Investments in Low-Carbon Energy Research and Development

Purpose: The indicator aims to assess the ability of states and regions to garner public investments in low-carbon energy R&D projects awarded by U.S. federal government agencies. It serves as an indicator of state and regional contributions to the resource mobilization and knowledge development functions.

Data Sources:

- USAspending.gov database[40]
- BEA Gross Domestic Product by County, 2021 dataset

Data/Methods: The indicator is based on the total dollar amount of federal low-carbon energy R&D prime awards and subawards awarded to states and regions in the various categories of low-carbon energy technologies in our taxonomy. All R&D prime awards and subawards granted in the years 2016–2021 were downloaded from the USAspending.gov website. The website's advanced search function was used to download all prime and subaward contracts labeled under the 862 R&D Product or Service Codes (PSCs) as well as all prime and subaward grants awarded by the 12 federal government agencies that have the largest R&D budgets (see table A2.1 in appendix 2 for the full list of agencies included). The federal R&D prime award search strategies listed in table A2.1 were used to identify federal R&D prime awards in the assistance grants dataset (see appendix 2). The 72 "AG Energy R&D" PSCs were used to identify and categorize energy R&D prime awards in the contracts dataset. The federal energy R&D prime award search strategies and categorization methods listed in table A2.2 were used to identify and categorize energy R&D prime awards in the assistance grants dataset. Additional energy R&D prime awards were identified and categorized manually by examining award transaction descriptions (note: a significant number of DOE Office of Science and Advanced Research Projects Agency – Energy (ARPA-E) awards were categorized manually). In many cases, individual prime awards were applied to more than one technology category. All additional non-R&D awards were deleted from the assistance grants dataset, the R&D contracts and R&D assistance grants prime award and subaward datasets were combined and the technology categories applied to each prime award were applied to their corresponding subawards. The R&D-focused awards were then separated from the demonstration- and public seed investment-focused awards. The total amounts of all R&D awards, energy R&D awards, low-carbon energy R&D awards, and technology-specific low-carbon energy R&D awards were summed for each state and regional level in each year. The following set of metrics was then generated:

Metrics/Weightings:

- Intensity: The average dollar amount of federal low-carbon energy R&D awards per thousand units of real GDP over the previous three-year period (90%)
- Change: The annual growth rate of federal low-carbon energy R&D awards over the previous year (10%)

Category 2: Knowledge

Indicators/Weightings:

- Generation of low-carbon energy research publications (50%)
- Diffusion of low-carbon energy research publications (50%)

Indicator 2: Generation of Low-Carbon Energy Research Publications

Purpose: The indicator aims to assess the quantity of low-carbon energy research publications generated in states and regions. It serves as an indicator of state and regional contributions to the knowledge development function.

Data Sources:

- Web of Science Core Collection database
- U.S. Census Bureau's Annual Estimates of the Resident Population for Counties tables

Data/Methods: The indicator is based on the total number of low-carbon energy research publications generated in the various categories of low-carbon energy technologies in our taxonomy. The data on publications was downloaded from the Web of Science Core Collection database. The website's documents search function was used to perform "Topic" searches of publication titles, abstracts, and author using keywords associated with each of the various categories of low-carbon energy technologies (see table A2.3 for a list of the keyword searches used for each technology category). The searches were limited by three search parameters: 1) Publication Date: 2016-01-01 to 2023-12-31, 2) Document Types: Articles, Books, Book Chapters, Book Reviews, Corrections, Data Papers, Early Access, Editorial Materials, Meeting Abstracts, Proceeding Papers, and Review Articles, and 3) Countries/Regions: USA. The results were downloaded and several key variables were extracted from the datasets, including the UT (Unique WOS ID), Article Title, Publication Year, Authors, Times Cited (All Databases), and Addresses. The UT (Unique WOS ID) and Addresses data was then extracted into a separate dataset to separate each of the authors and their affiliated addresses (i.e., zip code) into unique observations. The author addresses data was then remerged with the main dataset using the UT (Unique WOS IDs). Each publication was then fractionally counted by both authors and locations (i.e., authors affiliated with more than one organization were further fractionally counted to give weight to each of their affiliated organizations). The total number of publications was summed for each state and regional level in each year. The following set of metrics was then generated:

Metrics/Weightings:

- Intensity: The average number of low-carbon energy research publications per thousand population over the previous three-year period (90%)
- Change: The annual growth rate of the intensity of low-carbon energy research publications over the previous year (10%)

Indicator 3: Diffusion of Low-Carbon Energy Research Publications

Purpose: The indicator aims to assess the quality and diffusion of low-carbon energy research publications generated in states and regions. It serves as an indicator of state and regional contributions to the knowledge development and knowledge diffusion functions.

Data Sources:

- Web of Science Core Collection database
- U.S. Census Bureau's Annual Estimates of the Resident Population for Counties tables

Data/Methods: The indicator is based on the total number of citations received by low-carbon energy research publications generated in the various categories of low-carbon energy technologies in our taxonomy. The data on publications was downloaded from the Web of Science Core Collection database. The website's Documents search function was used to perform "Topic" searches of publication titles, abstracts, and author keywords using keywords associated with each of the various categories of low-carbon energy technologies (see table A2.3 for a list of the keyword searches used for each technology category). The searches were limited by three search parameters: 1) Publication Date: 2016-01-01 to 2023-12-31, 2) Document Types: Articles, Books, Book Chapters, Book Reviews, Corrections, Data Papers, Early Access, Editorial Materials, Meeting Abstracts, Proceeding Papers, and Review Articles, and 3) Countries/Regions: USA. The results were downloaded and several key variables were extracted from the datasets, including the UT (Unique WOS ID), Article Title, Publication Year, Authors, Times Cited (All Databases), and Addresses. The UT (Unique WOS ID) and Addresses data was then extracted into a separate dataset to separate each of the authors and their affiliated addresses (i.e., zip codes) into unique observations. The author addresses data was then remerged with the main dataset using the UT (Unique WOS IDs). The total number of citations received by each publication was then fractionally counted by both authors and locations (i.e., authors affiliated with more than one organization were further fractionally counted to give weight to each of their affiliated organizations). The total number of citations was summed for each state and regional level in each year. The following set of metrics was then generated:

Metrics/Weightings:

- Intensity: The average number of citations received by low-carbon energy research publications per thousand population over the previous three-year period (90%)
- Change: The annual growth rate of the intensity of citations received by low-carbon energy research publications over the previous year (10%)

Category 3: Invention

Indicators/Weightings:

- Generation of low-carbon energy inventions (50%)
- Diffusion of low-carbon energy inventions (50%)

Indicator 4: Generation of Low-Carbon Energy Inventions

Purpose: The indicator aims to assess the quantity of low-carbon energy inventions generated in states and regions. It serves as an indicator of state and regional contributions to the knowledge development function.

Data Sources:

- U.S. Patent and Trademark Office's (USPTO)'s PatentsView Bulk Downloads database
- Rassenfosse et al. (2019) Geocoding of Worldwide Patent Data dataset

- IEA's Methodology for identifying fossil fuel supply-related technologies in patent data
- Organization for Economic Cooperation and Development's (OECD)'s patent search strategies for the identification of selected environment-related technologies (ENV-TECH)
- U.S. Census Bureau's Annual Estimates of the Resident Population for Counties tables

Data/Methods: The indicator is based on the total number low-carbon energy pre-grant patent applications submitted to USPTO by U.S.-based inventors in the various categories of low-carbon energy technologies in our taxonomy. The pg_cpc_current, pg_inventor_disambiguated, and pg_location_disambiguated datasets were downloaded from the USPTO PatentsView Bulk Downloads database and combined. The Rassenfosse et al. dataset was downloaded and combined with the USPTO datasets to fill in missing inventor locations data. The IEA's patent search strategies were used to identify selected fossil fuel-related patent applications and the OECD's patent search strategies were used to identify selected low-carbon energy-related patent applications that fall within each technology category in our taxonomy (see table A2.3 in appendix 2 for a list of the Cooperative Patent Classification (CPC) classes, subclasses, and groups associated with each technology category). Each individual patent application was fractionally counted by both the number of relevant CPC groups and the number of inventors. The total numbers of all inventions, energy inventions, low-carbon energy inventions, and technology-specific low-carbon energy inventions were summed for each state and regional level in each year. The following set of metrics was then generated:

Metrics/Weightings:

- Intensity: The average number of low-carbon energy inventions per thousand population over the previous three-year period (40%)
- Specialization: The average number of low-carbon energy inventions as a share of all inventions generated by a state or region divided by the average number of low-carbon energy inventions as a share of all inventions generated by all states or regions over the previous three-year period (50%)
- Change: The annual growth rate of low-carbon energy inventions over the previous year (10%)

Indicator 5: Diffusion of Low-Carbon Energy Inventions

Purpose: The indicator aims to assess the quality and diffusion of low-carbon energy inventions generated in states and regions. It serves as an indicator of state and regional contributions to the knowledge development and knowledge diffusion functions.

Data Sources:

- USPTO PatentsView Bulk Downloads database
- Rassenfosse et al. (2019) Geocoding of Worldwide Patent Data dataset
- IEA's Methodology for identifying fossil fuel supply related technologies in patent data
- OECD's Patent search strategies for the identification of selected ENV-TECH
- U.S. Census Bureau's Annual Estimates of the Resident Population for Counties tables

Data/Methods: The indicator is based on the total number of citations received by low-carbon energy pre-grant patent applications submitted to USPTO by U.S.-based inventors in the various categories of low-carbon energy technologies in our taxonomy. The pg_cpc_current, pg_inventor_disambiguated, pg_location_disambiguated, and pg_us_application_citation datasets were downloaded from the USPTO PatentsView Bulk Downloads database and combined. The Rassenfosse et al. dataset was downloaded and combined with the USPTO datasets to fill in missing inventor locations data. The IEA's patent search strategies were used to identify selected fossil fuel-related patent applications and the OECD's patent search strategies were used to identify selected low-carbon energy-related patent applications that fall within each technology category in our taxonomy (see table A2.3 in appendix 2 for a list of the CPC classes, subclasses, and groups associated with each technology category). The number of citations received by each individual patent application was fractionally counted by both the number of relevant CPC groups and the number of inventors. The total numbers of citations received by all inventions, energy inventions, low-carbon energy inventions, and technology-specific low-carbon energy inventions were summed for each state and regional level in each year. The following set of metrics was then generated:

Metrics/Weightings:

- Intensity: The average number of citations received by low-carbon energy inventions per million population over the previous three-year period (40%)
- Specialization: The average number of citations received by low-carbon energy inventions as a share of the average number of citations received by all inventions generated by a state or region divided by the average number of citations received by low-carbon energy inventions as a share of the average number of citations received by all inventions generated by all states or regions over the previous three-year period (50%)
- Change: The annual growth rate of low-carbon energy citations intensity over the previous year (10%)

SUBINDEX 2: ENTREPRENEURIAL EXPERIMENTATION

Categories/Weightings:

- Demonstration (15%)
- Entrepreneurship (85%)

Category 4: Demonstration

Indicators/Weightings:

- Federal investments in low-carbon energy demonstration projects (100%)

Indicator 6: Federal Investments in Low-Carbon Energy Demonstration Projects

Purpose: The indicator aims to assess the ability of states and regions to garner public investments in low-carbon energy demonstration projects awarded by U.S. federal government agencies. It serves as an indicator of state and regional contributions to the resource mobilization, knowledge development, knowledge diffusion, and entrepreneurial experimentation functions.

Data Sources:

- USAspending.gov database
- BEA Gross Domestic Product by County, 2021 dataset

Data/Methods: The indicator is based on the total dollar amount of federal energy demonstration prime awards and subawards awarded to states and regions in the various categories of low-carbon energy technologies in our taxonomy. All R&D prime awards and subawards granted in the years 2016–2021 were downloaded from the USAspending.gov website. The website's advanced search function was used to download all prime and subaward contracts labeled under the 862 R&D PSCs as well as all prime and subaward grants awarded by the 12 federal government agencies that have the largest R&D budgets (see table A2.1 in appendix 2 for the full list of agencies included). The federal R&D prime award search strategies listed in table A2.1 were used to identify federal R&D prime awards in the assistance grants dataset (see Appendix 2). The 72 "AG Energy R&D" PSCs were used to identify and categorize energy R&D prime awards in the contracts dataset. The federal energy R&D prime award search strategies and categorization methods listed in table A2.2 were used to identify and categorize energy R&D prime awards in the assistance grants dataset. Additional energy R&D prime awards were identified and categorized manually by examining award transaction descriptions (a significant number of ARPA-E awards were categorized manually). In many cases, individual prime awards were applied to more than one technology category when appropriate. All additional non-R&D awards were deleted from the assistance grants dataset, the R&D contracts and R&D assistance grants prime award and subaward datasets were combined, and the technology categories applied to each prime award were applied to their corresponding subawards. The demonstration-focused awards were then separated from the R&D- and public seed investment and entrepreneurship-focused awards. The total amounts of all R&D awards, energy demonstration awards, low-carbon energy demonstration awards, and technology-specific low-carbon energy demonstration awards were summed for each state and regional level in each year. The following set of metrics was then generated:

Metrics/Weightings:

- Intensity: The average dollar amount of federal low-carbon energy demonstration awards per thousand units of real GDP over the previous three-year period (90%)
- Change: The annual growth rate of federal low-carbon energy demonstration intensity over the previous year (10%)

Category 5: Entrepreneurship

Indicators/Weightings:

- Federal seed investments in low-carbon energy demonstration start-ups and entrepreneurs (20%)
- Private venture capital investments in low-carbon energy start-ups (60%)
- Successful low-carbon energy company exits (20%)

Indicator 7: Federal Seed Investments in Low-Carbon Energy Start-Ups and Entrepreneurs

Purpose: The indicator aims to assess the ability of states and regions to garner federal seed investments in early-stage low-carbon energy start-ups and entrepreneurs awarded by U.S. federal government agencies. It serves as an indicator of state and regional contributions to the resource mobilization and entrepreneurial experimentation functions.

Data Sources:

- USAspending.gov database
- BEA Gross Domestic Product by County, 2021 dataset

Data/Methods: The indicator is based on the total dollar amount of federal seed investment prime awards and subawards awarded to states and regions in the various categories of low-carbon energy technologies in our taxonomy. All R&D prime awards and subawards granted in the years 2016–2021 were downloaded from the USAspending.gov website. The website's advanced search function was used to download all prime and subaward contracts labeled under the 862 R&D PSCs as well as all prime and subaward grants awarded by the 12 federal government agencies that have the largest R&D budgets (see table A2.1 in appendix 2 for the full list of agencies included). The federal R&D prime award search strategies listed in table A2.1 were used to identify federal R&D prime awards in the assistance grants dataset (see appendix 2). The 72 "AG Energy R&D" PSCs were used to identify and categorize energy R&D prime awards in the contracts dataset. The federal energy R&D prime award search strategies and categorization methods listed in table A2.2 were used to identify and categorize energy R&D prime awards in the assistance grants dataset. Additional energy R&D prime awards were identified and categorized manually by examining award transaction descriptions (a significant number of ARPA-E)awards were categorized manually). In many cases, individual prime awards were applied to more than one technology category when appropriate. All additional non-R&D awards were deleted from the assistance grants dataset, the R&D contracts and R&D assistance grants prime award and subaward datasets were combined, and the technology categories applied to each prime award were applied to their corresponding subawards. The public seed investment-focused awards were then separated from the R&D- and demonstration-focused awards. The total amounts of all R&D awards, energy public seed investment awards, low-carbon energy public seed investment awards, and technology-specific low-carbon energy public seed investment awards were summed for each state and regional level in each year. The following set of metrics was then generated:

Metrics/Weightings:

- Intensity: The average dollar amount of federal low-carbon energy seed investment awards per thousand units of real GDP over the previous three-year period (90%)
- Change: The annual growth rate of federal low-carbon energy seed investment intensity over the previous year (10%)

Indicator 8: Private Venture Capital Investments in Low-Carbon Energy Start-Ups

Purpose: The indicator aims to assess the health of state and regional entrepreneurial ecosystems, the degree to which early-stage financial resources are being mobilized to fund low-carbon energy start-ups, and the ability of states and regions to create new low-carbon energy start-ups the private sector deems worthy of venture capital investments. It serves as an indicator of state and regional contributions to the resource mobilization and entrepreneurial experimentation functions.

Data Sources:

- Cleantech Group i3 database
- BEA Gross Domestic Product by County, 2021 dataset

Data/Methods: The indicator is based on the total amount of venture capital investments received by low-carbon energy start-ups located in states and regions in the various categories of low-carbon energy technologies in our taxonomy. The data on all early-stage venture capital investments in U.S.-based low-carbon energy start-ups was obtained from Cleantech Group's i3 database. The start-ups receiving investments were identified and categorized using the Cleantech Group's classification scheme of "Industry Group," "Sector Tag," and "Primary Sector" labels and using keyword searches of the "Other Sectors" and "Short Descriptions" of companies. The total amounts of low-carbon energy venture capital investments and technology-specific low-carbon energy venture capital investments were summed for each state and regional level in each year. The following set of metrics was then generated:

Metrics/Weightings:

- Intensity: The average dollar amount of venture capital investments in low-carbon energy start-ups per thousand units of real GDP over the previous three-year period (90%)
- Change: The annual growth rate of the intensity of venture capital investments in low-carbon energy start-ups over the previous year (10%)

Indicator 9: Successful Low-Carbon Energy Company Exits

Purpose: The indicator aims to assess the health of state and regional entrepreneurial ecosystems and the ability of states and regions to create promising low-carbon energy start-ups and successfully usher them through the early stages of company development. It serves as an indicator of state and regional contributions to the resource mobilization and entrepreneurial experimentation functions.

Data Sources:

- Cleantech Group i3 database
- BEA Gross Domestic Product by County, 2021 dataset

Data/Methods: The indicator is based on the total number of U.S.-based low-carbon energy start-ups that successfully exited from venture capital investment, either through a private equity buyout, merger or acquisition, or IPO in the various categories of low-carbon energy technologies in our taxonomy. The data on successful low-carbon energy company exits was obtained from Cleantech Group's i3 database. The start-ups that successfully exited were categorized using the Cleantech Group's classification scheme of "Industry Group," "Sector Tag," and "Primary Sector" labels and using keyword searches of the "Other Sectors" and "Short Descriptions" of companies. Both the number of successful low-carbon energy company exits and technology-specific low-carbon energy company exits were summed for each state and regional level in each year. The following set of metrics was then generated:

Metrics/Weightings:

- Intensity: The average number of successful low-carbon energy company exits per billion units of real GDP over the previous three-year period (90%)
- Change: The annual growth rate of the intensity of successful low-carbon energy company exits over the previous year (10%)

SUBINDEX 3: SUPPLY CHAIN AND MARKET FORMATION

Categories/Weightings:

- Industry (70%)
- Technology Adoption (30%)

Category 6: Industry

Indicators/Weightings:

- Employment in low-carbon energy industries (100%)

Indicator 10: Employment in Low-Carbon Energy Industries

Purpose: The indicator aims to assess the health of state and regional supply chains and the ability of states and regions to generate jobs and steady employment in low-carbon energy industries. It serves as an indicator of state and regional contributions to the resource mobilization and supply chain formation functions.

Data Sources:

- U.S. Departments of Energy's (DOE) 2016, 2020, 2021, 2022, and 2023 U.S. Energy and Employment Report (USEER) County-Level USEER datasets[41]
- BEA Gross Domestic Product by County, 2021 dataset

Data/Methods: The indicator is based on the total number of low-carbon energy industry jobs in the various categories of low-carbon energy technologies in our taxonomy. The data on low-carbon energy industry jobs was downloaded from DOE's 2016, 2020, 2021, 2022, and 2023 USEER county-level datasets. To estimate the number of energy jobs in each technology category in the years in which county-level USEER data was not available (2017–2019), the difference between the 2016 and 2020 employment numbers in each county was determined and divided by four and the estimated increases were evenly distributed to the years 2017–2019. The total numbers of jobs in all industries, energy industry jobs, low-carbon energy industry jobs, and technology-specific low-carbon energy jobs were summed for each state and regional level in each year. The following set of metrics was then generated:

Metrics/Weightings:

- Intensity: The average number of low-carbon energy industry jobs per thousand units of real GDP over the previous three-year period (40%)

- Specialization: The average number of low-carbon energy industry jobs as a share of total jobs in all industries in a state or region divided by the total number of low-carbon energy industry jobs as a share of total jobs in all industries in all states or regions over the previous three-year period (50%)
- Change: The annual growth rate of low-carbon energy jobs intensity over the previous year (10%)

Category 7: Technology Adoption

Indicators/Weightings:

- Supply of low-carbon electricity generation and storage resources (100%)

Indicator 11: Supply of Low-Carbon Electricity Generation and Storage Resources

Purpose: The indicator aims to assess the health of state and regional supply chains and markets and the ability of states and regions to stimulate market demand and adoption of low-carbon energy technologies to ensure that industries have access to a plentiful supply of low-carbon electricity generation and storage resources to power their industrial activities. It serves as an indicator of state and regional contributions to the resource mobilization and supply chain and market formation functions.

Data Sources:

- U.S. Environmental Protection Agency's (EPA's) Emissions and Generation Resource Integrated Database (eGRID)
- U.S. Energy Information Administration's (EIA's) Form EIA-860 database

Data/Methods: The indicator is based on the share of annual electricity generated or stored from low-carbon electricity generation and storage resources. The data on electricity generation for the years 2016 and 2018–2022 was downloaded from the EPA's eGRID database. The electricity generation data is based on the Plant year datasets using the Plant annual net generation (MWh) data for each of the various technology categories. Estimates for the year 2017 at the county level were calculated by adding half the difference between the estimated percentages in 2016 and 2018 to the estimated percentages in 2016. The data on energy storage nameplate capacity for the years 2016–2022 was downloaded from the EIA's Form EIA-860 database using the 3_4_Energy_Storage_Yyyyy dataset and the Nameplate Capacity (MW) data. The total plant annual net generation, technology-specific plant annual net generation, plant nameplate capacity, and energy storage nameplate capacity were summed for each state and regional level in each year. The following set of metrics was then generated:

Metrics/Weightings:

- Share: The average amount of annual electricity generated from low-carbon electricity generation resources (MWh) as a share of total electricity generation (MWh) over the previous three-year period (or in the case of energy storage, the total amount of energy storage nameplate capacity (MW) as a share of total nameplate capacity (MW)) (90%)
- Change: The annual growth rate of the share of electricity generated and stored from low-carbon electricity generation and storage resources over the previous year (10%)

SUBINDEX 4: SOCIAL LEGITIMATION

Categories/Weightings:

- Public Goals and Strategies (70%)
- Social Values (30%)

Category 8: Public Goals and Strategies

Indicators/Weightings:

- State-level low-carbon energy-based economic development goals and strategies (40%)
- County-level low-carbon energy-based economic development goals and strategies (60%)

Indicator 12: State-Level Low-Carbon Energy-Based Economic Development Goals and Strategies

Purpose: The indicator aims to assess the extent to which states have assembled and formally published low-carbon energy-based economic development goals and strategies. It serves as an indicator of the social legitimation function.

Data Sources:

- Center for Regional Economic Competitiveness's (CREC's) State and Local Economic Development Strategies (SLEDS) database

Data/Methods: The indicator is based on the share of states within a state or regional territory that have assembled and formally published low-carbon energy-based economic development goals and strategies that strategically target the various categories of low-carbon energy technologies in our taxonomy. The full dataset was downloaded from the CREC's SLEDS tool website. To identify State Strategic Plans that strategically target the development of low-carbon energy technologies and industries, the identification strategy relied on the data in the Start Year, End Year, Approach, Strategy Summary, and Goal columns to tag relevant goals and strategies using a binary dummy variable. The Start Year and End Year data was first used to tag the years covered by all plans in the dataset using a binary dummy variable. The Approach data was then used to filter the dataset using the "Alternative/Renewable Energy," "Conservation/Climate Change," "Electric Vehicles and Buses," "Energy and Environment," and "Energy Utilities" categories and manually tag and categorize relevant goals and strategies using a binary dummy variable. The Strategy Summary and Goal columns were then used to perform keyword searches that identify and tag cells that contain specific keywords associated with each of the various technology categories. The dataset was then broken into multiple technology-specific datasets, which were then each restructured into a longitudinal structure to generate multiple distinct observations for plans and strategies covering multiple years. Hence, for each year and technology category, each state was tagged with a binary dummy variable representing whether it was associated with State Strategic Plans that were both in effect and strategically targeted technologies and industries associated with the technology category. The binary dummy variables were aggregated for each state and regional level in each year. The following set of metrics was then generated:

Metrics/Weightings:

- Share: The total number of states with low-carbon energy-based economic development goals and strategies in place as a share of all states located within a state or regional territory (90%)
- Change: The annual growth rate of the share of states with low-carbon energy-based economic development goals and strategies in place over the previous year (10%)

Indicator 13: County-Level Low-Carbon Energy-Based Economic Development Goals and Strategies

Purpose: The indicator aims to assess the extent to which regions have assembled and formally published low-carbon energy-based economic development goals and strategies. It serves as an indicator of the social legitimation function.

Data Sources:

- CREC's SLEDS database

Data/Methods: The indicator is based on the share of counties within a state or regional territory that have assembled and formally published low-carbon energy-based economic development goals and strategies that strategically target the various categories of low-carbon energy technologies in our taxonomy. The full dataset was downloaded from the CREC's SLEDS tool website. To identify Comprehensive Economic Development Strategies (CEDS) issued by economic development districts (EDDs) that strategically target the development of low-carbon energy technologies and industries, the identification strategy relied on the data in the Start Year, End Year, Approach, Strategy Summary, and Goal columns to tag relevant goals and strategies using a binary dummy variable. The Start Year and End Year data was first used to tag the years covered by all plans in the dataset using a binary dummy variable. The Approach data was then used to filter the dataset using the "Alternative/Renewable Energy," "Conservation/Climate Change," "Electric Vehicles and Buses," "Energy and Environment," and "Energy Utilities" categories and manually tag and categorize relevant goals and strategies using a binary dummy variable. The Strategy Summary and Goal columns were then used to perform keyword searches that identify and tag cells that contain specific keywords associated with each of the various technology categories. The dataset was then broken into multiple technology-specific datasets, which were then each restructured into a longitudinal structure to generate multiple distinct observations for plans and strategies covering multiple years. The technology-specific datasets were then merged with the County-EDD crosswalk dataset to identify and tag the counties associated with each EDD. Hence, for each year and technology category, each county was tagged with a binary dummy variable representing whether it was associated with EDD-issued CEDS that were both in effect and strategically targeted technologies and industries associated with the technology category. The binary dummy variables were aggregated for each state and regional level in each year. The following set of metrics was then generated:

Metrics/Weightings:

- Share: The total number of counties with low-carbon energy-based economic development goals and strategies in place as a share of all counties located within a state or regional territory (90%)

- Change: The annual growth rate of the share of counties with low-carbon energy-based economic development goals and strategies in place over the previous year (10%)

Category 9: Social Values

Indicators/Weightings:

- Public support for low-carbon energy research and development (50%)
- Public support for congressional climate action (10%)
- Public support for state-level climate action (10%)
- Public support for local-level climate action (10%)
- Public support for corporate climate action (10%)
- Public support for citizen climate action (10%)

Indicator 14: Public Support for Low-Carbon Energy Research and Development

Purpose: The indicator aims to assess the extent to which the citizens of states and regions support and value the funding of low-carbon energy R&D to spur energy innovation. It serves as an indicator of the social legitimation function.

Data Sources:

- Yale Program on Climate Change Communication (YPCCC) Yale Climate Opinion Maps 2021 dataset
- U.S. Census Bureau's Annual County and Puerto Rico Municipio Resident Population Estimates by Selected Age Groups and Sex tables

Data/Methods: The indicator is based on the estimated percentage of adults who support funding research into renewable energy sources. The data on public support for low-carbon energy R&D was downloaded from the YPCCC's Yale Climate Opinion Maps 2021 website. The data was available at the state level for the years 2016–2021 and at the county level for the years 2016 and 2018–2021. Estimates for the year 2017 at the county level were calculated by adding half the difference between the estimated percentages in 2016 and 2018 to the estimated percentages in 2016. Estimated percentages for each state and regional level in each year were generated by multiplying the estimated percentages at the county level by the U.S. Census Bureau's adult population levels and then dividing the new estimated population of adults who support funding research into renewable energy sources by the total population. The following set of metrics was then generated:

Metrics/Weightings:

- Share: The estimated percentage of adults who support funding research into renewable energy sources (90%)
- Change: The annual growth rate of the estimated percentage of adults who support funding research into renewable energy sources over the previous year (10%)

Indicator 15: Public Support for Congressional Climate Action

Purpose: The indicator aims to assess the extent to which the citizens of states and regions support and value congressional climate action and policy. It serves as an indicator of the social legitimation function.

Data Sources:

- YPCCC Yale Climate Opinion Maps 2021 dataset
- U.S. Census Bureau's Annual County and Puerto Rico Municipio Resident Population Estimates by Selected Age Groups and Sex tables

Data/Methods: The indicator is based on the estimated percentage of adults who think Congress should do more to address global warming. The data was downloaded from the YPCCC's Yale Climate Opinion Maps 2021 website. The data was available at the state level for the years 2016–2021 and at the county level for the years 2016 and 2018–2021. Estimates for the year 2017 at the county level were calculated by adding half the difference between the estimated percentages in 2016 and 2018 to the estimated percentages in 2016. Estimated percentages for each state and regional level in each year were generated by multiplying the estimated percentages at the county level by the U.S. Census Bureau's adult population levels and then dividing the new estimated population of adults who support congressional climate action by the total population. The following set of metrics was then generated:

Metrics/Weightings:

- Share: The estimated percentage of adults who think congress should do more to address global warming (90%)
- Change: The annual growth rate of the estimated percentage of adults who think Congress should do more to address global warming over the previous year (10%)

Indicator 16: Public Support for State-Level Climate Action

Purpose: The indicator aims to assess the extent to which the citizens of states and regions support and value state-level climate action and policy. It serves as an indicator of the social legitimation function.

Data Sources:

- YPCCC Yale Climate Opinion Maps 2021 dataset
- U.S. Census Bureau's Annual County and Puerto Rico Municipio Resident Population Estimates by Selected Age Groups and Sex tables

Data/Methods: The indicator is based on the estimated percentage of adults who think their governor should do more to address global warming. The data was downloaded from the YPCCC's Yale Climate Opinion Maps 2021 website. The data was available at the state level for the years 2016–2021 and at the county level for the years 2016 and 2018–2021. Estimates for the year 2017 at the county level were calculated by adding half the difference between the estimated percentages in 2016 and 2018 to the estimated percentages in 2016. Estimated percentages for each state and regional level in each year were generated by multiplying the estimated percentages at the county level by the U.S. Census Bureau's adult population levels and then dividing the new estimated population of adults who support state-level climate action by the total population. The following set of metrics was then generated:

Metrics/Weightings:

- Share: The estimated percentage of adults who think their governor should do more to address global warming (90%)
- Change: The annual growth rate of the estimated percentage of adults who think their governor should do more to address global warming over the previous year (10%)

Indicator 17: Public Support for Local-Level Climate Action

Purpose: The indicator aims to assess the extent to which the citizens of states and regions support and value local-level climate action and policy. It serves as an indicator of the social legitimation function.

Data Sources:

- YPCCC Yale Climate Opinion Maps 2021 dataset
- U.S. Census Bureau's Annual County and Puerto Rico Municipio Resident Population Estimates by Selected Age Groups and Sex tables

Data/Methods: The indicator is based on the estimated percentage of adults who think their local officials should do more to address global warming. The data was downloaded from the YPCCC's Yale Climate Opinion Maps 2021 website. The data was available at the state level for the years 2016–2021 and at the county level for the years 2016 and 2018–2021. Estimates for the year 2017 at the county level were calculated by adding half the difference between the estimated percentages in 2016 and 2018 to the estimated percentages in 2016. Estimated percentages for each state and regional level in each year were generated by multiplying the estimated percentages at the county level by the U.S. Census Bureau's adult population levels and then dividing the new estimated population of adults who support local-level climate action by the total population. The following set of metrics was then generated:

Metrics/Weightings:

- Share: The estimated percentage of adults who think local officials should do more to address global warming (90%)
- Change: The annual growth rate of the estimated percentage of adults who think local officials should do more to address global warming over the previous year (10%)

Indicator 18: Public Support for Corporate Climate Action

Purpose: The indicator aims to assess the extent to which the citizens of states and regions support and value corporate climate action. It serves as an indicator of the social legitimation function.

Data Sources:

- YPCCC Yale Climate Opinion Maps 2021 dataset
- U.S. Census Bureau's Annual County and Puerto Rico Municipio Resident Population Estimates by Selected Age Groups and Sex tables

Data/Methods: The indicator is based on the estimated percentage of adults who think corporations should do more to address global warming. The data was downloaded from the YPCCC's Yale Climate Opinion Maps 2021 website. The data was available at the state level for the years 2016–2021 and at the county level for the years 2016 and 2018–2021. Estimates for the year 2017 at the county level were calculated by adding half the difference between the estimated percentages in 2016 and 2018 to the estimated percentages in 2016. Estimated percentages for each state and regional level in each year were generated by multiplying the estimated percentages at the county level by the U.S. Census Bureau's adult population levels and then dividing the new estimated population of adults who support corporate climate action by the total population. The following set of metrics was then generated:

Metrics/Weightings:

- Share: The estimated percentage of adults who think corporations should do more to address global warming (90%)
- Change: The annual growth rate of the estimated percentage of adults who think corporations should do more to address global warming over the previous year (10%)

Indicator 19: Public Support for Citizen Climate Action

Purpose: The indicator aims to assess the extent to which the citizens of states and regions support and value citizen climate action. It serves as an indicator of the social legitimation function.

Data Sources:

- YPCCC Yale Climate Opinion Maps 2021 dataset
- U.S. Census Bureau's Annual County and Puerto Rico Municipio Resident Population Estimates by Selected Age Groups and Sex tables

Data/Methods: The indicator is based on the estimated percentage of adults who think citizens should do more to address global warming. The data was downloaded from the YPCCC's Yale Climate Opinion Maps 2021 website. The data was available at the state level for the years 2016–2021 and at the county level for the years 2016 and 2018–2021. Estimates for the year 2017 at the county level were calculated by adding half the difference between the estimated percentages in 2016 and 2018 to the estimated percentages in 2016. Estimated percentages for each state and regional level in each year were generated by multiplying the estimated percentages at the county level by the U.S. Census Bureau's adult population levels and then dividing the new estimated population of adults who support citizen climate action by the total population. The following set of metrics was then generated:

Metrics/Weightings:

- Share: The estimated percentage of adults who think citizens should do more to address global warming (90%)
- Change: The annual growth rate of the estimated percentage of adults who think citizens should do more to address global warming over the previous year (10%)

APPENDIX 3: SEARCH STRATEGIES

Table A3.1: Publication search strategies and categorization methods

Technology Categories	Keyword Search Terms	Publications
Clean Energy	Includes all publications identified using the keyword search strategies listed below	150,266
Advanced Energy Materials	("clean energy" OR "renewable energy" OR "alternative energy" OR "green energy" OR "sustainable energy" OR "low-carbon energy" OR "energy efficiency" OR "energy efficient" OR "green building*" OR "sustainable building*" OR "energy transition") AND ("critical mineral*" OR "critical material*" OR "critical element*" OR "critical metal*" OR "rare earth mineral*" OR "rare earth material*" OR "rare earth element*" OR "rare earth metal*" OR "materials science" OR "nano*" OR "aluminum" OR "copper" OR "silver" OR "zinc" OR "lithium" OR "nickel" OR "cobalt" OR "manganese" OR "graphite" OR "neodymium" OR "dysprosium" OR "uranium" OR "platinum" OR "electrical steel" OR "fluorine" OR "gallium" OR "iridium" OR "praseodymium" OR "silicon" OR "terbium" OR "vanadium" OR "graphene") OR ("energy material*")	5,869; 845
Bioenergy	("clean energy" OR "renewable energy" OR "alternative energy" OR "green energy" OR "sustainable energy" OR "low-carbon energy" OR "energy transition" OR "bioenergy" OR "biopower" OR "biofuel*") AND ("biomass" OR "biowaste" OR "biogas*" OR "biogasoline" OR "biomethane" OR "bioliquid*" OR "biobutanol" OR "bio-ccus" OR "beccs" OR "waste-to-energy" OR "biomass feedstock*" OR "jatropha" OR "lignocellulosic" OR "cellulosic" OR "biomass gasification" OR "biochemical conversion" OR "thermochemical conversion" OR "thermochemical liquefication" OR "biomethanation" OR "microalgae" OR "switchgrass" OR "sugarcane" OR "maize") OR ("bioenergy" OR "biopower" OR "biofuel*" OR "biodiesel" OR "bioethanol" OR "algae fuel*" OR "anaerobic digest*" OR "biorefine*")	14,959; 4,427
Carbon Capture, Utilization, and Storage (CCUS)	("carbon capture" OR "carbon dioxide capture" OR "CO_2 capture" OR "carbon scrubber*" OR "carbon dioxide scrubber*" OR "CO_2 scrubber*" OR "carbon absorption" OR "carbon dioxide absorption" OR "CO_2 absorption" OR "carbon separation" OR "carbon dioxide separation" OR "CO_2 separation" OR "carbon removal" OR "carbon dioxide removal" OR "CO_2 removal" OR "carbon utilization" OR "carbon dioxide utilization" OR "CO_2 utilization" OR "carbon sequestration" OR "carbon dioxide sequestration" OR "CO_2 sequestration" OR "carbon storage" OR "carbon dioxide storage" OR "CO_2 storage" OR "carbon capture and utilization" OR "carbon dioxide capture and utilization" OR "CO_2 capture and utilization" OR "carbon capture and sequestration" OR "carbon dioxide capture and sequestration" OR "CO_2 capture and sequestration" OR "carbon capture and storage" OR "carbon dioxide capture and storage" OR "CO_2 capture and storage" OR "carbon capture, utilization, and sequestration" OR "carbon dioxide capture, utilization, and sequestration" OR "CO_2	13,399; 2,912

Technology Categories	Keyword Search Terms	Publications
	capture, utilization, and sequestration" OR "carbon capture, utilization, and storage" OR "carbon dioxide capture, utilization, and storage" OR "CO_2 capture, utilization, and storage" OR "direct air capture")	
Clean Energy Manufacturing	((("industrial" OR "manufacturing") AND ("energy efficien*" OR "heat pump*" OR "clean hydrogen" OR "green hydrogen" OR "blue hydrogen" OR "electrolysis" OR "electrolyzer*" OR "fuel cell*" OR "biofuel*" OR "biofeedstock*" OR "bio-feedstock*" OR "biomass feedstock*" OR "anaerobic digest*" OR "solar thermal" OR "nuclear thermal" OR "thermal storage" OR "carbon capture" OR "carbon utilization" OR "carbon sequestration" OR "carbon storage" OR "carbon capture and storage*" OR "carbon capture, utilization, and storage*" OR "direct air capture")) OR ("sustainable manufacturing" OR "low-carbon manufacturing" OR "industrial energy efficien*" OR "industrial efficien*" OR "industrial decarbon*" OR "industrial emission*" OR "hard-to-abate" OR "difficult-to-decarbonize" OR "difficult-to-abate" OR "combined heat and power" OR "waste heat to power" OR "waste heat recovery" OR "industrial electrification" OR "electric arc furnace*" OR "electrowinning" OR "electric boiler*" OR "electric kiln*" OR "low-carbon fuel*" OR "low-carbon feedstock*" OR "green chemical*" OR "low-carbon chemical*" OR "green steel" OR "low-carbon steel" OR "green cement" OR "low-carbon cement")) OR ("clean energy industr*" OR "clean energy manufactur*" OR "renewable energy industr*" OR "renewable energy manufactur*" OR "bioenergy industr*" OR "bioenergy manufactur*" OR "biofuel* industr*" OR "biofuel* manufactur*" OR "biodiesel industr*" OR "biodiesel manufactur*" OR "ethanol industr*" OR "ethanol manufactur*" OR "bioethanol industr*" OR "electric vehicle* industr*" OR "ev industr*" OR "electric vehicle* manufactur*" OR "ev manufactur*" OR "energy storage industr*" OR "battery industr*" OR "battery manufactur*" OR "green hydrogen industr*" OR "electrolyzer* industr*" OR "fuel cell* industr*" OR "fuel cell* manufactur*" OR "solar energy industr*" OR "solar energy manufactur*" OR "solar photovoltaic* industr*" OR "solar PV industr*" OR "solar PV manufactur*" OR "photovoltaic* industr*" OR "PV industr*" OR "photovoltaic* manufactur*" OR "pv manufactur*" OR "solar manufactur*" OR "solar cell* industr*" OR "solar cell* manufactur*" OR "solar module* manufactur*" OR "solar panel* industr*" OR "solar panel* manufactur*" OR "wave energy industr*" OR "wave energy manufactur*" OR "tidal energy industr*" OR "wind industr*" OR "wind manufactur*" OR "wind energy industry*" OR "wind energy manufactur*" OR "wind turbine* industr*" OR "wind turbine* manufactur*" OR "wind blade* manufactur*")	6,889; 1,416
Clean Energy Transportation	("clean energy" OR "renewable energy" OR "alternative energy" OR "green energy" OR "sustainable energy" OR "low-carbon energy" OR "energy efficiency" OR "energy efficient" OR "energy transition" "carbon emission*" OR "CO_2 emission*" OR	18,700; 3,659

Technology Categories	Keyword Search Terms	Publications
	“greenhouse gas emission*” OR “clean fuel*” OR “renewable fuel*” OR “alternative fuel*” OR “green fuel*” OR “sustainable fuel*” OR “low-carbon fuel*” OR “biofuel*” OR “hydrogen fuel” OR “lithium-ion” OR “fuel cell*”) AND (“transport” OR “transportation” OR “mobility” OR “automotive” OR “automobile*” OR “vehicle*” OR “charging station*” OR “plug-in charging” OR “buses” OR “freight” OR “rail” OR “railroad*” OR “aviation” OR “airplane*” OR “maritime” OR “shipping”) OR (“clean energy transport*” OR “sustainable transport*” OR “sustainable fuel*” OR “electric vehicle*” OR “plug-in vehicle*” OR “battery vehicle*” OR “hybrid vehicle*” OR “EV charging” OR “fuel cell vehicle*” “sustainable freight” OR “sustainable rail*” OR “sustainable aviation” OR “sustainable maritime” OR “sustainable shipping”)	
Energy Efficiency	(“energy transition” OR “greenhouse gas emission*” OR “GHG emission*” OR “carbon emission*” OR “CO_2 emission*” OR “energy efficien*” OR “building efficien*” OR “green building*” OR “sustainable building*” OR “low-carbon building*” OR “net-zero building*” OR “leadership in energy and environmental design*” OR “leed certifi*”) AND (“building material*” OR “insulation” OR “heating and cooling*” OR “heating, ventilation, and air condition*” OR “hvac” OR “air condition*” OR “heat pump*” OR “heat exchang*” OR “space heat*” OR “elastocaloric cool*” OR “multicaloric cool*” OR “solid state energy conver*” OR “solar thermal energy conver*” OR “solar thermal storage” OR “seasonal thermal energy storage” OR “thermostat*” OR “water heat*” OR “hot water tank*” OR “hot water storage” OR “appliance*” OR “energy star” OR “refrigerat*” OR “washing machine*” OR “clothes dryer” OR “dishwash*” OR “lighting” OR “solid state light*” OR “light emitting diode*” OR “industrial efficien*” OR “industrial heat*” OR “advanced manufacturing”) OR (“energy efficien*” OR “building efficien*” OR “green building*” OR “sustainable building*” OR “leadership in energy and environmental design*” OR “leed certifi*”)	19,754; 4,220
Energy Storage	(“energy storage” OR “long duration storage” OR “battery storage” OR “lithium-ion batter*” OR “lithium-sulfur batter*” OR “lead acid batter*” OR “sodium sulfur batter*” OR “solid-state batter*” OR “zinc-bromine batter*” OR “flow batter*” OR “redox flow” OR “vanadium redox” OR “pumped hydro storage” OR “thermal storage” OR “molten salt storage” OR “sensible heat storage” OR “hydrogen storage” OR “H2 storage”) OR (“flywheel” AND “storage”)	29,069; 5,857
Geothermal Energy	(“geothermal”) AND (“dry steam” OR “flash steam” OR “binary cycle”) OR ("geothermal energy" OR "geothermal power” OR “geothermal system*” OR “geothermal heat”)	1,306; 230
Grid Technologies	((“electric grid*” OR “electricity grid*” OR “power grid*” OR “smart grid*” OR “microgrid*” OR “micro-grid*”) AND	16,607; 3,431

Technology Categories	Keyword Search Terms	Publications
	(“superconducting cable*” OR “high-temperature superconductor*” OR “power flow management” OR “topology optimization” OR “energy storage” OR “artificial intelligence” OR “machine learning”)) OR (“electric grid*” OR “electricity grid*” OR “power grid*” OR “grid modernization” OR “smart grid*” OR “microgrid*” OR “micro-grid*” OR “power flow controller*” OR “flexible alternating current*” OR “flexible AC transmission” OR “thyristor-switched” OR “thyristor-controlled” OR “static synchronous” OR “static var compensator*” OR “medium voltage direct current” OR “high-voltage direct current*” OR “multi-terminal direct current” OR “aluminum conductor composite core” OR “solid-state power substation*” OR “dynamic line rating*” OR “energy management system*” OR “supervisory control and data acquisition system*” OR “scada system*” OR “smart meter*” OR “demand response” OR “virtual power plant*” OR “grid operator*” OR “independent system operator*” OR “regional transmission organization*” OR “ISO/RTO”)	
Hydrogen and Fuel Cells	(“hydrogen” OR “fuel cell*” OR “electrolysis” OR “electrolyzer*” OR “water splitting”) AND (“solar thermochemical” OR “alkaline electroly*” OR “solid oxide electroly*” OR “proton exchange membrane*” OR “anion exchange membrane*” OR “photoelectrochemical” OR “photobiological” OR “microbial biomass conversion” OR “microbial fuel cell*” OR “polymer electrolyte membrane*”) OR (“clean hydrogen” OR “low-carbon hydrogen” OR “green hydrogen” OR “blue hydrogen” OR “turquoise hydrogen” OR “fuel cell*”)	11,186; 3,195
Nuclear Energy	(“nuclear energy” OR “nuclear power” OR “nuclear reactor*” OR “nuclear fusion” OR “advanced reactor*” OR “light water reactor*” OR “high temperature reactor*” OR “fast spectrum reactor*” OR “pressurized water reactor*” OR “boiling water reactor*” OR “pressurized heavy water reactor*” OR “reactor Bolshoy Moschnosti Kanalniy” OR “high power channel reactor*” OR “gas cooled reactor*” OR “small module reactor*” OR “liquid-metal fast breeder reactor*” OR “pebble bed reactor*” OR “aqueous homogenous reactor*” OR “advanced boiling reactor*” OR “advanced pressurized water reactor*” OR “enhanced CANDU 6” OR “hualong one” OR “vver-1000/392” OR “advanced heavy water reactor*” OR “very-high-temperature reactor*” OR “molten salt reactor*” OR “supercritical-water-cooled reactor*” OR “gas-cooled fast reactor*” OR “sodium-cooled fast reactor*” OR “lead-cooled fast reactor*” OR “liquid-core reactor*” OR “gas-core reactor*” OR “fission fragment reactor*” OR “hybrid nuclear fusion” OR “nuscale” OR “tokamak”)	9,334; 2,113
Solar Energy	(“solar”) AND (“PV” OR “cell*” OR “wafer*” OR “module*” OR “panel*” OR “shingle*” OR “tracker*” OR “tracking*” OR “inverter*” OR “building integrated” OR “grid-connected” OR “off-grid” OR “silicon” OR “multijunction” OR “two-junction” OR “three-junction” OR “four-junction” OR “single-junction” OR	35,372; 9,751

Technology Categories	Keyword Search Terms	Publications
	“crystalline” OR “monocrystalline” OR “multicrystalline” OR “polycrystalline” OR “thin-film” OR “amorphous silicon” OR “amorphous si” OR “cadmium telluride” OR “CdTe” OR “copper indium gallium selenide” OR “copper indium gallium diselenide” OR “CIGS” OR “copper indium selenide” OR “copper indium diselenide” OR “CIS” OR “organic PV” OR “organic cell*” OR “organic tandem” OR “inorganic cell*” OR “dye-sensitized” OR “polymer cell*” OR “quantum dot*” OR “copper zinc tin sulfide” OR “CZTS” OR “zinc phosphide” OR “carbon nanotube*” OR “nanocrystal*” OR “perovskite” OR “passive” OR “hot water” OR “water heating” OR “combisystem” OR “air condition*” OR “air heat*” OR “ventilat*” OR “furnace*” OR “cooker*” OR “cooking” OR “desalinat*” OR “CSP” OR “parabolic trough*” OR “power tower*” OR “solar tower*” OR “dish design*” OR “Fresnel” OR “microCSP” OR “enclosed trough” OR “steam accumulate*” OR “molten salt” OR “heliostat*”) OR (“solar energy” OR “solar power” OR “photovoltaic*” OR “concentrated solar” OR “solar thermal” OR “solar heating” OR “solar cooling” OR “solar storage”)	
Water Energy	(“water energy” OR “water power” OR “waterpower” OR “hydroelectric*” OR “hydro electric” OR “hydropower” OR “hydro power” OR “small hydro” OR “microhydro” OR “micro hydro” OR “marine and hydrokinetic” OR “marine energy” OR “marine power” OR “marine current energy” OR “marine current power” OR “hydrokinetic energy” OR “hydrokinetic power” OR “ocean energy” OR “ocean power” OR “oceanpower” OR “wave energy” OR “wave power” OR “wavepower” OR “tidal energy” OR “tidal power” OR “tidalpower” OR “tidal stream energy” OR “tidal stream power” OR “tidal barrage energy” OR “tidal barrage power” OR “ocean thermal energy” OR “ocean thermal power” OR “osmotic energy” OR “osmotic power” OR “run-of-river” OR “run-of-the-river” OR “pumped-hydro” OR “pumped-hydro storage” OR “pumped-storage” OR “hydroelectric turbine*” OR “reaction turbine*” OR “propeller turbine*” OR “bulb turbine*” OR “straflo” OR “tube turbine*” OR “kaplan turbine*” OR “francis turbine*” OR “kinetic turbine*” OR “impulse turbine*” OR “pelton turbine*” OR “cross-flow turbine*” OR “wave farm*” OR “wave park*” OR “wave turbine*” OR “hydrokinetic turbine*” OR “in-stream turbine*” OR “ocean current turbine*” OR “point absorber buoy*” OR “surface attenuator*” OR “oscillating wave surge converter*” OR “oscillating water column*” OR “overtopping device*” OR “submerged pressure differential converter*” OR “floating in-air converter*” OR “tidal turbine*” OR “tidal generator*” OR “tidal stream generator*” OR “tidal barrage*” OR “tidal lagoon*” OR “dynamic tidal”)	6,747; 1,266
Wind Energy	(“wind” OR “onshore” OR “offshore”) AND (“horizontal axis” OR “vertical axis” OR “wind tower*” OR “steel tower*” OR “nacelle*” OR “rotor*” OR “blade*” OR “small wind turbine*” OR “small-scale wind turbine*” OR “small turbine*” OR “microwind	9,370; 2,226

Technology Categories	Keyword Search Terms	Publications
	turbine*" OR "micro wind turbine*" OR "micro turbine*" OR "microturbine*" OR "microgeneration" OR "monopile*" OR "gravity base*" OR "tripod suction*" OR "suction caisson*" OR "steel jacket*" OR "floating wind turbine*" OR "floating wind" OR "floating turbine*") OR ("wind energy" OR "wind power" OR "windpower" OR "wind farm*" OR "windfarm*" OR "wind park*" OR "windpark*" OR "wind turbine*" OR "windmill*" OR "wind mill*" OR "onshore wind" OR "offshore wind")	

Table A3.2: Patent search strategies and categorization methods

Technology Categories	CPC Codes	Patents
Clean Energy	Includes all patents identified using the patent strategies listed below	126,394
Advanced Energy Materials	**Y02** + **B01J** 21/, B01J 23/, B01J 27/, B01J 29/, B01J 31/, B01J 32/, B01J 33/, B01J 35/, B01J 37/, B01J 38/, **B81**, **B82**, **C01B** 6/, C01B 17/, C01B 39/, **C01D** 15/, **C01F** 7/, C01F 17/, **C01G** 3/, C01G 5/, C01G 9/, C01G 15/, C01G 31/, C01G 43/, C01G 45/, C01G 51/, C01G 53/, C01G 55/, **C03C** 3/, **C04B** 7/, C04B 9/, C04B 11/, C04B 12/, **C07F** 5/06, C07F 15/04, C07F 15/06, **C08F** 4/, **C09B** 45/, **C09K** 5/, C09K 9/, C09K 11/, **C22B** 15/, C22B 19/, C22B 21/, C22B 23/, C22B 26/, C22B 34/, **C22B** 47/, C22B 58/, C22B 59/, C22B 60/, **C22C** 9/, C22C 18/, C22C 19/, C22C 21/, C22C 22/, C22C 27/, **C22C** 38/, C22C 45/, **C25B** 9/, C25B 11/, **C25C** 1/, C25C 3/, **C25D** 3/, C25D 5/, **C30B**, **C40B**, **H01B** 1/, H01B 3/, **H01F** 1/, H01F 6/, H01F 7/, H01F 10/,	17,616

Technology Categories	CPC Codes	Patents
	H01J, **H01M** 4/, H01M 8/, **H10K** 10/, H10K 85/	
Bioenergy	**Y02E50/00**, Y02E50/10, Y02E50/15, Y02E50/30	6,767
Carbon Capture, Utilization, and Storage (CCUS)	**Y02C10/00**, **Y02C20/00**, Y02C20/10, Y02C20/18, Y02C20/20, Y02C20/30, Y02C20/32, Y02C20/40	3,604
Clean Energy Manufacturing	**Y02P10/00**, Y02P10/10, Y02P10/122, Y02P10/134, Y02P10/143, Y02P10/146, Y02P10/20, Y02P10/25, Y02P10/32, **Y02P20/00**, Y02P20/10, Y02P20/129, Y02P20/133, Y02P20/141, Y02P20/143, Y02P20/145, Y02P20/151, Y02P20/155, Y02P20/156, Y02P20/20, Y02P20/30, Y02P20/40, Y02P20/50, Y02P20/52, Y02P20/54, Y02P20/55, Y02P20/582, Y02P20/584, Y02P20/59, **Y02P30/00**, Y02P30/20, Y02P30/40, **Y02P40/00**, Y02P40/10, Y02P40/121, Y02P40/125, Y02P40/18, Y02P40/40, Y02P40/45, Y02P40/50, Y02P40/57, Y02P40/60, **Y02P60/12**, Y02P60/14, Y02P60/52, Y02P60/80, Y02P60/85, Y02P60/87, **Y02P70/00**, Y02P70/10, Y02P70/50, Y02P70/62, **Y02P80/00**, Y02P80/10, Y02P80/14, Y02P80/15, Y02P80/20, Y02P80/30, Y02P80/40, **Y02P90/00**, Y02P90/02, Y02P90/30, Y02P90/40, Y02P90/45, Y02P90/50, Y02P90/60, Y02P90/70, Y02P90/80, Y02P90/82, Y02P90/84, Y02P90/845, Y02P90/90, Y02P90/95	26,551
Clean Energy Transportation	**Y02T10/00**, Y02T10/10, Y02T10/12, Y02T10/30, Y02T10/40, Y02T10/60, Y02T10/62, Y02T10/64, Y02T10/70, Y02T10/7072, Y02T10/72, Y02T10/80, Y02T10/82, Y02T10/84, Y02T10/86, Y02T10/88, Y02T10/90, Y02T10/92, **Y02T30/00**, **Y02T50/00**, Y02T50/10, Y02T50/14, Y02T50/145, Y02T50/30, Y02T50/40, Y02T50/50, Y02T50/60, Y02T50/672, Y02T50/675, Y02T50/678, Y02T50/80, **Y02T70/00**, Y02T70/10, Y02T70/50, Y02T70/5218, Y02T70/5236, **Y02T90/00**, Y02T90/10, Y02T90/12, Y02T90/14, Y02T90/16, Y02T90/167, Y02T90/32, Y02T90/34, Y02T90/40	31,569
Energy Efficiency	**Y02B20/00**, Y02B20/30, Y02B20/40, Y02B20/44, Y02B20/72, **Y02B30/00**, Y02B30/12, Y02B30/13, Y02B30/17, Y02B30/18, Y02B30/52, Y02B30/54, Y02B30/56, Y02B30/62, Y02B30/625, Y02B30/70, Y02B30/90, **Y02B40/00**, Y02B40/146, Y02B40/18,	35,512

Technology Categories	CPC Codes	Patents
	Y02B50/00, **Y02B60/00**, **Y02B70/00**, Y02B70/10, Y02B70/30, Y02B70/3225, Y02B70/34, **Y02B80/00**, Y02B80/10, Y02B80/22, Y02B80/32, **Y02B90/00**, Y02B90/20, Y02B90/241, **Y02D10/00**, Y02D10/126, Y02D10/151, Y02D10/171, Y02D10/22, Y02D10/24, **Y02D30/00**, Y02D30/50, Y02D30/70, **Y02E20/00**, Y02E20/12, Y02E20/14, Y02E20/16, Y02E20/30, Y02E20/34	
Energy Storage	**Y02B10/70**, **Y02B60/00**, YO2B60/10, YO2B60/13, YO2B60/14, YO2B60/16, YO2B60/78, **Y02B70/00**, YO2B70/30	25,507
Geothermal Energy	**Y02B10/40**, **Y02E10/10**	409
Grid Technologies	**Y02E40/00**, Y02E40/10, Y02E40/20, Y02E40/30, Y02E40/40, Y02E40/50, **Y02E40/60**, Y02E40/70, **Y02E60/60**, **Y04S10/00**, Y04S10/12, Y04S10/123, Y04S10/126, Y04S10/14, Y04S10/16, **Y04S10/18**, Y04S10/20, Y04S10/22, Y04S10/30, Y04S10/40, Y04S10/50, Y04S10/52, **Y04S20/00**, Y04S20/12, Y04S20/14, Y04S20/20, Y04S20/221, Y04S20/222, **Y04S20/242**, Y04S20/244, Y04S20/246, Y04S20/248, Y04S20/30, Y04S20/322, Y04S20/38, **Y04S30/00**, Y04S30/10, Y04S30/12, Y04S30/14, **Y04S40/00**, Y04S40/12, Y04S40/121, Y04S40/124, Y04S40/126, Y04S40/128, Y04S40/18, Y04S40/20, **Y04S50/00**, Y04S50/10, Y04S50/12, Y04S50/14, Y04S50/16	7,871
Hydrogen and Fuel Cells	**Y02B90/10**, **Y02E60/30**, Y02E60/32, Y02E60/34, Y02E60/36, Y02E60/50	6,277
Nuclear Energy	**Y02E30/00**, Y02E30/10, Y02E30/30	1,853
Solar Energy	**Y02B10/00**, Y02B10/10, Y02B10/20, Y02B10/00, **Y02E10/00**, Y02E10/40, Y02E10/44, Y02E10/46, Y02E10/47, Y02E10/50, Y02E10/52, Y02E10/541, Y02E10/542,	12,777

Technology Categories	CPC Codes	Patents
	Y02E10/543, Y02E10/544, Y02E10/545, Y02E10/546, Y02E10/547, Y02E10/548, Y02E10/549, Y02E10/56, Y02E10/60	
Water Energy	**Y02B10/50**, Y02E10/20, Y02E10/226, Y02E10/30	1,048
Wind Energy	**Y02B10/30**, Y02B10/70, Y02B10/72, Y02B10/727, Y02B10/728, Y02B10/74, Y02B10/76	3,405

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