

Regional Clean Energy Innovation

Regional factors for accelerating
the development and deployment
of climate mitigation technologies

February 2020



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FOREWORD

The Energy Futures Initiative (EFI) commissioned this report by the University of Maryland to enhance our understanding of U.S. innovation at the regional level, providing a foundation for policymakers and researchers to strategically expand and accelerate regional clean energy technology innovation. This report assembles and aligns U.S. clean energy innovation data at the subnational level. The data reveals trends in regional clean energy innovation, providing a baseline of activities for all 50 states. The report builds on this baseline with a bottom-up case study assessment of clean energy innovation in two states with contrasting energy innovation conditions, Colorado and Maryland; and articulates key lessons for developing stronger clean energy innovation systems in other regions of the country.

The U.S. has an unparalleled infrastructure for clean energy innovation that includes extensive collaboration among all levels of government, national laboratories, research and academic institutions, and the private sector. This collaboration involves sharing of knowledge and resources, and is based on an understanding that energy innovation is a critical contributor to economic growth, energy and national security, and environmental stewardship.

Energy systems in the U.S., however, have distinct features that make energy innovation— and disruptive changes—especially challenging. Energy is a highly capitalized commodity business, with complex supply chains and established customer bases, providing essential services to all sectors of the economy. This leads to systems with considerable inertia, a focus on reliability and safety, an aversion to risk, extensive regulation, and complex politics.

Even with the U.S. capacity to innovate, and the emergence of numerous technology opportunities, there are significant challenges going forward. Without an internalization of the costs of carbon, it can be difficult for firms to capture the full value of clean energy—including their contribution to recurring environmental and social damage—through market transactions alone. Meanwhile, the government has limited ability to animate U.S. clean energy innovation through deployment policy mechanisms. For example, a state’s renewable portfolio standard (RPS) may be met using solar and wind technologies manufactured outside the state or even outside the U.S.—effectively outsourcing any incremental innovation that may have been precipitated by the RPS.

Also, breakthrough innovations generally require decades of support from multiple stakeholders along the innovation process, with resources and coordination requiring support at the federal level. Examples include solar photovoltaics and hydraulic fracturing technologies. The U.S. Department of Energy (DOE) has long sponsored R&D of both breakthrough technologies.^{a,b} These investments paid off with technological advances and cost declines for solar PV that drove deployment and the emergence of a global market for solar modules. Similarly, hydraulic fracturing technology began with decades of R&D linked to DOE, starting with shale basin characterization shortly after DOE was established. Years of sharing knowledge and resources along the energy innovation process (combined with well-structured tax incentives) made the “shale revolution” possible.

Why Regional?

A key attribute of the U.S. energy innovation system is the robust knowledge and resources of the players along the innovation process: governments, research institutions, and the private sector. The U.S. has hundreds of research universities, 17 DOE national laboratories, four energy innovation hubs, 46 Energy Frontier Research Centers, and a high rate of private R&D funding. While resourcing and coordination from the federal government is essential, regional differences create a diversity of focus and approaches that enriches the U.S. innovation system overall.

Regional clean energy innovation ecosystems—active groups of geographically connected stakeholders that support the RD&D and deployment of clean energy technologies—are thus at the heart of clean energy innovation in the United States. This is in part due to shared interests in their local economies, people, and environments; by aligning local interests and resources, stakeholders can create new businesses and jobs, encourage outside investment, improve air and water quality, and reduce the impacts of climate change.

Locally-oriented clean energy innovation is also motivated by subnational efforts to reduce carbon emissions: over 3,800 businesses and investors, cities and counties, mayors, colleges and universities, tribes, cultural institutions, and other organizations—representing \$9.46 trillion in GDP and covering 48 percent of the U.S. population—have committed to stand by the goals of the Paris Agreement by reducing emissions and increasing the deployment of clean energy technologies.

Despite the important role regional clean energy innovation ecosystems already play in technology development, there are real opportunities to expand their impact. Economy-wide decarbonization will depend on multiple technology breakthroughs that address key issues in the energy sector, and more rapid adoption of those breakthroughs. The opportunity is here for the U.S. to leverage the full potential of its innovation ecosystems, by embracing the diversity of regional strengths and targeting federal and state planning accordingly. This report builds on previous EFI reports that show how working relationships between regional players in research, investment, and policy can drive clean energy innovation. This report provides new insights for policymakers and innovators on how to draw value from these relationships, and we encourage an expanded data-driven investigation into the motivations and outcomes of regional innovation ecosystems to drive us toward a deeply decarbonized economy.



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February 2020

^a <https://energy.gov/sites/prod/files/2016/06/f32/SunShot-factsheet-2016.pdf>

^b <https://www.energy.gov/fe/science-innovation/oil-gas-research/shale-gas-rd>

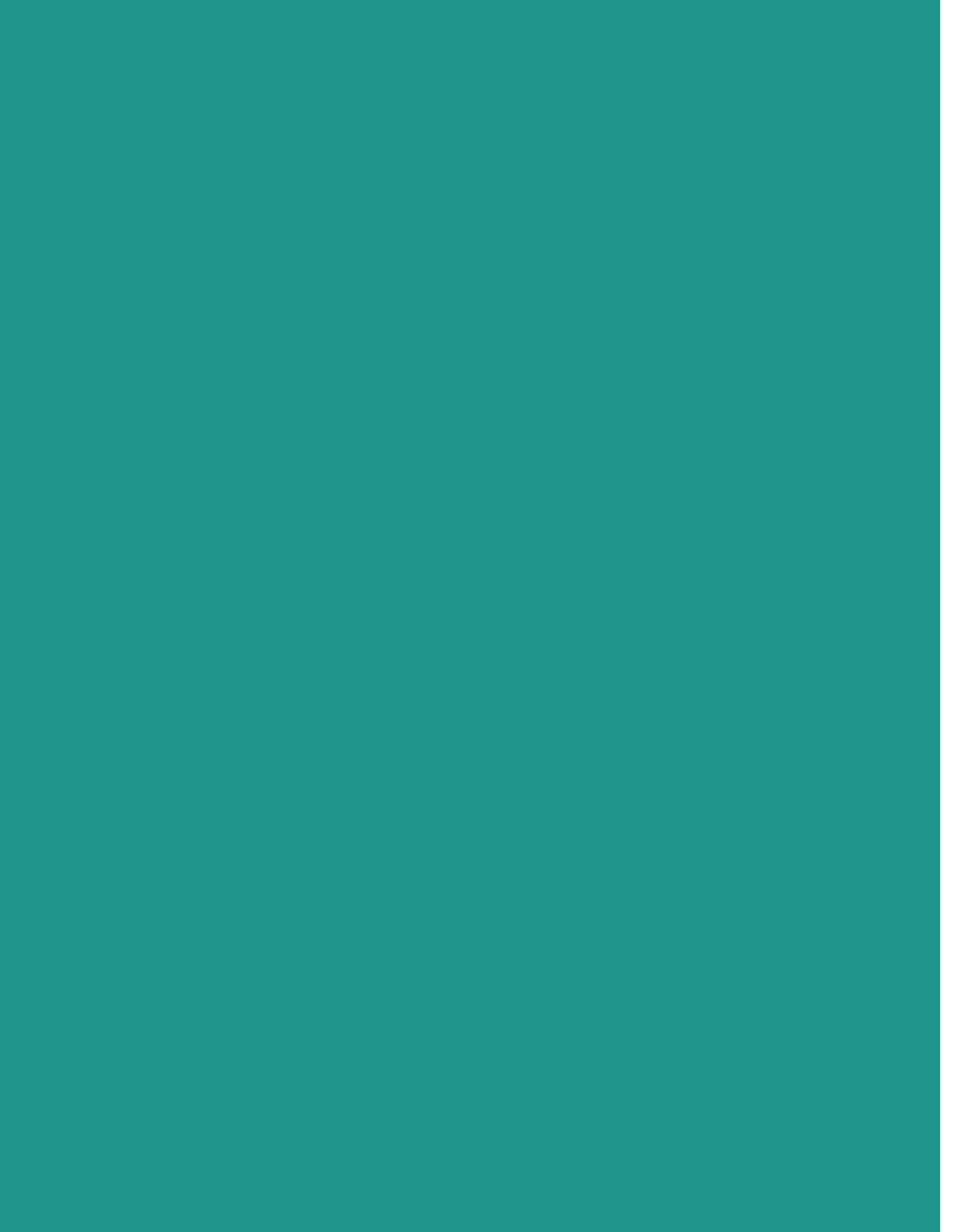


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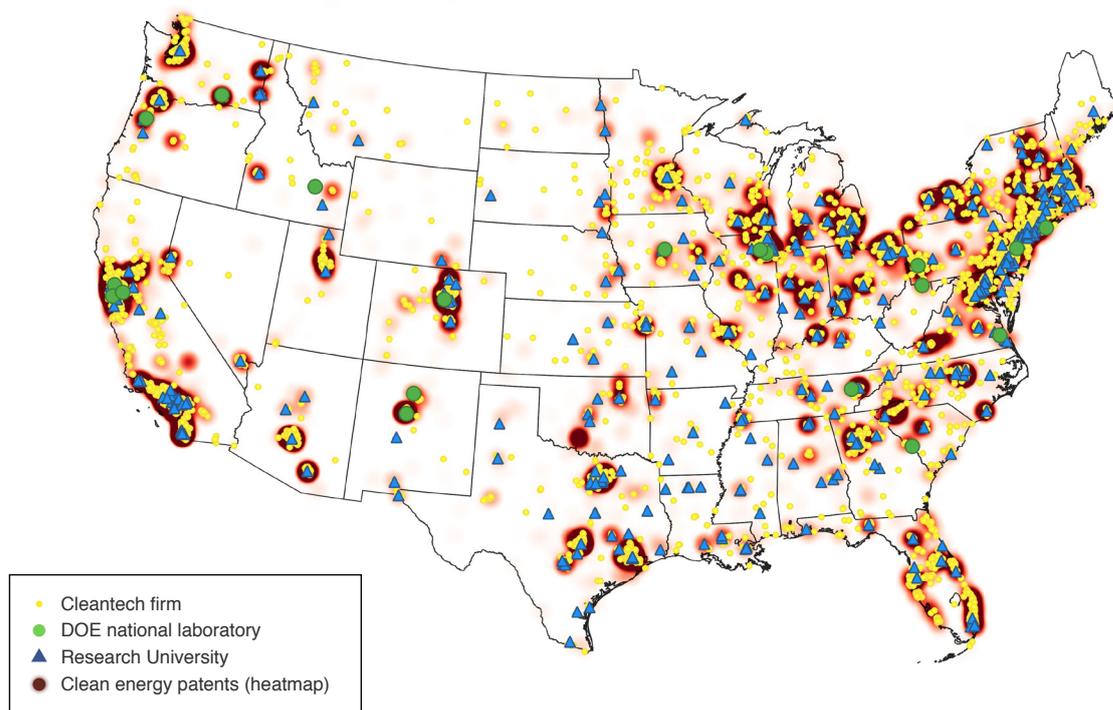
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EXECUTIVE SUMMARY

This report provides data-driven approaches and insights for federal and state planning to accelerate clean energy innovation by aligning programs with regional resources and economic development goals.

United States leadership in energy innovation in the past decades has enabled a dramatic transformation of the energy system. Federal support for energy innovation has been motivated by economic opportunities, energy security, and environmental considerations. More recent motivations have included reduction of greenhouse gas emissions and shifts to increasingly cost-competitive clean energy technologies. Participation in the US clean energy innovation process is dispersed across the country (Figure ES-1). The stakeholders involved include the US Department of Energy (DOE) national laboratories; industrial research laboratories; around 7,000 innovative clean energy or ‘cleantech’ companies¹; thousands of state and local government units²; over 400 research universities³; and around 3,000 public and private utilities⁴.

Figure ES-1: Clean energy innovation activity is dispersed across the United States



This report uses a data-driven approach to explore regional characteristics, defined at the state-level, in clean energy innovation. Clean energy is defined broadly to cover technologies that either contribute to climate mitigation or to modernizing the energy system. The exploration of data is presented in two stages: a 50-state assessment and detailed case studies comparing two states.

The 50-state assessment integrates a large number of publicly accessible data sources to reflect the regional economic drivers, environmental focus, and technology capacity (defined here as the technological, intellectual, and financial capacity) affecting state decisions about clean energy innovation and some of its quantifiable outcomes (see Appendix A for methodology). The results map across multiple clean energy technologies to reveal state-by-state differences from which hypotheses about motivations and success outcomes can be drawn.

Testing these hypotheses across the 50-states with statistical methods requires data that is not (and possibly cannot be) tabulated in a standardized 50-state database. Instead, two comparative case studies explore these hypotheses using additional data and 47 personal interviews with state-level stakeholders in clean energy innovation.

The case studies investigate two states, Colorado and Maryland, examining in depth the factors that lead to very different clean energy innovation outcomes despite the similarities in the states' overall innovation capability. The case studies include expanded data development in two focus areas: state governments' support for clean energy innovation in terms of technology stages and the states' early-stage cleantech companies in terms of their technology focus and patterns of growth.

The cleantech firms revealed in Figure ES-1 are a key focus of the analyses in this report. Cleantech firms are vital elements in robust, long-term clean energy based economic development. Such firms are valuable because they can create long-term export generating assets from the technology strengths of a state's research, development, and demonstration (RD&D) activities and create long-term employment opportunities through the development of new, competitive industries⁵. Their 'health' and rate of growth reflects a combination of economic development, environment, and technology capacity conditions required for new clean energy companies to develop and thrive.

These cleantech firms, along with other local stakeholders including universities, federal research facilities, public agencies, utilities, non-profits, and industry associations, comprise the regional clean energy innovation system. Each of these stakeholders may be directly or indirectly involved in different aspects of clean energy technology in the state.

An *idealized* regional clean energy innovation system has an intentional structure, designed to support the local development and growth of new technology concepts through the stages shown in Figure ES-2. The 50-state assessment and case studies together reveal instead a diversity of clean energy innovation patterns: many states selectively focus on different individual stages of clean energy innovation for different clean energy technologies. The detailed case studies reveal the role that economic development decisions play in the states' innovation outcomes.

Figure ES-2: A simple representation of clean energy innovation research, development, demonstration (RD&D) and deployment in terms of technology, company, and funding stages.

The Process of Clean Energy Innovation



Examples of the evidence developed in this report are presented in this Executive Summary, with expanded detail and coverage of topics in the body of the report. Some key observations and conclusions of this report are listed in Box ES-1.

Box ES-1: Key features of regional clean energy innovation

- **States are highly diverse** in both the types of clean energies that are represented in their energy innovation systems and the continuity with which each technology is represented in different metrics (e.g., state resources, RD&D activity, deployment, or commercial and environmental outcomes).
- **State policies are important** in shaping clean energy innovation outcomes. The outcomes of state energy policies and spending depend strongly on their linkages with economic development goals.
- **Data-driven approaches** can provide an evidence base for state and federal policymakers to characterize regional clean energy innovation. The data characteristics developed in this report integrate standard databases with assessment of state policies and spending, including:
 - Alignment of multiple observable metrics with a consistent definition of technology areas
 - Correlations among observable metrics related to regional economic factors, energy and environment factors, technology capacity (i.e., technological, intellectual, and financial capacity), and commercial outcomes (e.g., cleantech firms)
 - Quantification of how states operationalize their clean energy innovation policies in terms of funding and other support at different stages of innovation
- New areas of data development can provide greater insight on regional clean energy innovation and allow economic impact assessments. Future data needs include:
 - **Characterizing clean energy employment.** This includes time-dependent data with greater granularity for discerning employment in clean energy innovation (e.g., employment in RD&D, manufacturing, construction, and services). Such data may be collected over time through expanding annual surveys such as the US Energy and Employment Report.⁶
 - **Developing metrics of firm health and economic outcomes.** This includes time-dependent data with detailed information on cleantech firms (e.g., firm formation, growth, investments, and product deployment). Such data may be developed where there are trusted relationships between cleantech firms and state entities (e.g., state-supported incubators or industry associations) that provide strong developmental support to firms.

The Fifty States: Exploring the Economic, Environmental, and Technological Factors behind Regional Activity in Clean Energy Innovation

Data on state-level clean energy innovation allows an exploration of activities related to research, development, and demonstration (RD&D) and deployment by different stakeholders. Using these datasets, the 50-state assessment categorizes the motivations for regional clean energy innovation activity in terms of 1) the potential for economic development; 2) goals for social and environmental benefits, and; 3) local technology capacity in RD&D (i.e., technological, intellectual, and financial capacity). Table ES-1 lists, for each category, the data and metrics used to assess clean energy innovation for each of the 50-states along with examples of outcomes.

Table ES-1: Categories of 50-state data used for exploring correlations among factors and outcomes related to clean energy research and development, demonstration, and deployment

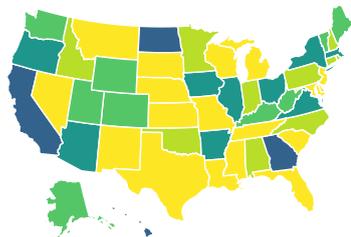
Description	Examples of Metrics
Economic Development	Natural resources – e.g., fossil fuels, biofuels, wind and solar State RD&D funding – energy, environment and natural resources
Energy and Environment	Energy efficiency standards and incentives Renewable Portfolio Standards (RPS) Other state clean energy policies
Technology Capacity	Overall innovation ranking and overall RD&D spending Department of Energy RD&D grants Number and technical areas of clean energy Small Business Innovation Research (SBIR) grants Number and technical areas of clean energy patents
Outcomes	Number and technical areas of clean energy firms Employment in clean energy sectors Deployment of clean energy technologies Reduction in greenhouse gas emissions

Following a single state through the stages shown in 50-state maps (Figure ES-3) immediately reveals that simple correlations are not the norm. For instance, Georgia has a large share of energy (all forms of energy) in its state government RD&D spending but has moderate strengths in energy efficiency, clean energy patenting, and employment; in contrast, Tennessee has strong clean energy employment metrics, but its other metrics are moderate. The difficulty of observing correlations can be partly explained by three factors. One, there is a strong overlay of the influence of the state’s Gross Domestic Product (GDP) or population on many of the metrics such as RD&D spending. Two, aggregating all the different technology areas potentially hides any technology focus within states (for example, differences in solar, wind, electric vehicles, biofuels, etc.). Three, employment figures are dominated by construction and service sectors, obscuring the growth of employment from RD&D or emerging clean energy firms.

Figure ES-3: Examples of different metrics for clean energy innovation. Data sources: Multiple^{1,6-12}

EXAMPLE OF ECONOMIC DEVELOPMENT METRIC

Energy in state government RD&D spending

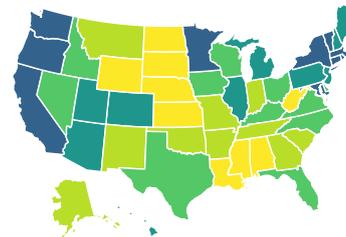


Percentage of total state RD&D spending, 2013–17



EXAMPLE OF SOCIAL AND ENVIRONMENTAL METRIC

Energy efficiency performance

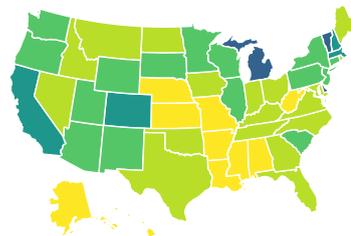


ACEEE rank, 2018



EXAMPLE OF TECHNOLOGY CAPACITY METRIC

Clean energy patents

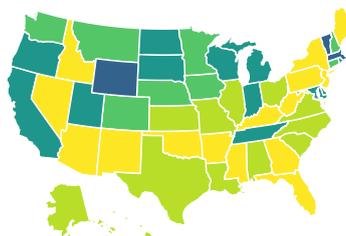


Patents per million people, 2007–2016



EXAMPLE OF OUTCOME METRIC

Clean energy employment



Employment per thousand people, 2017

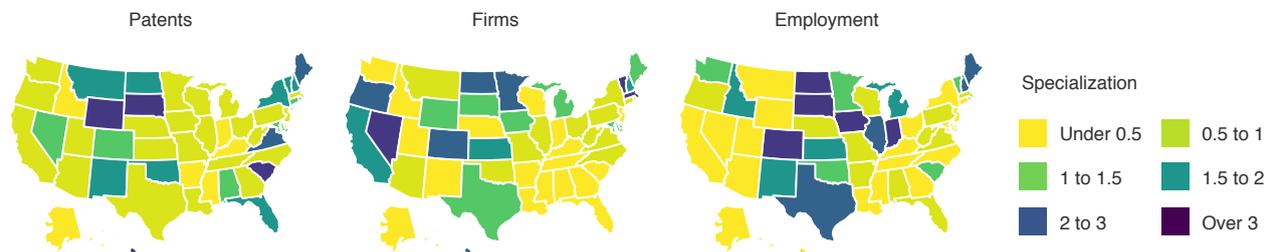


Breaking out data in terms of specific clean energy technology areas and considering state ‘specializations’^c relative to the US average can provide more clarity. Using this approach, comparative mapping (Figure ES-4) reveals that it is common for states to have strong specialization related to one of the areas of RD&D (e.g., patents), development of innovative clean energy (or ‘cleantech’) firms, or deployment (and related employment), without correlated strength in one or more of the others.

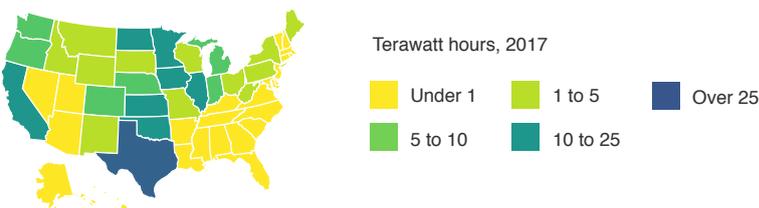
Takeaway: Relatively few states have an idealized regional clean energy innovation system with a coordinated process of research, development, demonstration, and deployment. Instead, specialization maps reveal that states’ individual choices about advancing different technology areas have often led to growth of individual stages of clean energy innovation (measured through metrics like patenting activity, cleantech firms, or deployment) with variable levels of coordination between stages.

Figure ES-4: Comparison of multiple specialization maps allows a rapid identification of correlations among patents (indicating technological and intellectual capacity), firms, and employment. For wind energy, correlations are most evident in states in the Northeast (e.g., Maine, Vermont, New Hampshire), Mountain region (e.g., Colorado), and parts of the Midwest (e.g., North Dakota and South Dakota). Correlations are less evident in states like Texas and Iowa, where strengths in wind energy employment and deployment are related to their excellent wind resource, but patenting is low, and the strength of firms is moderate.

SPECIALIZATION IN WIND ENERGY TECHNOLOGIES



ELECTRICITY GENERATION FROM WIND



^c The specialization metric (see Appendix A) compares the fraction of a state’s outcome in a certain technical area and compares that to the same ratio for the U.S. overall. A state specialization value of one indicates the state’s technology focus is the same as the average US focus, greater than one is stronger specialization, and less than one is weaker specialization.

Case Studies of Colorado and Maryland: How State Governments and other Local Stakeholders Support Regional Clean Energy Innovation

Understanding how clean energy innovation activities are organized at the state-level requires a deeper dive than the high-level explorations of the 50-state assessments. This report presents an analysis of two states, Colorado and Maryland, that have similar overall innovation capabilities (i.e., not specific to clean energy), yet have remarkably different clean energy innovation outcomes (Table ES-2). The difference in the number of cleantech firms is particularly striking as firm formation is a key stage in the commercial development of technologies.

There are a number of possible factors contributing to the differences between Colorado and Maryland: these include the states' natural resources and industrial bases, state energy policies and how they are implemented, the stakeholders involved in these processes (e.g., state agencies, universities, laboratories, private sector), and the state governments' distribution of spending or incentives across the stages of RD&D and deployment.

Table ES-2: Despite having similar histories of state-level energy policy related to clean energy, Maryland and Colorado have significantly different outcomes in areas related to in-state clean energy RD&D and deployment.

State	Overall innovation ranking (ITIF ¹³)	Number of cleantech firms (i3 ¹ and others)*	Energy efficiency ranking (ACEEE ¹⁴)	Wind and solar power generation (in state, 2018) ¹⁵	Clean energy employment (USEER ⁶)**	Energy-related per capita CO ₂ emissions reductions since 2005 ¹⁶
Colorado	Rank 7th of 50 states	513 firms in expanded dataset; 288 firms in best available industry dataset	Rank 14th of 50 states	10.8 million MWh (19.5% of total)	12 jobs per thousand people	21.7%
Maryland	Rank 6th of 50 states	189 firms in expanded dataset; 94 firms in best available industry dataset	Rank 7th of 50 states	0.97 million MWh (2.2% of total)	14 jobs per thousand people	34.9%

*Estimated using the i3 cleantech database¹ and expanded using additional datasets (clean energy patent assignees in state, cleantech firms that received SBIR funding, cleantech firms that received state grants)

**Maryland's clean energy employment is dominated by the buildings sector, while Colorado has a balanced representation across most technology areas, with greatest specializations in biofuels and wind.

The following points summarize the most notable features of clean energy innovation observed in Colorado and Maryland.

Both states have similar histories of clean energy policies. However, the two states' support for local RD&D and their outcomes in terms of local cleantech firms are very different. For example, both established renewable portfolios standards at the same time around 2004. Both have advanced energy efficiency programs⁹—although with significantly higher level of utilities' investment in Maryland.

Takeaway: Strong clean energy policies focused on energy and environmental goals such as energy efficiency and renewable portfolio standards may not be linked with strong in-state clean energy innovation outcomes such as cleantech firms, deployment, and employment in RD&D or manufacturing.

A crucial difference observed between Colorado and Maryland is in how they integrate clean energy innovation with economic development goals.

Colorado has identified clean energy innovation as an important component of its economic development priorities. The clean energy agenda was kicked off as the 'New Energy Economy' in the late 2000s and continued thereafter. The governor-led policy push initiated a coordinated engagement of multiple state agencies and other public and private stakeholders who shared similar goals for clean energy. Coordination between state agencies for energy (Colorado Energy Office) and economic development (Colorado Office for Economic Development and International Trade) helped the state attract wind manufacturing facilities and also, over time, deploy wind energy (and other forms of clean energy) to address its renewable energy standards. In addition, clean energy was designated as a target area for innovation funding in the economic development agency. Such policy signals contributed to the development of an industry association (Colorado Cleantech Industries Association) and the emergence of state-sponsored programs for coordination among RD&D stakeholders (including universities and the National Renewable Energy Laboratory) that supported innovative clean energy firms in the state.

Maryland's clean energy activities have predominantly been administered through the energy office (Maryland Energy Administration) and through substantial investment in utilities' programs encouraging energy efficiency (EmPOWER). State government incentives have focused on deployment of mature technologies rather than RD&D or deployment of early-stage clean energy technologies. The emphasis on mature energy efficiency products is a factor for Maryland's relatively strong clean energy employment in service and construction in the buildings efficiency sector and its strong energy efficiency ranking. However, Maryland has placed little emphasis on catalyzing economic development from in-state renewable power generation—it satisfies only about 25% of its renewable energy requirements from in-state generation with the rest met by imports from neighboring states¹⁷. Also, prior to the recent formation of the Maryland Energy Innovation Institute (MEI²), no program offered targeted seed funding or mentoring support for clean energy RD&D and cleantech firms, although some seed funding had been available from general innovation programs.

The differences between Colorado and Maryland can be captured in terms of state government spending on clean energy programs and how this spending is distributed across different technology stages.

For this assessment, each state government’s funding programs were categorized in terms of the stage of commercialization they support (see Figure ES-2): (1) research and development associated with companies in the proof of concept stage; (2) demonstration of technically viable product for early commercialization; (3) early deployment with companies shipping products and conducting pilots; and (4) late deployment generally related to mature companies.

The quantitative comparisons of actual state government spending on clean energy innovation show that Colorado spends significantly less than Maryland overall (Table ES-3). Colorado’s overall low spending is primarily due to lower spending on deployment and energy efficiency through utilities’ programs. However, Colorado spends about 50% more than Maryland on the early stages of research, development and technical demonstration. The absolute spending levels are modest, at approximately \$3 million/year in Colorado and approximately \$2 million/year in Maryland. The higher funding for early stage technologies in Colorado (compared to Maryland) undoubtedly influenced its striking advantage in the number of cleantech firms. Equally noteworthy were other factors that encourage innovation: such as the strategic links between clean energy and economic development, strong stakeholder coordination, and the presence of developmental support (e.g., through the industry association or through incubators).

Takeaway: To realize the economic benefits of clean energy RD&D (e.g., in-state startup firms or manufacturing), states need to distribute spending between RD&D, early deployment, and late deployment as well as offer support for developmental activities (e.g., incubators or local networks). Without such coordination, high state government spending on clean energy overall may fail to result in strengths in clean energy innovation.

Table ES-3: Comparison of spending by the state government for clean energy RD&D and deployment^d

Innovation stages	Colorado Average annual per capita (population 5.7 million)	Maryland Average annual per capita (population 6.04 million)
Late deployment, market growth, mature companies	\$12.31/year (78.2%)	\$44.90/year (90.6%)
Early deployment, companies shipping product or developing pilots	\$2.91/year (18.5%)	\$4.31/year (8.7%)
Research, development, and technical demonstration, companies developing prototype and product	\$0.52/year (3.3%)	\$0.33/year (0.7%)
Total per capita	\$15.74/year	\$49.55/year
Total dollars	\$90 million/year	\$310 million/year

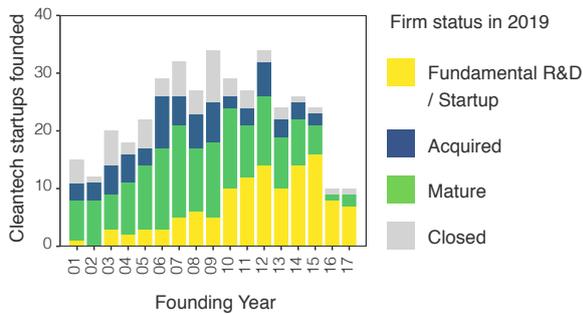
^d The numbers provided do not represent all of the states’ spending related to energy or utilities programs. The spending in each state has been evaluated to identify those programs that incentivize in-state RD&D and deployment of advanced clean energy technologies.

The impact of state commitment to early stage clean energy innovation can be measured in the health of cleantech firms. Detailed analyses of cleantech firms (Figure ES-5) conducted for the case studies show that existing estimates of cleantech firms in the best available standardized industry database (i3 cleantech)¹ are conservative—the actual number of firms is at least double the estimate. Although building such a comprehensive dataset requires considerable effort, it is valuable in capturing multiple success metrics and outcomes of regional clean energy innovation. For example, statistics on the dataset reveal that Colorado has nearly three times as many cleantech firms as Maryland. Maryland’s cleantech firms show a larger failure rate (24%) than Colorado (14%), and a smaller acquisition rate (7%) than Colorado (17%). Colorado’s cleantech startups were also more successful on a per-company basis than Maryland’s in attracting the private-sector investments needed to cross the ‘valley of death’ and growing subsequently to deliver economic benefits to the state.

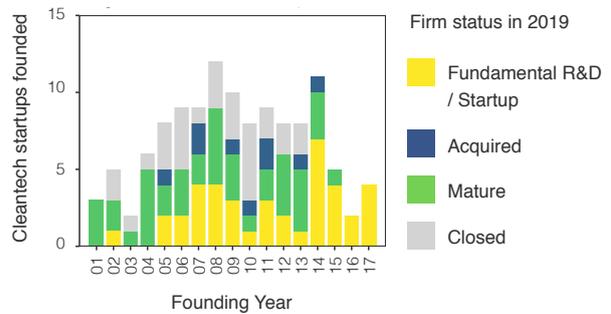
Takeaway: Cleantech firms reflect the ‘health’ of clean energy innovation in a state. However, using cleantech startups to assess progress requires substantial efforts to develop data on the number and type of cleantech firms and their performance over time.

Figure ES-5: Comparison of cleantech startups in Colorado and Maryland shows differences in ‘health’ of clean energy innovation in the two states. In the upper row, the histograms show the 2019 status of firms versus the year in which they were founded. In the lower row, the histograms show the level of investments versus the age of the companies (i.e., the years since they were founded).

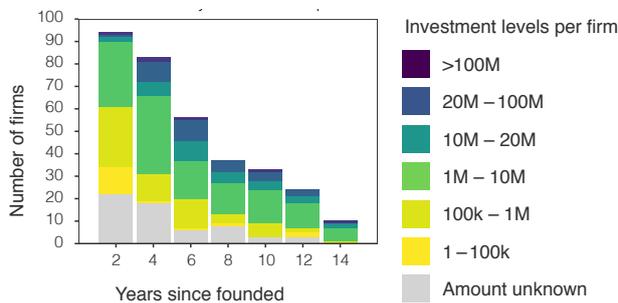
PROGRESSION OF CLEANTECH STARTUPS IN COLORADO



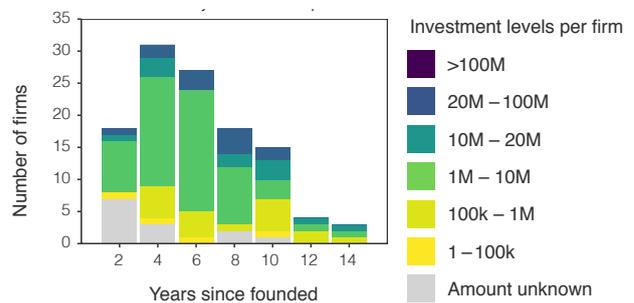
PROGRESSION OF CLEANTECH STARTUPS IN MARYLAND



INVESTMENT HISTORY OF 162 COLORADO COMPANIES



INVESTMENT HISTORY OF 62 MARYLAND COMPANIES



Conclusions

States and regions are highly diverse with different human, technical, and natural resources and are likely to take different policy approaches and prioritize different clean energy technology areas. A challenge in identifying regional strengths and opportunities is in the availability and comparability of localized data on different metrics of clean energy innovation. To address this challenge, this report develops data and analyses that capture the differences in the 50-states and allow comparisons across a variety of metrics.

The data-driven insights from this report provide a foundation of actionable information for efforts to strategically expand regional clean energy innovation. A key finding is the importance of balancing economic and environmental motivations in state support for clean energy. State governments may coordinate economic and environmental goals or may favor one over the other for different technology areas. Their choices impact the distribution of state support among the stages of commercial development, in particular clean energy RD&D versus deployment of mature technologies. The data approaches and types of analyses presented here demonstrate a process that can inform federal and state planning efforts to accelerate clean energy innovation by aligning programs with regional resources, economic development goals, and environmental priorities.

Chapter One

INTRODUCTION

This chapter presents a regional perspective on clean energy innovation in the United States. It introduces approaches to explore the motivations of regional stakeholders related to local economic development, energy and environment, and technology capacity, and their correlated outcomes such as cleantech firms, clean energy employment, and decarbonization. The approach emphasizes the innovation stages of research, development, demonstration, and deployment of clean energy technologies. The rest of the report uses detailed data and case studies to examine regional differences.

United States leadership in energy innovation has enabled a dramatic transformation of the energy system in the past decades. The engagement of multiple federal and regional stakeholders, both public and private, has propelled many technologies spanning shale oil and gas, nuclear, renewables, and energy efficient lighting from early stages of research and development, through demonstration, to the widespread deployment levels that we see today. Federal and regional stakeholders have acted on energy innovation in the past because of economic opportunities, energy security, and environmental stewardship. More recent motivations additionally include action on climate change and shifts towards cost-competitive clean energy technologies.

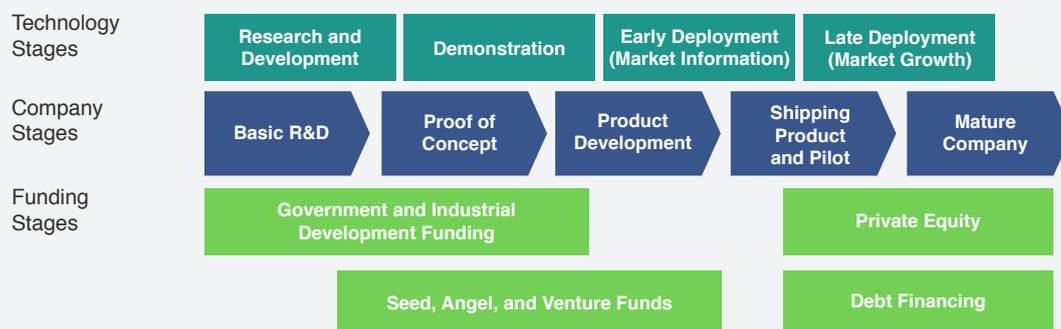
In broad strokes, clean energy innovation has principally been encouraged by pushing technology research, development, and demonstration (RD&D) through public spending and encouraging deployment through policy-induced incentives (See Box 1-1). The historic emphasis on federal action is reasonable given the magnitude of investment needed to change the energy system. For example, the U.S. Department of Energy (DOE, with its 17 national laboratories;¹⁸ 4 energy innovation hubs;¹⁹ 46 energy frontier research centers²⁰) spent on average around \$3.6 billion annually on energy RD&D between 2013-2017²¹. The DOE administers around 75% of the federal spending on energy RD&D, with the rest from agencies such as the Department of Defense (DOD), United States Department of Agriculture (USDA) and the Department of Transportation (DOT).²²

Box 1-1: The process of clean energy innovation

Experts have analyzed clean energy innovation at the national level or for specific technologies in multiple detailed studies. Some key findings from expert literature are as follows:

- The process of clean energy innovation involves multiple technology stages of research, development, demonstration (RD&D), and early to late deployment (top row in Figure 1-1). This process is rarely a linear innovation chain and is instead a complex and dynamic innovation system. It involves different stakeholders (notably universities, firms, federal and local government, and industry) that interact or coordinate with each other in a variety of planned or indirect interactions across different technology stages.^{23–26}
- RD&D stages are critical for accelerating innovation, but deployment is also critical for improving cost and performance.^{24,26} RD&D can lead to breakthrough discoveries and to new technologies that may be commercialized and deployed. The ‘learning’ experience from early deployment of these technologies (and the corresponding manufacturing expansion) can lead to continuing RD&D that targets performance improvements and cost reduction. Assessments at the national or global level have attributed clean energy technology cost reductions or performance improvements to a combination of deployment and RD&D for technologies such as solar, wind, and lithium-ion storage.^{23,27,28} However, assessments at the regional level are limited—one recent example indicates that state-level deployment may influence local RD&D depending on the type of incentive.²⁹
- Cleantech firms or innovative clean energy companies, including small businesses and startups, are key stakeholders in advancing technologies through the stages of innovation (middle row in Figure 1-1).^{30–32} These companies often interact or coordinate activities with universities, federal and local government, industry partners, companies in the supply chain, and private investors. Early-stage firms such as university spinoffs conduct basic RD&D and may develop a proof of concept that demonstrates technology feasibility. Firms that already have a proof of concept may identify suppliers to develop products and conduct initial pilots to demonstrate commercial feasibility. Mature companies will have products that are both technically and commercially feasible.
- Cleantech firms’ ability to commercialize products relies on appropriate funding availability^{33–35} (bottom row in Figure 1-1). Early-stage firms working on basic RD&D tend to benefit from financial support from federal and industrial stakeholders and from state intervention in the form of technology incubators or ‘seed funding’ awards. More mature companies are able to attract private investment. However, they may still rely on federal and state incentives or loans, or on local regulatory structures that expand the markets into which emerging technologies can grow.

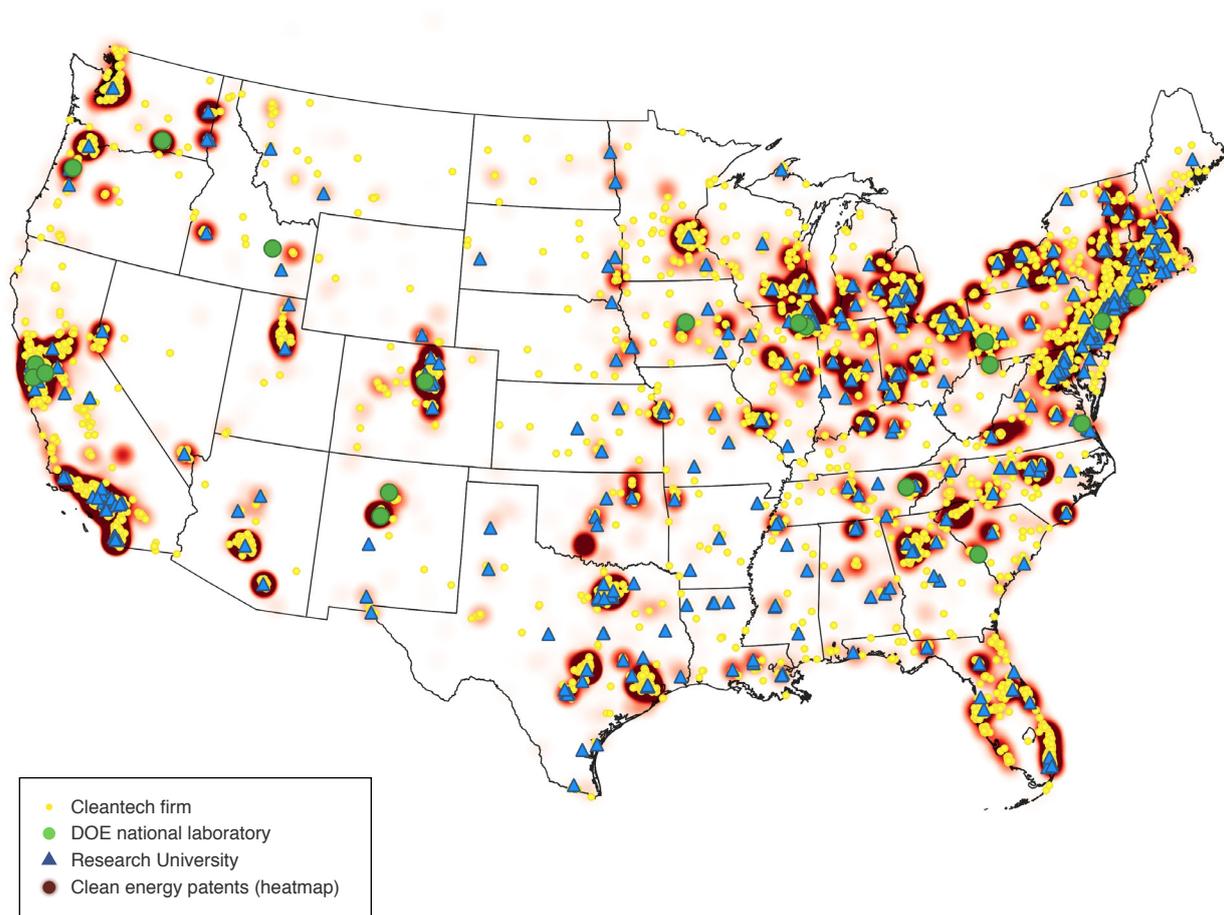
Figure 1-1: A simple representation of the process of clean energy innovation and its technology, company, and funding stages



The US innovation process also is influenced by the engagement of different regional stakeholders dispersed around the country (Figure 1-2). Many receive some form of federal support, but local priorities shape outcomes in different ways. The stakeholders involved include around 7,000 innovative clean energy or ‘cleantech’ companies¹; thousands of state and local government units²; over 400 research universities³; around 3,000 public and private electricity utilities⁴; and millions of consumers. Measures of clean energy innovation activity (clean energy patenting, cleantech firms, etc.) illustrated in Figure 1-2 highlight this geographical dispersion.

It is likely that engagement of regional players could be used more effectively to complement federal action for accelerating clean energy innovation. Research on innovation shows that, ideally, federal and regional stakeholders would coordinate activities for sharing of knowledge and resources under common policy contexts and societal goals to accelerate clean energy innovation.³⁰ However, encouraging such results requires a better understanding and acceptance of regional motivations and constraints.

Figure 1-2: Clean energy innovation activity is dispersed across the United States



Why Regions?

The motivations that drive clean energy technology innovation vary by stakeholder and by geographical location within the United States. This is partly because the costs and the benefits of changes in the energy system can affect people in different regions very differently—for example in the pressures on incumbent industries or in the opportunities to develop new industries and minimize health and environmental impacts. Accelerating the process of clean energy technology innovation and reaping its benefits compels closer attention to regions.

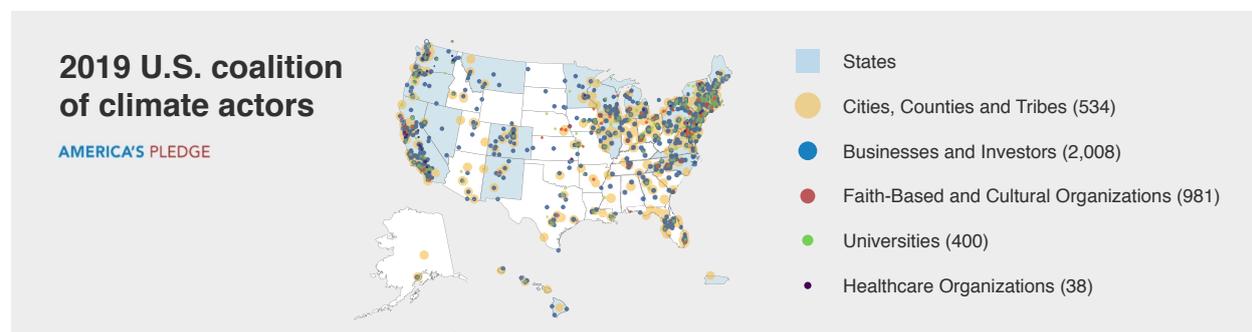
The motivations of stakeholders and their regional differences can be categorized under three broad, interrelated factors:

Economic development-related factors include entrepreneurship, employment, and revenue, and are influenced by regional resources and industrial base. Key stakeholders may include state and local economic development agencies, private sector companies, and universities or research institutes focused on technology commercialization and entrepreneurship.

Energy and environment-related factors link to societal motivations such as grid reliability, affordable electricity, pollution reduction, and action on climate change.^{36,37} Key stakeholders may include governors and mayors, private sector companies, universities, utilities, and other local organizations and community groups. A prominent example highlighting these motivations is 'Americas Pledge' that aims to meet the goals of the Paris Agreement, and involves over 3,800 non-federal entities (including 25 states) representing over \$9.4 trillion in GDP and over 158 million people (Figure 1-3).³⁸

Technology capacity-related factors associate with the technological, intellectual, and financial capacity to innovate and include the RD&D in universities, research institutes, startups, and private firms. These are influenced by the knowledge and supply chains associated with local industries and are also connected to local communities and their economic, societal, and environmental priorities.

Figure 1-3: Stakeholders across the US announced efforts to stand by the goals of the Paris Agreement and reduce greenhouse gas emissions. Figure source: America's Pledge³⁸



Each of these motivations may give rise to state policy decisions that drive areas of individual change but may not create an effective state clean energy innovation system.

One indicator for an effective clean energy innovation system is the growth of clean energy companies, or cleantech companies with new products and processes that in the future may be designed and manufactured in the state. These companies often spin out from federally supported programs at local universities or from industrial RD&D, receive state or local incentives for commercial growth, and develop technologies that can meet environmental goals.

This report defines **regional clean energy innovation** as the engagement of geographically connected regional stakeholders in the multi-stage process of innovation—including the stages of research, development, demonstration, and deployment. Factors in creating such regional engagement may include shared natural resources, shared geographical features, shared infrastructures such as power lines or transportation, similar culture and history, or metropolitan clusters. The resulting engagement can result in an effective clean energy innovation system if there is coordination of programs and distribution of resources among the different stages of innovation leading to positive outcomes in all of these stages (Figure 1-1). Selective emphasis on one stage of innovation, or one area of technology, which may be driven by regional factors, can yield very different outcomes for clean energy innovation in different regions.

Report Objective

The objective of this report is to present approaches for characterizing the variability of regional clean energy innovation activity and use these methods to assess the factors that influence clean energy innovation outcomes. The data and analysis presented provide a foundation for future efforts to strategically expand clean energy technology innovation at the regional level.

There is no silver bullet solution or one-size-fits-all approach to strengthening a regional clean energy innovation system. This report applies the existing wealth of knowledge on analyzing national or global clean energy innovation at the regional level, in two ways.^{25,39} First, this report focuses on the entire process of clean energy innovation because past experiences have highlighted the importance of distributing attention and resources across all stages and ensuring coordination rather than a focus on any one of research, development, demonstration, or deployment.²⁴ Second, this report shows correlations between clean energy innovation outcomes and stakeholder motivations rather than causal links, consistent with experts' caution against seeking causal mechanisms through mathematical models or pursuing fixed policies.^{25,39}

Regional clean energy innovation in this report is assessed at the state-level. The focus on states is because the large majority of sub-national policies on energy, budgets from federal to sub-national governments, and agencies that administer these budgets are organized at the state level. Similarly, regulation for electricity, transportation, etc. is set at the state-level. State governments also understand, and may be able to influence, different groups of regional stakeholders such as municipal governments, local industry, and regional non-profit organizations.

The innovative areas considered in this report aim to cover all clean energy technologies that play a role in climate mitigation or contribute to modernizing the energy system while ensuring reliability and affordability (Box 1-2).

Box 1-2: Defining clean energy

A broad definition of clean energy technologies is needed to capture the benefits of innovation across all sectors of the energy system. In addition to alternative (non-fossil-fuel based) fuels and power generation, and all forms of energy efficiency, the definition must also include a broad range of enabling technologies, systems integration, and carbon storage and use approaches that contribute to reducing greenhouse gas emissions.

Examples of this breadth include:

- Renewables, including solar and wind energy
- Energy storage, grid modernization and demand reduction
- Biotechnology – clean energy and clean agriculture
- Carbon dioxide removal, management and re-use
- Clean fuels and displacement of energy-intensive products
- Mobility – electric vehicles (EV), vehicle automation, transportation systems
- Integrated systems – artificial intelligence (AI) and ‘internet of things’
- New concepts in nuclear power to improve safety and lower costs

The technologies included in this report were dependent on the availability of data and the classifications across different metrics in the different data sources (see Appendix A).

The remainder of this report describes the variability in regional clean energy innovation through a broad assessment of activities for all 50 states (Chapter 2); provides a bottom-up case study characterization of clean energy innovation in two states, Colorado and Maryland, with different innovation outcomes (Chapters 3 to 6); and articulates key lessons that may be used to strengthen innovation in other regions of the country (Chapter 7).

Chapter Two

AN OVERVIEW OF REGIONAL CLEAN ENERGY INNOVATION

This chapter highlights the motivations that drive stakeholder engagement in regional clean energy innovation activity in the 50 states. Metrics to assess these motivations can reveal regional priorities and the reasons behind correlated regional outcomes such as cleantech firms and employment. In a given state, the clean energy innovation activity may differ between individual technologies with different distribution of resources at the stages of research, development, demonstration, and deployment.

As outlined in Chapter 1, motivations for stakeholder engagement in a regional clean energy innovation system can be linked to three broad and interrelated drivers: economic development, energy and environment, and technology capacity. The rest of this chapter characterizes the regional variations among metrics related to some of these drivers and their correlated outcomes in greater detail.

Motivations for Regional Clean Energy Innovation

Economic Development

State government policymakers generally value the prospects of green jobs and local economic growth from rapidly expanding clean energy industries.^{36,37} The benefits have been increasingly evident for technologies such as wind and solar that are now at the late deployment stages of the energy innovation process. New US investments in clean energy, with over a third in wind and solar, have exceeded \$50 billion annually since 2014.⁴⁰ In 2018, the US solar industry employed over 242,000 workers and the wind industry employed over 111,000 workers.⁶ Solar photovoltaic installers and wind turbine service technicians are expected to be the two fastest growing occupations economy-wide in the coming decade.^{41,42} Clean energy also offers some opportunities for domestic manufacturing. Although domestic solar manufacturing faces pressures from international markets, there are over 500 wind supply chain manufacturing facilities across the US and exports have grown from \$16 million in 2007 to over \$100 million annually today.⁴³

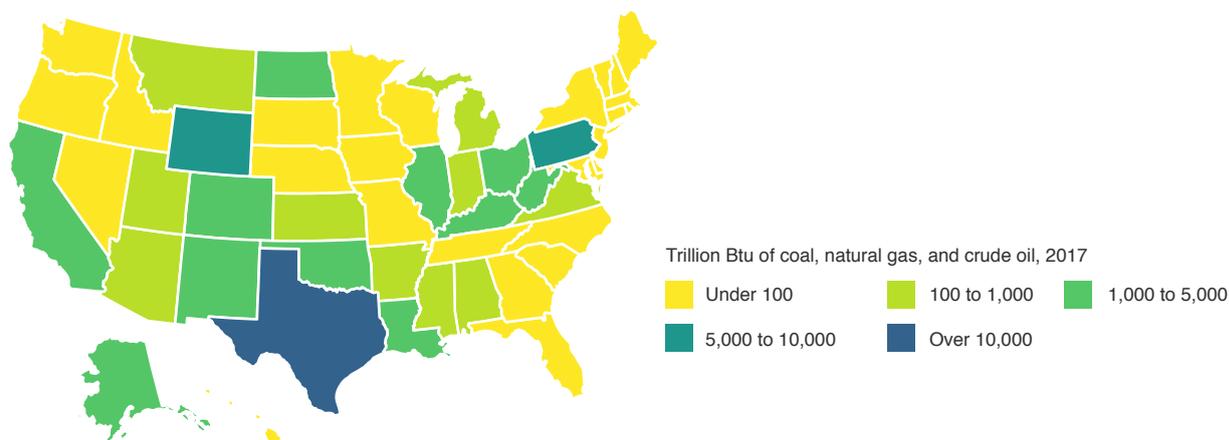
The anticipation of job creation and economic impact can increase local public support for state clean energy policy.⁴⁴ Governors, legislators, and state agencies consequently may provide policy support and funding for development of clean energy-based private industries.

As clean energy technologies became more cost-effective, the following three examples highlight how profit-driven opportunities from new clean energy related industries or transitions in existing industries may motivate clean energy innovation activity in different stages of the innovation process.

First, historic boom-and-bust cycles associated with extractive energy industries have motivated some state-level stakeholders to consider long-term diversification of their energy-reliant economies.⁹ For example, Colorado targeted diversifying its energy economy in the past decade.⁴⁶ More recently, stakeholders in states like New Mexico⁴⁷ and Wyoming⁴⁸ have discussed minimizing the impact of fossil fuel volatility on communities by including clean energy innovation in their economic development options. In making such choices, states must also consider how lower costs and growing demand for clean energy could threaten local communities that have so far been reliant on fossil fuel industries (Figure 2-1).

Figure 2-1: Primary energy production from coal, natural gas, and crude oil in 2017. Data source: EIA⁹

PRIMARY ENERGY PRODUCTION FROM FOSSIL FUELS

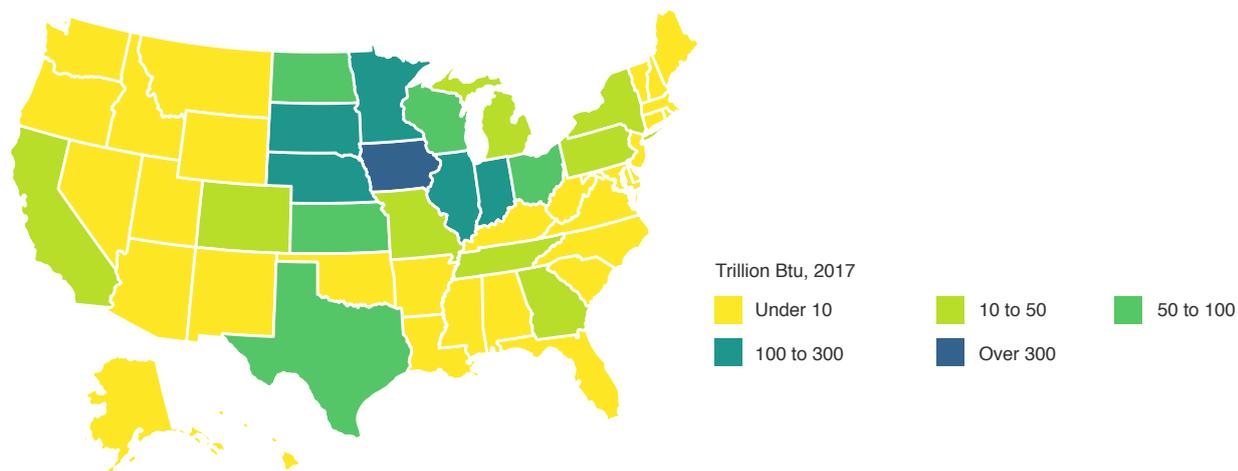


⁹ The recent 'bust' in coal energy that has negatively impacted local economies and the ongoing 'boom' in natural gas that has generated new wealth have mirrored past experiences with 'boom-bust' cycles of fossil fuels that arise because of exposure to external market forces⁴⁵

Second, indigenous industries offer motivations in some regions to seek new, profitable opportunities in clean energy and to maintain competitiveness in national and global markets. One example is agriculture, traditionally linked to clean energy innovation through biofuels and increasingly through approaches such as reduction in fertilizer use or increase in carbon storage in soil.^f For example, Iowa has capitalized on its existing agriculture industry which, in addition to growing food, is now growing fuel in the form of biofuels; this is supported by a federal mandate and by several dedicated research centers focused on RD&D in biofuels⁵⁰ (Figure 2-2).

Figure 2-2: Primary energy production from biofuels in 2017. Data source: EIA⁸

PRIMARY ENERGY PRODUCTION FROM BIOFUELS



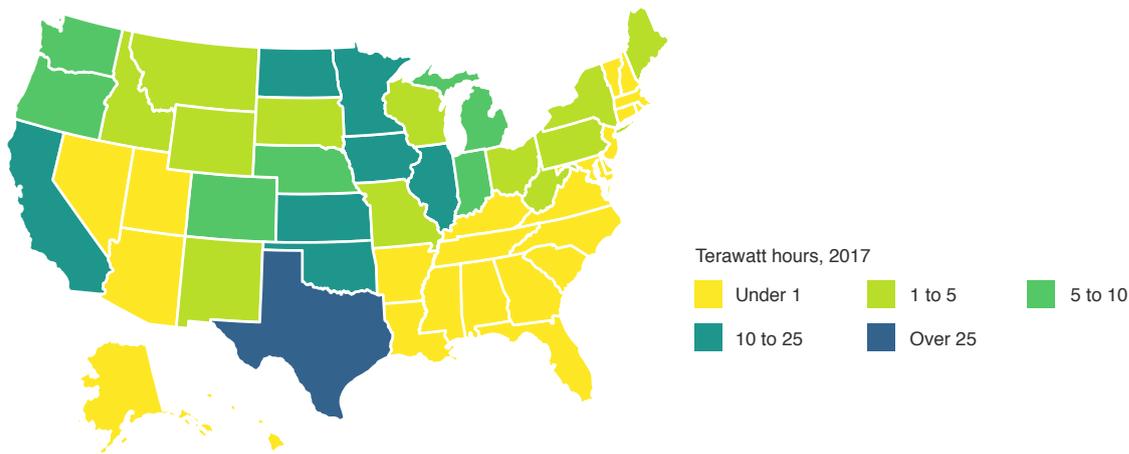
Third, regions rich in clean energy resources have benefited from the profitable deployment of mature clean energy technologies. Federal and state incentives, growing demand, policy targets, and plummeting costs (over 88 percent decline in costs of solar and 69 percent decline in cost of wind from 2009 to 2018⁵¹) have increasingly made clean energy technologies attractive to private sector investors and project developers. New investments have led to greater deployment of wind in the west and midwestern states and solar in the southwest (Figure 2-3). Hawaii has set aggressive clean energy deployment targets with parallel support for RD&D, expecting that expensive oil imports could be offset with improved energy security from local, clean energy generation.^{52,53}

^f Agriculture is a major economic driver in rural communities that cover 72% of the US land area.⁴⁹ The industry is a major contributor to emissions and simultaneously vulnerable to water availability and temperature changes. Agriculture is also a promising sector to lower or sequester carbon emissions. Emissions can be lowered traditionally through biofuels production or through increasing innovative approaches such as fertilizer reduction that can reduce nitrous oxide emissions, which is another greenhouse gas more potent than carbon dioxide. Emissions can be sequestered through increased retention of carbon in soils.

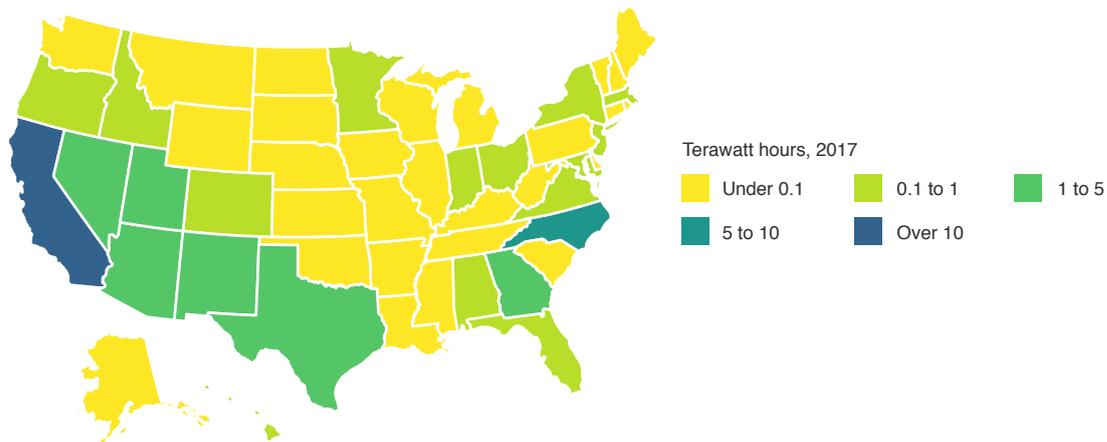
For the reasons outlined above, state policymakers may support clean-energy technology as an economic development strategy.⁵⁴ Some economic benefits may be developed quickly by deploying mature technologies produced out of state. But other longer-term benefits may be realized by expansion or relocation of established manufacturing firms in-state or by the commercial development of local technical innovations. Some of the many ways in which the public and private sector coordinate to promote in-state innovation include supporting commercialization of local RD&D, incentivizing local manufacturing, and supporting innovative startups and export-oriented small businesses through access to local and federal resources. State economic development agencies are often key stakeholders as they support early innovation stages of RD&D through grants or seed funds and through incubators.

Figure 2-3: Electricity generated in 2017 from wind energy and solar energy. Data source: EIA¹²

ELECTRICITY GENERATION FROM WIND



ELECTRICITY GENERATION FROM SOLAR

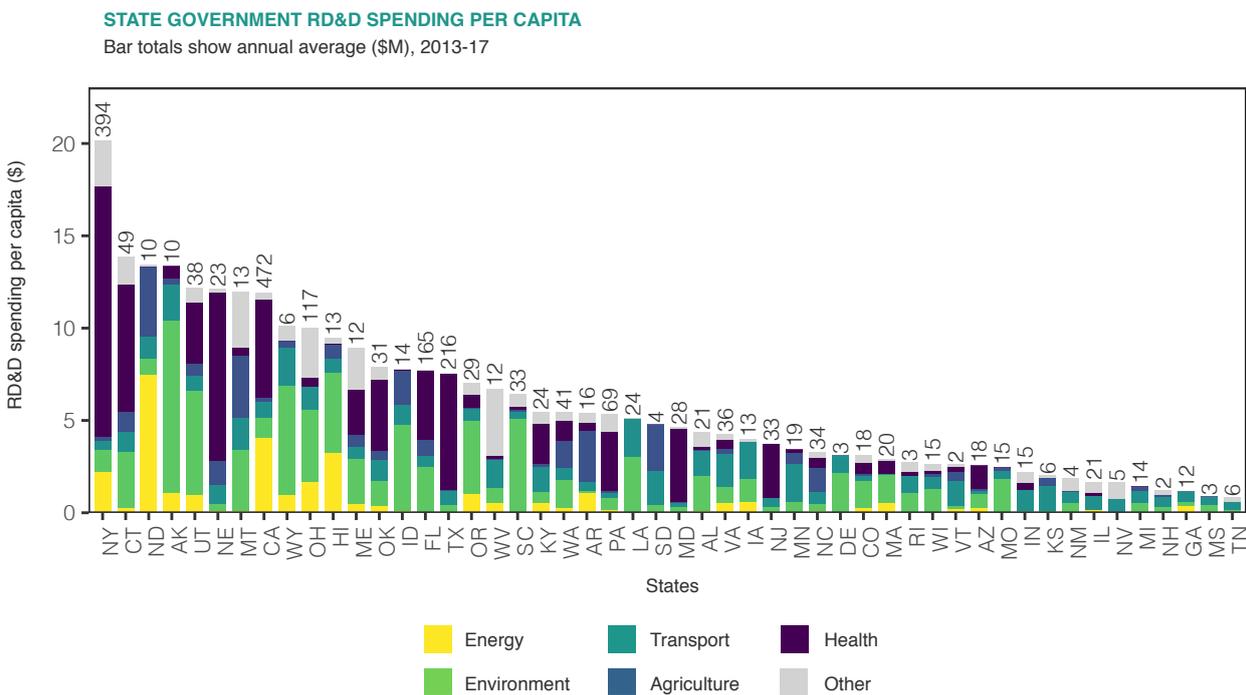


State economic development agencies may not have a specific focus on clean energy, however, and may not coordinate activities with state energy offices. Because clean energy is not well-suited to the historical venture capital model,³³ some state innovation agencies have been hesitant to embrace its opportunities (see Appendix B on which state agencies spend on energy RD&D). However, new investment practices tailored to cleantech firms have been demonstrated through public and private funding models such as DOE’s Advanced Research Projects Agency – Energy (ARPA-E), Sustainable Development Technology Canada (SDTC),⁵⁵ Prime Coalition, and Breakthrough Energy Ventures.³⁴ These investment practices are reviewed in Chapter 3, and the case studies of Chapters 4 and 5 illustrate their importance in the success of state clean energy innovation activities.

The allocation of state governments’ RD&D spending towards different sectors provides a clear indication of regional differences in economic development priorities:

First, technology push in broader energy RD&D is evident (yellow bars in Figure 2-4) in California, Hawaii, North Dakota, and New York even when accounting for their different populations. However, data on whether and how broader energy funds are allocated to clean technologies is not available in the survey by the National Science Foundation (NSF) used for this tabulation.

Figure 2-4: State government spending on RD&D in different sectors. Data source: NSF⁷



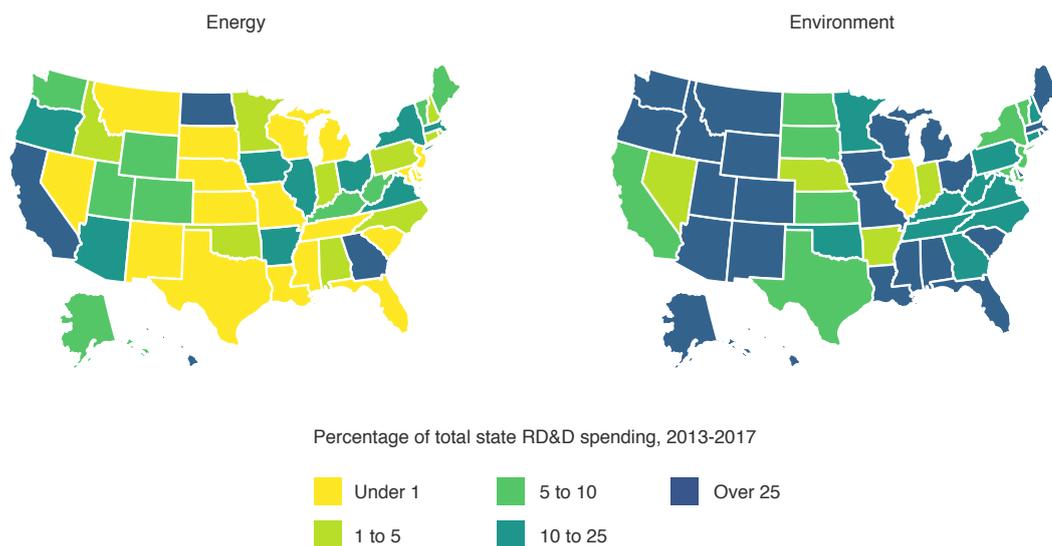
Second, the states’ spending patterns are useful for highlighting the relative importance of energy in the state government RD&D, and thus whether clean energy may be a strategic focus of the state’s economic development planning.

Third, the near absence of energy RD&D in states like Texas, Nebraska, Maryland, and New Jersey is striking when compared with high RD&D spending in health. Two possible explanations are as follows. States like Texas, with the country’s largest energy production, have a large energy industry⁵⁶ that may already conduct RD&D and state governments may choose to divert their RD&D resources elsewhere; states like Maryland, with a small fossil energy industry but a large life sciences cluster,⁵⁷ may strategically choose to bolster existing innovation activity outside clean energy rather than support a new sector.

Fourth, the state agencies that spend on energy RD&D include commerce and economic development agencies along with energy, transportation, tourism, agriculture, and others depending on the state (see Appendix B).⁷ Given the multitude of technologies involved in the energy system, it is likely that sectors like environment & natural resources (where percentage of state spending is much higher than in energy, as shown in Figure 2-5) also may include a component of clean energy RD&D that is not directly visible in the data shown. Other relevant sectors include transportation and agriculture, but details on the breakdown of spending in any of these sectors are not available in NSF’s tabulation.⁷

Figure 2-5: State government spending on RD&D in energy and environment (environment includes natural resources). Data source: NSF⁷

STATE GOVERNMENT RD&D SPENDING



Energy and Environment

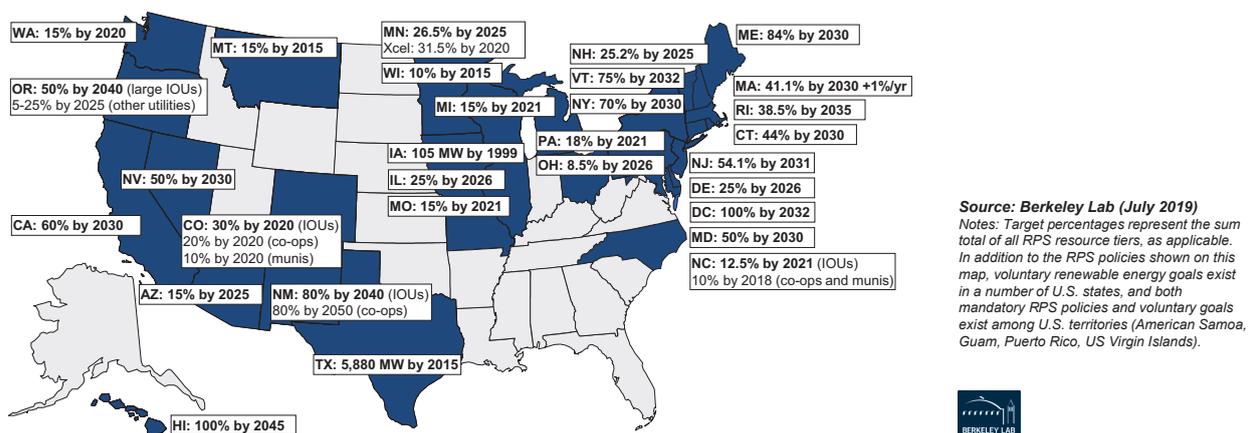
Energy and environment priorities may incentivize leadership from state and local government stakeholders to design and implement policies that contribute to clean energy innovation activity. Energy related priorities—including improving energy services, ensuring affordability, and increasing energy system reliability—are generally the responsibility of state energy offices and involve grid operators, public utilities, regulators, etc.⁵⁸ State energy offices engage in energy planning, provide incentives for energy efficiency and conservation, and in some cases promote the deployment of clean energy. These efforts are not necessarily linked to economic development goals.

Two stable sources of funding for state energy offices are the DOE’s State Energy Program, primarily linked to advancing energy efficiency and clean energy policy, and the DOE’s Weatherization Assistance Program for reducing energy costs of low-income households. Environmental priorities—including protecting environmental resources, reducing air pollution, and reducing negative industrial impacts may be managed through state environment agencies.⁵⁹

State environmental and energy programs tend to focus on deployment (including both early and late deployment, see Chapter 1). These deployment policies create demand for clean energy technologies which may generate local technical expertise around the new technologies as well as rapid growth in construction and service jobs. Three examples of such energy- or environment-oriented policies highlight the support primarily for deployment stages of the innovation process.

First, the Renewable Portfolio Standard⁹ (RPS) enacted in 37 states (including 8 with voluntary goals) has driven utilities to deploy clean energy technologies (Figure 2-6). Eleven states have a target of at least 50% renewables. RPS policies in the Northeast, Mid-Atlantic, and the West have been substantial drivers of deployment of clean energy with capacity installations to meet demand.⁶⁰ Although RPS policies can generate local demand and may spur related RD&D, there is evidence that policies like tax incentives that are state location-specific, are more likely to induce local RD&D.²⁹

Figure 2-6: Mandatory RPS policy by state. Figure source: Lawrence Berkeley National Laboratory²⁹



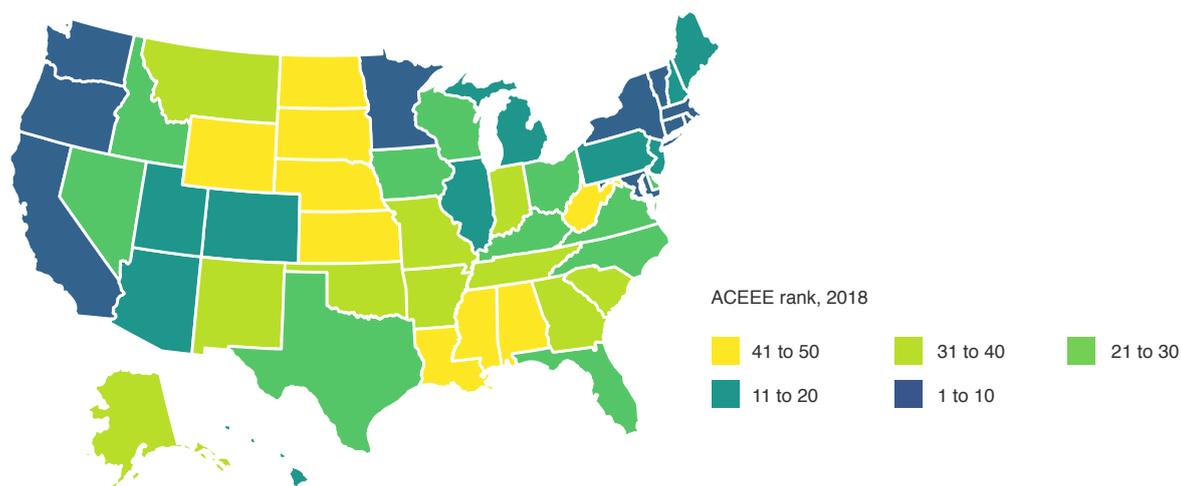
⁹ The RPS requires a specified percentage of the electricity sold by retail electric suppliers to come from eligible renewable resources. Failure to comply results in penalties for suppliers and compliance is often facilitated through tradeable renewable energy certificates.

Second, participation in the Regional Greenhouse Gas Initiative (RGGI) by 10 northeastern states has created financial incentives to lower greenhouse gas emissions and has generated revenues to support clean energy technologies. RGGI members set a cap of CO₂ emissions in the participating region that can be met through tradeable allowance auctions^h. Proceeds from emission allowances are spent on consumer benefits for end-use energy efficiency (58% of cumulative investments by 2016), renewable energy (14% of cumulative investments), and greenhouse gas abatement (8% of cumulative investments).⁶¹ While much of the focus has been on the late deployment (or market growth stage), states like New York have spent part of the auction proceeds to support cleantech companies, technology commercialization, and early deployment projects.^{62,63}

Third, loans and grant programs supporting energy efficiency have boosted deployment of energy efficient technologies for homeowners, businesses, and utilities (see Figure 2-7 on rankings of states based on policy and program efforts, performance and best practices, developed by the American Council for an Energy-Efficient Economy, or ACEEE¹⁴). The ACEEE score includes, for example, Property Assessed Clean Energy (PACE) programs active in 36 states that are designed to incentivize and facilitate energy efficiency and renewable energy upgrades to homes and businesses.ⁱ PACE offers long-term private financing for making these upgrades. In parallel, 40 state governments support some form of energy efficiency RD&D with notable programs in Colorado, Delaware, Florida, and New York.¹⁴

Figure 2-7: American Council for an Energy-Efficient Economy (ACEEE) energy efficiency scorecard. Data source: ACEEE¹⁴

ENERGY EFFICIENCY PERFORMANCE



^h RGGI was introduced in 2005. The ten participating states are Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont. Each participating state sets its CO₂ Budget Trading Program that limits emissions of CO₂ from electric power plants, issues CO₂ allowances and establishes participation in regional CO₂ allowance auctions.

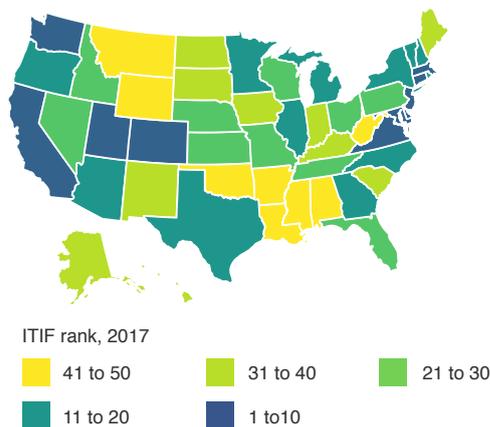
ⁱ Property Assessed Clean Energy (PACE) programs and utilities-based efficiency programs target energy savings through state-enabled financing. Most investments go to well-established and widely known technologies and solutions available on the market. Hence, the programs primarily create a bigger market demand for existing technologies rather than directly stimulating RD&D.

Technology Capacity

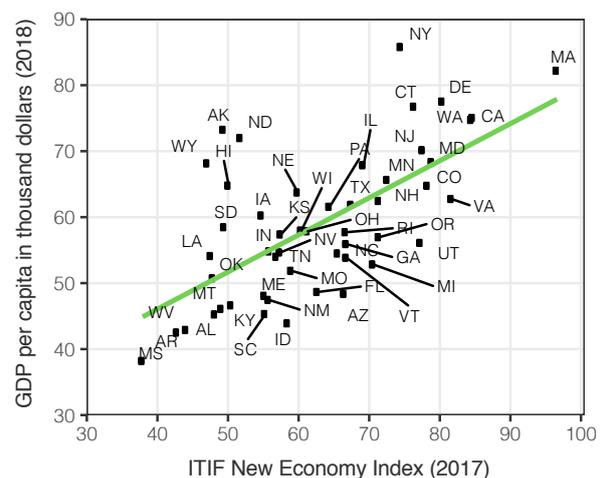
Technology capacity in this analysis refers to the technological, intellectual, and financial capacity to develop and take technologies through the different stages of innovation. A state's capacity and capability for broad-based innovation can set the basis for the state's ability to innovate in clean energy. States and regions with a broad innovation economy, such as California with Silicon Valley or Massachusetts with the Boston area, also have higher GDPs because of the mutually reinforcing effects of higher productivity, a skilled workforce, etc. Metrics of broad-based state innovation economies include a combination of related factors—for example, the ITIF New Economy Index measures how well the structure of the 50 state economies matches the ideal structure of a 'New Economy' that is knowledge-based, globalized, entrepreneurial, information technology-driven, and thus innovation-based (Figure 2-8 shows a strong, linear correlation, with $R^2 = 0.42$, between overall innovation and GDP).¹³

Figure 2-8: The innovation economy estimated with the State New Economy Index has a strong, linear, and positive correlation with the states' GDP ($y=0.56x+23.59$; $R^2 = 0.42$). Data source: ITIF¹³

STATE NEW ECONOMY INDEX



GDP PER CAPITA VS ITIF NEW ECONOMY INDEX

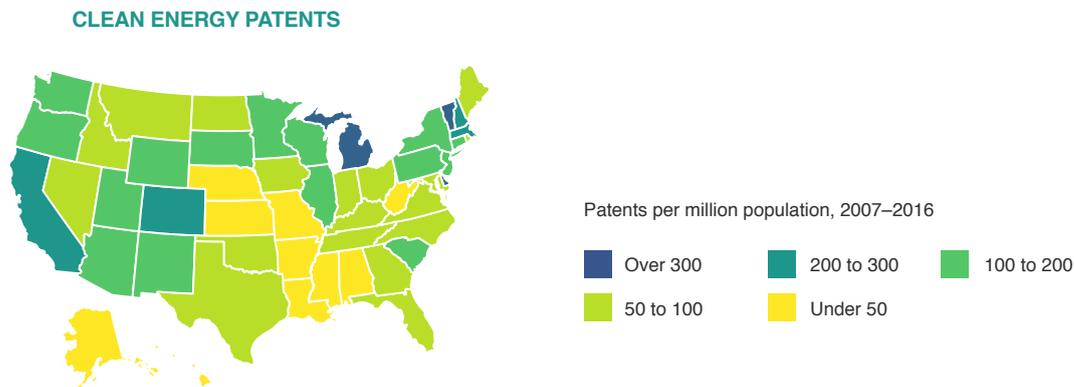
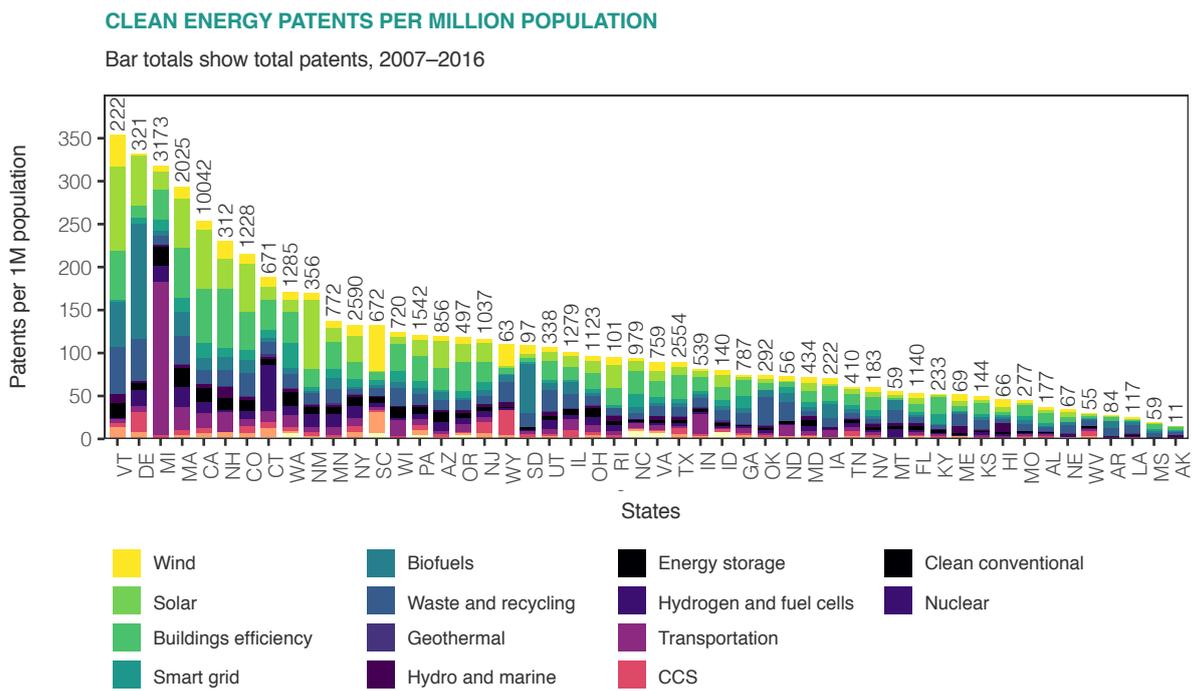


The technological and intellectual capacity to innovate in clean energy typically involves many stakeholders (see Chapter 1). While universities generally have diverse research programs, federal and private research facilities may be more specialized. For example, DOE's National Energy Technology Laboratory (NETL) in West Virginia focuses on fossil energy and the National Renewable Energy Laboratory (NREL) in Colorado focuses on renewables and energy efficiency. Industrial RD&D centers primarily focus on the technologies relevant to the business lines of their parent companies.

Patents are one indicator of the capacity to innovate in specific clean energy technologies as they measure RD&D activity that is specifically focused on commercialization. However, patents are a lagging indicator because of their reliance on historical RD&D patterns and the long timescale for award of patents. Although not all patents are innovative and not all innovation is patented, patents still matter because they indicate to potential investors an intention to commercialize. The technology transfer and commercialization offices in universities recommend patenting as a means of protecting innovation and attracting commercial interest in new technologies. The United States Patent and Trademark Office maintains a classification of patents for climate mitigating technologies¹¹ (see Appendix A).

The distribution of climate mitigating patenting activity in states, based on location of inventors rather than location of business headquarters, points to localized technology advantages (Figure 2-9). In other words, each state is unique in its technology strengths. These strengths may be linked to existing innovation in specific technologies in the state (for example, Michigan’s uniquely high patenting activity in clean transportation builds on its strong automobile industry) or on general RD&D strengths (for example, in California and Massachusetts). In per capita terms, Delaware, Vermont, Michigan, Massachusetts, California, New Hampshire, and Colorado have the strongest clean energy technology patenting.

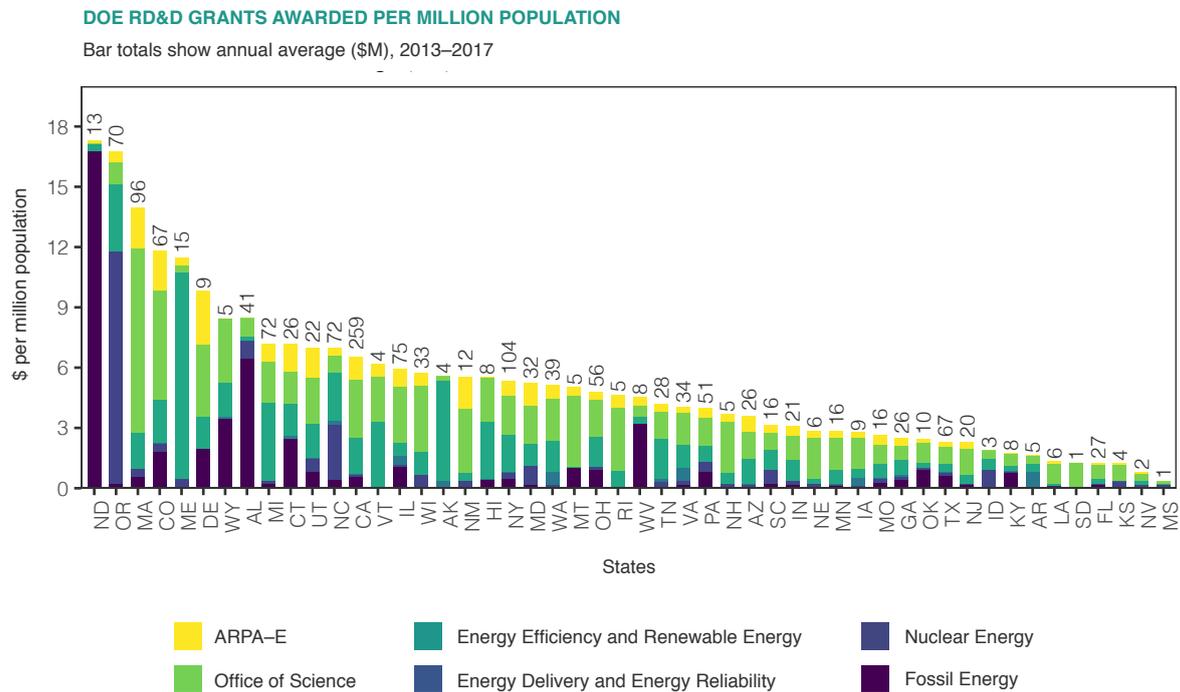
Figure 2-9: Clean energy patents per million population. Source: Authors’ analysis from USPTO data¹¹



As noted in Chapter 1, the availability of appropriate financial support can be instrumental for advancing technology innovation. DOE’s grant awards support development of innovative ideas or enable proof of concept and early commercialization steps (Figure 2-10). Competitive federal grants such as those offered by the Small Business Innovation Research (SBIR) program through DOE or those from DOE’s ARPA-E are specifically designed to reduce the risks faced by small businesses and early stage companies. Such grants can help cleantech companies in their efforts to commercialize technologies.

State programs can provide small seed funds and developmental support to help young companies compete for federal grants or enhance their ability to attract private investments. Public and quasi-public agencies and programs like the New York State Energy Research and Development Authority, California Energy Commission, Massachusetts Clean Energy Center, Connecticut Innovations, and Michigan Pre-seed Capital Fund provide such support to cleantech companies.^{1,7} Incubators that receive some form of local government support include the Rocky Mountain Innosphere that supports Colorado’s energy and other advanced industries, Greentown Labs in Massachusetts, and VertueLab (formerly Oregon BEST) working on environmental challenges.

Figure 2-10: DOE RD&D grants awarded in each state. Data source: USASpending⁶⁴



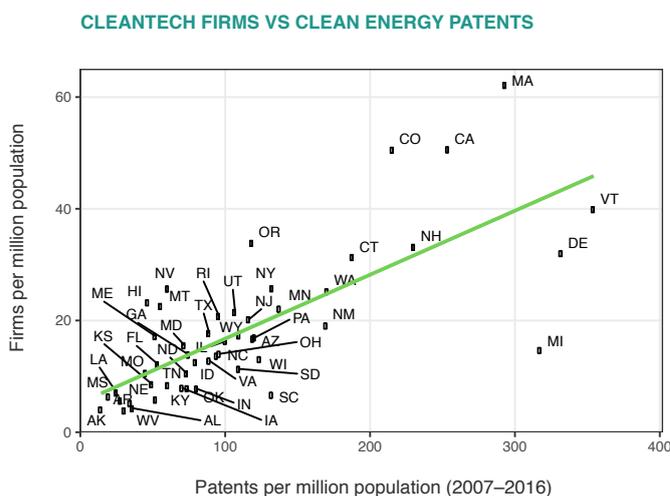
Outcome Metrics of Regional Clean Energy Innovation

There is no single outcome that defines ‘successful’ regional energy innovation. Nonetheless, progress towards economic development goals can be monitored through metrics such as cleantech firms or employment. Progress in energy-environment goals can be measured through metrics related to the deployment of clean energy technologies and decarbonization, or the reduction in greenhouse gas emissions.

A mapping of such different metrics can draw attention to how states and state-focused stakeholders have been able to achieve their goals. Outcomes may be correlated with driving factors such as GDP and industrial base and do not necessarily imply causality. As discussed in Chapter 1 and in the following discussion of firms, positive outcomes may feed back into the clean energy innovation process reinforcing many of the factors that initially led to strong performance.

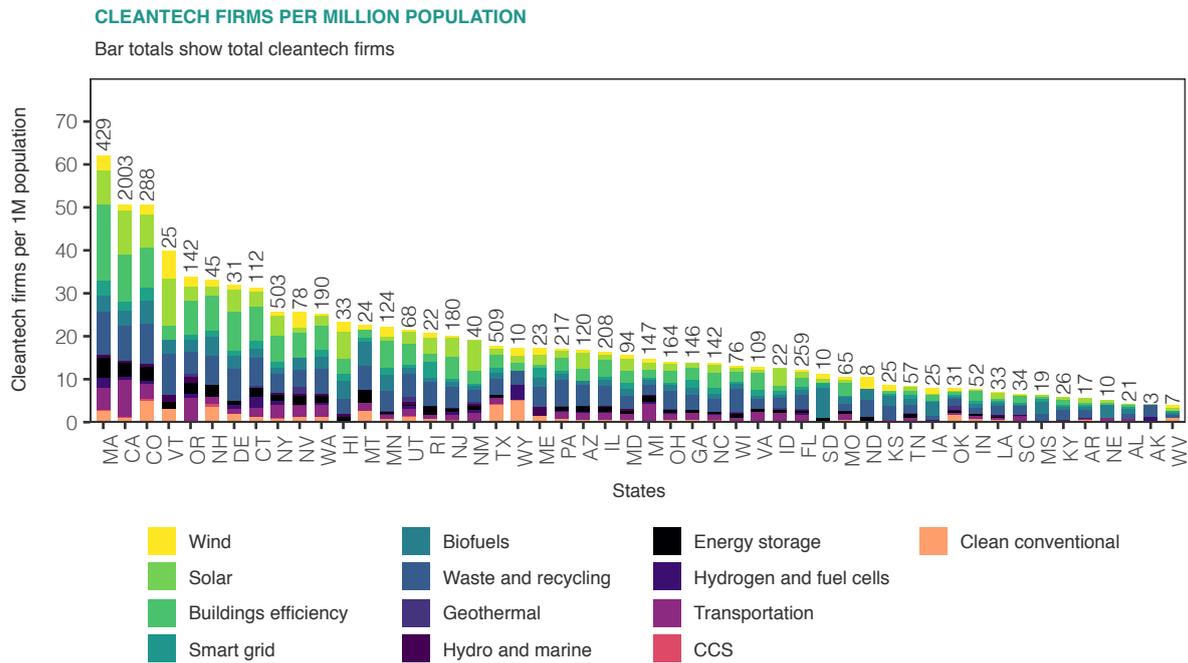
A key outcome that captures a combination of the three motivations (i.e., economic development, environment, and technology capacity) is the number and health of innovative clean energy companies (or cleantech companies). Cleantech firms are vital elements of robust, long-term, clean energy based economic development. Such firms are valuable because they can create long-term export generating assets from the technology strengths of a state’s RD&D and create long-term employment opportunities through the development of new, competitive industries.⁵ Their health and rate of growth reflects an alignment of the underlying motivators that create suitable local conditions for new clean energy companies to develop and thrive. These cleantech firms are both the product and source of innovation (Figure 2-11 shows the strong, linear correlation, with $R^2=0.55$, between cleantech firms and patents). They may be spinoffs from university research or may conduct their own research that is then commercialized leading to new technology strengths, indicating a multitude of collaborations with universities, investors, government, and industry that continue to strengthen regional innovation.

Figure 2-11: Cleantech firms have a strong, positive correlation with clean energy patents ($y = 0.12x + 5.29$; $R^2 = 0.55$). Sources: i3 and USPTO^{1,11}

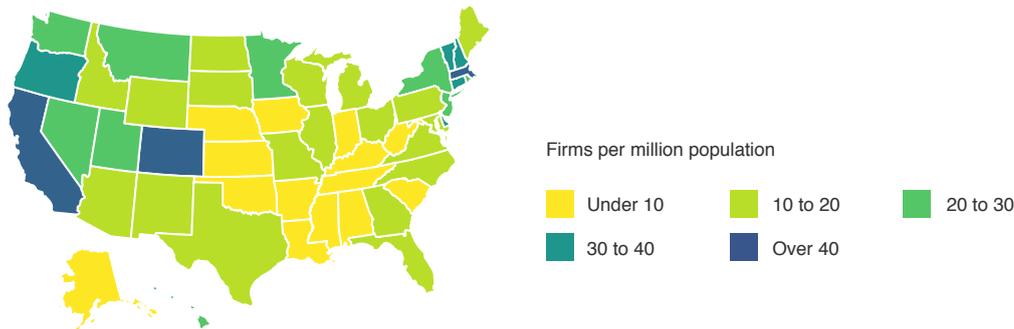


California, with 2003 cleantech firms, and Massachusetts with 423, lead in the number of cleantech firms even when accounting for their populations (Figure 2-12). Small states like Vermont (25 firms) and New Hampshire (45 firms) rank high even with a relatively small number of firms because of their lower populations. Note that there is no centralized database for all cleantech companies, this report uses the i3 cleantech database which captures information on many (but not all) cleantech companies (Appendix A).

Figure 2-12: Ranking of states in distribution of cleantech firms, adjusted for population. Source: Authors' analysis of i3 data¹



CLEANTECH FIRMS



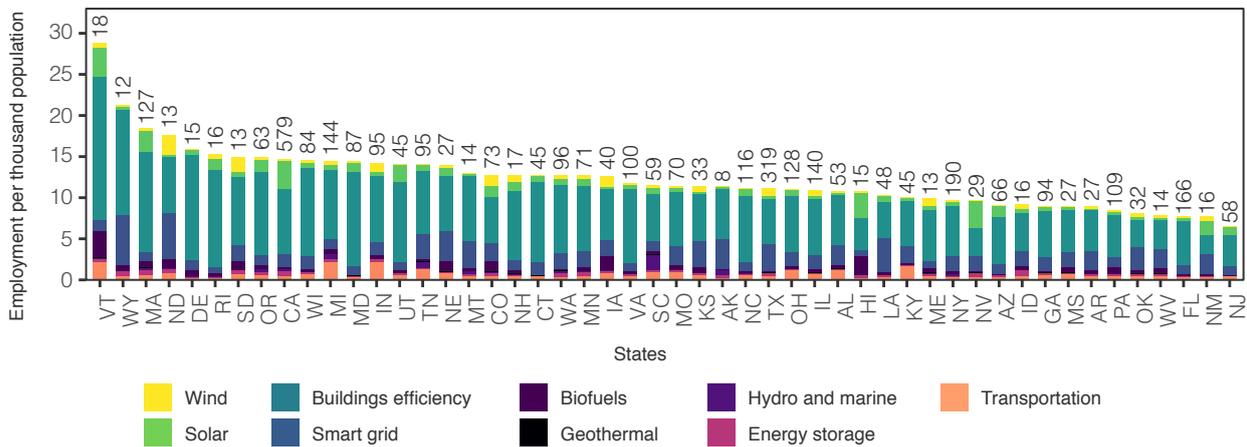
The presence of cleantech firms also brings in green jobs. However, the employment trends in clean energy sectors largely represent employment in services and construction, rather than in manufacturing or other technology-based activities.¹ States with higher employment in clean energy have often benefited from incentives for deployment (including out-of-state incentives).

The largest number of employees work in construction or professional and business services—for example, only 14 percent of employees in solar energy and 24 percent of employees in wind energy work in manufacturing compared to 53 percent in solar construction and 33 percent in wind construction.⁶ This indicates that a large fraction of clean energy employment is associated with deployment of mature technologies, rather than with clean energy RD&D or cleantech firms (corroborated by the moderate correlation, with $R^2 = 0.17$, between employment and cleantech firms in Figure 2-13). The difference in the types of jobs is important from the perspective of states' economic development as the employment that results from the growth of innovative firms will likely have a larger component of research and manufacturing positions. Ultimately, longer-term growth in manufacturing jobs from innovative cleantech firms will provide future benefits to the state.

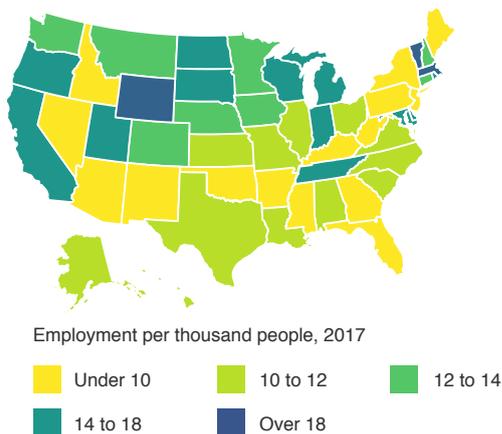
Figure 2-13: Clean energy employment includes a large number of construction and service jobs as well as the smaller numbers of research and manufacturing jobs more likely to be related to innovative clean energy firms ($y=0.13x+9.99$; $R^2 = 0.17$). Data source: USEER and i3 cleantech^{1,6}

CLEANTECH ENERGY EMPLOYMENT PER THOUSAND POPULATION

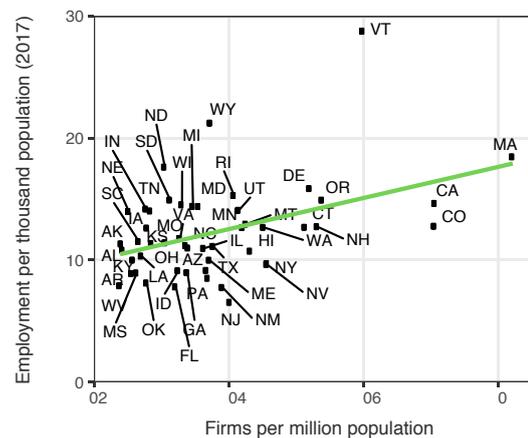
Bar totals show total employment in thousands, 2017



CLEAN ENERGY EMPLOYMENT



CLEAN ENERGY EMPLOYMENT VS CLEANTECH FIRMS



¹ Overall energy jobs are spread around 7 industries: Mining and Extraction; Utilities; Construction; Manufacturing; Wholesale Trade; Professional and Business Services; and Repair and Maintenance.⁶

A More In-Depth Look at Regional Clean Energy Innovation Activity for Specific Technologies

The clean energy innovation activity in different states will vary by the type of technology as well as by the stage of the innovation process. This variation exists because different clean energy technologies have diverse scientific and technical basis, scales of investment needs, timelines towards commercialization, and needs for natural resources or infrastructures—and the support for each of these may vary by state and its stakeholders. For example, energy storage RD&D builds on materials science expertise, while geothermal RD&D builds on mechanical engineering and its application requires the presence of specific natural resources. Overall, this means that it is normal that the motivation and participation of states in clean energy innovation activity vary by technology.

States' performance in clean energy innovation measured through patents, cleantech firms, or employment represents cumulative innovation activity over time but does not capture relative competitiveness that can help build economic advantage. A valuable metric for measuring competitiveness is the states' specialization⁶⁵ (See Appendix A for methodology). Specialization helps compare the technology distribution of clean energy innovation activity in a state to the distribution of clean energy activity in the reference area, i.e., the US. Specialization is therefore a measure of the competitiveness of a state for a particular technology relative to the US. Values above the US average of 1 indicate specialization (a stronger focus in the state relative to the average of all states) in a given technology.

Technologies such as wind, solar, and those related to energy efficiency have advanced to substantial levels of deployment, and therefore have had time to develop strong indicators of where states have competitive advantage. The presence or absence of observable correlations among specializations in patents, firms, and employment, along with the level of deployment, provides insight on the balance of clean energy RD&D with deployment of mature technologies.

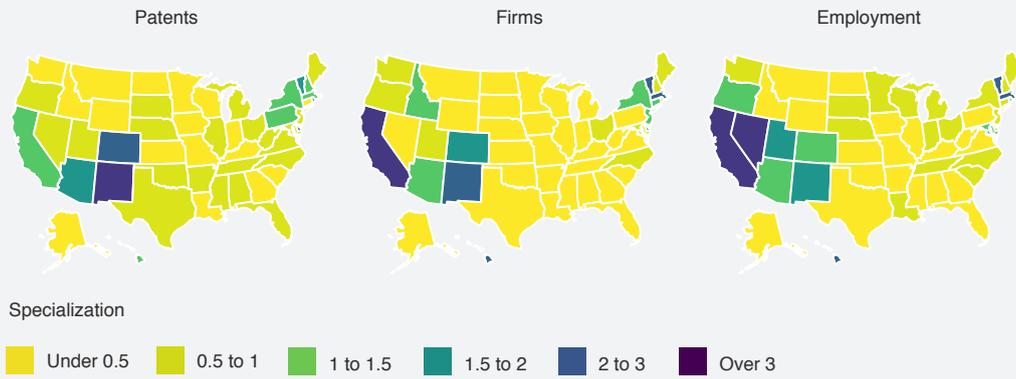
As is always the case, correlations should not be assumed to indicate causality. The correlations between patents and firms highlight the states' experiences in taking innovative technologies from RD&D to cleantech firms. However, correlations between deployment and cleantech firms may highlight knowledge and supply chain opportunities that incentivize firm formation. The comparisons shown in Box 2-1, Box 2-2, and Box 2-3 reveal rather different correlation patterns for solar, wind, and building efficiency technologies.

Box 2-1: Regional innovation patterns in solar energy

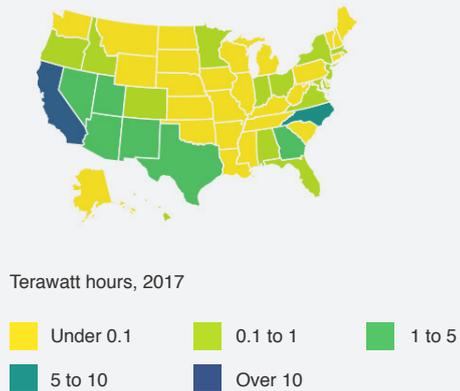
Regional innovation for solar energy is most developed in states with strong solar resource in the West (e.g., California, Arizona, New Mexico, and Colorado) and in New England (e.g., Massachusetts and Vermont) with clear alignment of RD&D measured through patenting activity, cleantech solar firms, solar energy deployment, and employment. Other states like Nevada and Maryland, while strong in employment that is mostly related to installations of PV systems or services, are less competitive in RD&D measured through patenting and firm formation.

Figure 2-14: Specialization metrics for patents, firms, and employment in comparison to electricity generation from solar energy technologies

SPECIALIZATION IN SOLAR ENERGY TECHNOLOGIES



ELECTRICITY GENERATION FROM SOLAR

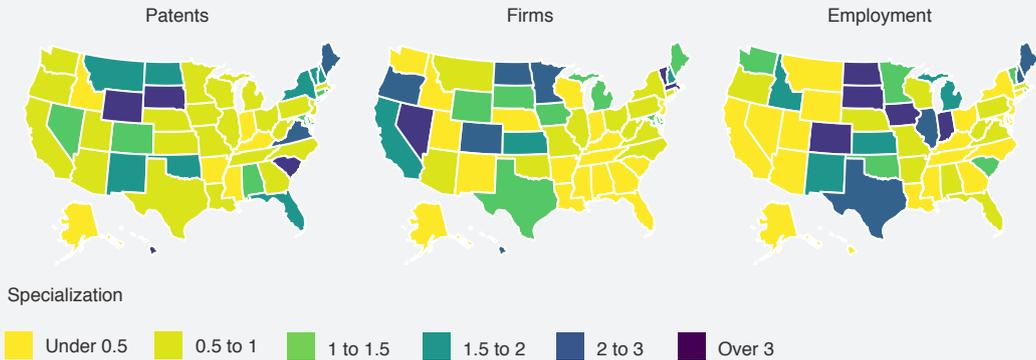


Box 2-2: Regional innovation patterns in wind energy

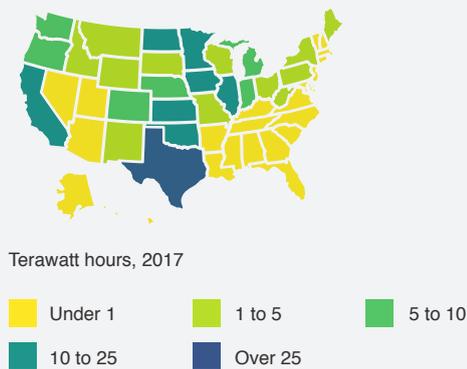
Regional innovation for wind energy is most developed in states in the Northeast (e.g., Maine, Vermont, New Hampshire), Mountain region of the West (e.g., Colorado), and parts of the Midwest (e.g., North Dakota and South Dakota) (See Figure 2-15). The correlations between patents, firms, employment, and deployment are less evident in other states. For example, Texas’s strengths in wind energy employment is thanks to its excellent wind resource and large deployment—but the market demand for wind energy does not appear to have incentivized RD&D measured through wind energy patenting activity or more than moderate growth of innovative cleantech firms.

Figure 2-15: Specialization metrics for patents, firms, and employment in comparison to electricity generation from wind energy technologies

SPECIALIZATION IN WIND ENERGY TECHNOLOGIES



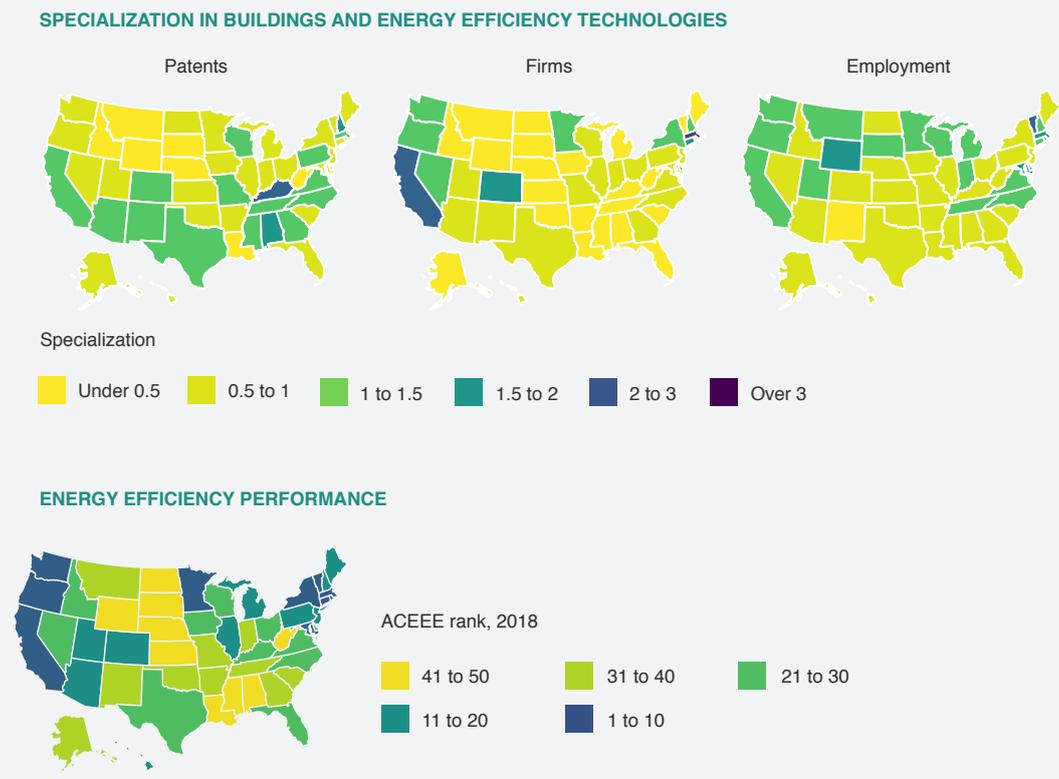
ELECTRICITY GENERATION FROM WIND



Box 2-3: Regional innovation patterns for buildings and energy efficiency

Buildings and energy efficiency technologies appear to have little correlation between technology strengths in patenting, firms, employment (Figure 2-16). Additionally, employment in buildings efficiency has only a moderate correlation trend with the ACEEE¹⁴ rank shown in the lower panel. This suggests that policy incentives to improve energy efficiency performance may be largely disconnected from regional RD&D activity. Overall, the diversity of technologies included in buildings and energy efficiency and the difficulty in discriminating which construction or service jobs qualify as ‘clean energy’ employment make analysis particularly challenging.

Figure 2-16: Specialization metrics for patents, firms, and employment in buildings and energy efficiency technologies in comparison to the ACEEE energy efficiency score¹⁴



The state-level technology focused assessments discussed in this chapter can help identify patterns in technology specialization and competitive advantage in technologies to give a preliminary idea of regional priorities. Detailed analyses of individual states are necessary, however, to understand how the regional clean energy innovation system actually operates, who the stakeholders are, and how resources are distributed and coordinated across the different stages of innovation.

Chapter Three

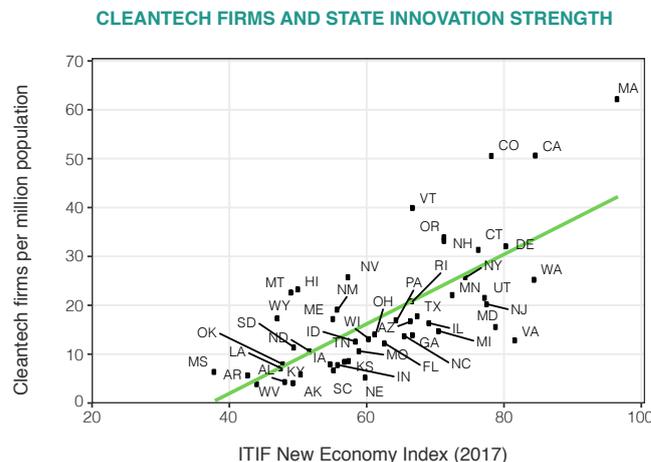
CASE STUDIES: CHARACTERIZATION OF CLEAN ENERGY INNOVATION

This chapter introduces two in-depth case studies comparing regional clean energy innovation activity. The two states discussed in this chapter, Colorado and Maryland, have had different clean energy innovation outcomes despite the similarities in their broader innovation capacity.

The previous chapters emphasized that few states may have an idealized clean energy innovation system with strong coordination across the stages of innovation from RD&D through deployment. Instead, individual states may demonstrate a purposeful focus on one stage or on one of the specific technology areas of clean energy. These choices are likely to be linked to the states' evaluations of potential economic, societal, and environmental benefits specific to their regions. Understanding how these decisions impact clean energy outcomes is essential for effective planning of regional clean energy innovations systems.

As noted in previous chapters, one indicator of system health is the number cleantech firms in the state. Using the New Economy Index (detailed in Chapter 2), Figure 3-1 demonstrates that there is a strong, linear correlation (with $R^2 = 0.51$) between clean energy innovation outcomes (measured by the number of cleantech firms) and a state's overall innovation capabilities. There are, however, clear deviations. At the high end of innovation scores, states like California, Massachusetts, and Colorado have more cleantech firms than expected while states like Maryland, Virginia, and Michigan have fewer than expected.

Figure 3-1: Cleantech firms per million population and the ITIF New Economy Index on states' innovation-based economies shows a linear relationship ($y = 0.71x - 26.5$; $R^2 = 0.51$). However, some states clearly deviate from the linear trend, and thus are described as having more or fewer firms than expected.^{1,13} In particular, Colorado and Maryland both have an innovation score under 80, but fall well above and below the trend line respectively. Data sources: i3 and ITIF



Maryland and Colorado were chosen for the comparative case studies because, despite the difference in the number of their cleantech firms, they are similar in many other aspects. The overall New Economy Index rankings (last column of Table 3-1) of Colorado (7th) and Maryland (6th) suggest that states are comparable in many aspects of their innovation economies. For example, both states rank in the top 10 in high-tech jobs and scientists and engineers; both rank in the lower 25 in high-tech exports.¹³

The states are also comparable in their socio-demographics. Colorado's labor force is 3.1 million compared to Maryland's labor force of 3.2 million.⁶⁶ In 2017, Colorado's GDP of \$342.7 billion ranked 19th, around 15% lower than Maryland's GDP of \$393.6 billion that ranked 15th.⁶⁷ Both states have comparable urban population—87.2% in Maryland and 86.2% in Colorado.⁶⁸ The most notable difference between the states is in investments in research and development or commercialization activity (e.g., venture capital and initial public offerings) where Colorado ranks higher (Table 3-1).

Table 3-1: Selected rankings for Colorado and Maryland in the New Economy Index. Source: ITIF¹³

	Workforce Education	Scientists and Engineers	Patents	Industry Investment in R&D	Non-Industry Investment in R&D	Venture Capital	Initial Public Offerings	Overall Rank
Colorado	2nd	4th	6th	15th	10th	7th	5th	7th
Maryland	2nd	5th	17th	25th	22nd	15th	12th	6th

These similarities in the states remove intrinsic sources of variability that might affect the observed outcomes and allow the comparative case studies to focus on factors that can be influenced by state policy decisions. The differences in outcomes between the two states are large: the number of innovative or investor-oriented cleantech firms per million people is three times as high in Colorado (51) as in Maryland (16).¹ The differences in the number of cleantech firms are mirrored in the 2017 U.S. Clean Tech Leadership Index^k that ranks Colorado (7th) higher than Maryland (15th)⁶⁹ (last column of Table 3-2). This index ranks states in three categories related to technology deployment, policy, and capital (financial, human, and intellectual capital) based on 80 different indicators. In this ranking, Colorado outperforms Maryland in clean energy technology deployment and Maryland outperforms Colorado in the strength of its clean energy policies—but the most striking difference is in the strength of Colorado's score for financial, human, and intellectual capital in clean energy.

Table 3-2: Selected rankings for Colorado and Maryland in the Clean Tech Leadership Index⁶⁹

	Clean Energy Technology Deployment	Clean Energy Policy	Financial, Human, and Intellectual capital for clean energy	Overall Rank
Colorado	7th	16th	4th	7th
Maryland	12th	8th	35th	15th

^k The Clean Tech Leadership Index uses 80 indicators to rank states in three categories related to technology deployment, policy, and capital (financial, human, and intellectual).⁶⁹

The next two chapters (Chapter 4 and Chapter 5) develop case studies on Colorado and Maryland to explore the factors that have led to the marked differences in the key metric of clean energy firm formation, and the ‘Clean Tech Leadership Index’ assessment of the differences in clean energy financial, human, and intellectual capital.

The case studies characterize the differences in clean energy innovation activity in each state over the last decade, analyzing clean energy innovation in terms of the motivations described in Chapter 2—i.e., economic development, energy and environmental factors, and technology capacity. Using data from the 50-state assessment, the case studies discuss how Colorado and Maryland perform relative to other states and relative to US average. For consistent comparisons, the following terminology has been used to illustrate performance: high (corresponds to ranks 1 to 12 of the 50 states), moderate-to-high (ranks 13 to 25), moderate-to-low (ranks 26 to 38), and low (ranks 39 to 50).

The case studies move beyond the 50-state assessment with deeper data development designed to reveal more about the states’ priorities and innovation outcomes. For both Colorado and Maryland, the states’ clean energy spending was evaluated in terms of the stages of commercial development illustrated in Chapter 1 (Figure 1-1), and linked to the states’ relative focus on the drivers of economic development versus energy and environment. In addition, multiple data sources were tapped to discover many more cleantech firms in each state and extract their profiles to explore key correlated outcome metrics—i.e., rates of formation and maturation of firms and their success in attracting private sector investment.

The approaches used in the two states for supporting clean energy technologies were assessed in terms of best practices tailored to cleantech firms, demonstrated through public and private funding models over the last decade.³⁴ These require supplementing seed, grant, or investment funding with a range of developmental support related to the firm’s stage of commercialization. Examples of such developmental support include: mentoring in technical and business issues essential to commercialization; space and support for product development and early scale-up for manufacturing (incubator support); guidance in accessing federal, state, and local incentives and funding opportunities; networking to develop supply chains, early markets, and investment opportunities; and networking and incentives for partnerships with established businesses.

The analysis presented builds on rigorous data collection and over 47 interviews or stakeholder discussions (with current and former state energy and economic development officials, entrepreneurs, investors, and other key stakeholders involved in the states’ clean energy innovation activities). Details on definitions, methodology, and data are available in Appendix A.

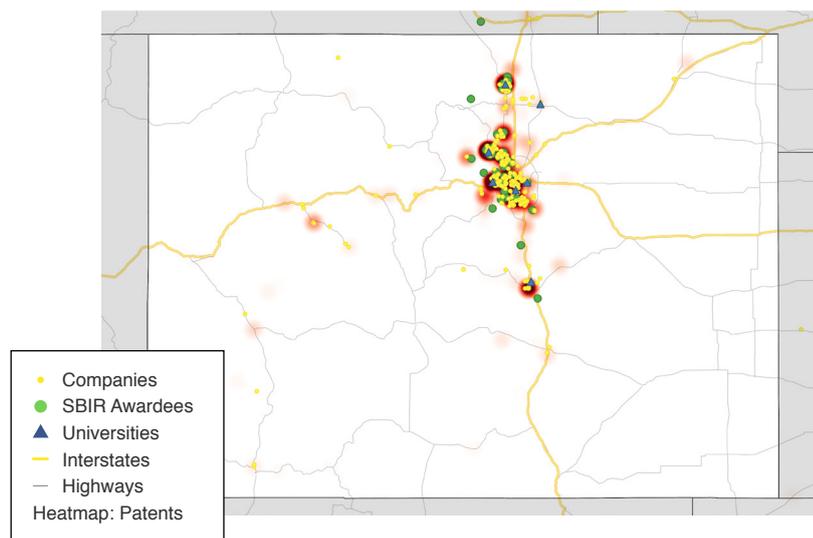
Chapter Four

COLORADO: ENERGY INNOVATION AND ECONOMIC DEVELOPMENT

The chapter discusses how Colorado’s approach to clean energy innovation has focused on economic development and support for cleantech companies. Consequently, the state ranks among the top 5 states in terms of cleantech companies per capita. Colorado’s cleantech companies are largely diversified across technologies and have capitalized on local human and natural resources, local RD&D, and active coordination among stakeholders. However, when compared to other states, Colorado’s clean energy outcomes related to deployment and decarbonization are mixed—they include high share of electricity generation from renewables, moderate-to-high clean energy employment in several sectors, but moderate reduction of per capita carbon dioxide emissions in the past.

Colorado’s stakeholders involved in clean energy innovation are spread in and around urban clusters in the ‘Front Range Urban Corridor’ (Figure 4-1). Key stakeholders in the energy technology innovation process—i.e., research universities, cleantech firms, clean energy technology innovators (or patent inventors), and state energy and economic development agencies—agglomerate in Denver-Aurora-Lakewood, Boulder, Fort Collins, and the Colorado Springs metropolitan areas.

Figure 4-1: Clean energy innovation activity in Colorado is concentrated in and around urban areas in the ‘Front Range Urban Corridor’



Motivations for Clean Energy Innovation in Colorado

The motivations that drive stakeholder engagement in regional clean energy innovation are related to policy signals from state leadership (i.e., the legislature and governors). In Colorado, the priorities and actions of three governors have reinforced the linkages between energy and economic development, with variable focus on clean energy versus energy overall (Box 4-1). Multiple state planning reports indicate that implementing these priorities has involved significant coordination among several state and local agencies.^{70,71} At present there is a strong focus on ‘green jobs,’ sending positive policy signals to public and private stakeholders on the future of clean energy in the state.

Box 4-1: Colorado’s Governors’ priorities related to clean energy innovation

Governor Ritter (2007-2011) targeted developing a New Energy Economy built on the goals of promoting alternative energy and energy efficiency, encouraging cleaner extraction of fossil fuels, supporting RD&D and manufacturing around clean energy, and driving change in these new sectors by engaging rural Colorado.⁷² Under Governor Ritter, Colorado increased the goal of its RPS—to 20% by 2020 (in 2007) and to 30% by 2020 (in 2010). In 2010, the state also passed the Colorado Clean Air, Clean Jobs Act that required replacement of 900 MW of coal-fired power plants with natural gas or low emission fuels, in order to improve air quality and reduce emissions.¹ According to the interviews conducted for this report, stakeholders in Colorado credit Governor Ritter for the stimulus provided to the clean energy economy.

Governor Hickenlooper (2011-2019) prioritized supporting the linkages between Colorado’s natural resources, both fossil and clean energy, and economic development. For example, in 2010, the goals articulated in his election campaign were related to post-recession job creation and economic recovery in five sectors: aerospace, energy, biosciences, agriculture, and tourism. Under his leadership, the state included energy as a priority in the Advanced Industries Accelerator (AIA) Act in 2013. In 2017-18, the state joined the bipartisan United States Climate Alliance.

Governor Polis (2019-current) aims to shift Colorado’s electric grid to 100% renewable sources by 2040. His economic development goals have emphasized “good-paying green jobs” and entrepreneurship across the state, while his vision for energy and environment has included renewables, electrification of transportation, energy efficiency, and conservation.⁷³ His inaugural speech mentioned “protecting our precious air, water, and land — and making sure that every Colorado family can live a great Colorado life with clean air and cheap, abundant renewable energy.”⁷⁴

The following sections explore the motivations and activities of key stakeholders in Colorado and the apparently well-developed linkages between economic development, energy and environment, and technology capacity.

¹ Governor Ritter continues to work on clean energy since 2011, leading the Center for the New Energy Economy (CNEE) at Colorado State University.

Economic Development

This section highlights how Colorado’s industry strengths in science and technology and in energy (both clean energy and energy overall) have catalyzed its regional clean energy innovation system. The state’s economy also relies on other sectors (such as outdoor recreation)^{m,75} that often value the environmental benefits of clean energy. Perhaps because of these multiple industry strengths, Colorado’s stakeholders have linked clean energy and economic development priorities, leading to commercially focused RD&D for clean energy.

Colorado’s technology and energy industries have identified potential opportunities in clean energy

Colorado identifies seven ‘advanced industries’—advanced manufacturing, aerospace, bioscience, electronics, infrastructure engineering, technology and information, and finally energy and natural resources—as its private sector strengths.⁷⁶ This diversified technology-oriented industry is a product of conscious regional stakeholder efforts in bottom-up economic development, for example through the Colorado Advanced Industries Acceleration (AIA) Act of 2013. Colorado’s advanced industries generate high employment in broadly defined technology-oriented sectors such as information and scientific and technical services.⁷⁷ The strong technology-trained workforce implies transferable skills for technology innovation including in clean energy.

Energy (both clean energy and energy overall) and natural resources have been integral to Colorado’s economy for decades. The substantial presence of energy-based industries has been pivotal in regional politics and policy and has helped engage stakeholders to focus on energy innovation despite the potential conflicts between fossil- and clean energy interests (as discussed in Chapter 2). The upstream fossil fuels industry is currently a major employer with a recent increase in natural gas and crude oil prices and productionⁿ; however, employment in coal production has declined by over 40 percent in the last decade.⁸¹ 17.3 jobs per 1000 jobs in Colorado are in oil and gas extraction, mining, and quarrying, compared to the US average of 7.8.⁷⁷ The clean energy industry, however, has the potential to grow rapidly given Colorado’s large resources in most forms of clean energy.^{o,82} Details on employment in clean energy are presented later in this chapter.

^m According to Colorado’s Statewide Comprehensive Outdoor Recreation Plan (SCORP), outdoor recreation employs nearly 19% of the labor force and is associated with 10% of the state GDP. Environmental conservation (land, water, and wildlife conservation) is a priority for the future planning to support the industry.⁷⁵ Interviews conducted for this report highlighted the synergies between Colorado’s outdoor recreation activities and its clean energy innovation motivations.

ⁿ Natural gas and crude oil are currently experiencing a massive boom especially in the Denver-Julesburg Basin in the northeast and in the Piceance Basin in the west—natural gas production (5.1% of the US total) more than doubled from 2001 levels while crude oil production (3.8% of the US total) increased nearly seven-fold since 2001, both relatively higher than the US increase.⁷⁸⁻⁸⁰ Colorado is also the largest coalbed methane producing state, with production in the San Juan and Raton Basins. The importance of fossil fuels can hardly be overstated given that the state has the 6th largest natural gas reserves in the US.⁷⁸

^o Solar resource potential is particularly high in the southern parts of Colorado that border New Mexico and Oklahoma. Wind resource potential is high in the mountain crests and in the eastern plains bordering Nebraska and Kansas. Parts of central Colorado have relatively high potential for developing geothermal energy. Solid biomass resources in parts of northwestern counties of Colorado are high because of urban wood waste and forest residues.

Many of Colorado's other industries put a high premium on environmental conservation.⁷⁵ The state has a large outdoor recreation industry and recent state-led plans for the future of the industry target preservation of the natural environment through clean air and clean water.⁷⁵

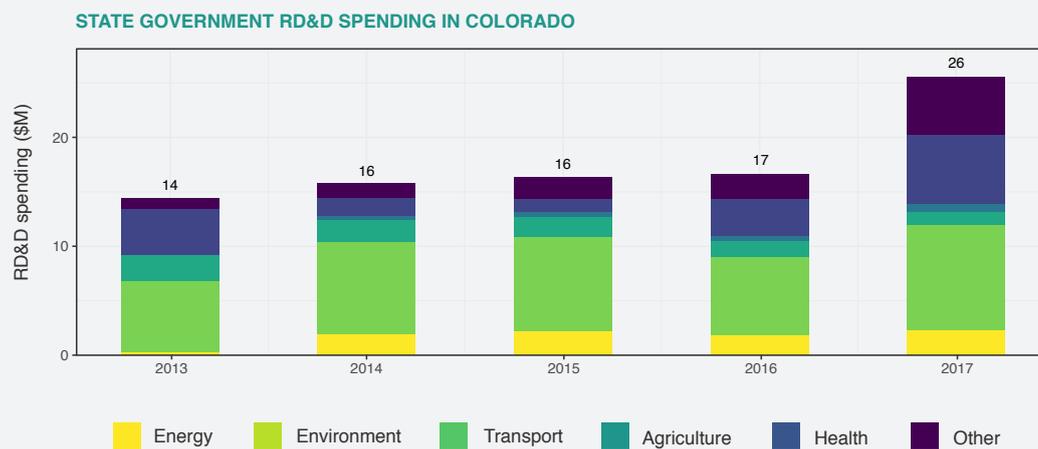
Coordination among stakeholders integrates clean energy innovation with economic development

Colorado’s public agencies and non-profits demonstrate an integration of the state’s clean energy and economic development priorities^{70,71} (Box 4-2). Two state agencies have specific mandates related to clean energy—the Colorado Office of Economic Development and International Trade (OEDIT) and the Colorado Energy Office (CEO)—with support from other agencies such as the Colorado Department of Natural Resources and the Colorado Department of Public Health and Environment. Two non-profits—the Colorado Cleantech Industries Association (CCIA) and the Metro Denver Economic Development Corporation (Metro Denver EDC)—coordinate activities with business interests and local industry associations, regional development, etc. (Box 4-3).

Box 4-2: Colorado's state government RD&D spending patterns

Colorado state government's RD&D patterns indicate a greater prioritization of energy and environment (including natural resources) compared to other states (See Chapter 2). Colorado ranks 15th among 50 states in the fraction (9.8%) of state RD&D funding spent on energy (including both clean and fossil fuel-based energy), compared to the 50-state average of 7.7% (Figure 4-2). Colorado state government's largest RD&D spending area is environment, which accounts for 45.7% of the total, compared with 28.8% average in all states.⁷ Several state agencies report spending on energy RD&D: OEDIT, CEO, Colorado Department of Natural Resources, Colorado Higher Education Competitive Research Authority, Colorado Department of Public Health and Environment, and the Colorado Department of Transportation (see Appendix B).

Figure 4-2: Spending by Colorado state government in RD&D in different sectors. Data source: NSF⁷



OEDIT, the state's economic development agency, runs programs supporting the growth and retention of emerging companies, including clean energy companies. OEDIT awards competitive grants to innovative early stage companies operating in the state's advanced industries through the AIA program. The companies go through an extensive vetting process that brings in experts from other state agencies such as the CEO, exemplifying the strong coordination between economic development, energy, and RD&D stakeholders in the state (See Box 4-3 for other examples). Financed by the state's limited gaming fund and a payroll income tax on specific industries, the AIA's mandate involves offering grants to companies at different stages of technology (mostly for RD&D) to help pre-revenue companies be commercially ready, raise their institutional profile, and get through the 'valley of death'. Approximately 25% of OEDIT's annual budget is spent on energy (but not all on clean energy).

Box 4-3: Examples of coordination between economic development and energy stakeholders for clean energy innovation in Colorado

- Energy companies that receive OEDIT's AIA awards are vetted extensively in a competitive process that brings in experts including those from state agencies such as the Colorado Energy Office.
- OEDIT and CEO coordinate in corporate recruitment of energy-relevant companies looking to relocate to the state. For example, Vestas, one of the world's largest wind turbine manufacturers has four factories in Colorado. Vestas invested over \$700 million in the late 2000s and chose to manufacture in Colorado rather than other competing states.⁸³ This was partly because OEDIT and the Governor's Energy Office (later the CEO) coordinated efforts to demonstrate a supportive administrative structure while Governor Ritter's New Energy Economy agenda sent clear policy signals on the future of clean energy in the state.⁸⁴
- CCIA and CEO partner on the Oil and Gas Cleantech Challenge whose goals include methane mitigation, resource usage, water quality and operational risks—focusing on resources that matter for the state's economy.
- CCIA gives out awards to Colorado cleantech innovators and companies (both startups and more mature high impact companies) and organizes annual events to showcase local achievements and bring together the cleantech community in the state. OEDIT, NREL, CEO, Metro Denver EDC have been part of these annual events in the past years.

Along with OEDIT, Colorado's industry and economic development-oriented organizations coordinate clean energy innovation activities among different governmental and industry stakeholders. CCIA is dedicated to promoting Colorado's cleantech industry and provides policy advocacy, capacity building, education, and training to the cleantech sector. Metro Denver EDC is a public-private organization that partners with 60 cities, counties, and economic development groups in the Metro Denver and Northern Colorado area to provide services to help site selectors and companies with location, expansion, and market decisions. The Colorado Energy Coalition, one of Metro Denver EDC's four industry-focused affiliates concentrates on the broad energy industry in the region.

The presence of CCIA and its emphasis on cleantech has made Colorado one of the few states in the US with a dedicated cleantech industry association that represents the interests of the broader clean energy sector that includes multiple technologies.⁹⁵ CCIA was established in 2008 when various industry-oriented stakeholders realized the need for an entity committed to supporting cleantech policy associated with the growing momentum from Governor Ritter's 'New Energy Economy'. The CCIA conducts multiple activities in support of the clean energy innovation system: it runs innovation challenges (the Commercial Vehicle Cleantech Challenge, the Mining Cleantech Challenge, and the Oil and Gas Cleantech Challenge); offers annual awards to boost local cleantech companies; helps build networks between the cleantech community in Colorado through regular events and engagement with different stakeholders (such as the National Renewable Energy Laboratory); and highlights the leadership of Colorado in the country such as through its Energy Fellows program.

The active involvement of OEDIT and CCIA in industry-oriented activities and cleantech startups has meant a commercially oriented focus on RD&D and early deployment in the state. In this process, both OEDIT and CCIA have played a prominent role in facilitating and strengthening coordination with various stakeholders involved in clean energy innovation (Box 4-3).

Energy and Environment

Colorado's energy and environment policies are linked to energy affordability and reliability, along with the potential for environmental protection, job creation, and rural development opportunities.⁸⁶ The stakeholders involved in implementing clean energy policies include the Colorado Energy Office (CEO), the Colorado Public Utilities Commission (PUC), and the state's 52 utilities.⁸⁷ Key policies include the RPS and the supporting Renewable Energy Standard Adjustment (RESA) (see Box 4-4 and 4-5). In addition, the Colorado Energy Office (CEO) administers multiple programs including for energy efficiency (the state ranks 13th in the ACEEE scorecard¹⁴). As discussed below, most activities focus on the deployment stages of clean energy innovation but recent increase in ambition from utilities⁸⁸ is potentially prompting RD&D and early deployment.

Box 4-4: Summary of Colorado's Renewables Portfolio Standard⁸⁹

Colorado's primary mechanism for the deployment of clean energy is the RPS, along with its affiliated incentives, initiated through a voter-approved process in 2004.⁸⁶

Current goals (by 2020):

(a) 30% for investor owned utilities (IOUs) (b) 20% for large cooperatively owned utilities (co-ops) (c) 10% for municipally owned utilities and for small co-ops. Each of these has specific carve-outs for distributed energy resources.

Eligible technologies:

Geothermal electric, solar thermal electric, solar photovoltaics, wind (all), biomass, hydroelectric, landfill gas, wind (small), anaerobic digestion, fuel cells using renewable fuels, and recycled energy. In addition, the RPS also includes coal mine methane and pyrolysis of municipal solid waste (if the PUC deems it is a greenhouse gas neutral technology).

Compliance:

Renewable energy credits (RECs) are used for compliance. Credit multipliers exist for specific types of projects (e.g., community-based projects). Retail customers pay a Renewable Energy Standard Adjustment (RESA)⁹⁰ (see Box 4-5).

Box 4-5: Utility programs in Colorado for energy efficiency and renewable energy

Colorado has only two investor owned utilities (IOUs)—Xcel Energy and Black Hills—whose power purchase decisions are regulated by the Colorado Public Utilities Commission (PUC); a large number of co-ops and munis remain unregulated. In 2016, the IOUs had around 51% of electricity sales, co-ops had 27%, and munis 22%.⁸⁷

The primary program affecting utilities and clean energy deployment investments are the RPS and associated RESA. The two investor owned utilities have the largest RPS compliance requirements and are the most prominent sources of demand for clean energy technologies in power generation. For IOUs and coops, the net retail rate impact of RPS compliance cannot exceed 2% of the total electric bill annually for each customer through the RESA. The RESA applies to solar, wind, or biomass. The revenues received by utilities from RESA can be used to pay for the incremental costs of renewable energy over traditional energy resources.⁹⁰

The Colorado Energy Office, the primary agency focused uniquely on energy, runs state and federal programs for promoting energy efficiency, improving affordability, and lowering barriers to investment and deployment of clean energy and clean transportation^p. CEO's scope of activities has shifted between clean energy and energy overall, possibly because of tensions between fossil and clean energy interests in the state^q. Nonetheless, the CEO receives state funding and engages with various federal and local stakeholders, making it integral to Colorado's clean energy innovation activities. The CEO works with the federal government to administer the Weatherization Assistance Program and receives federal funding for the State Energy Program. It works with other state agencies, for example the Colorado Department of Agriculture where it offers a statewide Agricultural Energy Efficiency Program to reduce energy expenses of the agriculture industry. With the private sector and individual consumers, CEO runs public-private-partnership (PPP) based financing programs — Energy Performance Contracting (EPC), Property Assessed Clean Energy (C-PACE), and the Residential Energy Upgrade Loan (RENU) Program.

Much of CEO activity is related to the late deployment (market growth) stage of innovation. This is because funding from federal or state programs is allocated to achieve specific goals (often clean energy deployment or energy efficiency) and these programs may not directly relate to clean energy RD&D. However, exceptions have occurred in the past when additional sources of funding became available—for example, the CEO was awarded \$144 million from the federal government's Recovery Act funds in 2009-2012, which it used to set up a Revolving Loan Fund to support early-stage Colorado companies with commercialized products, aiming to stabilize, grow or expand their operations and create jobs.⁹¹

^p CEO's budget includes The Innovative Energy Fund (\$1.5 million annually) funded from severance taxes imposed on minerals and mineral fuels, and The Clean & Renewable Energy Fund (\$1.6 million annually) funded from general fund dollars.

^q Given the importance of energy for Colorado's economy, tensions between stakeholders involved in fossil fuel and clean energy sources have moderated CEO operations since it was formed, alternating its focus between clean energy and energy overall. The Governor's Energy Office (GEO) was codified by Gov. Bill Ritter in 2008 to advance energy efficiency and renewable energy resources. In 2012, the GEO was restructured and renamed as the Colorado Energy Office (CEO) under Gov. Hickenlooper, extending the goals for Colorado's energy economy to all types of energy. The CEO initially secured funding for 5 years (through 2016). When funding expired after 2016, the reauthorization bill in 2017 failed to pass partly due to its attempts to refocus on hydropower and nuclear – and the CEO was funded through a federal loan. The CEO was authorized again in 2018.

Triggered in part by the rapid decline in the cost of renewables, Colorado’s utilities have increased their ambition for clean energy deployment. The two large IOUs and other stakeholders developed and presented the Colorado Energy Plan to the state regulators, which was approved in August 2018.⁸⁸ Xcel proposed to achieve 55 percent renewable energy on their power grid by 2026 and to reduce carbon emissions by about 60 percent (from 2005 levels) by 2030 in the state of Colorado. In 2018, Xcel Energy also committed to providing its customers across all states with 100 percent carbon-free electricity by 2050 and to reducing carbon dioxide emissions 80 percent below 2005 levels by 2030.

The ambitious deployment goals from large utilities have prompted an accelerated need for RD&D. For example, Xcel stated that while it could achieve 60 percent carbon reductions from currently available technologies, its long-term ambition of carbon free electricity would require commitment to the development of innovative technologies not available today.⁹² The utility has already set up multiple demonstration and early deployment projects in Colorado for battery testing.⁹³

Technology Capacity

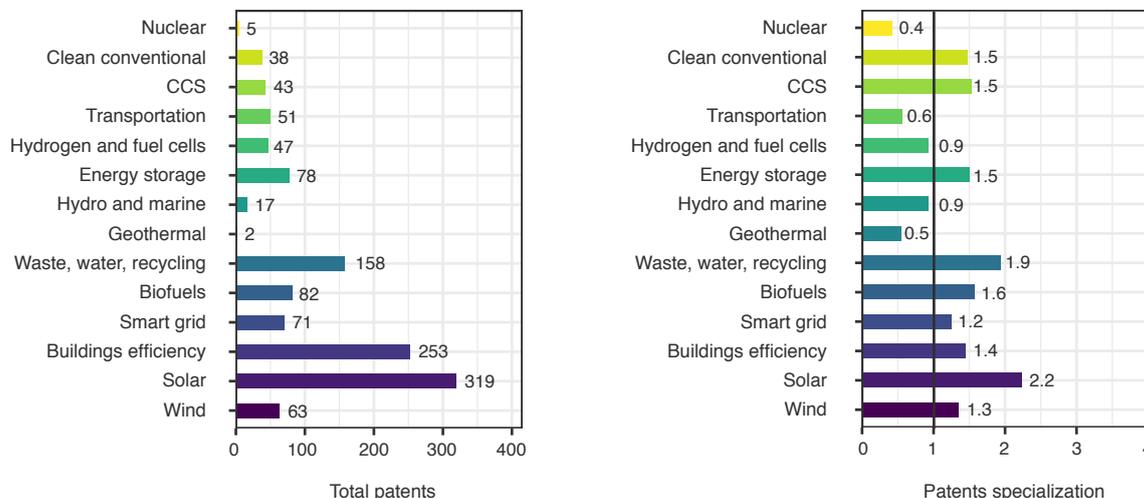
This section discusses some of the factors in Colorado’s technology capacity to innovate in clean energy. These include a strong university system and a highly educated workforce, substantial federal resources, coordination of RD&D between federal infrastructures and universities with a specific focus on clean energy, and effective state spending on clean energy RD&D that complements other funding resources for early stage companies.

Strong capacity for innovation overall with a specific focus on clean energy

Using clean energy patents as one metric of innovation activity, Colorado stands out because of strengths across a wide range of climate mitigating technologies (Figure 4-3). Colorado ranks 7th among 50 states in clean energy patents per million people (using fractional counts of inventor location, see Appendix A for methodology). Inventors resident in the state had a total of 1228 clean energy patents compared to the 50-state average of 824 in the decade between 2007 and 2016. In per capita terms, Colorado had 216 clean energy patents per million people, compared to the 50-states average of 112 clean energy patents per million people.¹¹ 706 of the 1228 patents were from Colorado based organizations (i.e., patent assignees), with prominent activity from the Alliance for Sustainable Energy (or the National Renewable Energy Laboratory, NREL) (80 patents), the different universities (48 patents), and startups or small businesses such as PrimeStar Solar (34 patents) and Ampt (25 patents). In absolute terms, patenting activity by local inventors in solar, buildings energy efficiency, and waste technologies has been the highest. The technology specialization metric, where the US average is represented by 1, shows that Colorado’s clean energy RD&D is diversified in multiple technologies—the state scored similar or greater than the US average in 9 out of 14 measured categories.

Figure 4-3: Climate mitigation patents in Colorado (2007-2016), based on fractional counting of the location of inventors (see Appendix A). Data source: USPTO¹¹

PATENTING ACTIVITY IN COLORADO



Several local circumstances underpin Colorado's relatively high patenting activity and the correlated strength in technology capacity for clean energy RD&D.

First, a strong science and engineering university system has spurred multiple cleantech startups. In Colorado, 36% of all degrees awarded (i.e., bachelor's, master's, and doctoral degrees) are in science and engineering, higher than the US average of 31%.⁹⁴ Multiple doctoral-granting universities have a legacy of strengths in major science and engineering fields of study and are also located in the hubs of clean energy innovation activity⁹⁵ (Table 4-1). University of Colorado Boulder (CU-Boulder) has contributed to the formation of numerous cleantech firms that continue to be based locally—for example, Solid Power and Forge Nano. The Colorado State University has spun off more than 20 cleantech startups over the past decade.⁹⁶

Table 4-1: Eight research universities in Colorado grant doctorates in science and engineering fields of study (defined by NSF to include life sciences, physical sciences and earth sciences, mathematics and computer sciences, psychology and social sciences). Source: NSF⁹⁴

Universities with science and engineering research in Colorado	Number of doctorates in science and engineering (2017)
U. Colorado Boulder	305
Colorado State U., Fort Collins	194
Colorado School of Mines	98
U. CO, Denver, Aurora, Anschutz Medical Campus	73
U. Denver	43
U. Northern Colorado	25
U. Colorado Denver	16
U. Colorado Colorado Springs	14
Nation-wide university average	97

Second, the presence of a large number of federal research resources and infrastructures—most notably in wide-ranging energy and environment related topics (Table 4-2)—has attracted capable and like-minded researchers from around the country and across the globe.⁹⁷ Most relevant to clean energy innovation has been the DOE’s National Renewable Energy Laboratory (NREL) located in Golden, Colorado. NREL has been a leader in clean energy RD&D in the US and has brought substantial human and financial resources into the state.^r Other federal institutions such as the National Science Foundation’s National Center for Atmospheric Research (NCAR), National Oceanic and Atmospheric Administration (NOAA), Bureau of Reclamation (BuRec), and Rocky Mountain Research Station (RMRS) conduct research on environment and earth systems related issues (e.g., forests, water) that link to clean energy, environment, and climate change. In total, Colorado’s own estimates find representation from 23 federal research organizations providing significant funding (in clean energy and beyond) to 33 different research facilities.⁹⁷

Table 4-2: Federal or federally supported research institutions with some level of activity related to energy and environment in Colorado. Source: NSF and Federal Laboratory Consortium^{98,99}

Notable federal infrastructures and resources related to energy and environment
National Renewable Energy Laboratory (NREL)
National Oceanic and Atmospheric Administration (NOAA)
National Institute for Standards and Technology (NIST)
National Center for Atmospheric Research (NCAR)
Bureau of Reclamation (BR)
U.S. Forest Service - Rocky Mountain Research Station (RMRS)
U.S. Geological Survey (USGS)
National Wildlife Research Center (NWRC)

Third, the state was able to tap into the research potential of federal resources and universities through locally organized consortia that coordinated activities between various RD&D stakeholders. A notable example is the state-initiated Collaboratory, established in 2006 as a research consortium between Colorado School of Mines, Colorado State University, NREL, and the University of Colorado Boulder, specifically to support commercialization and workforce development in clean energy. Between 2008-2015, nearly \$8 million state investment leveraged into nearly \$97 million from DOE, NSF, and other sources.¹⁰⁰ Although not limited to clean energy, CO-LABS is another example of how federal resources were leveraged by state RD&D stakeholders. CO-LABS was set up by local stakeholders in 2007 to facilitate coordination across all federal research infrastructures, universities, and local agencies in the state and help create pathways to utilize federal RD&D resources for technology commercialization and local benefit.^{97,101} Stakeholder interviews mentioned that having such ‘go-to’ resources facilitated the development of partnerships between researchers, innovators, and companies.

^r NREL’s average annual expenditures between 2013 and 2017 were \$361 million⁹⁸

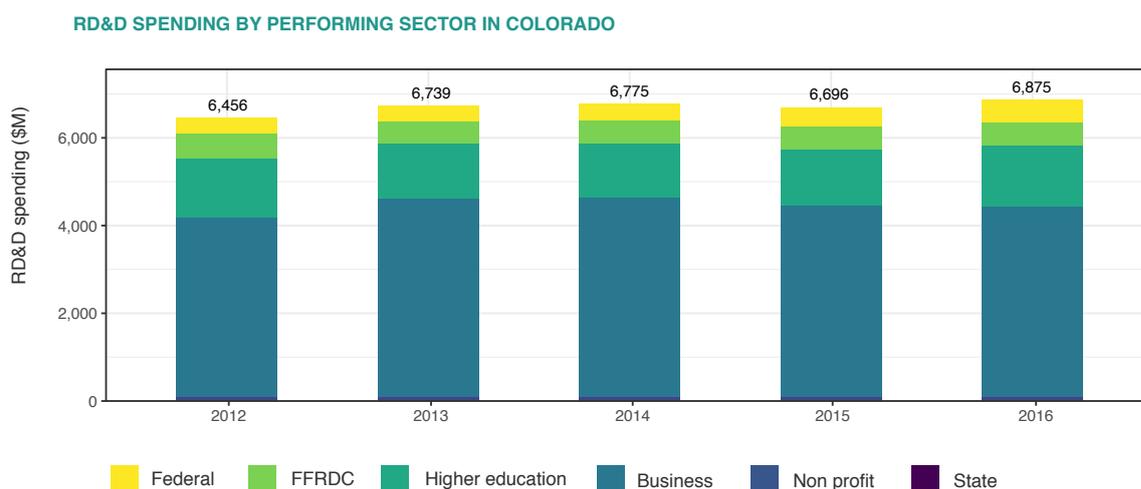
Fourth, complementing an already strong research system, the metropolitan areas around Denver also experienced domestic in-migration of highly educated person.[§] Stakeholder interviews note the in-migration aspect to be a key feature enabling innovation in Colorado. Interviews indicate that the factors that attract and retain highly educated people to Colorado are related to the outdoor recreational activities and the associated quality of life, perceptions of state leadership on clean energy and environment issues,[†] employment opportunities, as well as the entrepreneurial culture.¹⁰⁴

And fifth, other infrastructures such as incubators, accelerators, and testing facilities for innovation helped enable commercially oriented RD&D in the state. Incubators and accelerators such as the Rocky Mountain Innosphere and the Telluride Venture Accelerator helped technology-oriented stakeholders network and collaborate to access markets. Examples of testing facilities for new technologies related to energy and transportation include the National Center for Photovoltaics (NCPV) at NREL, the Solar Technology Acceleration Center (SolarTAC), the National Wind Technology Center at NREL, and state policy support for testing of autonomous vehicles.¹⁰⁵

Local public and private financing for early-stage clean energy technologies

The overall funding for RD&D performed in Colorado has been \$6.7 billion (annual average) which is lower than the 50-states average of \$8.9 billion¹⁰⁶ (Figure 4 4). In energy, however, state spending patterns have outperformed other states (Figure 4-5).

Figure 4-4: Funding for RD&D performed in Colorado by sector. Data source: NSF¹⁰⁶



[§] An estimated 72,000 in-migrants with a bachelor, graduate, or professional degree moved in from a different state in 2016 (ranking 8th in the US in absolute terms).¹⁰² Partially because of the growing number of educated in-migrants, among the population over 25 years of age, 24.8% of people in Colorado have a bachelor's degree (compared to US average of 19.1%) and 14.6% have a graduate or professional degree (compared to US average of 11.8%).¹⁰³

[†] Stakeholder interviews specifically noted that the presence of organizations like NREL and Rocky Mountain Institute that work on renewable energy, environment issues further increase the perception related to the state being active in environmental issues.

The strong technology capacity for clean energy in the state is correlated with competitive federal awards for RD&D in clean energy. Colorado ranks 4th among the 50 states in per capita DOE energy RD&D grant awards, based on primary location of performance⁶⁴ (Figure 4-5). Colorado also ranks 3rd of the 50 states in per capita energy-related SBIR funding from 2008-2017.¹⁰ The large amount of funding received by small businesses and startups spans multiple clean energy technologies (Figure 4-6). The state’s SBIR award patterns suggest specialization that is higher or comparable to the US average in nearly all clean energy technologies examined in this study—geothermal energy, wind energy, clean conventional energy, energy storage, smart grid, solar energy, CCS, biofuels, buildings efficiency, hydrogen and fuel cells, and transportation. This diversification mirrors Colorado’s diversified advanced industry and its technology capacity measured through patents.

Figure 4-5: Department of Energy’s RD&D-related grants awarded in Colorado (by year of award and by location of performance). Data source: USASpending⁶⁴

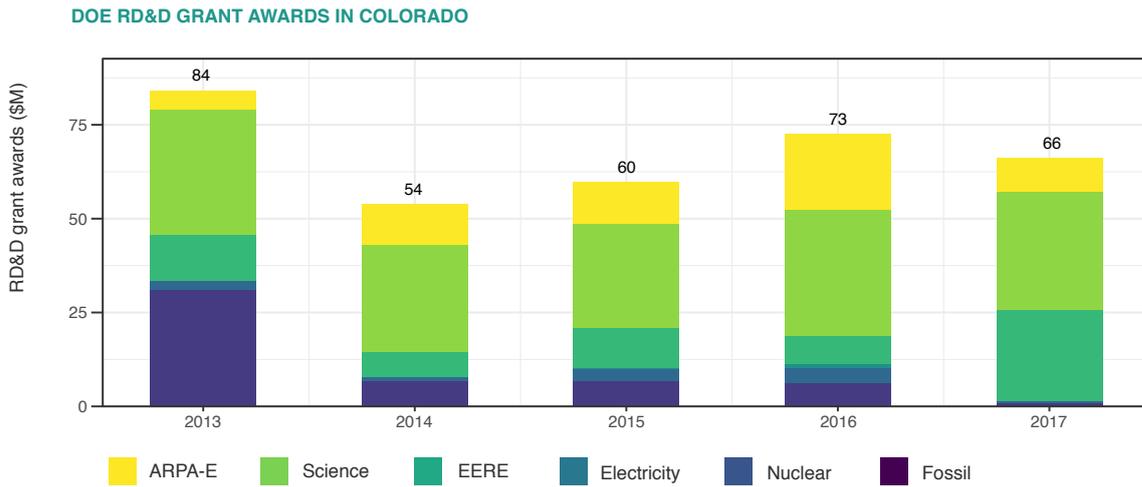
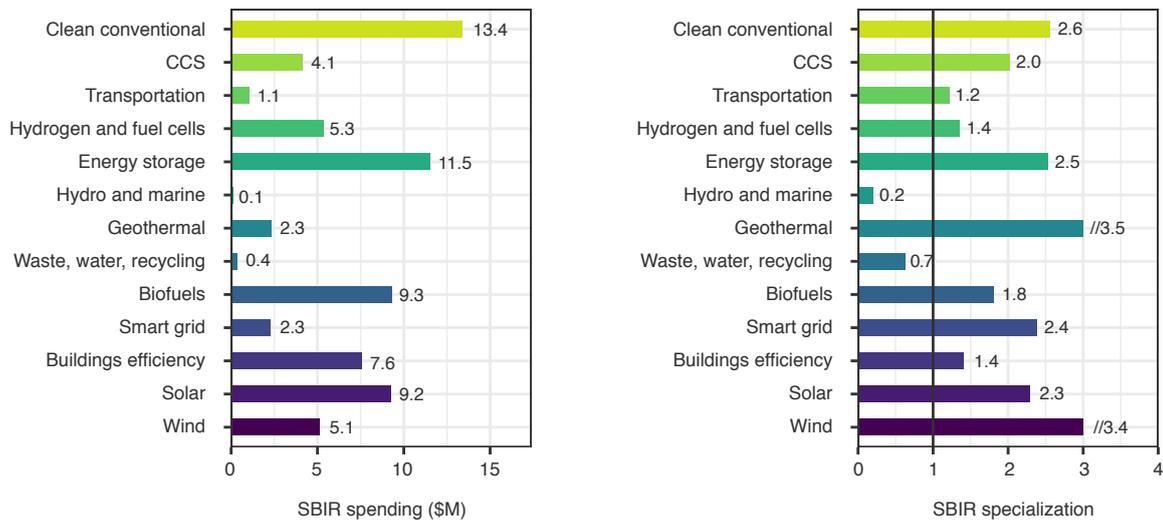


Figure 4-6: Estimated clean energy-related SBIR awards in Colorado (by all federal agencies except the Department of Defense)¹⁰



The state government provides support for clean energy innovation and local cleantech startups. A detailed analysis¹⁰⁷ of Colorado's state-level public spending in clean energy (from OEDIT, other state agencies, and utilities surcharges) reveals over \$90 million spending in the different stages of clean energy innovation, with around 3% of the total spending, i.e., around \$3 million, in RD&D (Table 4-3, See Appendix A).

Table 4-3: Summary of Colorado's state government spending on clean energy innovation¹⁰⁷ (see Appendix A for methodology).

Technology innovation stages	Average annual	Average annual per capita (population 5.7 million)	Percentage
Late Deployment (market growth)	\$70.1 million/year	\$12.31/year	78.3%
Early Deployment (market formation)	\$17 million/year	\$2.91/year	18.5%
Demonstration (proof of concept)	\$2.68 million/year	\$0.43/year	2.7%
Research and development (R&D)	\$0.38 million/year	\$0.07/year	0.42%
Total	\$90 million/year	\$15.72/year	

State spending on clean energy RD&D (corresponding to rows for R&D and demonstration in Table 4-3) primarily comes from OEDIT which specifically includes early stage clean energy companies in its portfolio of funded projects. OEDIT's Advanced Industries Accelerator program offers grants to companies at different technology stages and also offers travel grants for conferences or for accessing international markets.^u As discussed earlier in this chapter, the AIA grants are competitively awarded after a review process that involves energy experts. Although the amounts are relatively small compared to potential federal or private sources of funding, stakeholder interviews consistently highlighted how AIA grants have been helpful in growing early stage companies in the state and have often complemented federal or private funding.

^u Three types of grants from the AIA program are: (a) proof-of-concept that must be linked to a technology transfer office in universities located in the state (up to \$150,000, with a 3 to 1 match); (b) early-stage capital and retention (\$250,000, with 2 to 1 match); and (c) infrastructure (large scale, large ecosystem-building \$50,000-\$500,000 of matching).⁷⁶ Also, OEDIT offers grants of up to \$15,000 available to use for travel or international conferences for companies interested in export markets.

The cleantech activity in Colorado has been supported by a small but growing local private investor base.¹⁰⁸ Local investors such as Aravaipa Ventures focus exclusively on local clean energy startups, while other local investors such as TechStars may be more diversified. The state’s Advanced Industry Investment Tax Credit Extension has helped incentivize local investment—qualified investors making equity investment in a qualified small business from an advanced industry are allowed an income tax credit that is equal to a percentage of the investment, up to a maximum credit of \$50,000. Nonetheless, stakeholders perceive the lower availability of private investor funding for clean energy RD&D relative to Silicon Valley to be a hindrance. Recent funding from OEDIT awarded to Rockies Venture Club aims to reduce this barrier by targeting the expansion of angel investment in the state to support its advanced industries (including clean energy).¹⁰⁸

Table 4-4: Examples of investors located in Colorado that have supported local cleantech companies

Type of investor	Examples of investors located in Colorado
Public Sector	National Renewable Energy Laboratory, Office of Economic Development and International Trade
Venture Capital	Access Venture Partners, Aravaipa Ventures, Foundry Group, High Country Venture, TechStars Ventures
Private Equity	Bohemian Investments

It is worth adding that stakeholder interviews with innovators and investors highlight the value of Denver’s geographical location in the middle of the US. The Denver airport, with its direct national and international flights, has helped innovators engage with investors and access attractive markets for clean energy, for example in Europe. Convenient airport access has made Denver an attractive stopover destination for cleantech investors typically located in Silicon Valley or the East Coast.

Outcome metrics for clean energy innovation in Colorado

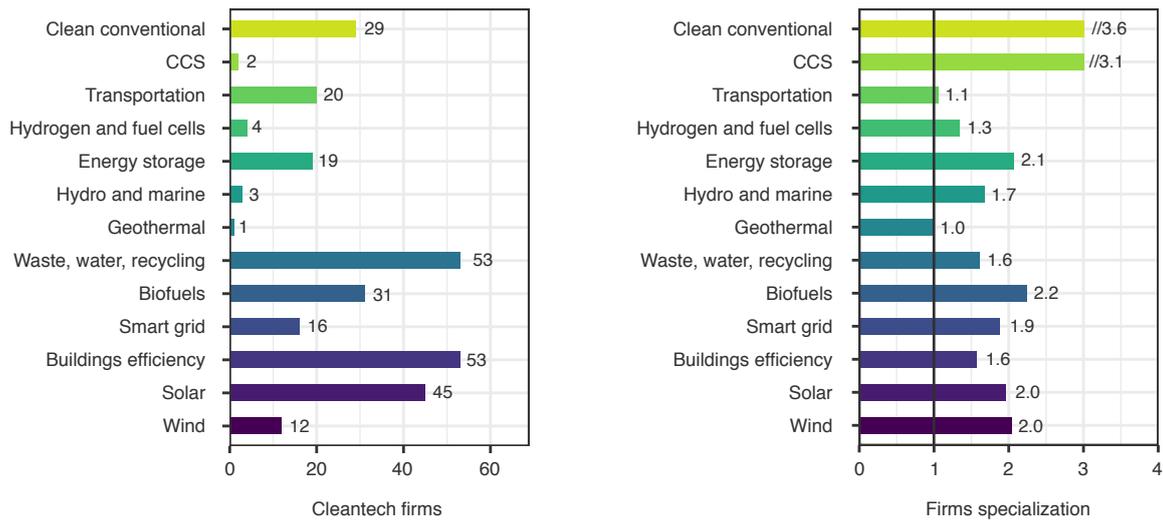
Colorado has had high per capita levels of innovative cleantech firms, moderate-to-high levels of employment in clean energy, and high levels of clean energy deployment. These outcomes are likely attributable to the state’s emphasis on early-stage startup support and clean energy deployment policies. However, the state has had moderate levels of per capita carbon dioxide reductions because of population increase, steady or growing energy demand, and large share of fossil-fuels based electricity in the state.

Cleantech Firms

Colorado ranks 3rd among 50 states in numbers of cleantech firms per capita, estimated from a standard industry dataset (the i3 cleantech database¹). Colorado has 288 cleantech firms listed in the standard dataset, compared to 50-states’ average of 141 (See Figure 4-7). In per capita terms, Colorado has 51 cleantech firms per million people compared to the US average of 18 cleantech firms per million people.¹

Figure 4-7: Estimated number of cleantech firms in Colorado from a standard database. Data source: i3¹

CLEANTECH FIRMS IN COLORADO



Colorado’s distribution of cleantech firms reveals emphases in all of the technologies examined (see Appendix A)—i.e., CCS, clean conventional energy, biofuels, energy storage, wind energy, solar energy, smart grid, hydro and marine energy, waste and recycling, buildings efficiency, hydrogen and fuel cells, and transportation as compared with the US average.¹ The specialization in nearly all technologies shows that clean energy innovation activities are diversified across different technologies and corresponds with the diverse strengths in patents and SBIR awards noted earlier. In absolute terms, the highest number of cleantech firms are in buildings efficiency, waste-wastewater and recycling, and solar (see Box 4-6 for examples of cleantech firms).

Box 4-6: Colorado's cleantech firms

The diversity of Colorado's clean energy innovation is evident in the profiles of its cleantech firms. Examples of these firms include:

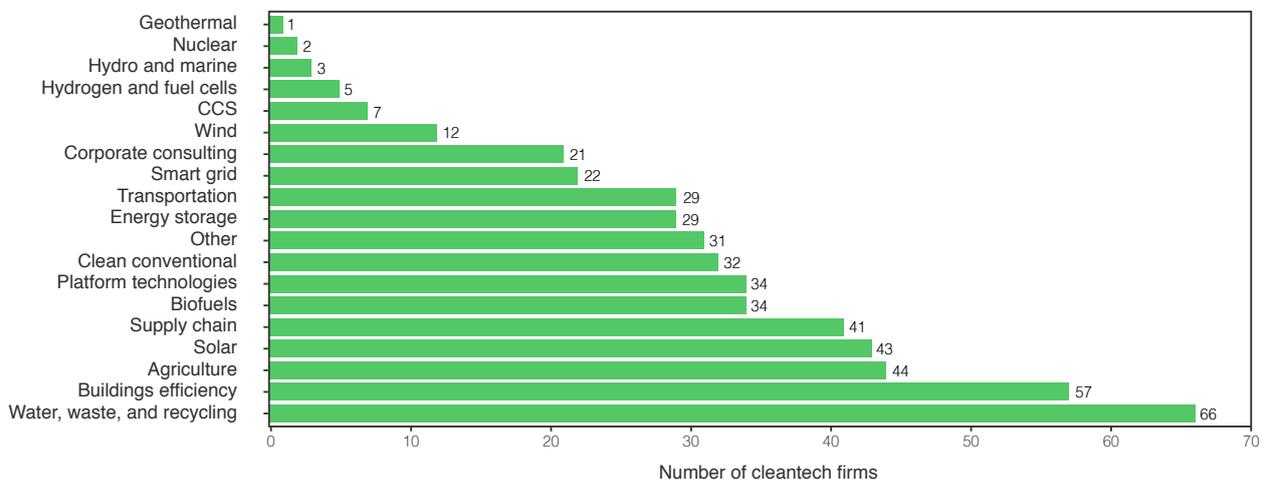
- **AMP Robotics** is a startup that applies artificial intelligence software and robotics hardware to lower the cost of sorting at recycling facilities. The founder, originally from Colorado, returned after a doctorate degree from Caltech to set up the company. The company has received a state OEDIT grant, federal NSF support, and substantial venture investments from different parts of the country.
- **Solid Power** is a startup that is developing a low-cost, all-solid-state battery for electric vehicles with greater energy storage capacity and a lighter, safer design compared to lithium-ion batteries. The company is a CU Boulder spinoff and has received funding from OEDIT and SBIR, ~\$3.5 million from ARPA-E, and around \$26 million Series A investment from private investors. The company has partnered with the Oak Ridge National Laboratory. Private sector investors and partners include Ford Motors and BMW.
- **Forge Nano** is a startup that works on surface engineering and commercial-scale precision nano-coatings, including for battery applications using technology initially developed at CU Boulder. The company has received funding from OEDIT, SBIR, DOE, and DOD, and has raised sizeable venture capital investment, including from Volkswagen, LG Technology Ventures, and Mitsui-Kinzoku-SBI Material Innovation Fund. The company partners with multiple DOE laboratories including the National Renewable Energy Laboratory, Argonne National Laboratory, and Oak Ridge National Laboratory.
- **Tendril Networks** was a Colorado based startup that acquired multiple companies and merged with another Colorado based startup, Simple Energy, to form **Uplight** in 2019. The company worked on energy management applications for energy service providers and large utilities across the US and expanded its operations under the new Uplight brand, including working with Colorado's utilities such as Xcel Energy. Tendril's (and now Uplight's) Chief Executive Officer is an experienced entrepreneur who relocated to Colorado. Being a software company that works with utilities across the US provided flexibility in selecting the location of the company. Under its operation as Tendril, the company raised over \$100 million in capital and was awarded multiple accolades from the state, including an 'innovator of the year' award for the Chief Executive Officer from the CCIA in 2016.

A deeper analysis of the cleantech firms in Colorado reveals that the number of cleantech firms from the standard i3 cleantech database used in the rest of this report (Figure 4-7) is conservative. Accessing additional data sources and analyzing each firm in detail reveals that at least 513 firms engage in broadly defined clean energy sectors, including those related to supply chains for the clean energy industry, platform technologies, agriculture, consulting, etc. (Figure 4-8a). The large number of agriculture companies corresponds with the presence of biosciences as another major advanced industry in the state with potential spillovers in clean energy (broad biosciences receive about 50% of OEDIT’s AIA funding and the state employs over 20,000 people in the sector).

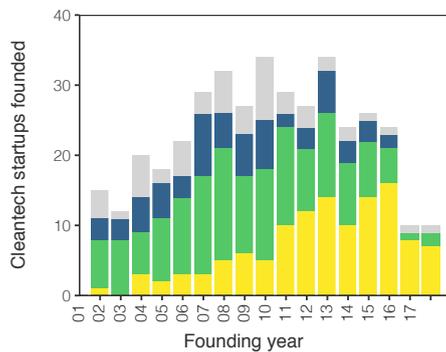
Because such detailed data is not available for all states, this report uses the standard database estimate (288) and the standard technology classifications (Appendix A) when comparing cleantech firms in Colorado with the 50 states.

Figure 4-8: (a) Estimated number of cleantech firms in Colorado from the expanded database, (b) progression of cleantech startups over time (i.e., the 2019 status of firms versus the year in which they were founded), and (c) investment history of cleantech firms relative to the year of their founding (i.e., level of investments versus the age of the companies). (See Appendix A)

(a) EXPANDED ASSESSMENT OF CLEANTECH FIRMS IN COLORADO



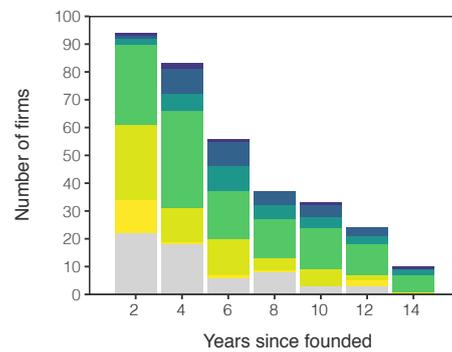
(b) PROGRESSION OF CLEANTECH STARTUPS IN COLORADO



Firm status in 2019



(c) INVESTMENT HISTORY OF 162 COLORADO COMPANIES



Investment levels per firm

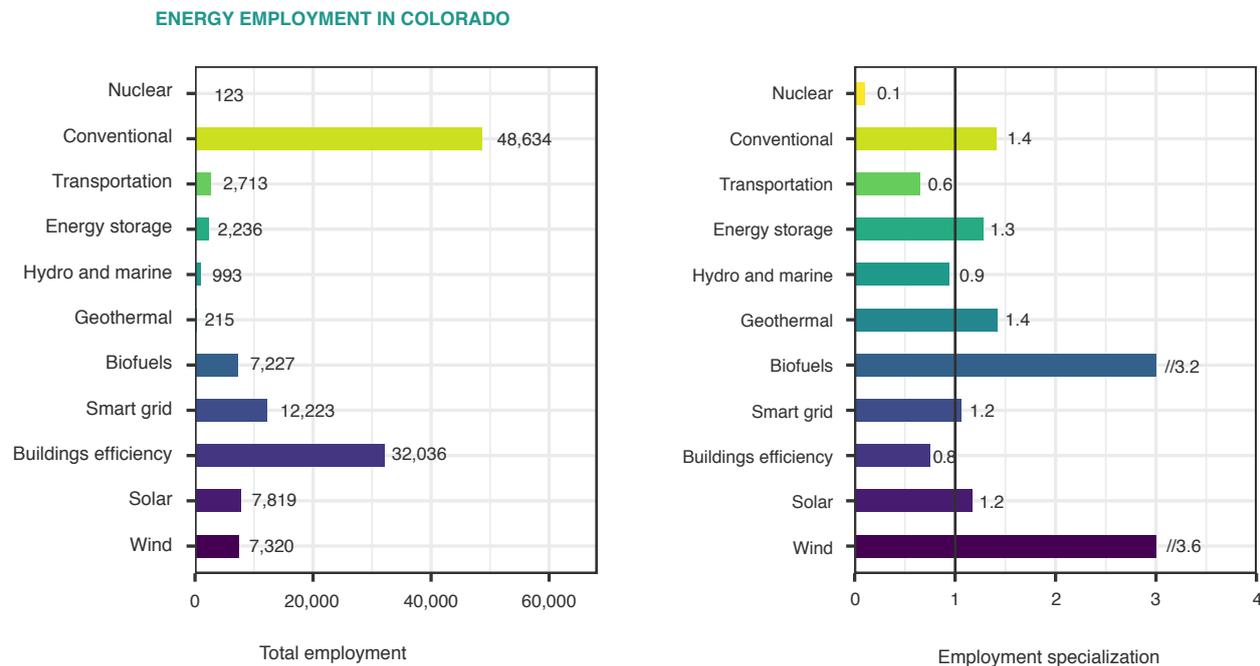


The detailed dataset also reveals that Colorado’s cleantech firms went through a stable progression from the early R&D/startup phase of development to maturity or acquisition—both important indicators of startup success (Figure 4-8b). Colorado’s companies established since 2001 had a failure rate of 14% and an acquisition rate of 17%. Between 1999 and 2019, quantitative investment information available for 113 out of the 513 known cleantech firms in Colorado shows that investment in that period was \$3.7 billion, of which \$3.1 billion was raised between 2009 and 2019.

Employment in Clean Energy

Colorado ranks 18th among the 50 states in employment in clean energy per capita. Its employment distribution is higher than or similar to US average in biofuels, wind energy, geothermal energy, conventional energy, energy storage, solar energy, and smart grid technologies⁶ (Figure 4-9). The presence of diversified energy resources and the consequent development of industry around different technologies explains the specialization in multiple energy technologies.⁶ The high employment in wind comes from deployment of wind turbines, the component manufacturing facilities set up by Vestas (Box 4-3), and the additional supply chain that they attracted. Employment in conventional energy is reported to be 40% of all energy jobs, compared to 50-states’ average of 31%.

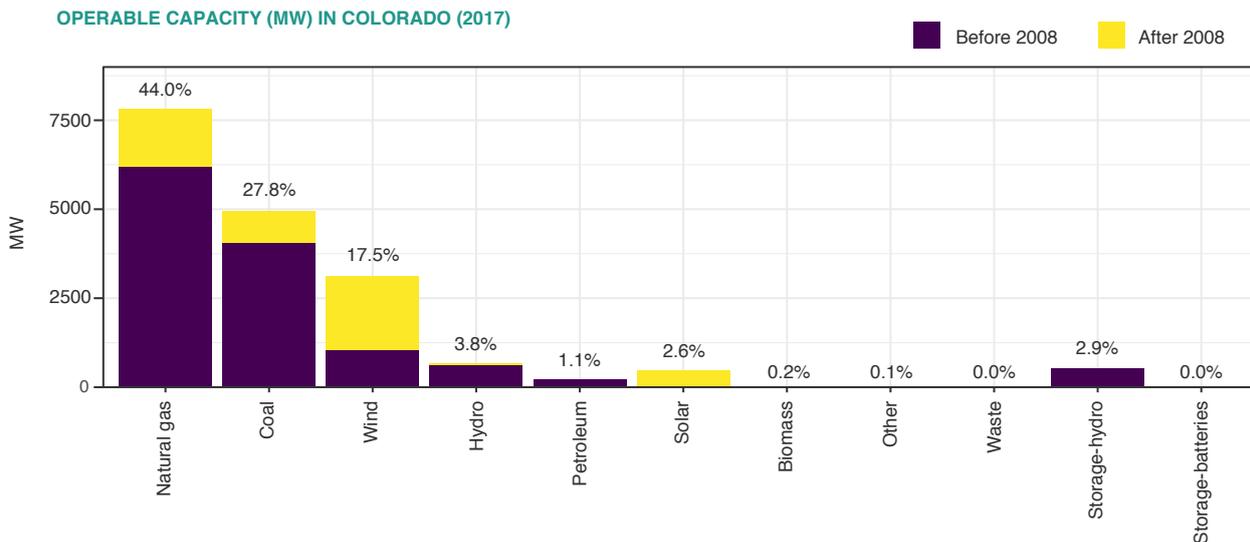
Figure 4-9: Estimated employment in energy in Colorado. Data source: USEER⁶



Deployment of Clean Energy Technologies and Impact on Decarbonization

In Colorado, 19% of electricity is generated from non-hydro renewables (12th highest among the 50 states in terms of percentage). However, 78% is still from fossil fuel sources (15th highest).¹² Between 2008 and 2017, 49.7% of new capacity additions were in wind and solar (ranking 25th among the 50 states in percentage terms and 11th among the 50 states in nameplate capacity terms) while 31.8% of new capacity additions were in natural gas (Figure 4-10). Additionally, a large coal-fired power plant came online in 2009-2010 (the supercritical coal-fired Comanche Unit 3). With 17.8 GW of total operable nameplate capacity in 2017, Colorado's installed capacity was dominated by natural gas (7.8 GW, 44.0%) coal (4.9 GW, 27.8%) and wind (3.1 GW, 17.5%)¹⁵

Figure 4-10: Operable power generation capacity in Colorado (based on nameplate capacity). Percentage totals show share of total operable capacity. In order to differentiate recent developments in power generation capacity, yellow bars show recent capacity additions while purple bars show capacity that was added before 2008. Data source: EIA¹⁵



Colorado's per capita energy-related emission reductions were ranked 25th in the US, reducing by 21.7% from 2005 levels compared to the 50-state average of 20% reduction.¹⁶ Without adjusting for population, which increased by about 20% since 2005, Colorado's energy-related emission reductions ranked 40th in the US, reducing by 7.5% from 2005 levels compared to the 50-state average of 13.4% reduction. Despite the successes in deployment of clean energy technologies in electric power generation (and the moderate-to-high ranking in energy efficiency discussed earlier), emissions reductions continue to be modest.

Past factors working against emissions reductions include strong population growth (~20%) with associated expanded electric power demand; a relatively stable, moderate-to-high level of energy use in the industrial sector that is difficult to decarbonize; and continued use of fossil-powered electricity generation.¹⁰⁹ In the future, dynamic changes in deployment-related policies and the utilities' aggressive Clean Energy Plan of 2018 mean that reduction in emissions is likely to accompany the benefits from clean energy RD&D strengths in the state.

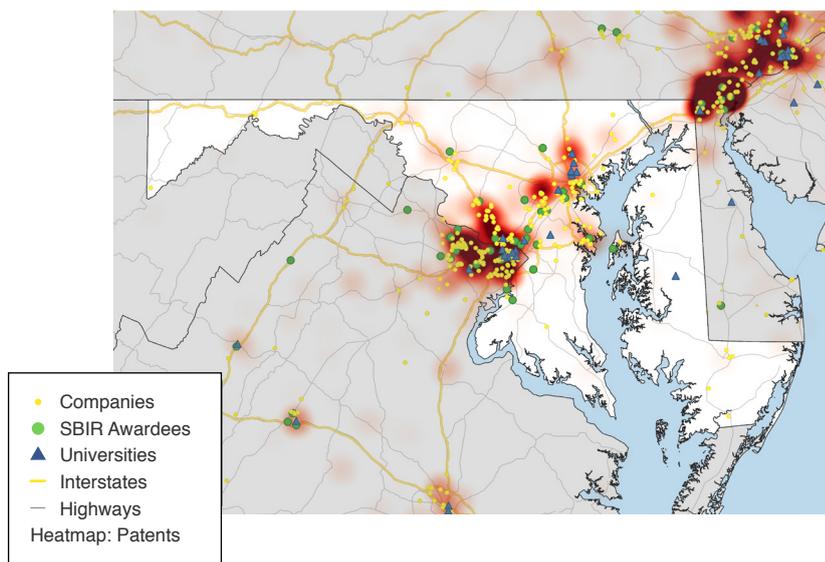
Chapter Five

MARYLAND: ENERGY AND ENVIRONMENT

The chapter shows how Maryland’s clean energy efforts have focused on the societal and environmental benefits of reducing electric power demand, providing cost savings from energy efficiency to consumers, and reducing emissions. Consequently, Maryland ranks among the top 10 states in terms of energy efficiency and emissions reductions and has a larger than average number of green jobs in the buildings energy efficiency sector, primarily in construction and service. However, state efforts on energy, until recently, were not linked to economic development goals. Maryland’s deployment of renewable power is low and renewable energy targets have been largely met with imports from neighboring states. The state’s number of cleantech companies per capita is below the expected number for states with similar strengths in innovation.

Maryland’s clean energy innovation activity is spread in and around the urban areas between Baltimore and the neighboring ‘DMV’ area (District of Columbia, Maryland, Virginia) (Figure 5-1). DC and Baltimore are connected by a continuous stretch of urban infrastructures and over 70% of Maryland’s companies are found between or around these two cities.

Figure 5-1: Clean energy innovation activity in Maryland is concentrated in and around urban areas connecting Baltimore with the neighboring Washington DC



Motivations for Clean Energy Innovation in Maryland

In Maryland, policies for the state’s climate, energy, and environment goals have not been strongly linked with broader efforts for economic development. In the past, the broad state energy priorities laid out by the governors have been explicit on reducing electricity prices, ensuring affordability, and improving energy efficiency rather than on using clean energy innovation as a component of economic development (Box 5-1). More recent efforts have added emphasis on expanding clean energy jobs and clean energy innovation.¹⁰⁷

Box 5-1: Maryland’s Governors’ priorities related to clean energy innovation

Governor Martin O’Malley (2007-2015) envisioned goals of “Defending Maryland Against Rising Energy Prices” including through energy efficiency and alternative fuels.¹¹⁰ His 2007 inaugural speech, mentioned that “the state has the possibility of becoming a world leader in the development of clean and renewable energy, alternative fuels, green building technologies and cleaner burning cars.”¹¹¹ His second term added new emphasis on advancing renewable energy and tapping into emerging technology such as offshore wind and electric cars.¹¹²

In this period, Maryland expanded its RPS goals, passed the Clean Cars Act in 2007, and passed the Maryland Wind Offshore Act in 2013. The Greenhouse Gas Emissions Reduction Act of 2009 set a statutory requirement to reduce emissions by 25 percent by the year 2020. The EmPOWER Maryland Energy Efficiency Act of 2008 established a goal to reduce per capita electricity usage and peak demand.

Governor Hogan (2015-current) targeted jobs, economic development, and retention of small business and families in the state. In 2018, he mentioned the expansion of the state’s climate change commission and stringent clean air standards, for example through the “Clean Cars Act” and supported clean and renewable energy solutions and green energy jobs within the state. Key policies were enacted recently in 2018-19, when the state joined the bipartisan United States Climate Alliance and passed the Clean Energy Jobs Act. The act requires 50% of electricity from renewables by 2030 and is expected to create solar and offshore wind jobs while reducing emissions. Maryland’s reliance on nuclear energy is reflected in the recent proposal of the Clean and Renewable Energy Standard (CARES) act, which sets a goal of 100% clean electric power by 2040.

The following sections explore the motivations and activities of key stakeholders in Maryland and the apparently under-developed linkages between economic development, energy and environment, and technology capacity.

Economic Development

This section highlights Maryland's existing economic strengths and correlated economic development priorities in the areas of health and biotechnology, national security, and related technologies and services. Many of Maryland's economic strengths support its strong innovation capabilities and technically oriented workforce.

Maryland's industry strengths are in health, national security, and related technologies, services

Maryland's industry concentrates in health and biotechnology, national security, defense-based industries, and service industries.⁷⁷ Many of these sectors have thrived because of the state's proximity to Washington, DC and the consequent presence of a large number of federal agencies and laboratories working in these areas. Employment in the federal government is disproportionately high because of the large number of federal office locations in the state.⁷⁷ Per 1000 jobs, 47.8 jobs in Maryland are civilian jobs in the federal government, compared to the US average of 14.8.⁷⁷ Similarly, employment in broadly-defined professional, scientific, and technical services is much higher than the US average, accounting for 97.6 jobs per 1000 jobs compared to the US average of 69.9.⁷⁷ This high employment in services encompasses the economy around federal contractors, including for information technology (IT) and cybersecurity, aerospace and defense. Finally, the presence of the National Institutes of Health (NIH) and the Food and Drug Administration (FDA) have bolstered a thriving biotechnology and life sciences industry.⁵⁷

The broad energy industry has historically not been a major contributor to Maryland's economy compared to other states or to other industries. The state ranks low in terms of primary energy production with low employment in the oil and gas extraction, mining, and quarrying sectors and low in-state renewables generation.^{v,8} However, Maryland's economy has somewhat benefited from the fossil fuel industry through the use of its port facilities in exports of coal and natural gas^w. In the future, Maryland has the potential to grow rapidly in offshore wind because of its location in the mid-Atlantic region.⁸² Details on employment in clean energy are presented later in this chapter.

While employment in farming, forestry, and fishing is overall lower than US average, these sectors are significant employers in rural non-metropolitan areas.⁷⁷ The economic (and environmental) impacts on these important industries has motivated stakeholders to engage in activities potentially related to clean energy innovation—for example, the Maryland Department of Natural Resources partners with the University of Maryland and the Environmental Protection Agency to run the Innovation Technology Fund supporting RD&D for restoration of the Chesapeake Bay, one of the state's most important natural resources.¹¹⁵ The Innovative Technology Fund has supported cleantech companies working on sequestering carbon dioxide and nitrous oxides using enhanced microalgal growth, enzymes for biofuels industries, etc.

^v In 2017, Maryland's energy production of 256 trillion Btu (including coal, nuclear, and renewable energy) was the 38th among US states.⁸ Maryland has low coal production (0.2% of the US total) and insignificant or no natural gas and crude oil production.⁷⁸⁻⁸⁰ Even though areas in Western Maryland are part of the Marcellus Shale formation, Maryland banned hydraulic fracturing in 2017 (HB 1325).

^w In 2018, the port of Baltimore was the second highest exporter of coal in the country.¹¹³ Similarly, Cove Point, a liquified natural gas shipping terminal in the Chesapeake Bay, became the second operating terminal in the country to export domestic LNG in March 2018.¹¹⁴

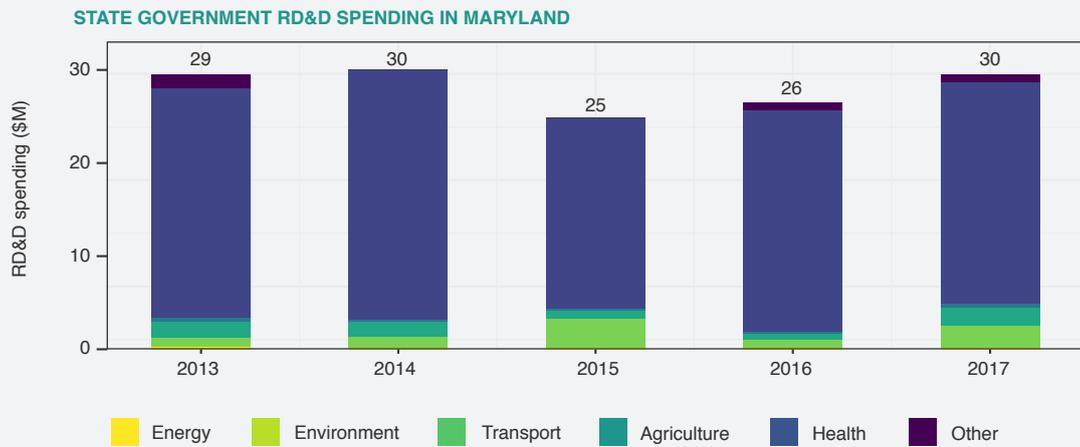
Historic Low Prioritization of Clean Energy Innovation in State Economic Development Planning

Maryland’s public agencies have historically not demonstrated any meaningful linkages between the state’s clean energy and economic development priorities. Maryland’s economic development programs run through the Department of Commerce (DOC) and the Maryland Technology Development Corporation (TEDCO). Until recently, these programs had not prioritized or targeted clean energy innovation (Box 5 2). Clean energy programs have run primarily through the Maryland Energy Administration (MEA).

Box 5-2: Maryland’s state government RD&D spending patterns

Maryland state government’s reported RD&D spending indicates a low prioritization of clean energy compared to other states (Figure 5-2). Maryland, on average, targets 85% of its RD&D funding to biotechnology and health. The state ranks 34th among 50 states in the fraction of state RD&D funding spent on energy (including both clean and fossil fuel-based energy), with 0.8% of total compared to the 50-state average of 7.7%. The state government’s reported RD&D spending demonstrates a clear prioritization on health which accounts for 85.1% of the total state spending compared with 19.6% average in all states.⁷ The state agencies that report spending on energy RD&D through general innovation programs include Maryland TEDCO and the Maryland Department of Natural Resources (see Appendix B).

Figure 5-2: Spending by Maryland state government in RD&D in different sectors. Data source: NSF⁷



DOC's economic development programs support growing companies in all sectors—for example, through Research and Development Tax Credits and the Enterprise Zone Program—and are therefore not specific to clean energy RD&D. While DOC's Agribusiness and Energy Program supports clean energy businesses, its actual amounts are unclear from reported data. DOC's purposeful support for innovation in other sectors—for example the Investment Tax Credits for Biotechnology—could potentially have spillover effects in advanced bioenergy. TEDCO promotes technology and technology-based economic development in the state. TEDCO is primarily supported through the state general fund, and also has revenue from external grants, royalties, and investment earnings. The largest fraction of its spending goes to biotechnology and life science companies and only about 4% of its budget is spent on clean energy.¹⁰⁷

Maryland also has two small public agencies that link clean energy with economic development.^x The Maryland Clean Energy Center (MCEC) was originally established in 2008 by the General Assembly as a non-budgeted entity, with the purpose of promoting economic development through clean energy by advancing the adoption of clean energy, energy efficiency products, services, and technologies—thereby focusing on early or late deployment. Since 2017, MCEC was provided additional authority to carry out convening and networking activities for the state clean energy industry. The Maryland Energy Innovation Institute (MEI²), signed into law in 2017, has been tasked to catalyze and develop clean energy technologies (in the RD&D stages) and facilitate the transfer of technologies into marketable products or services—for example through its seed awards for energy innovation.¹¹⁶

While the overall coordination between economic development and energy has been weak, there are some indications of an emerging positive trajectory (see Box 5-3).

Box 5-3: Examples of coordination between economic development and energy stakeholders for clean energy innovation in Maryland

- The MCEC holds an annual clean energy summit that convenes stakeholders involved in energy and economic development. MEI², MEA, DOC, and multiple other private sector stakeholders have participated in the summit in past years.
- Commercialization-oriented clean energy technologies that receive seed grants from MEI² are vetted in a competitive process involving experts from TEDCO and the state's university system
- The Maryland Offshore Wind Energy Act of 2013 emphasized both in-state electricity generation and in-state employment during the development, construction, and operating phase of offshore wind projects to be incentivized by the state.¹¹⁷

^x The joint budget for these two agencies, Maryland Clean Energy Center and Maryland Energy Innovation Institute, is \$1.5 million per year.

Energy and Environment

Maryland's energy and environment related policies and programs are linked to energy efficiency, affordability, and climate change. The effects of climate change experienced in the state are one of the driving factors for clean energy activity.^{118,119} The impacts Maryland is experiencing include sea level rise, increased water temperature, and heavy rains and flooding. These impacts have affected local communities while also hindering efforts for conservation and restoration of the Chesapeake Bay.¹¹⁸

Two major policy-led efforts represent the state's clean energy activities—these are the EmPOWER Energy Efficiency and Conservation program, participation in the Regional Greenhouse Gas Initiative (RGGI), and the state's RPS (see Box 5-4 and Box 5-5). RGGI and RPS related activities fund the Strategic Energy Investment Fund (SEIF).^y As discussed below, the implementation of these policies involves a large number of stakeholders whose activities highlight an overwhelming emphasis on deployment. While there are no clear linkages or incentives for RD&D in the state, there is some evidence of support for early deployment and market formation.

Box 5-4: Summary of Maryland's Renewables Portfolio Standard⁸⁹

Maryland first enacted its RPS in 2004—initially setting a goal of 7.5% from non-hydro renewables by 2019 that has been revised multiple times in subsequent years. The RPS includes notable technologies that align with the state's resources—it includes not only solar and wind, but also technologies like poultry-litter incineration, and specific goals for offshore wind. In the update in 2017, the legislative assembly increased the state's renewable portfolio standard from previous 20% by 2022 to 25% by 2020. The RPS was revised to 50% in 2019.

Goals (by 2030): In 2019, the legislature passed the Clean Energy Jobs Act which sets new ambitious targets for 50% of electricity from renewable energy by 2030 and assess steps needed to reach 100% clean energy by 2040. The 50% RPS includes 14.5% solar and aims to add at least 1,200 MW of offshore wind.

Eligible technologies: Tier 1: solar, wind, biomass, anaerobic decomposition, geothermal, ocean, fuel cells powered through renewables, small hydro, poultry-litter incineration facilities, and waste-to-energy facilities, and Tier 2: hydroelectric power other than pumped storage.

Compliance: Renewable energy credits (RECs) are used for compliance. Failure to comply results in 'alternative compliance payments' that feed the Maryland Strategic Energy Investment Fund (SEIF).

^y Spending from EmPOWER and SEIF related programs in clean energy deployment (at the market growth stage) averaged \$269 million annually from 2014-2018 (see Appendix A)

Box 5-5: Utility programs in Maryland for energy efficiency and renewable energy

Maryland has two major energy efficiency and renewable energy deployment programs that dominate its clean energy activities. Multiple agencies are involved in the implementation.

The **EmPOWER** Energy Efficiency and Conservation program, established in 2008, is funded through surcharges on electric power to meet energy efficiency goals. EmPOWER incentivizes the purchase and use of efficient appliances, HVAC systems, lighting, and building efficiency, etc. EmPOWER programs are managed by utilities: Baltimore Gas and Electric Company (BGE), Potomac Edison Company (PE), Delmarva Power & Light (Delmarva), Potomac Electric Power Company (PEPCO), Southern Maryland Electric Cooperative, Inc. (SMECO), and Washington Gas Light Company (WGL).

The **Strategic Energy Investment Fund (SEIF)** is derived primarily from auction revenues of the **Regional Greenhouse Gas Initiative (RGGI)**, with additional inputs from RPS alternative compliance payments, and other payments to the state related to energy, such as settlements related to PSC issues. Maryland participates in RGGI with 10 other states in the east and north-east United States. RGGI, effective in 2009, is a market-based program to cut greenhouse gas emissions that issues allowances, sets up mechanisms for regional CO₂ allowance auctions and limits emissions of CO₂ from electric power plants. In addition, it set up statutory goals in 2009 to reduce emissions. RGGI non-compliance payments feed into the SEIF and are used for the deployment of various clean energy technologies through multiple agencies.

The Maryland Public Service Commission (PSC) provides oversight of delivery of customer benefits and state-wide efficiency outcomes and sets regulation to implement policies. The Maryland PSC oversees the EmPOWER program that is delivered by Maryland's utilities and the Maryland Department of Housing and Community Development (DHCD) (Box 5-5). While it has created market-demand for mature energy efficient products and thus increased deployment, the program has no incentives for products manufactured in-state.

The SEIF is funded primarily from RGGI along with compliance failure payments from the state's RPS. Slightly less than half of the SEIF budget goes to the Maryland Energy Administration or MEA (42.8% in 2018) (Box 5-5). MEA's mission is to promote affordable, reliable and cleaner energy. Some of MEA's programs, such as the Clean Energy Communities Low-to-Moderate Income Grant Program and the Smart Energy Community Program focus on expanded deployment of clean energy technologies that are well established commercially. Other programs reveal expanded benefits from combining established technologies, such as the Net-Zero Energy Schools and Community Solar and Community Wind programs. Programs for offshore wind, transportation, and combined heat and power support early deployment or market formation stages.

Besides MEA, many other agencies receive SEIF funding to help implement program goals.² Examples include the Maryland Department of the Environment (MDE) that oversees the Climate Change Program and the Maryland Department of Agriculture (MDA) that manages the Animal Waste Technology grant. Finally, as discussed earlier, the Department of Natural Resources supports clean energy innovation RD&D primarily under the motivation for restoring the Chesapeake Bay.

Maryland's RPS compliance has largely been met with generation deployed outside of the state. In 2017, only around 25% of the RPS requirement was met with in-state deployment.¹⁷ While over 9 TWh of generation was required for RPS compliance in 2017,⁶⁰ solar, wind, geothermal, and biomass power generation in the state was around 1.4 TWh.¹² Some technologies, i.e., solar energy, geothermal, poultry litter-to-energy, waste-to-energy, or refuse-derived fuel, are required to connect to the state's distribution grid, effectively ensuring some in-state generation (examples of supporting incentives include the Residential/Commercial Clean Energy Rebate Program, Animal Waste Technology grant, etc.). But beyond these requirements, utilities that operate in Maryland have had little incentive to innovate or engage with local innovators since there is plentiful renewable power available from other states in the regional transmission organization's (or PJM's) territory. And while MEA uses the alternative compliance payments to fund programs that create incentives for the purchase of advanced energy technologies, there is no mechanism in place to prioritize the use of technologies developed in-state for economic development purposes.

Maryland's different policy mechanisms have aimed to generate deployment of clean energy technologies at the market growth or late deployment stage, and in some cases for technologies at the early deployment stage. However, these policies have largely not been paired with economic goals for development of in-state clean energy firms or for local RD&D. Maryland's recent small economic development investment in early stage clean energy technologies (through MEI²) will benefit in the future by greater coordination with MCEC and with the much larger emphasis on deployment designed to meet RPS, RGGI, and EmPOWER goals.

² These agencies include the Maryland Department of the Environment (MDE), Maryland Department of Transportation (MDOT), Maryland Department of Agriculture (MDA), the Department of License and Labor Regulation (DLLR), and the Department of Housing and Community Development (DHCD). The MDE oversees the Climate Change Program and MDE offers the Energy-Water Infrastructure Program (EWIP). MDOT administers an excise tax credit for qualifying plug-in electric drive vehicles and participates in Maryland Electric Vehicle Infrastructure Council. The MDA manages the Animal Waste Technology grant. The DLLR administers the Employment Advancement Right Now (EARN) Maryland Green Jobs Initiative. DHCD implements the Multifamily Energy Efficiency and Housing Affordability Program, the Weatherization Assistance Program and the Energy Efficient Homes Construction Loan (Net Zero Homes) Program. DHCD also implements the EmPOWER low-income programs.

Technology Capacity

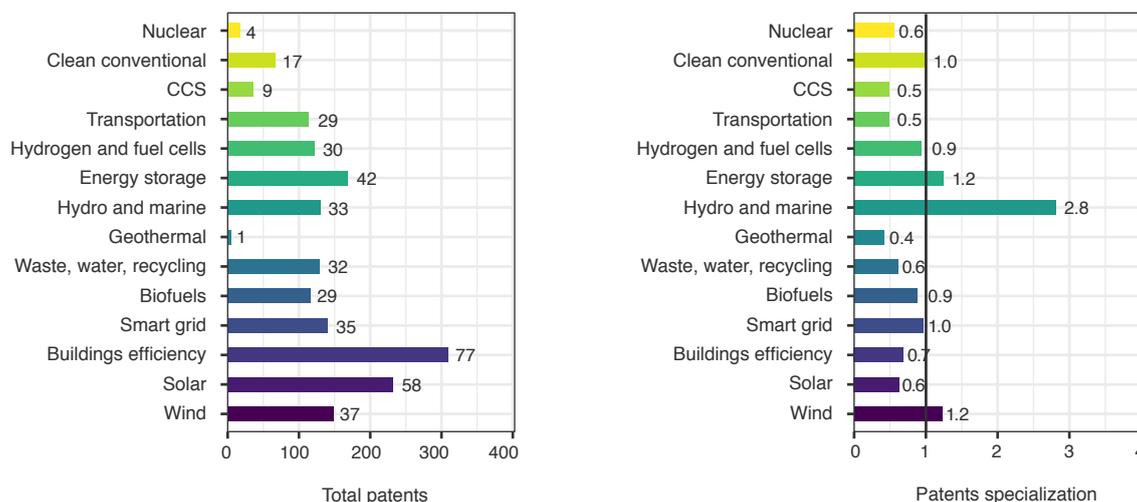
This section discusses some aspects of Maryland's technology capacity to innovate in clean energy. The state is strong in overall RD&D activity and has a highly educated workforce. However, support for RD&D activity is dominated by IT, biotechnology, and national security rather than clean energy. Nonetheless, the state has the potential to strengthen its clean energy innovation RD&D given the state's strong human capital and strong societal commitment to clean energy and the environment.

Strong capacity for innovation overall but less focus on clean energy

Using patents as one of the indicators for innovation activity, Maryland ranks moderate-to-low (33rd among the 50) states in terms of patents in clean energy per million population (using fractional counts of inventor location, see Appendix A for methodology). Inventors resident in the state had a total of 434 clean energy patents compared to the 50-state average of 825 in the decade between 2007 and 2016. 168 of the 434 patents were from Maryland based organizations (i.e., patent assignees), with some notable examples in the different universities (31 patents), large organizations such as Lockheed Martin (10 patents), and startups or small businesses such as Differential Dynamics (21 patents) and Current Technologies (10 patents). In per capita terms, Maryland had 72 clean energy patents per million people, compared to the 50-states average of 112 clean energy patents per million people.¹¹ In absolute terms, patenting activity by local inventors has been highest in buildings efficiency, solar energy, and energy storage (Figure 5-3). However, in terms of the technology specialization metric where the US average is represented by 1, Maryland's patenting is above or similar to the US average in hydro and marine, energy storage, and wind energy technologies.

Figure 5-3: Climate mitigation patents in Maryland (2007-2016), based on fractional counting of the location of inventors (see Appendix A). Data source: USPTO¹¹

PATENTING ACTIVITY IN MARYLAND



Patent data is a lagging indicator of RD&D activity (see Chapter 2) and may not accurately represent the current status of clean energy innovation in a dynamically evolving research and policy landscape in the state. Maryland's historical lack of focus on clean energy as an economic development activity, mentioned above, is a factor in the moderate-to-low performance in clean energy patenting. Other factors suggest a positive trend in clean energy innovation activity in the state.

First, Maryland's university system is strong and has a legacy of research in science and engineering. Overall, 40% of all degrees awarded (i.e., bachelor's, master's, and doctoral degrees) are in science and engineering, higher than the US average of 31%.⁹⁴ Two major science and engineering doctoral-granting universities have highly regarded research programs⁹⁵—Johns Hopkins University and the University of Maryland, College Park (UMCP) pointing to strong RD&D capacity (Table 5-1). These universities have a growing focus on innovation, for instance in University of Maryland's UM Ventures,¹²⁰ Johns Hopkins Technology Ventures,¹²¹ and the MEI² hosted at UMCP but supporting cleantech companies across the state.¹²² The universities are associated with an increasing number of startups, some in the clean energy sector. However, these trends are relatively recent and will not be apparent in the data on granted patents alone.

Table 5-1: Ten research universities in Maryland grant doctorates in science and engineering fields of study (defined by NSF to include life sciences, physical sciences and earth sciences, mathematics and computer sciences, psychology and social sciences). Source: NSF⁹⁴

Doctoral degree granting institutes in Maryland	Number of doctorates in science and engineering (2017)
Johns Hopkins U.	456
U. Maryland, College Park	437
U. Maryland, Baltimore County	87
U. Maryland, Baltimore	80
Uniformed Services U. of the Health Sciences	23
Morgan State U.	17
Towson U.	15
U. Maryland, Eastern Shore	6
Loyola U., Maryland	4
Bowie State U.	3
Nation-wide university average	97

Second, the sizeable federal RD&D activity in the state is overall not strongly linked to clean energy RD&D. There are over 65 federal research infrastructures in Maryland alone and even more in neighboring Washington DC and Virginia (Table 5-2).^{98,99} This federal activity is largely related to health or biotechnology, cybersecurity, and national security with some small but potentially meaningful linkages to clean energy issues—examples include using biotechnology expertise to advance energy technologies or helping advance energy technologies through a first niche market related to national security such as in energy storage. Stakeholder interviews indicate that some individual innovators and researchers have collaborated with these available research infrastructures (e.g., US Department of Agriculture and Army Research Laboratory), especially for energy storage, fuel cells, and agriculture related technologies that are all linked to clean energy innovation. Such interactions may expand in the future with the MEI² supporting commercialization from the state’s universities and the MCEC now expanding its convening and networking function.

Table 5-2: Federal or federally supported research institutions with some level of activity related to energy and environment in Maryland. Source: NSF and Federal Laboratory Consortium.^{98,99}

Notable federal research infrastructures with programs related to energy and environment
Army Research Laboratory (ARL)
Center for Information Technology (CIT)
Johns Hopkins Applied Physics Laboratory
NASA Goddard Space Flight Center
National Institute of Standards and Technology (NIST)
National Center for Advancing Translational Sciences (NCATS)
National Oceanic and Atmospheric Administration (NOAA)
National Centers for Coastal Ocean Science
National Security Agency (NSA) Technology Transfer Program
Office of Research Services (ORS)
U.S. Army Center for Environmental Health Research
U.S. Food and Drug Administration (FDA)
USDA Agricultural Research Service (ARS)

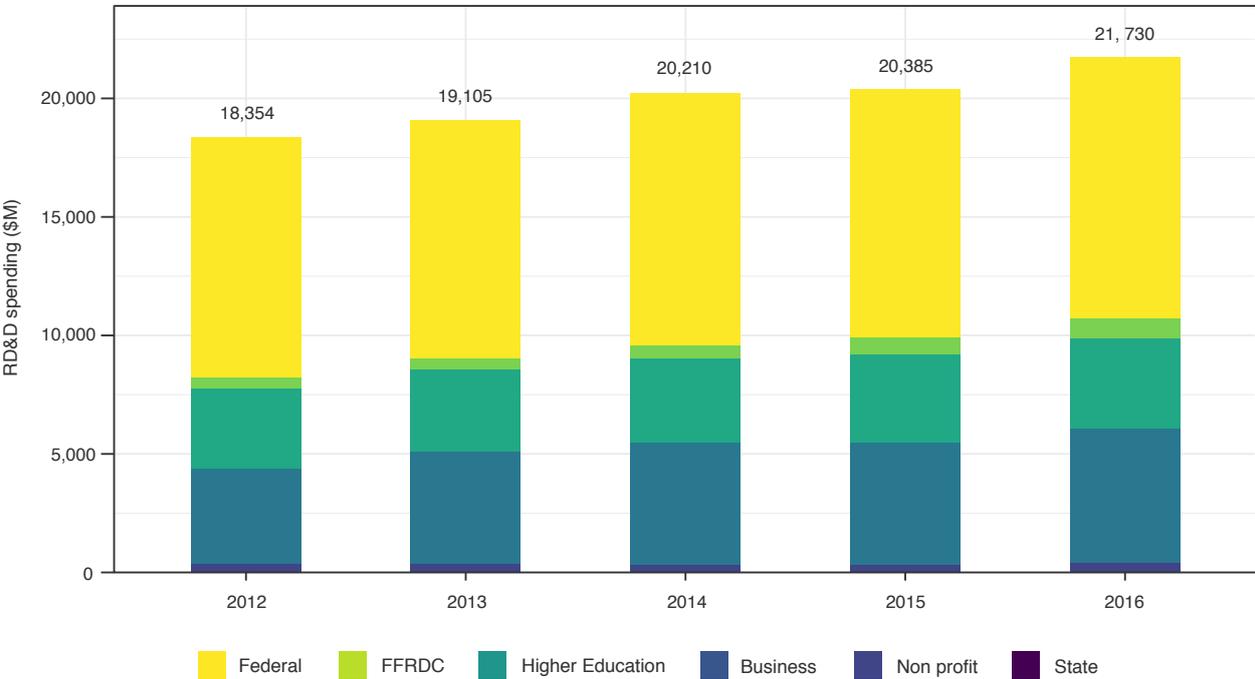
Third, the state has a strong technology-trained workforce and the adult population strongly supports clean energy RD&D.¹²³ The state’s workforce is highly educated because of the service-oriented economy (and the research universities and labs) that trains local residents and also leads to in-migration of highly educated people from other states^{aa}. In parallel, 88 percent of the state’s adult population supports RD&D in clean energy, 3 percentage points above the US national average.^{123,124} These factors provide an opportunity for the state to increase workforce engagement in clean energy RD&D.

Local Public and Private Financing for Early-Stage Clean Energy Technologies

The overall RD&D performed in Maryland has been \$20.0 billion (annual average), significantly higher than the 50-states average of \$8.9 billion.¹⁰⁶ Over half of the funding is spent in federal agencies (Figure 5-4).

Figure 5-4: RD&D performed in Maryland, representing where money is spent. Data source: NSF¹⁰⁶

RD&D SPENDING BY PERFORMING SECTOR IN MARYLAND



^{aa} Among the population over 25 years of age, 21% of people have a bachelor’s degree (compared to US average of 19.1%) and 18% have a graduate or professional degree (compared to US average of 11.8%).¹⁰⁹ An estimated 54,000 in-migrants with a bachelor, graduate, or professional degree moved in from a different state in 2016 (ranking 14th in the US in absolute terms).¹⁰²

Maryland's clean-energy RD&D stakeholders in universities and businesses have been able to attract moderate-to-high levels of federal awards. DOE spending on energy RD&D in Maryland (Figure 5-5) is moderate-to-high as Maryland ranks 21st among the 50 states in per capita DOE energy RD&D grant awards, based on primary location of performance.⁶⁴ Maryland also ranks 21st in per capita SBIR funding from 2008-2017.¹⁰ The state's SBIR patterns indicate the highest awards in biofuels, buildings efficiency, and wind energy (Figure 5-6). However, there is no particularly strong relative specialization in the SBIR funding received in the state.

Figure 5-5: Department of Energy's RD&D-related grants awarded in Maryland (by year of award and by location of performance). Data source: USASpending⁶⁴

DOE RD&D GRANT AWARDS IN MARYLAND

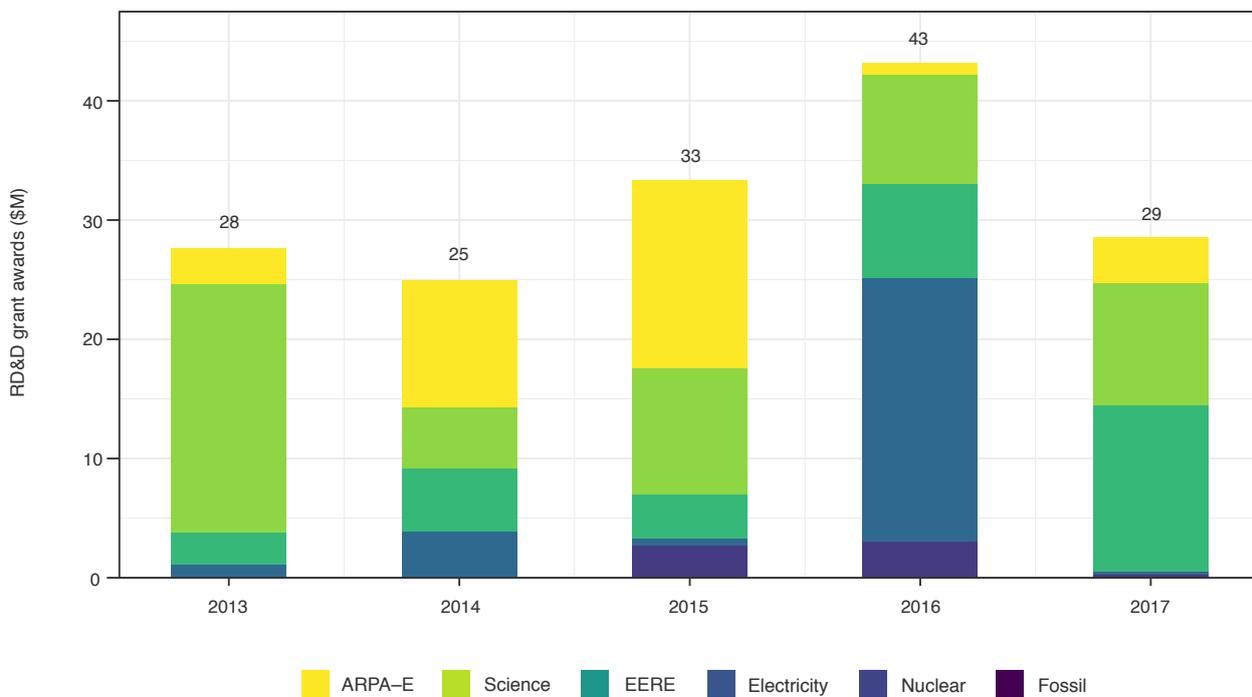
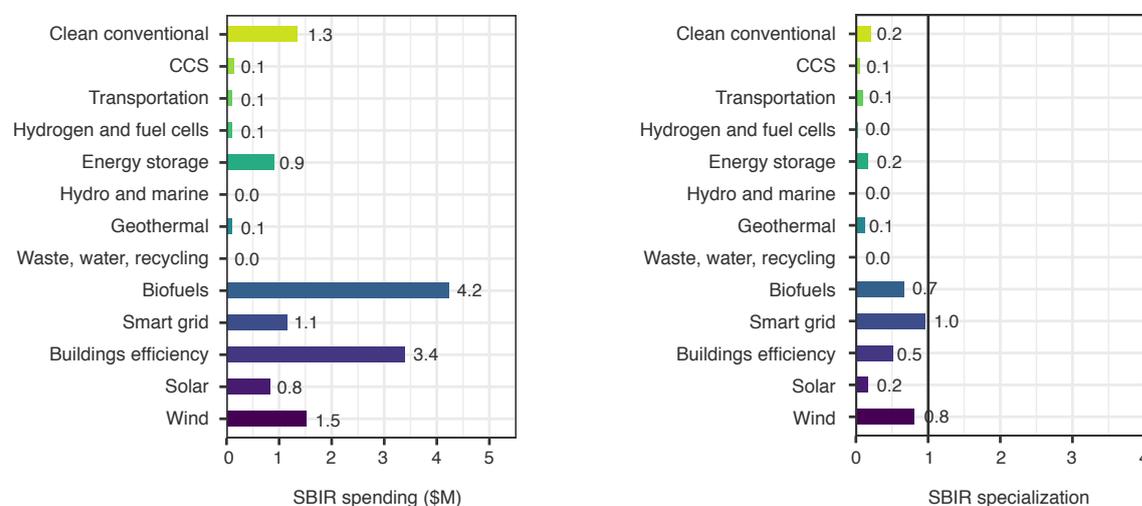


Figure 5-6: Estimated clean energy-related SBIR awards in Maryland (by all federal agencies except the Department of Defense)¹⁰**CLEAN ENERGY SBIR AWARDS IN MARYLAND**

The state government provides some support for clean energy innovation and local cleantech startups, but the government spending patterns indicate a relatively low prioritization of clean energy (Box 5-2). Nonetheless, a detailed analysis¹⁰⁷ of Maryland's state-level public spending in clean energy reveals over \$310 million spending in the different stages of clean energy innovation, with less than 1% of the total spending, i.e., around \$2 million, in the early RD&D stages of clean energy innovation (Table 5-3, see Appendix A).

Table 5-3: Summary of Maryland's state government spending on clean energy innovation¹⁰⁷ (see Appendix A for methodology).

Technology innovation stages	Average annual	Average annual per capita (population 6.04 million)	Percentage
Late Deployment (market growth)	\$281 million/yr	\$47/year	90.6%
Early Deployment (market formation)	\$27 million/year	\$4.47/year	8.71%
Demonstration (and proof of concept)	\$0.98 million/year	\$0.16/year	0.32%
Research and development (R&D)	\$1.02 million/year	\$0.17/year	0.33%
Total	\$310 million/year	\$51.32/year	

State spending on clean energy RD&D (corresponding to rows for R&D and demonstration in Table 5-3) comes from TEDCO, Maryland Industrial Partnerships, and (beginning 2018) MEI².

TEDCO is the state government’s main technology-based economic development agency, and it supports both biotechnology-specific programs and some technology-neutral programs. Some of TEDCO’s funding programs, such as the Maryland Innovation Initiative,^{bb} Technology Validation Program, and TEDCO & NIST Science and Technology Entrepreneurship Program (N-STEP) program are designed to move research conducted in Maryland onto a commercialization pathway. Other programs help the early commercialization of new technologies, such as Maryland Venture Fund, Technology Commercialization Fund, and Rural Business Innovation Initiative. Over a 5 year period, an average 4.1% of TEDCO’s overall expenditures of \$22 million/year have been spent on in-state clean energy technologies¹⁰⁷ (see Appendix A).

At the university level, technology-neutral state funding has been available for innovation programs through the Maryland Technology Enterprise Institute’s (Mtech) Maryland Industrial Partnerships (MIPS). MIPS provides seed funding for research at the host university with significant matching funding requirement from the company partner. Beginning in 2018, MEI² has provided seed funding for university-related cleantech companies.¹⁰⁷ In 2018 and 2109, MEI² provided seed funding to 5 companies at UMCP and 2 companies in other in-state universities.¹¹⁶

Similar to the state government, the private investor community in Maryland has been slow to invest in cleantech. Between 2014 and 2018, publicly available information reveals only two venture capital investors located in Maryland that have invested in in-state cleantech companies¹ (Table 5-4). Stakeholder interviews emphasized the lack of local private investors. However, they also noted that a key local stakeholder is The Abell Foundation, a private foundation that has supported several cleantech companies. It supports early-stage companies with “technologies that offer attractive returns and environmental and social benefit” and are either located in or willing to locate to Baltimore. The absence of private investment is compounded due to lack of incentives for investors in clean energy—the Biotechnology Investment Incentive Tax Credit and the Cybersecurity Investment Incentive Tax Credit provide income tax credits equal to 50%, but they are not intended to apply to cleantech companies.

Table 5-4: Examples of investors located in Maryland that have supported local cleantech companies

Type of investor	Examples of investors located in Maryland
Public Sector or Quasi-public	Maryland Energy Innovation Institute, Maryland Clean Energy Center, Maryland Technology Development Corporation
Venture Capital	ABS Capital Partners Greenspring Associates
Family Office / Foundation	Abell Foundation

^{bb} Qualifying Universities for these funds are Johns Hopkins University, University of Maryland College Park, University of Maryland Baltimore County (UMBC), University of Maryland Baltimore, Morgan State University

Stakeholder interviews also suggest that, despite the absence of local investors, one factor that has helped some successful cleantech companies bring in early stage investment is the state's location and transportation infrastructure. Maryland is well positioned in terms of transportation and connection to DC and the Northeast industrial corridor, through the interstate system, three major airports, and railway infrastructures. These have helped startups reach investors in innovation clusters elsewhere (e.g., in New York or Silicon Valley) and reach markets across the country and the world.

Outcome Metrics for Clean Energy Innovation in Maryland

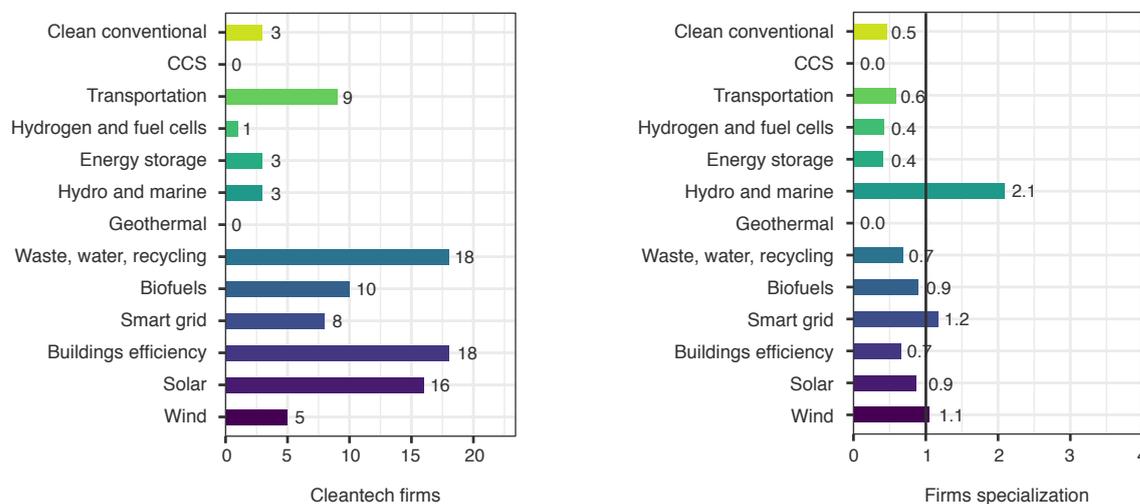
Maryland's activities to support clean energy have focused on the deployment stage, which can, in principle, motivate clean energy innovation by creating market-pull for new products. However, the state's clean energy programs have not directly incentivized in-state companies, leading to mixed economic development outcomes. Specifically, the state has above average employment in the clean energy building sector (concentrated in installation and service jobs), but only moderate presence of innovative cleantech firms. Maryland has had relatively high energy efficiency gains which yields consumer benefits and supports emissions reduction. However, in-state renewable power generation and its associated employment benefits have lagged.

Cleantech Firms

Maryland ranks 25th among 50 states in the number of cleantech firms per capita, estimated from a standard industry database (the i3 cleantech database¹). Maryland has 94 cleantech firms listed in the standard database compared to 50-states' average of 141. In per capita terms, Maryland has 16 cleantech firms per million people compared to the US average of 18 cleantech firms per million people¹ (See Figure 5-7).

Figure 5-7: Estimated number and specialization of cleantech firms in Maryland from a standard database. Data source: i3¹

CLEANTECH FIRMS IN MARYLAND



Maryland's distribution of cleantech firms reveals slightly above-average participation in wind energy and in smart grid technologies, as well as relative strength in hydro and marine power generation (see Appendix A). The evidence on the importance of hydro and marine energy is weak given that there are only 3 companies. The relatively high number of firms in buildings efficiency and solar could potentially be a consequence of the demand generated by aggressive deployment policies—but the absence of specialization relative to other states reinforces the findings on moderate RD&D activity from both patent and SBIR data. In absolute terms, the highest number of cleantech firms are in buildings efficiency, waste-wastewater and recycling, and solar (see Box 5-6 for examples of cleantech firms).

Box 5-6: Maryland's cleantech firms

Examples of Maryland's standout cleantech startups highlight the diversity that has developed in clean energy innovation in the state

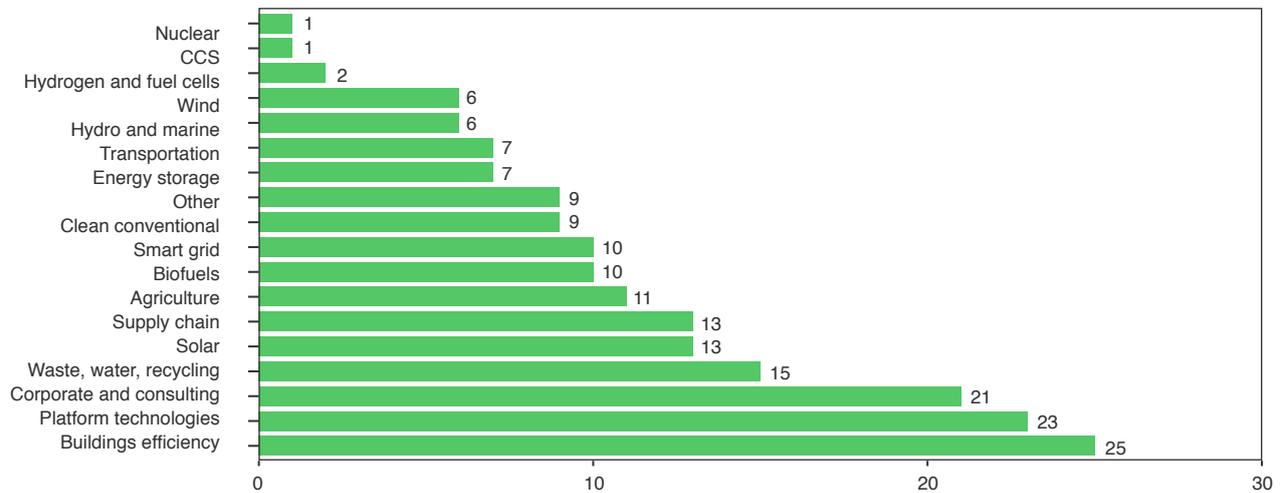
- **Plant Sensory Systems** is a young firm that is expanding deployment of its advanced bio-agricultural technologies that reduce the need for energy-intensive pesticides or fertilizer and improve crops that are feedstocks for the bio-energy industry. The firm has been supported by incubation at UMBC, by DOE and NSF awards, by interactions with USDA, and has attracted private sector investors who have benefited from the Biotechnology Investment Incentive Tax Credit. The company has developed partnerships on the Eastern Shore and in Frederick. It also has developed relationships for licensing production to firms in other states and internationally.
- **Ion Storage Systems** is a young firm that is commercializing an innovative solid-state battery technology that solves battery safety concerns and increases the amount of energy a Li battery contains by 50%. The new technology is based on innovation by a UMCP team, leveraging \$13M in federal funds to date. The development team progressed through patenting, obtained commercialization funding from DOE, NASA and Lockheed Martin, and established supply chain partnerships with other Maryland firms. It has obtained Stage A Venture funding of \$8M and is establishing its first production capability in an MEI²/MTECH incubator.
- **ETCH, Inc.** is a startup developing a clean and economical approach to producing hydrogen as an alternative to fossil fuels, using an innovative concept developed at Johns Hopkins University. The production method delivers valuable side products – solid carbon, heat, and water, along with hydrogen gas. The value of this new approach has been demonstrated through techno-economic analysis and market analysis. The firm was recognized as a finalist in the COSIA ARCTIC Natural Gas Decarburization Challenge and has recently received an ARPA-E award of \$3.7M for proof of concept and early commercial development.
- **Invent Wood** is a startup that is developing wood-based products that are strong and long-lived enough to replace energy-intensive building materials such as steel and concrete. The company is using innovative concepts developed at UMCP. Their research publications on their new wood products such as transparent wood, super wood and cooling wood have attracted international interest, and led the team to establish their startup firm. The firm is part of a ~\$4.0M ARPA-E award for scaling up and commercializing super wood led by the PI at University of Maryland, and also received ~ \$1.25M SBIR funding from USDA and the DOE Building Technology Office (BTO).

A deeper analysis of the cleantech firms in Maryland reveals that the number of cleantech firms from the standard i3 database, used in the rest of this report for comparison across all fifty states, is conservative. Accessing additional data sources and analyzing each firm in detail reveals at least 189 firms that engage in clean energy (Figure 5-8). The expanded data set also reveals a broader range of clean energy technology approaches, including three new areas—i.e., platform technologies, corporate consulting, and supply chain, where there is evidence of companies working on clean energy while also supporting other sectors. It is likely that some of these new areas are related to the emphasis on energy efficiency, with a high number of service jobs and spillovers from other technology areas that can apply to clean energy (in a state that is strong in RD&D overall).

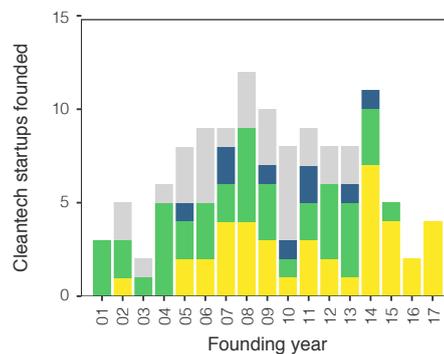
Because such detailed data is not available for all states, this report has used the standard database estimate (94) and the standard technology classifications (Appendix A) when comparing cleantech firms in Maryland with the 50 states.

Figure 5-8: (a) The estimated number of cleantech firms in Maryland from the expanded database, (b) the progression of cleantech startups over time (i.e., the 2019 status of firms versus the year in which they were founded), and (c) the investment history of cleantech firms relative to the year of their founding (i.e., level of investments versus the age of the companies). (See Appendix A)

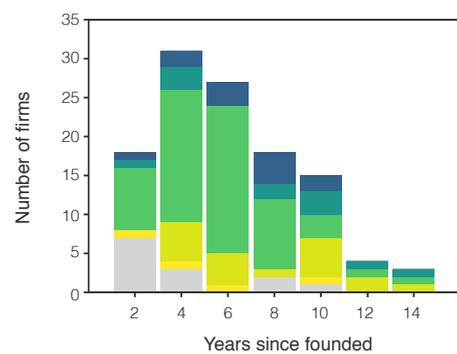
(a) EXPANDED ASSESSMENT OF CLEANTECH FIRMS IN MARYLAND



(b) PROGRESSION OF CLEANTECH STARTUPS IN MARYLAND



(c) INVESTMENT HISTORY OF 62 MARYLAND COMPANIES



Firm status in 2019

- Fundamental R&D / Startup
- Acquired
- Mature
- Closed

Investment levels per firm

- >100M
- 20M-100M
- 10M-20M
- Amount unknown
- 1M-10M
- 100k-1M
- 1-100k

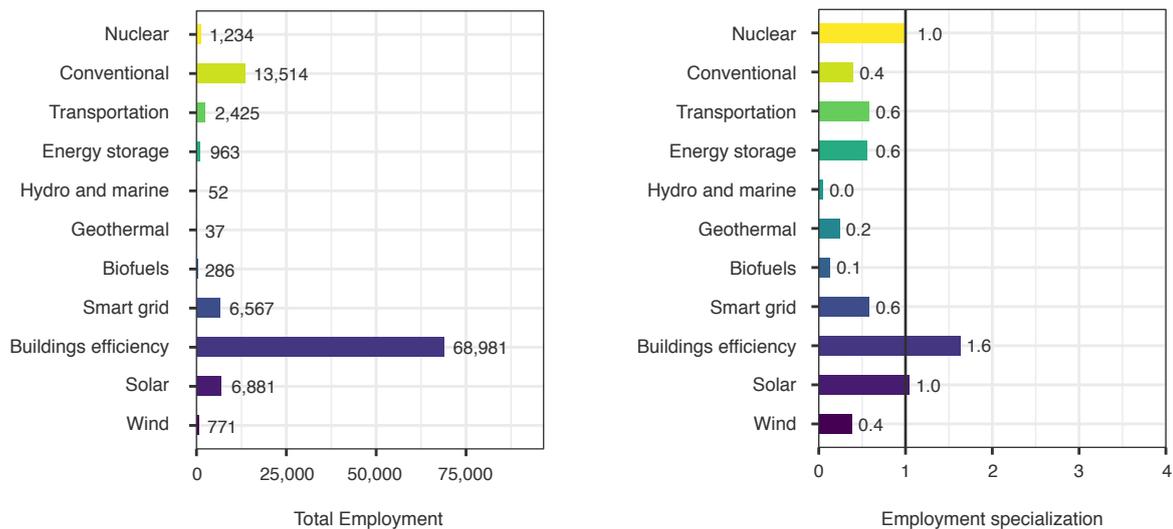
The detailed dataset also reveals that the progress of Maryland’s cleantech firms from early RD&D to maturity or acquisition has been rather erratic (Figure 5-8). Maryland companies established since 2001 have a failure rate of 24% and only 7% of companies have been acquired. Between 1999 and 2019, quantitative investment information on 44 out the 189 known cleantech firms in Maryland shows that investment raised in that period was \$0.90 billion, of which \$0.79 billion was raised between 2009 and 2019.

Employment in Clean Energy

Maryland ranks 12th among the 50 states in employment in clean energy per capita, primarily due to employment in buildings efficiency. Its employment distribution is higher than or similar to the US average in buildings efficiency, solar, and nuclear technologies⁶ (Figure 5-9). The dominant employment in buildings efficiency is likely related to the vast resources that have gone into the EmPOWER program and its goals of increasing energy efficiency. Similarly, employment in solar is comparable to US average, related to the demand creation for residential and commercial solar power from the SEIF and the RPS with its carve-out requirement for connection to the distribution grid within the state. The employment in nuclear is because of the state’s nuclear power plant—Calvert Cliffs. Of all energy jobs, employment in different forms of conventional energy is approximately 13% compared to 50-states’ average of 31%.

Figure 5-9: Estimated employment in energy in Maryland. Data source: USEER⁶

ENERGY EMPLOYMENT IN MARYLAND

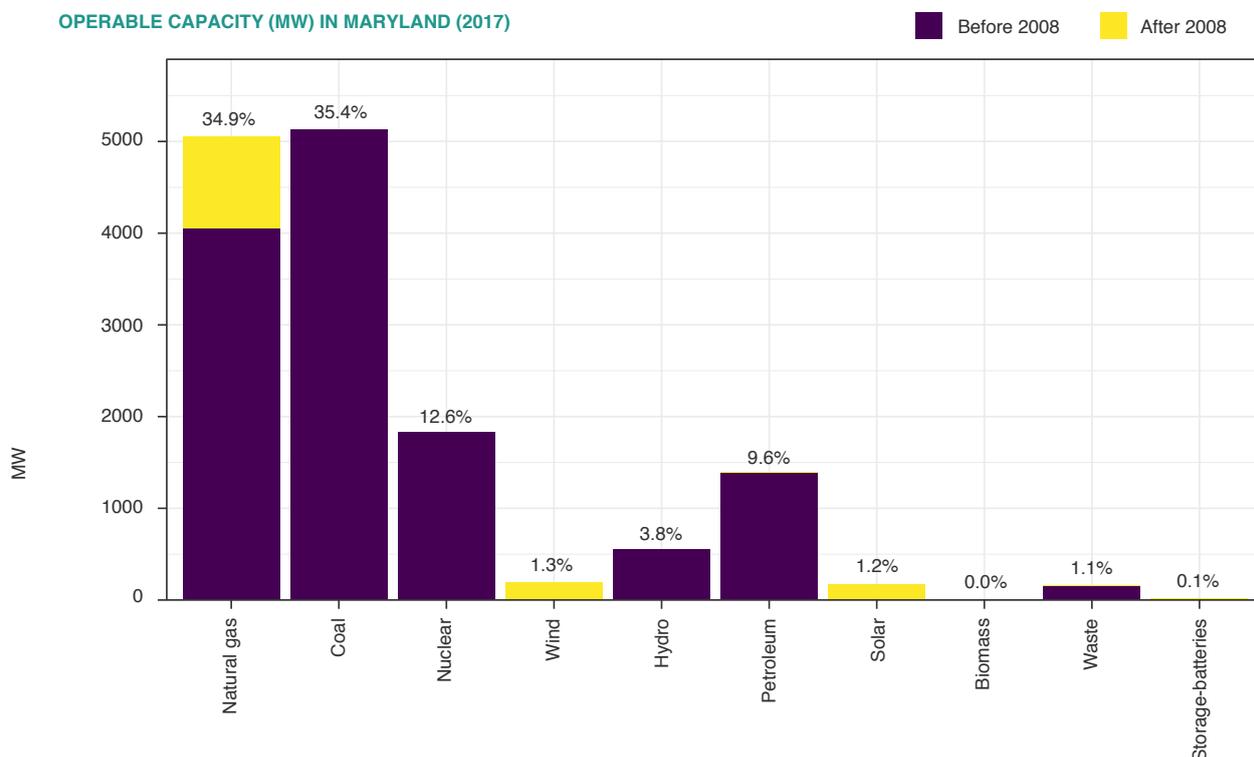


Deployment of Clean Energy Technologies and Impact on Decarbonization

In Maryland, up to half of electrical power consumption has been provided by imports from other states in the mid-Atlantic PJM regional transmission organization in the last years.¹²⁵ Of the electricity generated in state, in 2017 only 4% was from non-hydro renewables (ranking 34th among the 50 states in terms of percentage) and 46% from fossil fuel sources (ranking 38th), with 44% from nuclear energy.¹² Between 2008 and 2017, 26% of new capacity additions (greater than 1 MW) in Maryland were in wind and solar (ranking 34th among the 50 states in percentage terms and 36th in among the 50 states in nameplate capacity terms), while 72% were in natural gas (Figure 5-10). With 14.5 GW of operable capacity in 2017, Maryland's installed capacity was dominated by coal (5.1 GW, 35.4%)^{cc}, natural gas (5.1 GW, 34.9%, including 0.7 GW that came online in 2017), and nuclear (1.8 GW, 12.6%).¹⁵

The relatively low deployment of renewables in the past decade despite the RPS is not surprising because of electricity trade with PJM states. Only about 25% of the RPS compliance requirement was met with in-state resources in 2017 (and only 20% in 2016).¹⁷ The trend may change in the next years with recent and more aggressive goals towards renewables and the ambitious goals for offshore wind that will be generated in the state.

Figure 5-10: Operable power generation capacity in Maryland. Percentage totals show share of total operable capacity. In order to differentiate recent developments in power generation capacity, yellow bars show recent capacity additions while purple bars show capacity that was added before 2008. Maryland's total capacity additions have been limited because it imports a significant amount of its electrical power. Data source: EIA¹⁵



^{cc} Although installed coal capacity remains large in Maryland, capacity factors have declined from 63.8% in 2008 to 21.3% in 2017.¹²⁶

Maryland's energy-related decarbonization has been high. In 2016, Maryland's per capita energy-related emission reductions were ranked 5th in the US, reducing by 34.9% from 2005 levels compared to the 50-state average of 20% reduction.¹⁶ Without adjusting for population, Maryland's energy-related emission reductions were 2nd highest in the US, reducing by 30.6% from 2005 levels compared to the 50-state average of 13.4% reduction. Some of the reasons behind the state's high reductions in emission include participation in RGGI, recent deployment of natural gas and renewables along with coal retirements, the strong support for energy efficiency, and a dramatic decrease in industrial energy use since 2005.¹²⁷

Recent efforts to accelerate clean energy innovation RD&D in Maryland (e.g., through MEI²) will take a few years to pay off. The regional benefits will likely depend on how the state's clean energy policies evolve and integrate with economic development goals.

Chapter Six

COMPARING REGIONAL CLEAN ENERGY INNOVATION

Despite strong similarities in innovation capabilities and broad policy support for adoption of clean energy, Maryland and Colorado have very different approaches, spending, and outcomes for clean energy innovation. Colorado's focus on integrating energy and economic development has included dedicated support to RD&D and growth of strong networks for young clean energy firms. Colorado's approach has led to diversified strengths in cleantech firms ranging from average to well-above the US average specialization in most technology areas. Maryland's clean energy activities include a strong focus on societal benefits, evident in the scale of its utility energy efficiency programs. Maryland's clean energy programs have not incentivized in-state power generation or manufacturing, and until recently, clean energy and energy innovation were not economic development priorities. Maryland has a moderate number of cleantech firms, at or well below the US average specialization in most technology areas. Differences in the states' outcomes are likely to have been most influenced by two factors: the status of clean energy among the state's economic development priorities, and the availability of clean energy developmental support through the state's universities and agencies, federal laboratories, and non-profit organizations.

Differences Between Colorado and Maryland

Differences observed in Colorado and Maryland are rich in information on the different motivations and outcomes related to regional clean energy innovation and deployment. The observed differences between the two states' approaches for economic development, energy, and environment provide a basis for understanding the metrics of technology capacity and outcomes.

The different metrics reviewed for each state, some of which are summarized in Table 6-1, correspond to different stages of commercial development, deployment and impact. The early stages are most directly linked to innovation activity. Here, Colorado excels, with strong technology capacity indicators (patents, coordination, state support, and investors) which are linked to its large number of cleantech firms. The later stage deployment of clean energy technologies is revealed in metrics such as the energy efficiency ranking, renewable power generation, and clean energy employment. While Maryland excels in energy efficiency, Colorado produces almost 20% of its electricity from in-state wind and solar. These deployment outcomes are not direct causal results of each state's innovation activities but are related through state policies and through the innovation opportunities created by deployment. The overarching outcome of greenhouse gas mitigation is affected by factors, such as population growth and related growth in energy demand, the level of industrial activity in each state, as well as clean energy technology commercialization and deployment. The more detailed assessment of the case studies expands these high-level observations with more information on states' clean energy firms, different technologies, and the operationalization of clean energy goals.

Table ES-2: Despite having similar histories of state-level energy policy related to clean energy, Maryland and Colorado have significantly different outcomes in areas related to in-state clean energy RD&D and deployment.

State	Overall innovation ranking (ITIF ¹³)	Number of cleantech firms (i3 ¹ and others)*	Energy efficiency ranking (ACEEE ¹⁴)	Wind and solar power generation (in state, 2018) ¹⁵	Clean energy employment (USEER ⁶)**	Energy-related per capita CO ₂ emissions reductions since 2005 ¹⁶
Colorado	Rank 7th of 50 states	513 firms in expanded dataset; 288 firms in best available industry dataset	Rank 14th of 50 states	10.8 million MWh (19.5% of total)	12 jobs per thousand people	21.7%
Maryland	Rank 6th of 50 states	189 firms in expanded dataset; 94 firms in best available industry dataset	Rank 7th of 50 states	0.97 million MWh (2.2% of total)	14 jobs per thousand people	34.9%

*Estimated using the i3 cleantech database¹ and expanded using additional datasets (clean energy patent assignees in state, cleantech firms that received SBIR funding, cleantech firms that received state grants)

**Maryland's clean energy employment is dominated by the buildings sector, while Colorado has a balanced representation across most technology areas, with greatest specializations in biofuels and wind.

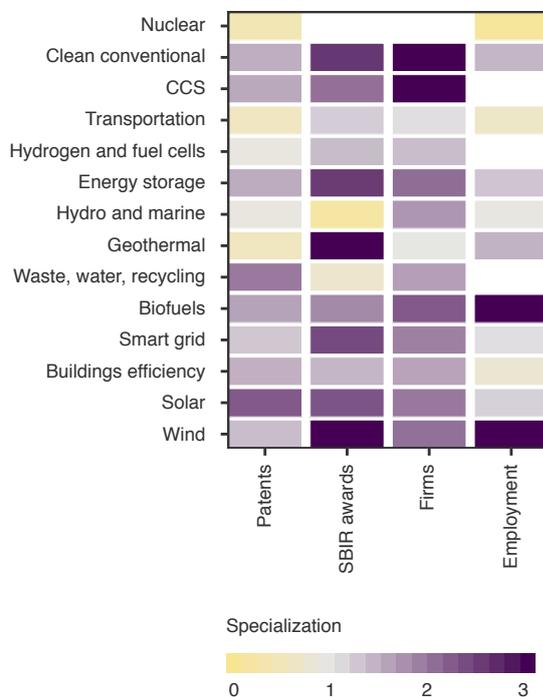
The activity in cleantech startup firms is a primary metric indicating positive outcomes of clean energy innovation in terms of the potential to generate economic development opportunities and employment over time. The differences in Colorado's and Maryland's approaches and priorities for clean energy innovation are evident in the health of these cleantech firms (in Chapter 4, Figure 4-8, and Chapter 5, Figure 5-8). Since 2000, Colorado has had more rapid formation of innovative clean energy firms (23/year on average) than Maryland (7/year) and as a result now has more than two and a half times as many such firms than Maryland. Maryland companies show a larger average failure rate (24%) than Colorado companies (14%), and a smaller acquisition rate (7%) than in Colorado (17%). Investment information, where available, shows that in both states firms are successful in attracting private sector investment, at the average rate over the last decade of \$1.8M/year/company in Maryland and \$2.7M/year/company in Colorado. This is particularly striking given the challenges that cleantech companies face in crossing the 'valley of death'. While Colorado's clean energy innovation activities are more effective on average in generating not only a larger, but also a healthier population of cleantech firms than Maryland's, many firms in Maryland also do well.

A closer look at individual clean energy technologies presents an additional perspective on clean energy innovation in the two states (Figure 6-1). Colorado's clean energy innovation activity is strong and diversified across multiple clean energy technologies. A comparison of specialization metrics relative to the US indicates participation across the innovation stages with RD&D (patenting activity) translating into cleantech firms that have the ability to attract federal grants (e.g., SBIR). Colorado's firms' specialization correlates with employment in many sectors, most strongly wind and biofuels. In contrast, while Maryland's firms also cover a diverse technical landscape, they are near or below average specialization for the majority of technology areas. Notably, Maryland's strongest employment specialization, in buildings efficiency, does not correlate with strength in firms, funding, or patents.

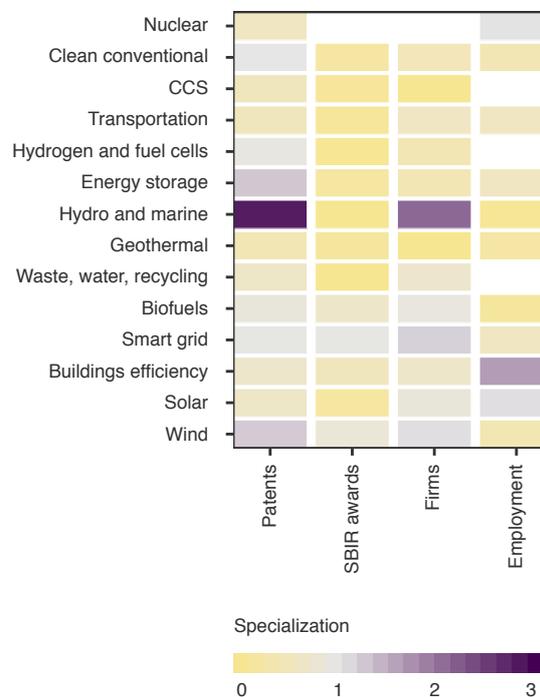
Overall clean energy employment figures are dominated by workers in established firms and in construction and service jobs,⁶ and do not reflect the RD&D and nascent manufacturing jobs of young, growing firms. It is, however, likely that the presence of economic activity in certain clean energy technology areas provides opportunities for young firms in terms of expertise, supply chains, and potential customers.

Figure 6-1: Specialization across different measures of innovative activity in Colorado and Maryland. Yellow areas indicate weaker specialization compared to US average of 1. Purple areas indicate stronger specialization compared to US average. Light grey areas indicate specialization similar to the US average. No data available for white areas.

SPECIALIZATION IN COLORADO



SPECIALIZATION IN MARYLAND



State decisions about financial resources and their distribution over the stages of clean energy technology innovation (RD&D and deployment) provide clear indication of their priorities and approaches. As shown in Table 6-2, annual per capita spending related to clean energy technology in Colorado (about \$90 million/year) is less than a third of the spending in Maryland (about \$310 million/year). However, the distribution of spending among the stages of innovation is quite different. Specifically, in early stage RD&D, Colorado's spending (about \$3 million/year) has been one and a half times larger than Maryland's (about \$2 million/year), and represents a much larger fraction of the total spending (3.3% vs 0.7%) than in Maryland. In both states, most of the spending is from utility programs for renewable energy or energy efficiency in the later stages of deployment. This emphasis is very heavily skewed in Maryland where, 90% of the funding is used for late deployment and ten time less, i.e., 9%, in early deployment. In contrast 78% of Colorado's spending is for late deployment and a larger share, 18%, for early deployment. Colorado's Advanced Industries Accelerator program, with dedicated investment in energy, provides early stage funding and is a concrete demonstration of state support for clean energy innovation that provides a clear message on the importance of the sector to the state's clean energy startup firms and other stakeholders.

Additional forms of developmental support—e.g., training, networking, incubators, and access to investors are often intangible and are not included in the budgets shown in Table 6-2. In Colorado, such support was catalyzed with the help of the state government over a decade ago and has continued with the help of non-profit organizations, universities, and federal research infrastructures (including the National Renewable Energy Laboratory, NREL). In Maryland, there was no such developmental support targeted for clean energy firms prior to the formation of MEI².

Overall, the experience from Colorado hints that relatively small levels of financing from the state, when coupled with a strongly messaged economic development focus and a network of clean energy stakeholders (with incubators, training, and access to investors), can positively impact outcomes for clean energy startup firms.

Table ES-3: Comparison of spending by the state government for clean energy RD&D and deployment^d

Innovation stages	Colorado Average annual per capita (population 5.7 million)	Maryland Average annual per capita (population 6.04 million)
Late deployment, market growth, mature companies	\$12.31/year (78.2%)	\$44.90/year (90.6%)
Early deployment, companies shipping product or developing pilots	\$2.91/year (18.5%)	\$4.31/year (8.7%)
Research, development, and technical demonstration, companies developing prototype and product	\$0.52/year (3.3%)	\$0.33/year (0.7%)
Total per capita	\$15.74/year	\$49.55/year
Total dollars	\$90 million/year	\$310 million/year

Different Priorities Correlate with Different Outcomes

The comparisons between Colorado and Maryland, drawn from the detailed descriptions in Chapters 4 and 5, can be summarized in four key points.

First, differences in the two states' resource and industrial base have shaped state activities in clean energy innovation. Colorado's technology-oriented industry coupled with its rich natural resources for clean energy (as well as fossil fuels) made the clean energy industry attractive for the state's economic development priorities. The government in Colorado prioritized clean energy (or energy overall) for economic development over multiple years sending consistent signals on its importance for the state's economy. Maryland's low reliance on an energy economy and its focus on biotechnology, national security, and other industries potentially decoupled its economic development priorities with its clean energy goals.

Second, different emphases on energy and environment motivations shaped deployment and decarbonization outcomes. Maryland's multiple policies (RPS, RGGI, and EmPOWER) indicated strong ambition related to the use of clean energy, energy efficiency, and related decarbonization. However, while the state has achieved high per capita decarbonization and ranks high in energy efficiency, deployment of clean energy technologies to meet RPS requirements was largely outside the state because of cost-competitive electricity imports from neighboring states. Overall, the state's clean energy ambitions have not been linked to goals for economic development and did not create a local clean energy industry or support local RD&D. Colorado's RPS policy and its abundant natural resources helped in local clean energy technology deployment and high in-state renewable electricity generation. However, the continued dependence on fossil-fuel based generation, stronger industrial energy use, and higher population growth than Maryland contributed to Colorado's moderate-to-low per capita decarbonization.

Third, the coordination between clean energy and economic development stakeholders was intentionally fostered in Colorado. Examples of coordination in Colorado include the presence of a dedicated energy innovation program at the state's economic development agency (OEDIT), state funding to establish the Collaboratory research network, and the dedicated clean energy industry (CCIA) and economic development associations (Metro Denver) that brought together different stakeholders. Maryland's state and local agencies have coordinated policies and programs for energy efficiency and renewables deployment through the Strategic Energy Investment Fund (SEIF). However, prior to recent efforts from the Maryland Clean Energy Center (MCEC) and the Maryland Energy Innovation Institute (MEI²), clean energy activities were not integrated with the state's economic development agency or with state supported RD&D.

Fourth, universities and federal infrastructures or laboratories differed in their focus on clean energy RD&D. Both Colorado and Maryland have a strong scientific and technical workforce, strong science and engineering research universities, and multiple federal research infrastructures and resources. But Colorado's federal research infrastructures include strong linkages to energy and environment—most notably NREL. Maryland's large number of federal research infrastructures and major industrial RD&D are mostly in health or national security related topics, with some linkages with clean energy (e.g., US Department of Agriculture, Army Research Laboratory, Lockheed Martin). The presence of federal research or industry RD&D alone does not imply coordination—in Colorado, programs like Collaboratory were specifically designed to coordinate clean energy research among universities and NREL. Such efforts had been lacking in Maryland until the recent development of The Center for Research in Extreme Batteries¹²⁸ under MEI² guidance.

Lessons from Case Studies for Understanding Regional Differences in the US

The case studies highlight the multitude of factors that motivate clean energy innovation and how they can combine to create very different outcomes even in two states that are comparable in terms of their high innovation capabilities. The case studies reinforce the broader assessment of the 50 states presented in Chapter 2: states are unique in their human, technological, and natural resources; they are likely to take different policy approaches and may prioritize multiple clean energy technologies (e.g., in Colorado) or specifically develop one or more specific clean energy technology areas (e.g., in planning for offshore wind in Maryland).

The two case studies also demonstrate the dynamic and rapid evolution in clean energy activity. While the current assessment represents a detailed snapshot of state clean energy innovation activities across a limited set of indicators, it is also evident that both Colorado and Maryland have recent or new policies that will likely strengthen their clean energy innovation systems. The impacts of these efforts are not captured in this analysis.

The case studies also strongly reinforce the understanding that the commercial development pathways illustrated in Figure 1-1, are not realized as a causal sequence of events. Instead, they include feedback linkages such as the positive effect of deployment of mature technologies in creating opportunities for innovative firm formation in related technical areas. Recognizing and fostering such linkages is important in developing an effective regional clean energy innovation system. In addition, including both economic and environmental goals for clean energy innovation is important in delivering successful outcomes. States can adapt these general precepts in developing their own unique pathways in clean energy innovation.

Chapter Seven

CONCLUSIONS: STRENGTHENING REGIONAL CLEAN ENERGY INNOVATION

State-by-state motivations for clean energy innovation and their outcomes are far from simple. The overview in Chapter 2 demonstrated the dramatic variation in the 50 states in their emphasis on different stages of clean energy innovation and for different clean energy technologies. This variability was evident through metrics such as patents, federal funding, formation of cleantech firms, and their correlation with clean energy employment and deployment. The detailed case studies of Colorado and Maryland (Chapters 3 to 6) explored these differences in the context of the strikingly distinctive clean energy innovation outcomes of the two states. The case studies revealed that states' choices concerning the role of clean energy in economic development can influence the outcomes of similar state clean energy policies. For example, both in-state deployment of renewable power generation and the development of innovative technologies were positively impacted by a strong economic development focus in Colorado. As discussed throughout this report, there is no standard, or 'silver-bullet,' pathway to strengthening regional clean energy innovation systems. Nonetheless, the analysis presented provides some key observations on how regional clean energy innovation can be analyzed, the important factors in supporting RD&D, and the measures that can be used to monitor progress in state-level clean energy innovation activity.

Key Observations and Recommendations

This report's characterization of the regional innovation activity in 50 states and the two case studies shows that the differences between regions are revealed by viewing indicators such as federal funding, patents, firm formation, employment, and deployment through the lens of specialization in individual technology areas. The findings highlight that two important aspects are central to analyzing clean energy innovation in regions: one, the coordination between clean energy, environmental, societal, and economic development goals and two, the extent of different types and levels of support provided by the state at the different stages of in-state commercial development.

The following points discuss the key insights from this report and offer some recommendations for state- and local-policymakers aiming to strengthen regional clean energy innovation activity.

Aligning local industrial and technology strengths with clean energy innovation. Regional differences in natural resources, federal facilities, industry and associated supply chains, and technology capabilities underpin state decisions about clean energy innovation. In some cases, a state's technology focus, as revealed by state RD&D, patents or firms, reflects its dominant economic sector. In other cases, states have chosen to support many areas of clean energy innovation, or to focus on specific areas of technology to expand their economic base. A broad definition of clean energy related to climate mitigation technologies will increasingly be needed to encompass many approaches that some stakeholders may not currently consider relevant for clean energy (e.g., related to greenhouse gas mitigation via agriculture or new approaches to low-carbon materials).

Takeaway: A broader view of clean energy coupled with technology-specific specialization metrics can help pinpoint local technology competitiveness relative to the US average.

Integrating goals for economic development, energy efficiency, environment, and decarbonization. State and local policymakers have multiple reasons to support clean energy innovation – as an economic development opportunity, to reduce the cost of electricity for consumers, or as an environmental priority for clean air, clean water, as well as climate change. Such differentiating factors are not revealed in the standardized data used for the 50 states assessment. However, the case studies illustrate how the goals and the corresponding activities in these areas may be disconnected, leading to less positive outcomes than would be expected based on policy strength and level of funding. The case studies show how the presence of economic development-oriented activities correlates with strengths in clean energy RD&D and cleantech startups (in Colorado). In contrast, efficiency and environment-oriented policies correlate with strong deployment and employment in the buildings efficiency sector and decarbonization (in Maryland).

Takeaway: Integrating economic development and environment-oriented policies can simultaneously advance multiple goals for clean energy with greater overall impact.

Coordinating programs for clean energy innovation between state economic development agencies and energy offices. The distinction between an economic development focus, observed for Colorado, and a social and environmental focus for clean energy, observed for Maryland, correlates with differences in state administrative structures. Clean energy innovation can be supported under economic development agencies, as has been the case in Colorado where there are strong outcomes in early stage clean energy innovation. In contrast, energy offices often deal with regulatory issues, the administration of incentives programs, or support for state efficiency programs, but may not have a legislative mandate to support development of local, in-state clean energy companies.

Takeaway: State-led programs to accelerate clean energy innovation must take into account that working individually, economic development offices and energy offices will support different aspects of a clean energy innovation system and fail to realize the full potential of coordinated in-state research, development, demonstration, and deployment.

Offering financial support for clean energy RD&D and deployment. Delivery of concrete short-term benefits from clean energy deployment is a clear state priority, as seen in the case studies and in other recent analysis.^{dd} Funding for deployment of emerging technologies such as energy storage, can be a significant factor in successful clean energy innovation, and is a higher priority (~20% of spending) in Colorado's economically oriented programs than in Maryland's socially-oriented programs (~10% of spending). Support for early stage innovation in the form of seed grants and demonstration opportunities also higher (>3% of spending, ~\$3 million/year) in Colorado and lower (<1% of spending in Maryland, ~\$2 million/year).^{cc}

Takeaway: Even small levels of early stage funding provided by the state can be important in helping clean energy innovation and cleantech firms as it can complement federal or private funding.

^{dd} Legislatively mandated report on Maryland's Clean Energy Innovation System, Maryland Energy Innovation Institute, December 2019. Analysis of spending patterns for MD, CO, NY and CT shows that the dominant clean energy spending is for deployment of mature technologies, with decreasing amounts for the earlier stages of commercialization.

^{cc} Similar observations hold for NY and CT as well, see previous reference.

Providing developmental support for clean energy innovation through incubators, accelerators, etc. A key difference between Colorado and Maryland has been in the areas of developmental support. As part of its economic development focus for clean energy, Colorado created an infrastructure of support mechanisms for clean energy based around its universities and the National Renewable Energy Laboratory, including industry associations, incubators, and research collaborations. Maryland's innovation system was shaped by the state's focus on biotechnology as an economic development opportunity, and in the past was not designed or motivated to support clean energy innovation.

Takeaway: States or regions can support infrastructures such as local incubators or accelerators and facilitate clean energy-specific research collaborations or consortia to help emerging local clean energy innovators and companies.

Catalyzing local private sector investments in clean energy RD&D. Policies that incentivize local private investors to support clean energy can help early stage cleantech firms. For example, Colorado offers tax credits for investors targeting a range of advanced industries, including clean energy. However, industry-specific incentive programs that exclude clean energy can arise when, as in Maryland, clean energy innovation is not a focus of state economic development.

Takeaway: States or regions can create a friendly environment for the private sector by introducing appropriate incentive programs for private investment in clean energy.

Facilitating coordination among regional stakeholders through regional consortia and industry associations. A striking feature of Colorado's clean energy innovation has been the presence of multiple organizations that served a coordination and convening function, including a dedicated cleantech industries association, a regional economic development association with specific emphasis on energy, and multiple locally led research collaborations. Maryland has begun to develop a similar approach in recent years.

Takeaway: Designating a central local organization or industry association to lead coordination between clean energy innovation stakeholders can strengthen the community and help provide additional developmental support, for instance in the form of networking to identify supply-chain partners or potential investors.

Designing success metrics for in-state commercial development of clean energy RD&D. Numbers and types of clean energy firms are a useful comparative metric for commercialization success in different states. For states engaged in active support of early-stage innovation or RD&D, metrics that can identify the potential for success in in-state commercial deployment are needed. This requires deeper analysis, as in the case studies where the health and investment levels for cleantech firms in Colorado and Maryland were compared. The semi-publicly accessible data used for these assessments is limited and requires significant effort to extract.

Takeaway: States seriously interested in assessing the success of their innovation programs should use trusted relationships with in-state firms to collect data for in-state databases that provide such information while maintaining confidentiality of firms' proprietary information.

Aligning databases with evolving technology categories of innovation. One issue in the databases available for analysis of state innovation is the different time periods that are represented in the different stages of deployment. Technology areas represented in mature markets (e.g., solar and onshore wind power, LED lighting) are well-past the stages of early innovation and RD&D. Technology areas relevant for early stage innovation will include improvements of more mature technologies but will increasingly focus on new areas of impact.

Takeaway: Tracking innovation activities in the future will require databases to include greater granularity in categories such as transportation, carbon capture and storage, and grid modernization, and expand attention in agricultural approaches to greenhouse gas mitigation, as distinct new technology pathways arise in each.

Opportunities for Expanded Impact

The data and analysis in this report provide a foundation of actionable information for future efforts to strategically expand regional clean energy innovation. The key general findings of the report are summarized in Box 7-1.

Box 7-1: Findings from the report and opportunities for expanded impact

- **States are highly diverse** in both the types of clean energies that are represented in their energy innovation systems and the continuity with which each technology is represented in different metrics (e.g., state resources, RD&D activity, deployment, or commercial and environmental outcomes).
- **State policies are important** in shaping clean energy innovation outcomes. The outcomes of state energy policies and spending depend strongly on their **linkages with economic development goals**.
- **Data-driven approaches** can provide an evidence base for state and federal policymakers to characterize regional clean energy innovation. The data characteristics developed in this report integrate standard databases with assessment of state policies and spending, including:
 - Alignment of multiple observable metrics with a consistent definition of technology areas
 - Correlations among observable metrics related to regional economic factors, energy and environment factors, technology capacity (i.e., technological, intellectual, and financial capacity), and commercial outcomes (e.g., cleantech firms)
 - Quantification of how states operationalize their clean energy innovation policies in terms of funding and other support at different stages of innovation
- **New areas of data development** can provide greater insight on regional clean energy innovation and allow economic impact assessments. Future data needs include:
 - **Characterizing clean energy employment.** This includes time-dependent data with greater granularity for discerning employment in clean energy innovation (e.g., employment in RD&D, manufacturing, construction, and services). Such data may be collected over time through expanding annual surveys such as the US Energy and Employment Report.⁶
 - **Developing metrics of firm health and economic outcomes.** This includes time-dependent data with detailed information on cleantech firms (e.g., firm formation, growth, investments, and product deployment). Such data may be developed where there are trusted relationships between cleantech firms and state entities (e.g., state-supported incubators or industry associations) that provide strong developmental support.

Clearly, there is no single ‘silver bullet’ solution to success in regional clean energy innovation. However, the data approaches and types of results presented here can inform federal and state planning to accelerate clean energy innovation by aligning programs with regional resources and economic development goals.

APPENDIX A. DATA SOURCES AND METHODOLOGY

Patent data was obtained from the United States Patent and Trademark Office (USPTO) using the PatentsView application programming interface (API). Patents were selected based on the Cooperate Patent Classification (CPC) system, where climate mitigation technologies are classified under the Y02 category. Some patents are classified under multiple Y02 CPC categories and may repeat across technologies (for example, electric vehicles and transportation). Patents include only granted utility patents – because there is a lag in patent application and grant dates, the analysis was limited to 2016 because of data availability. Patents were counted based on the address of inventors (rather than the location of their institute or the patent assignee). Patents were credited on a fractional count basis where the location attribute of each patent is calculated based on number of inventors in that location (or state) divided by the total number of inventors (methodology similar to that used by NSF⁹⁴).

Small Business Innovation Research (SBIR) awards for clean energy (including the awardee and location) were identified from a broad dataset of all SBIR awards (excluding those from the Department of Defense).¹⁰ The SBIR awards were first filtered from the full dataset using a string search with keywords “energy”, “climate”, and “greenhouse gas”. These were then classified into cleantech categories using additional keyword searches and manual classifications. Awards may be linked to multiple clean energy technologies but only one technology was used to categorize the awards based on an estimation of the primary technology area of the award.

Department of Energy spending in states was estimated in two ways:

- **DOE grant award data** in the state was obtained from USAspending.⁶⁴ Data includes DOE assistance for prime awards (including SBIR awards) and excludes loans, sub-awards, and contracts. Dollar values represent obligated amount by year of award and primary place of performance. Awards were selected based on the following Catalog of Federal Domestic Assistance (CFDA) codes: Office of Science (81.049), Energy Efficiency and Renewable Energy (81.086, 81.087), Fossil Energy (81.089, 81.057), Nuclear Energy (81.121), Electricity Delivery and Energy Reliability (81.122), Advanced Research Projects Agency (81.135).
- **DOE enacted budget data** was obtained from congressional budget request reports.^{129–133} State-wise data was collected from 5 offices: Office of Science, Energy Efficiency and Renewable Energy, Electricity Delivery and Energy Reliability, Nuclear Energy, and Fossil Energy. However, the DOE enacted budget to states may not always reflect the actual location of RD&D activity (for example ARPA-E awards are not reported at the state-level).

Given the importance of actual location of RD&D activity, the analysis in this report uses the grant award data rather than allocated budget.

Cleantech firms and their locations were extracted from the i3 database.¹ Firms may be active in multiple clean energy technologies. However, only the primary ‘tags’ from the i3 database were selected for the initial analysis for 50 states. Additional analyses were conducted for the case studies on Maryland and Colorado.

- **Detailed cleantech firm analysis and classification.** For the detailed analysis of companies for Colorado and Maryland, i3 data was complemented with additional data on firms from USPTO (patent assignees), SBIR awardees, PRIME Coalition, Crunchbase, in addition to data obtained from state level organizations such as Maryland Industrial Partnerships (MIPS) and Colorado Office of Economic Development and International Trade (OEDIT). These databases provided various amounts of information on the given company: short and long descriptions of a company’s operations, the company founding year, address, etc. Some of the source databases mentioned above, i3 and patent in particular, are not clean energy specific. To remove irrelevant companies, we created a list of keywords to flag companies of interest when searching our dataset’s descriptions fields. In addition to rejecting trivialities, this list of keywords also functioned as a means of sorting the flagged companies into their respective technological categories. For example, companies flagged with high incidences of the keywords “PV,” “photovoltaic,” “solar,” or “perovskite” could reasonably be assumed to be a cleantech company focusing on solar. These categorizations were later checked manually using an online search. To ensure uniformity of data, missing fields were filled manually by referencing additional sources such as Bloomberg, Crunchbase, LinkedIn, and news reports.
- **Cleantech company maturity.** For the detailed case studies on Colorado and Maryland, company maturity of each cleantech company was assessed, i.e., whether the company was either a **Fundamental R&D & Startup** or a **Mature** company; or rather, if the company had been **Acquired** or since **Closed**.
 - Fundamental R&D & Startup – Companies in the early stages of business development. Businesses were assigned to this category if they fit a number of these criteria:
 - Have not developed a product
 - Total revenues less than \$5 million
 - Do not have an established business structure (executives, board, etc.)
 - Founded since 2015
 - Fewer than 10 employees
 - Mature – Established companies with consistent products and customers. Businesses were assigned to this category if they fit a number of these criteria:
 - Selling product(s)
 - Total revenues greater than \$10 million
 - Publicly Traded Stock
 - Have established business structure (executives, board, etc.)
 - Founded before 2000
 - Greater than 200 employees
 - Closed – Companies that have closed operations or have been inactive for four years.
 - Acquired – Companies that have undergone acquisition.

- **Cleantech company's technology phase.** For the detailed case studies on Colorado and Maryland, the current state of each company's technology was assessed – whether in the early stages of Concept, Product Development, or later stages of Shipping Product/Pilot and Wide Commercial Availability. Some companies had been previously classified in the i3 database. The following definitions were created to best match these entries:
 - Concept – Technology has recently been patented and has had little to no product development.
 - Recently patented
 - No products with given technology
 - Product Development – The company is actively developing their technology into, but has not yet created, a minimum viable product.
 - Product prototypes, made in small scale, subject to alterations
 - Published reports on the benefits of tested devices with given technology
 - Shipping Product/Pilot – The company has established a product and has begun shipping and testing their technology in pilot programs.
 - Product or product line with technology are limited to a few companies
 - Shipping technology products to customers for pilot / beta testing
 - Selling product in limited quantities
 - Wide Commercial Availability – The technology is widely available and is well known throughout the industry.
 - Established technology prevalent in a large number of companies
- **Cleantech companies' investment levels.** For the detailed case studies on Colorado and Maryland, the investment history of cleantech firms relative to the year of their founding was estimated using the Crunchbase database. Results were binned in two-year intervals. All companies counted were founded after 1996. "Amount unknown" indicates that the company is known to have received funding, but the amount is not reported.

Clean energy employment data was obtained from the USEER report.⁶ The 2018 report was used because of greater granularity of state-level data. The employment numbers from USEER were re-allocated under the following assumptions. (i) Traditional T&D was distributed between Smart Grid (61%) and Conventional (39%). (ii) Employment from Micro Grid & Other (including commodity flows) was distributed between Conventional (87%) and Smart Grid (13%). (iii) Employment from Other fuels was distributed between Conventional (60%) and Biofuels (40%).

Specialization is based on the location quotient metric used by the Bureau of Labor Statistics.⁶⁵ It is measured as the share of patents (or SBIR awards, firms, employment) in technology *t* in the state, divided by share of patents (or SBIR awards, firm, employment) in technology *t* in the US. For example, specialization in solar patenting activity in Colorado is measured as (patents in solar in CO)/(all patents in CO) divided by (patents in solar in the US)/(all patents in the US).

Values above the US average of 1 indicate specialization (a stronger focus in the state than average of all states) in a given technology. Sources and assumptions for technology *t* are described above. Sources for state and US totals are: (i) USPTO for patent data,¹¹ (ii) Allard SBIR dataset for all SBIR awards,¹⁰ (iii) US Census Bureau for total firms,¹³⁴ (iv) Bureau of Economic Analysis for total employment.⁷⁷

Technology classifications across different datasets. The datasets used in this report (patents, SBIR awards, cleantech firms, clean energy employment) utilize different technology classifications. Table A-2 (at the end of this section) shows how these were mapped across different datasets.

State spending patterns across the stages of innovation were extracted from a report on Maryland's Clean Energy Innovation System¹⁰⁷ where they were estimated through a detailed analysis of state budget documents and spending distribution across the stages of innovation. Examples of state spending in the late deployment / market growth stage includes spending on technologies such as Energy Star appliances, HVAC and building insulation, compact fluorescent and LED lighting, hybrid vehicles, and also commercial solar PV and onshore wind farms that have matured in recent years. Examples of state spending in early deployment / market formation include technologies such as plug-in electric vehicles, off-shore wind, grid-scale energy storage (other than pumped hydro), micro-grids/distributed generation, net-zero buildings, 'smart' buildings, 'smart' grid, and alternative (zero-carbon) fuels. Examples of state spending mechanisms in demonstration / proof-of-concept include direct funding through publicly operated angel or round-A venture funding programs for different technologies. Other support may include provision of mentoring and development infrastructure (e.g., technology accelerators), testing facilities, opportunities for demonstration, and investment tax credits. Examples of state government support in research and development includes grants (seed-funding) designed to allow entrepreneurs to create a proof of concept and preliminary market plan, matching funding for other development grants (e.g., federal grants), mentoring (e.g., I-Corps program), or development infrastructure such as early stage incubators.

Power plant capacity data is based on the U.S. Energy Information Administration Form EIA-860 that lists existing power plants with nameplate capacity of at least 1 MW. Distributed solar PV is not listed in this dataset.¹⁵

Population estimates for per capita calculations were based on 2018 population estimates from the US Census Bureau.¹³⁵

RD&D performed in the state: Data represents US R&D expenditures, by state, performing sector, and source of funds. (a) Businesses includes own funds, federal sources of funds, as well as non-federal sources of funds (i.e., other companies, universities, or research centers located in or outside the United States, and state government agencies). (b) Higher education includes federal, other government, business, higher education, nonprofit, and other sources of funds. (c) FFRDC includes federal and non-federal sources of funds (i.e., state and local governments, business, nonprofit organizations, and all other sources) (d) Non-profit only includes federal sources of funds (e) State represents internal performers in support of an internal RD&D project (e.g., by state agency and department employees or services performed by others).

Relative performance of the state: This report compares states with the 50-state average and mentions their relative performance on several occasions using different rankings. For consistent comparisons, the following terminology has been used:

- high (ranks 1 to 12)
- moderate-to-high (ranks 13 to 25)
- moderate-to-low (ranks 26 to 38)
- low (ranks 39 to 50).

Stakeholder interviews and general discussions: 47 interviews were conducted for this report, summarized in Table A-1. Numbers represent number of stakeholders interviewed and not number of organizations.

Table A-1: Summary of interviews.

Description	Colorado	Maryland	Other
State energy and economic development agencies (current and former officials)	6	15	8
Non-profits	3	0	2
Cleantech companies and investors	8	5	0
Total	17	20	10

Table A-2: Technology classifications used in this report and their mapping across different datasets

Technology classification	Cleantech firms (Source: i3 database ¹)		Patent classifications for climate mitigating technologies (Source: USPTO ¹¹)	Keywords used to identify clean energy SBIR awards (Source: SBIR dataset ¹⁰)	Classification of jobs into different clean energy categories (Source: USEER ⁶)	Installed capacity (Source: EIA ¹⁵)
	i3 cleantech firm classification	i3 description				
Solar	Solar	Harvest of solar energy for heating, lighting, or electric power production	Y02E 10/40 Solar thermal energy, Y02E 10/50 Photovoltaic [PV] energy, Y02E 10/60 Thermal-PV hybrids	Solar energy, solar cell, solar technolog, solar panel, solar modul, solar power, thin film solar, solar thermal, solar array, solar farm, csp, perovskite, photovoltaic	Generation - solar,	Solar thermal without energy storage, solar thermal with energy storage, solar photovoltaic,
	Advanced materials – solar	Materials that improve durability and efficiency as well as decrease toxicity				
Wind	Wind	Enable the harvest of wind energy for electric power production	Y02E 10/70 Wind energy	Wind turbine, wind technolog, wind power, wind farm, wind component, wind operation	Generation - wind	Wind onshore, wind offshore
Geothermal	Geothermal	Harvest of geothermal energy for heating and electric power production	Y02E 10/10 Geothermal energy	Geotherm, Geo therm	Estimated from 'other generation'	Geothermal
Hydro & marine	Hydro & marine power	Systems used to harvest energy from water, either as kinetic energy from moving water, thermal energy from temperature gradients, or through osmosis capitalizing on salinity differentials; and convert that energy into electric power	Y02E 10/20 Hydro energy, Y02E 10/30 Energy from the sea	Wave energy, wave power, tidal energy, tidal power, tidal stream, hydro electr, hydroelectr, hydro power, hydropower, water power, marine power, marine energy, ocean wave, tidal wave, run of river	Generation - traditional hydropower	Conventional hydroelectric
Biofuels	Biofuels & biochemicals	Production of liquid fuels and chemicals from biomass	Y02E 50/10 Biofuels	Biofuel, bio fuel, biomass, bio mass, algae derived oil, algal oil, algae fuel, bioenergy, bio energy, wood waste, bio refinery, biorefinery, fuel grade ethanol, bio diesel, biodiesel	Fuels - corn ethanol, other ethanol / non-woody biomass, woody biomass, other fuel	Wood/ wood waste, biomass, other waste biomass
	Biomass generation	Production of electricity, heat or solid fuel from solid biomass				
Nuclear	Nuclear	Cutting-edge innovation in nuclear power production, not traditional nuclear power plant designs	Y02E 30/00 Energy generation of nuclear origin		Generation - nuclear	Nuclear

Table A-2 (continued): Technology classifications used in this report and their mapping across different datasets

Technology classification	Cleantech firms (Source: i3 database ¹)		Patent classifications for climate mitigating technologies (Source: USPTO ¹¹)	Keywords used to identify clean energy SBIR awards (Source: SBIR dataset ¹⁰)	Classification of jobs into different clean energy categories (Source: USEER ⁶)	Installed capacity (Source: EIA ¹⁵)
	i3 cleantech firm classification	i3 description				
CCS	Air	Removing active pollutants and greenhouse gases (GHG) from the air, after their release into the air	Y02C Capture, storage, sequestration or disposal of greenhouse gases [GHG]			
	Others					
Conventional	Conventional fuels	Improve the efficiency or generally lower the environmental impact of incumbent natural resource and energy industries including oil, natural gas, and coal	Y02E 20/00 Combustion technologies with mitigation potential		Generation - natural gas, coal, oil and other fossil fuels; Fuels - coal, oil (petroleum and other fossil fuels), natural gas, other fuels; Transmission, distribution and storage - traditional T&D, micro grid and other	Natural gas steam turbine, conventional steam coal, natural gas fired combined cycle, natural gas fired combustion turbine, petroleum liquids, Natural gas internal combustion engine, coal integrated gasification combined cycle, petroleum coke, natural gas with compressed air storage, other natural gas
Energy efficiency (buildings)	Energy efficiency	Energy efficiency in buildings, data centers, built infrastructure, appliances, and consumer electronics	Y02B Climate change mitigation technologies related to buildings, e.g. housing, house appliances or related end-user applications		Energy efficiency - energy STAR & efficient lighting, traditional HVAC, high efficiency HVAC, renewable heating and cooling, advanced materials, other	
Smart grid	Smart grid	Bringing a century-old electric grid into the information age; typically through the introduction of communications, monitoring, and control infrastructure to do things like increase system reliability and efficiency, enable active participation by utility customers, and integrate more diverse generation and energy storage assets with existing grid infrastructure	Y04S Systems integrating technologies related to power network operation, communication or information technologies for improving the electrical power generation, transmission, distribution, management or usage, i.e. Smart grids		Transmission, distribution and storage - traditional T&, micro grid and other, smart grid	

Table A-2 (continued): Technology classifications used in this report and their mapping across different datasets

Technology classification	Cleantech firms (Source: i3 database ¹)		Patent classifications for climate mitigating technologies (Source: USPTO ¹¹)	Keywords used to identify clean energy SBIR awards (Source: SBIR dataset ¹⁰)	Classification of jobs into different clean energy categories (Source: USEER ⁹)	Installed capacity (Source: EIA ¹⁵)
	i3 cleantech firm classification	i3 description				
Waste	Waste & recycling	Reduction, reuse, or recycling of waste streams	Y02E 50/30 Fuel from waste, Y02W Climate change mitigation technologies related to wastewater treatment or waste management			Landfill gas, municipal solid waste
	Water & wastewater	Reduce the strains placed on the hydrologic cycle by expanding global population and industry while ensuring reliable access to clean water for domestic or industrial use				
Energy storage	Energy storage	Technologies enabling the storage of energy, generally in mechanical, electrical, chemical, thermal, or potential (gravity) forms, over time for the later application to productive work	Y02E 60/10 Energy storage, Y02E 70/30 Systems combining energy storage with energy generation of non-fossil origin		Transmission, distribution and storage - Storage	Pumped storage, batteries, flywheel
	Advanced materials – energy storage	Materials that improve durability and efficiency as well as decrease toxicity				
Hydrogen and fuel cells	Fuel cells & hydrogen	Proliferation of fuel cells as a power source and hydrogen as a fuel	Y02E 60/30 Hydrogen technology, Y02E 60/50 Fuel cells, Y02E 70/10 Hydrogen from electrolysis with energy of non-fossil origin, e.g. PV, wind power, nuclear, Y02E 70/20 Systems combining fuel cells with production of fuel of non-fossil origin			
	Advanced materials – fuel cells & hydrogen Transportation	Materials that improve durability and efficiency as well as decrease toxicity				
Transportation (non-ICE)		Utilization of more sustainable transport options for people and goods	Y02T 10/62 Hybrid vehicles, Y02T 10/64 Electric machine technologies for applications in electromobility, Y02T 10/92 Energy efficient charging or discharging systems for batteries, ultracapacitors, supercapacitors or double-layer capacitors specially adapted for vehicles, Y02T 90/00 Enabling technologies or technologies with a potential or indirect contribution to GHG emissions mitigation, Y02T 90/10 Technologies related to electric vehicle charging, Y02T 90/30 Application of fuel cell technology to transportation, Y02T 90/40 Application of hydrogen technology to transportation		Motor vehicles - hybrid electric vehicles, plug in hybrid vehicles, electric vehicles, natural gas vehicles, hydrogen and fuel cell vehicles	

APPENDIX B. STATE AGENCIES INVOLVED IN ENERGY RD&D

Table B-1: State agencies that spent more than \$10,000 on energy RD&D between 2013 and 2017. Source: NSF⁷

State	State agencies involved in spending on energy RD&D	State	State agencies involved in spending on energy RD&D
Alabama	Geological Survey Innovation Fund	Indiana	Economic Development Corporation
Alaska	Housing Finance Corporation Department of Natural Resources	Iowa	Economic Development Authority - Energy Office
Arizona	Geological Survey	Kansas	
Arkansas	Economic Development Commission Science and Technology Authority	Kentucky	Cabinet for Economic Development Department for Energy Development and Independence Council on Postsecondary Education
California	Energy Commission Office of Environmental Health Hazard Assessment Public Utilities Commission	Louisiana	
Colorado	Office of Economic Development & International Trade Energy Office Higher Education Competitive Research Authority Department of Natural Resources Department of Transportation	Maine	Department of Environmental Protection Governor's Energy Office Maine Technology Institute
Connecticut	Green Bank Connecticut Innovation Inc.	Maryland	Department of Natural Resources Technology Development Corporation
Delaware	Sustainable Energy Unit	Massachusetts	Clean Energy Center Water Resources Authority
Florida	Department of Agriculture and Consumer Services Department of Environmental Protection Space Florida	Michigan	
Georgia	Southern States Energy Board	Minnesota	Department of Agriculture
Hawaii	Department of Agriculture Department of Business, Economic Development, and Tourism	Mississippi	Department of Transportation
Idaho	Department of Commerce	Missouri	
Illinois	Department of Commerce and Economic Opportunity		

Table B-1 (continued): State agencies that spent more than \$10,000 on energy RD&D between 2013 and 2017. Source: NSF⁷

State	State agencies involved in spending on energy RD&D	State	State agencies involved in spending on energy RD&D
Montana	Board of Research and Commercialization	Rhode Island	Atomic Energy Commission Commerce Corporation
Nebraska	Department of Economic Development	South Carolina	Department of Agriculture Research Authority Sea Grant Consortium
Nevada		South Dakota	Oilseeds Council Science and Technology Authority
New Hampshire	Department of Transportation	Tennessee	Department of Environment and Conservation
New Jersey		Texas	Water Development Board
New Mexico	Department of Higher Education Department of Transportation	Utah	Office of Economic Development Office of Energy Development
New York	Energy Research and Development Authority Power Authority State Museum	Vermont	Agency of Agriculture, Food, and Markets Public Service Department
North Carolina	Department of Agriculture and Consumer Services Department of Environmental Quality Office of Science, Technology and Innovation Department of Transportation	Virginia	Center of Innovative Technology Department of Mines, Minerals and Energy Tobacco Region Revitalization Commission
North Dakota	Lignite Research Council Department of Mineral Resources Oil and Gas Research Program Renewable Energy Research Program	Washington	Department of Commerce Department of Natural Resources
Ohio	Development Services Agency Department of Natural Resources Water Development Authority	West Virginia	Geological and Economic Survey Higher Education Policy Commission
Oklahoma	Center for the Advancement of Science and Technology	Wisconsin	Economic Development Corporation
Oregon	Department of Business Development Department of Energy Department of Environmental Quality Department of Transportation	Wyoming	Enhanced Oil Recovery Commission State Geological Survey Water Development Commission
Pennsylvania	Department of Community and Economic Development Energy Development Authority Game Commission		

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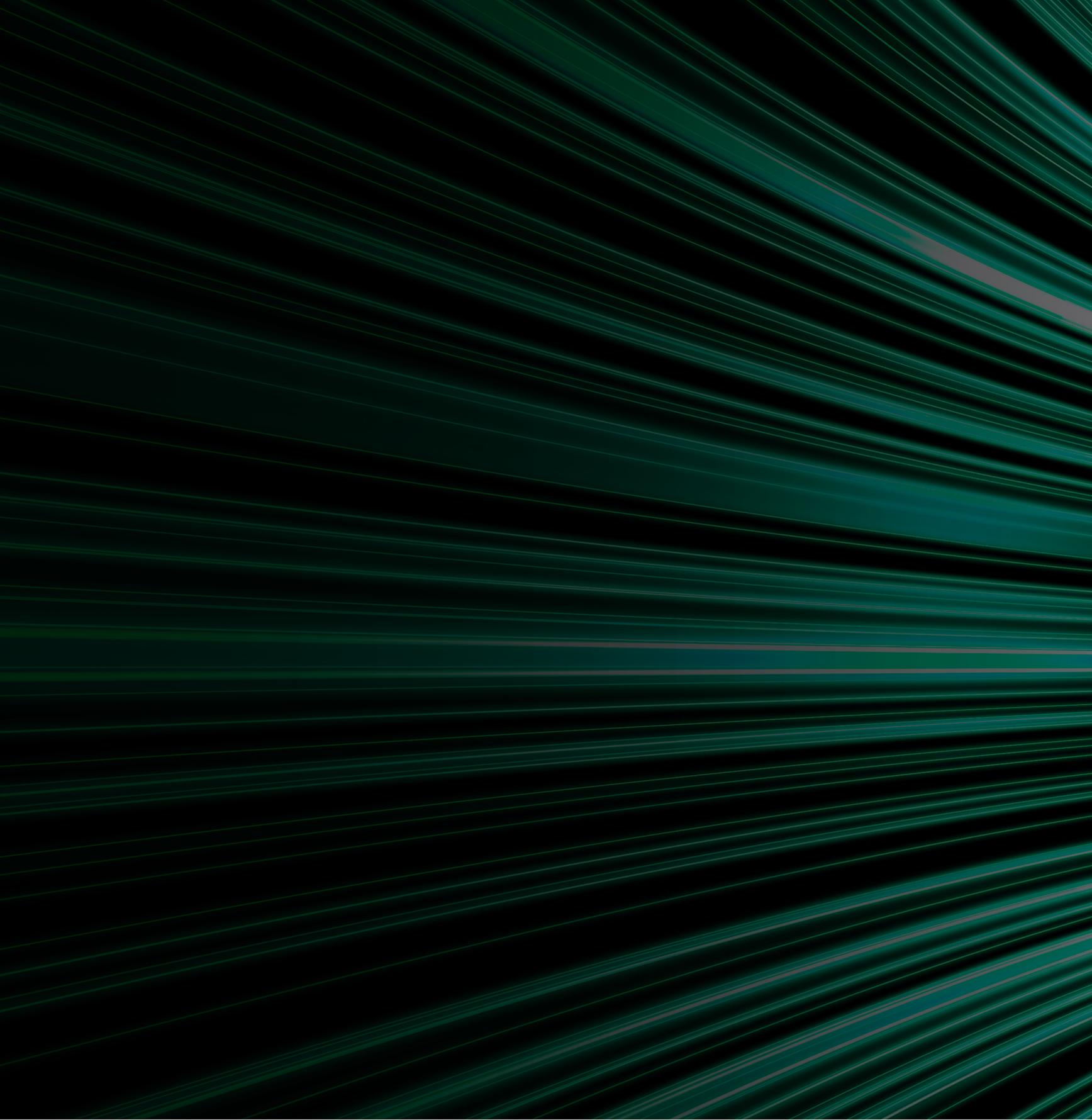
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