Breakthrough Energy

Advancing the Landscape of Clean Energy Innovation

Executive Summary
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IHS Markit and Energy Futures Initiative

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ENERGY FUTURES INITIATIVE

Foreword

We are pleased to submit our report, "Advancing the Landscape of Clean Energy Innovation." In this report we describe today's U.S. ecosystem of clean energy innovation from the perspectives of technological potential, investment patterns, institutional roles, and public policy.

The report identifies critical strengths and weaknesses of this ecosystem and offers recommendations for making that ecosystem more effective. It examines the different technology readiness stages through which innovation passes and the importance of feedback among those stages. It also discusses the significant opportunities to accelerate the pace of clean energy innovation that are presented by rapid advances occurring today across a myriad of technologies originating outside the energy sector.

We would like to emphasize three observations from our report.

- First, the U.S. has shown over many decades an unparalleled capacity to nurture energy innovation. This capacity reflects a rich and durable collaboration among government, universities, research institutions, industry, and entrepreneurs. This collaboration is grounded in the belief that energy innovation contributes importantly to economic growth, energy security, and environmental stewardship.
- Second, even with our capacity to innovate, and even with the emergence of innumerable technological opportunities, there are significant challenges in moving forward with clean energy technology. These challenges arise from the sheer size and complexity of existing systems, the degree to which these systems are embedded in our economy, and the high public expectations of safety and reliability they must meet. Energy systems traditionally have evolved incrementally.
- Third, these challenges can be met only by building on the collaborative strengths that our ecosystem has already demonstrated. Clean energy innovation depends on a national commitment to technological research; private-sector efforts to develop, apply, and commercialize products incorporating that research; and public policy.

In this report we convey the need for a comprehensive approach involving both public and private sectors in order to expand the current landscape of clean energy innovation and accelerate its processes. We hope that our report contributes to an understanding of the challenges presented and the approaches needed to address those challenges effectively. There is no final word on the subject. We see this report as a contribution to a continuing national dialogue and hope that it will stimulate further discussion, understanding, and action.

We are grateful for the opportunity that Breakthrough Energy and its partners have provided to explore this topic and recognize their commitment to advancing a meaningful and timely national dialogue. We hope that our report informs an appreciation of the complexity, reach, inherent dynamism, and promise of the U.S. clean energy innovation landscape and of the leadership that the United States can continue to provide.

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The analysis and conclusions of this report are those of IHS Markit and Energy Futures Initiative. IHS Markit and Energy Futures Initiative are solely responsible for its contents.

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Executive Summary

The United States has been at the forefront of energy innovation for many decades. One of the most important reasons is the unique and extensive collaboration along the entire chain of innovation, from basic research to deployment, that engages the federal government, national labs and research institutes, universities, private sector, and state and local governments. This system has given the U.S. a global advantage for many decades.

The increasing focus on clean energy technology solutions and the potential for disruptive changes in energy systems points to the need for an objective review of the current clean energy innovation ecosystem. How does the clean energy innovation system work? What are its strengths and weaknesses? Is it up to the challenges? And how can it be improved and accelerated?

These are the questions that this study seeks to answer. Significant opportunities for clean energy innovation are presented by the changing U.S energy supply profile; by advances in platform technologies such as digitalization and big data analytics; by expansion of electrification in the transportation and industrial sectors of the U.S. economy and the resulting electricity dependence of these sectors; by increases in urbanization and the emergence of smart cities; and by broad social and economic forces pushing to decarbonize energy systems in response to the risks posed by global warming and associated climate change.

Clean energy innovation supports multiple national goals: economic competitiveness, environmental responsibility, energy security, and national security. In serving these goals the need to address climate change is the challenge that calls most urgently for accelerating the pace of clean energy innovation.

Key features of energy systems, however, impede accelerated innovation. Energy is a highly capitalized commodity business, with complex supply chains and established customer bases, providing essential services at all levels of society. These features lead to systems with considerable inertia, focus on reliability and safety, aversion to risk, extensive regulation, and complex politics. Existing innovation processes face challenges as they work within these boundary conditions. The rapid pace of international energy investment, the commitments of most countries to Paris climate goals, and the ability of some countries such as China to rapidly increase clean energy investments challenge the preeminent position of the U.S. in clean energy innovation.

Successful clean energy innovation on a large scale in the U.S. requires alignment of key players, policies, and programs among the private sector, the federal government, and state and local governments. This report considers

these alignment needs through an assessment of the roles of these various groups. It also identifies critical clean energy technologies. It further suggests the value of regional efforts to advance innovation, and discusses ways in which federal tax policy could accelerate innovation. The report offers recommendations in each of these areas.

The Role of the Private Sector

The private sector is central to clean energy innovation, providing entrepreneurial vision, channeling financial resources, and connecting innovation to the rest of the energy system and the economy. At the same time, fundamental dynamics of the energy sector present significant challenges to clean energy innovation, stemming from basic industry characteristics and from the difficulty of capturing the full value of clean energy through market transactions alone. Innovators in clean energy face significant challenges in securing financial support and in demonstrating the compatibility of new technologies with existing systems. Over the past several years, venture capital has reduced its engagement in clean energy innovation, and traditional energy companies are exploring new models and mechanisms for innovation and investment.

While the initial stages of clean energy innovation are supported by a diverse, world-class set of U.S. research institutions, the innovation support system weakens as inventions move toward commercialization. The clean energy incubators that have emerged in recent years have so far tended to support software solutions. The availability of testing facilities for product demonstration is limited by the small number of facilities suitable for sustained testing and by their specialization.

Because of the energy system's long cycles of adoption, a broad range of approaches should be deployed to make it easier for adopters to understand, anticipate, and support the innovations that are being generated at the early stages of the innovation process. These efforts include, on the part of energy companies, open innovation, standardization of procurement requirements, encouragement of innovation testing either through dedicated evaluation staffs or through performance metrics, and active outreach to become familiar with innovations at the development stage or earlier. They include, on the part of innovators, early attention to the needs of adopters as indicated by expressed needs and by the past performance of innovation efforts.

Investments are needed from foundations and from federal, state, and local governments to expand the availability of open-access testbeds and strengthen the effectiveness of incubators in accelerating commercialization of innovative technologies. Some of these investments could fund research into best practices and performance results of incubators and testbeds and of state and local programs supporting innovation.

Because clean energy innovation incentivizes only modest financial investments at precommercial stages, and because strategic corporate investment is focused primarily on those innovations recognized as useful to business objectives, strategic philanthropic investors and coalitions of industry investors with long-term horizons could play an important role in identifying and supporting promising technology ventures that are otherwise not commercially viable in the near term.

Recommendations for Near-Term Actions

- Adopters of new technology, such as utilities, should consider a variety of approaches to support the innovations that are being generated at the early stages of the innovation process, including: open innovation; standardization of procurement specifications; encouragement of innovation testing (either though dedicated evaluation staffs or through performance metrics); and active outreach to become familiar with innovations at the development stage or earlier.
- Strategic philanthropic investors and coalitions of industry investors with long-term horizons should play an active role in identifying and supporting promising technology ventures that are otherwise not commercially viable in the near term.
- Foundations, as well as federal, state, and local governments, should make investments to expand the availability of open-access testbeds and incubators to accelerate commercialization of innovative technologies (e.g. Cyclotron Road).

Technologies with Breakthrough Potential

A shared agenda of primary technology objectives can help ensure that programs pursued by multiple stakeholders in the clean energy space are timely, durable, and mutually supportive. It can give entrepreneurs and creative innovators a framework for assessing the prospects of a particular area of initiative and the steps needed to sustain critical innovations over long time spans, and it can give corporate adopters, financial investors, and policymakers visibility into the evolving future of clean energy.

A four-step methodology is suggested for identifying breakthrough technologies to address national and global challenges and help meet near, mid- and long-term clean energy needs and goals. These steps consider technical merit, potential market viability, compatibility with other elements of the energy system, and consumer value. Application of these considerations to a list of 23 potential technology candidates yields a key technology shortlist:

Storage and battery technologies

Advanced nuclear reactors

Technology applications for industry and buildings as sectors that are difficult to decarbonize

- Hydrogen
- Advanced manufacturing technologies
- Building energy technologies

Systems: electric grid modernization and smart cities

Deep decarbonization/large-scale carbon management

- Carbon capture, use, and storage at scale
- Sunlight to fuels
- Biological sequestration

Recommendations for Near-Term Actions

- Federal investments in energy research, development, demonstration, and deployment (RDD&D) should be planned within a portfolio structure that supports potential breakthrough technologies at various timescales. There should be special focus on a critical subset of those technologies deemed to have very high breakthrough potential.
- Federal energy RDD&D portfolio investments should adopt a formal set of major evaluation criteria—such as technical merit, market viability, compatibility, and consumer value—with specific metrics for each criterion. These criteria should be used to prioritize programming and budget allocation decisions, as well as to develop public-private partnerships.
- Public and private sector stakeholders should collaborate in planning for and piloting of emerging technologies. A key component of these efforts is systems-level development plans that delineate technical challenges and risks; R&D pathways; cost and schedule assumptions; institutional roles (including public-private partnership opportunities); pathways to commercialization and diffusion; economic benefits; and consumer value.
- The Department of Energy (DOE) should lead a national effort to update the Basic Research Needs Assessments, originally initiated in 2001, to inform the assessments of emerging technologies with breakthrough potential, as well as the development of system-level roadmaps.

The Federal Government Role

The Federal government has long played a central role in supporting energy innovation. Through research grants, loan programs, tax incentives, laboratory facilities, pilot programs, and public-private partnerships, it has set the direction and pace of energy R&D, with profound impact on the national economy.

The principal agency funding clean energy innovation is the Department of Energy (DOE), which administers about 75 percent of all Federal energy R&D spending. DOE performs its role in partnership with its 17 national laboratories, academia, states, regions, other agencies, and the private sector. There are, however, several other Federal agencies with significant clean energy innovation budgets, including: the Department of Defense (DOD), the Department of Transportation (DOT), and the Department of Agriculture (USDA). Portfolios at these agencies are mission-focused, however, as opposed to being broadly based across all energy sectors.

As the primary Federal funder of energy R&D, DOE has played a critical role in changing the U.S. energy landscape over several decades. Shortly after its establishment in 1977, DOE characterized U.S. shale basins and supported the development of key drilling technologies that enabled horizontal drilling. It has had an ongoing and central role in developing supercomputing, an enabling technology for digitalization, artificial intelligence, smart systems, and subsurface characterization. Its investment in phasors and sensors support the smart grid. The Advanced Research Projects Agency — Energy (ARPA-E) – a DOE program —

has led to the creation of dozens of clean energy start-up companies which have raised more than $2.6 billion in private-sector follow-on funding.

However, DOE's performance in advancing clean energy innovation would benefit from several institutional modifications. For example, the fuels-based organizational structure of the DOE, which has been in existence since 1979, is not optimized for modern energy systems and needs. It tends to lead to budget allocations by fuel, rather than prioritization by innovation potential.

The lack of long-term stable and predictable funding is also a concern for future R&D efforts at DOE. Although the Federal clean energy RD&D portfolio is significant (approximately $6.4 billion in FY 2016 if expenditures by all Federal agencies and by DOE on basic science research are included), some prominent government and industry leaders have recommended the need for funding levels at two to three times the current levels based on the energy industry's current value to the economy (roughly $1.37 trillion). While the Bipartisan Budget Act of 2018 (BBA) set new caps for discretionary spending that are as much as 25 percent higher than the Administration's budget — providing considerable headroom for near-term increases in spending for clean energy innovation — this agreement extends through FY 2019 only. The highly uncertain budget outlook for FY 2020 makes it difficult to plan an effective energy innovation portfolio focused on technologies with high breakthrough potential.

Recommendations for Near-Term Actions

- Congress and the Administration should initiate efforts to reorganize the Federal energy RDD&D portfolio and the Department of Energy toward a fuel- and technology-neutral structure that (1) aligns with the highest priority opportunities, (2) enables systems-level integration, and (3) avoids gaps in crosscutting programs.
- Congress and the Administration should consider dedicated funding sources for energy innovation as a means to ensure predictable and increasing levels of clean energy RDD&D funding based on international and cross-sectoral benchmarks.
- Federal policymakers should expand demonstration projects for key breakthrough technologies, while ensuring accountability via stage-gated project management, risk-based cost sharing, and assignment of demonstration project oversight to a single office within DOE.
- DOE and other agencies, as appropriate, should increase collaboration with the private sector and academia, including:
  - Instituting a multi-year and multi-agency portfolio planning process with broad-based stakeholder involvement from the private sector and academia.
  - Expanding use of prize authority to foster competition and open innovation.
  - Simplifying public-private partnerships with flexible financial vehicles like Technology Investment Agreements.

The Role of State, Local and Tribal Governments

State and city governments have regulatory authority over most of the myriad consumer, commercial, and industrial activities that collectively shape the country's patterns of energy use. They play central roles in advancing clean energy innovation, above all by creating markets for the application of clean energy technologies and encouraging diffusion of those technologies through supportive financial mechanisms.

Cities are crucial clean energy innovation testbeds. Urbanization trends make "smart cities" especially important as technology platforms for a clean energy future. Enhanced federal-state-city, public-private, and private-private partnerships can help unleash smart city innovation for tailored urban services, mobility, and standard-of-living improvements in the 21st century. "Smart" improvements could also provide significant value to rural communities by enabling decentralized generation and manufacturing, improving energy efficiency, and supporting economic development.

The contribution of state, local, and tribal governments to clean energy innovation could be further strengthened by development of program best practices and standardization, capacity and resource enhancement, increased funding, and modernization of ratemaking and business models. Programs that support and promote clean energy and energy innovation require significant state and local administrative resources and expertise; offices and officials that run them often have limited resources. Also, traditional ratemaking policies and methodologies at the state and local level can act as barriers to deployment of innovative energy technologies due to their reliance on proven track records associated with reliability and cost savings.

Recommendations for Near-Term Actions

- States should consider adopting technology-neutral clean energy portfolio standards and zero-emissions credits in order to strengthen markets for clean energy innovation — to include renewables and other forms of zero or low-carbon energy.
- State and local regulatory agencies should consider new ways in which existing ratemaking principles could be adapted to incentivize utilities to deploy established clean energy technologies, test emerging energy technologies, and realize value from behind the meter technologies.
- States should collaborate to identify best practices in the deployment of clean energy technologies, including financing mechanisms, consumer protections and equitable sharing of benefits among all socio-economic groups and geographic locations.

The Role of Regional Clean Energy Innovation Ecosystems

Many of the innovation opportunities and risks faced by the energy sector are highly regional in nature and are appropriately managed by strategies tailored to each region's specific needs. Strong regional relationships, for example, are observable among innovation, job creation, and technology deployment in the solar and wind energy industries.

Many energy innovation clusters in the U.S. are in the process of evolving into fully integrated innovation ecosystems. While federally funded RDD&D historically has not been well connected to state and regional economic development, activating these regional clusters to break down the barriers among federal, state, and local resources will create new synergies. National labs could serve as anchors for these efforts. While Federal support is important, regional leadership is critical. State and local governments, the private sector, universities, and philanthropies all have important roles in developing the particular strengths and shaping the particular contributions of regional innovation ecosystems.

Recommendations for Near-Term Actions

- Universities, private industry, philanthropies, state and local governments, and DOE should seek to expand and strengthen incubator capabilities within regional clusters to provide additional tools to enable innovators to conduct R&D and prototyping.
- DOE national laboratories, other federal laboratories, and Federally Funded Research Centers (FFRCs) can serve as anchors for regional clean energy innovation — and should be given sufficient flexibility in the expenditure of discretionary funds to support regional clean energy innovation options.

Mobilizing Increased Private Sector Investment in Energy Innovation

For U.S.-based entities, budget caps, reduced discretionary spending, and the Tax Cuts and Jobs Act (TCJA) will put downward pressure on Federal spending but will incentivize corporations to increase significantly business investments over the next decade (with estimates of up to $1.5 trillion in incremental new investment, some of which could be targeted to energy innovation and infrastructure. Attracting these funds into clean energy innovation will depend on success in aligning the various elements of the innovation ecosystem discussed in this report: public policies that encourage a robust pipeline of research and that create markets for clean energy applications, combined with private-sector institutions that facilitate the commercialization of innovations.

The TCJA left unchanged the existing tax credits for renewable energy (wind, solar and geothermal), but did not extend the so-called "orphan" tax credits for fuel cells, combined heat and power projects, geothermal heat pumps, and new nuclear power plants. Most of these credits had expired at the end of 2016. The Bipartisan Budget

Act of 2018 (BBA), passed in February, modified and extended the nuclear power PTC; other credits were extended only through 2017 and their fate is uncertain.

In addition, the BBA included expanded provisions for carbon dioxide (CO_2) capture, utilization and storage (CCUS). The new 45Q provisions have the potential to significantly enhance the development and market diffusion of CCUS technologies and processes in both industrial and power applications, creating commercial opportunities both in the U.S. and abroad. The provisions provide greater market and financing certainty to help attract additional follow-on investment from the private sector.

Recommendations for Near-Term Actions

- DOE should set aside a small portion of its existing applied energy RDD&D funding to support accelerated de-risking of near-commercial innovative energy technologies and systems on an accelerated basis, to make these options more attractive for private capital investment.
- The new Section 45Q provisions expanding tax credits for carbon dioxide (CO_2) capture, utilization, and storage (CCUS) have the potential to significantly enhance the development and market diffusion of CCUS technologies and processes in both industrial and power applications, creating commercial opportunities both in the U.S. and abroad. Congress should consider additional measures to facilitate and accelerate CCUS deployment, including addressing uncertainties regarding long-term post-injection carbon management, monitoring, reporting and verification.