Executive Summary

Innovation continues to be the most important driver of economic growth for developed economies, and creating novel energy technologies is essential for solving the world's most pressing environmental problems and enabling clean growth. Basic scientific research is a fundamental component of technological innovation, giving rise to the discoveries that drive targeted research and development (R&D). Projects that have the capacity to solve distant, large-scale problems by first asking questions about the fundamental nature of the world can be called blue sky research. Such efforts are often conducted not so much with an eye toward specific practical applications, but rather with a broad awareness of the potential nascent and perhaps as-yet-unknown utility for future innovations. These types of projects often depend on public funding, since the scientific discoveries they drive generate large societal benefits that can be difficult to capture.

The Innovation Landscape

Innovation is critical to address the growing challenges presented by energy systems across the globe. In developed countries, legacy energy systems must adapt, evolve and decarbonize to meet the international goal of limiting global warming below 2°C. Energy systems are also rapidly becoming integral to the economies of developing countries, and new technologies are necessary for sustainable development that facilitates increasing electrification and industrialization without growing emissions. Recent technology developments have shown great promise, often with larger impacts than anticipated. Reduced costs of efficient lighting, wind and solar generation and lithium batteries have reduced energy demand, reduced generation emissions, and facilitated a transition away from petroleum fuels, respectively.

However, more innovation and greater investment are necessary to meet the coming challenges. To prioritize investments, governments need to be aware of the innovation landscape and the role that relationships among government agencies, private firms, and academic and research institutions play in the innovation process. To further innovation, policymakers must consider the funding landscape, the people and researchers that contribute to breakthroughs, the means and mechanisms of knowledge flow, and how innovation relates to the wider energy sector.

Despite the critical role blue sky research plays in the innovation process, calculating and expressing the value of such efforts is a persistent challenge. On a project level, it is difficult, even impossible, to demonstrate the future value of unanticipated and unplanned innovation. Furthermore, securing private funding for blue sky research is uncommon, because the benefits of fundamental scientific discoveries—while large for society—can be difficult for private companies to capture.

Therefore, funding for energy-based blue sky research is limited, and efforts are needed to incentivize greater public and private investment in blue sky research goals. Global spending on clean-energy-related research, development, and demonstration (RD&D) (in energy efficiency, renewables, nuclear, and carbon capture and sequestration [CCS]) have stabilized at a global total of $26 billion annually. Various efforts are underway to address this funding gap. For example, through

Mission Innovation [1] 22 countries and the European Union aim to double clean energy R&D investment over five years. In the private sector, the 30 members of the Breakthrough Energy Coalition[2] have committed to invest USD1 billion, as well as work to direct promising research efforts. More efforts such as these are needed to incentivize greater public and private investment to drive energy innovation.

Blue Sky Research and Innovation

Innovation is often non-linear, despite some models framing innovation as a linear process. The default conceptual model of innovation imagines a straight line from basic scientific research through application of discoveries to targeted R&D that results in a novel technology. In this model, there is tension between the 'technology push' of technologies trying to convince the market of their utility and the 'market pull' of needs-driven innovation. However, new technologies or improvements to existing technologies can be invented or discovered at any point throughout the process, whether intentionally or serendipitously. Likewise, applied R&D can often open new questions appropriate for basic scientific inquiry, such as the fundamental nature of materials or physical interactions.

The timing, value, and content of blue sky research can never be accurately and completely expressed and evaluated until after the fact, and patience is often required. Supportive institutional policies that accommodate funding a particular research competence, rather than a creating a specific product or solving a particular problem are needed. Blue sky research often delivers results that are useful, but not necessarily in the way that was initially expected. Policymakers and industry must have the flexibility for unintended but beneficial results to fully capture the benefits of blue sky research.

Knowledge sharing is an essential aspect of transforming research findings into breakthrough innovations. Identifying critical stakeholders for a research project and incorporating their input at the planning stage enables maximum utilization of the innovation. Outputs of blue sky research should be communicated such that those with the competency to utilize them can benefit from their findings.

Innovation for Energy

A large number of critical energy technologies are ripe for innovation and can benefit from near-term improvements in economics, performance, efficiency, and sustainability of energy technologies, as well as transformational discoveries that could lead to replacements for current technologies in the long term. While near-term innovations are largely the result of targeted R&D to address specific challenges, blue sky research plays an important role in creating or enabling the long-term innovations that could replace or disrupt today's cutting-edge energy technologies.

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[1] Mission Innovation, launched following negotiations of the 2015 Paris Agreement, aims to dramatically accelerate global clean energy innovation. Participating countries have committed to seek to double their governments' clean energy research and development (R&D) investments over five years, while encouraging greater levels of private sector investment in transformative clean energy technologies.

[2] The Breakthrough Energy Coalition (BEC) is a partnership of 30 multinational enterprises which have committed to broadening investment in new energy technologies by investing their own capital. BEC works with over 20 governments which have committed to significantly increase public investments in the basic research that leads to breakthrough innovations.

Near-term innovations are necessary to bring the performance and cost of some clean-energy-enabling technologies in line with competing legacy technologies. These performance and cost improvements require innovations to enable existing technologies such as comprehensive industrial energy efficiency, battery electric vehicles and drop-in biofuels for transportation, and wide-scale deployment of renewable generation technologies. Associated research subjects include industrial control systems, integration, and systems planning; battery chemistry; novel catalysts, catalyst support structures, and designs; and pyrolysis technologies for biofuels.

Over the long run, blue sky research is needed to solve fundamental scientific problems that will enable future generations of clean energy technology. Examples of long-term technologies include next-generation solar cells including high-efficiency multi-junction cells and low-cost thin-film cells; net-negative carbon generation technologies that remove carbon dioxide from the atmosphere; and nuclear fusion reactors that can generate power without harmful emissions or toxic waste.

Process, Policy, and Programs for Innovation

The non-linearity of innovation in practice highlights the fundamental problem of policymakers, academic research directors, or private managers in planning, evaluating, and funding blue sky research. Because blue sky research does not always anticipate the practical end uses that result from investments, it can be difficult to justify the expense. Compared with targeted R&D focused on an incremental technological improvement, blue sky research presents greater uncertainty and, therefore, greater risk. Designing programs that enable innovation can present challenges associated with cost, uncertainty, knowledge management, and communicating stakeholder value. Maintaining awareness of the need for these types of research, as well as the need for clear processes to evaluate, disseminate, and incentivize these types of research is a challenge for researchers, institutions, industries, and policymakers. The following lessons can be drawn from the experiences of successful past research programs, such as those coordinated by the IEA, as well as national and international efforts. Effective collaboration is important, both within governments and among governments, businesses, and research institutions.

Recommendations

- As the societal benefits of blue sky research are indirect, they can be non-obvious and difficult to convey. Policymakers often lack understanding of its value to society and the importance of public sector funding. Therefore researchers and their institutions could make greater efforts to consistently communicate the benefits of blue sky research to policymakers and emphasize the importance of public resources and continued support. Developing processes and methodologies to document and measure the value that blue sky research affords to society can help build the case for such research and boost additional public and private sector funding.
- The timing, value, content, and outputs of blue sky research may be uncertain. Unfortunately supporters generally fund a particular research competence rather than a specific result. Up addition, outputs from blue sky research are often useful, but not necessarily in the way that was initially expected. Therefore to fully capture the benefits of blue sky research policymakers and industry actors need to have the flexibility to make use of unintended but beneficial research outputs. With increased flexibility, promising

discoveries will not be abandoned in favor of short-term achievements that meet predetermined research goals.

- Public–private research collaborations are invaluable for blue sky research and innovation. Public private partnership can help in de-risking blue sky research for private enterprise. However, a clear understanding of the ownership and benefits is vital to avoiding. A research pathway that may benefit a particular industry. Policies that support such collaborations, as well as regulatory policies that incentivize private sector investment in innovation to reduce risk are needed.
- Inspired creativity does not occur in isolation. Highly interactive organizations - that foster cross-fertilization of ideas, are challenge-driven, and encourage cross-sector partnerships - demonstrate greater innovation. Therefore research institution programs could encourage both individual and collaborative endeavors.
- The ideal enabling environment for blue sky research comprises a simple management structure without funding concerns or the pressure to publish. Research institutions undertaking blue sky research could incentivize risks. For example, projects and grants could be designed with selection criteria and evaluation processes that incentivize innovative approaches. Currently researchers are pressured to publish to demonstrate added value for the investment. And most often researchers are rewarded for positive results yet knowledge attained through 'failures' is equally valuable.
- Collaborations among governments should be explored, both to share the burden of expensive cutting-edge research facilities and to foster knowledge exchange. Partnerships among entities that share world-class laboratory facilities not only provide cost efficiencies but also allow for cross-fertilization of ideas, a key element of innovation.