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Workshop

Accelerating development of energy innovation ecosystems: strengthening links across institutions and actors

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Workshop report

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The workshop was organised as part of the research project *'What factors drive innovation in energy technologies? The role of technology spillovers and government investment*,' funded by the Alfred P. Sloan Foundation.

Executive summary

On June 18-19, 2023, the Cambridge Centre for Environment, Energy and Natural Resource Governance in the University of Cambridge hosted an in-person international Workshop entitled '**Accelerating development of energy innovation ecosystems: strengthening links across institutions and actors.**' The Workshop was funded by the Alfred P Sloan Foundation as part of the research project *'What factors drive innovation in energy technologies? The role of technology spillovers and government investment*' led by Professors Laura Diaz Anadon (University of Cambridge), Venkatesh Narayanamurti (Harvard University) and Gabriel Chan (University of Minnesota) as co-PIs. The Workshop brought together researchers from the project and world-leading experts and scholars in energy technology and innovation policy, academic entrepreneurs, and policy makers from the UK, US, and the EU.

This report summarises the findings about the factors contributing to the successes and failures of energy innovation ecosystems identified by participants of the Workshop over a course of three panel discussions. The report provides a background for the following recommendations for action by national or regional policy makers in the UK and beyond to **accelerate energy innovation through improvements in the energy innovation system** put forward by participants as the key takeaways from the Workshop:

1. **Fill the gaps in the energy innovation system**
   - Create new or reform existing 'National laboratory'-style R&D-oriented organisations with mission orientation, long-term planning horizons, cross-disciplinary expertise, block funding to support discovery research, and a focus on integrated scientific and technological research and development activities with clear links and pathways to manufacturing.
   - Create new or reform existing actors and institutions responsible for providing early stage (and low-cost) finance and tasked with improving the bankability for the early deployment and commercialization of innovative clean energy technologies.
   - Provide institutional support for technology demonstration, early deployment, and manufacturing scale-up.
   - Foster the creation of institutions and public-private partnerships with a broad mandate for cross-sectoral and temporal coordination and integration of innovation activities across the life cycle of innovation.

2. **Strengthen the linkages in the energy innovation system and beyond**
   - Support cross-domain and cross-sectoral collaborations, consortiums, and industry groups to ensure knowledge exchange across the value chain of innovation to enable technology spillovers.
   - Collaboratively work on an adaptive industrial strategy, standards, and necessary regulation early to help coordinate innovation activities across different actors, sectors, and time horizons.
   - Encourage open innovation whenever possible, while being mindful of the limitations posed by intellectual property regimes and demands of national security.
   - Encourage and support diversity and interdisciplinarity in education, training and hiring practices.

3. **Facilitate conducive government policy**
    - Ensure the consistency and continuity of funding and policy support while keeping it flexible and adaptive to changing environments.
    - Support programmes that encourage diversity and interdisciplinarity in education, training, and talent mobility across countries, sectors, and knowledge domains.
    - Establish new or modify existing policy instruments to support integrated scientific & technological research and development.
    - Allow for flexibility in funding instruments and overlaps in their mandates to enable and support ‘risky’ R&D project proposals.
    - Stimulate broader private sector participation in the financing of energy innovation.
    - Involve the private sector in conversations about policy design.
    - Track progress and adapt policies as we learn about their effectiveness.
    - Learn from instructive experiences in other policy domains.

4. **Change organisational and leadership culture**
    - Encourage long-term thinking about innovation as opposed to ‘short-termism,’ particularly in the government and industry.
    - Support risk-taking leadership in all sectors, including academia and the government.
    - Foster flexibility and organisational autonomy to take risks, change and adapt in all sectors.
    - Promote positive societal framing of entrepreneurial risk and failure, including in the government.
    - Stimulate creativity, imagination, curiosity, and serendipity by creating ‘safe spaces’ or ‘sandboxes’ for discovery research insulated from the pressures of public accountability, academic incentives, and shareholder capitalism.
    - Foster nimbleness and adaptability in R&D, demonstration, and deployment.
    - Change the linear thinking about innovation by policymakers, encouraging a whole-systems approach to innovation and competitiveness.

Introduction

On June 18-19, 2023, the Cambridge Centre for Environment, Energy and Natural Resource Governance hosted an in-person international Workshop entitled '**Accelerating development of energy innovation ecosystems: strengthening links across institutions and actors**' at the Old Divinity School in St. John's College, University of Cambridge.

This Workshop was co-led by Professors Laura Diaz Anadon (University of Cambridge), Venkatesh Narayanamurti (Harvard University) and Gabriel Chan (University of Minnesota), who were co-PIs in a major project funded by the Alfred P Sloan Foundation titled '*What factors drive innovation in energy technologies? The role of technology spillovers and government investment*' ('*Energy Technology Spillovers project*' below for short). This project investigated, using multiple research methods, the role of knowledge spillovers between different areas of science and technology in the development of clean energy technologies, including solar photovoltaics, lithium-ion batteries, and solid-state lighting.

The Workshop was funded by the Energy Technology Spillovers project, which formally concluded later in 2023. The Workshop provided an opportunity to exchange project insights with key external experts. The focus of the Workshop, however, was broader and considered the role and effectiveness of different energy innovation policy interventions and the links between energy technology innovation and the wider innovation system in the context of the energy transition. The event was held under Chatham House rules.

The Workshop consisted of the following three panel sessions:

1) Lessons from the history of innovation in selected energy technologies
2) Links between energy innovation and broader innovation ecosystems
3) New institutions and capabilities for energy innovation.

Each of the three panels included input and insights from researchers and experts from the Energy Technology Spillovers project and from 'external' invited speakers that included world-leading technology experts and researchers on energy, science, technology and innovation policy, academic entrepreneurs, and policy makers from the UK, US, and the EU. Each panel had four speakers providing opening remarks for 5-7 minutes; the rest of the panel was devoted to a group discussion of the topic at hand, partly responding to presentations and introducing new points. The Workshop concluded with a discussion that synthesised its findings and outlined directions for future work.

The remainder of this report summarises the main points made during each panel of the Workshop.

Panel 1: Lessons from history of energy innovation ecosystems in key technologies

The Workshop kicked off with a discussion of the factors that contributed to innovation in key clean energy technologies in the past, particularly focusing on the role of energy innovation ecosystems in this process. The conversation was broadly structured around the following questions:

- What have been the generalizable drivers of energy innovation historically, including energy and innovation policies and institutions?
- How have technology spillovers contributed to energy innovation?
- What other historical perspectives help understand the implications of energy innovation ecosystems for policy and economic development?

The discussion started with a high-level overview of the state of institutional support for energy innovation, highlighting that public funding for energy research, development and demonstration (RD&D) across major economies, including the UK, US, EU, and China, is on a moderate upward trend, with China in particular becoming a major player in energy RD&D in recent years. This upward trend in RD&D funding has been accompanied by increases in demand-pull policies (e.g., feed-in tariffs, renewable energy auctions or obligations), as well as growing interest in green industrial policy in general.

Funding and policy support is, however, not sufficient to ensure that energy innovation evolves in ways that meet societal challenges, as it takes place in an innovation system that comprises many interlinked actors and institutions, including different policies, norms, culture, and management structures. While innovation is not constrained by national borders and there are regional and international dimensions to it, different countries have idiosyncratic innovation systems with their own sets of actors and institutions, as well as gaps in the system that can create country-specific challenges and barriers to innovation. For example, comparative analysis of energy innovation systems in the US and UK shows that the UK, in particular, may be missing specific actors, links and institutions that exist in the US (e.g., national laboratories, or a robust early-stage financing system). There are also many questions about the role of links between energy innovation and a wider innovation system, including industries, institutions or societal actors not directly involved in the energy sector. Another related question is how innovation in one technology area can contribute to advances in another area, a process known as technology spillover. Exploration of these systemic and knowledge gaps guided the discussion during the rest of the Workshop.

On the topic of technology spillovers, the findings of the Energy Technology Spillovers project showed that spillovers identified in three key energy technologies—crystalline silicon photovoltaics (PV), lithium-ion batteries (LIB), and solid-state lighting (SSL)—were critically important at the early stages of technology emergence, enabling the development of key technology processes and components. However, the contributions of technology spillovers were not restricted to the research and development (R&D) stage, as spillovers also occurred during technology demonstration, market formation, and manufacturing scale-up. In most cases, spillovers took place through targeted learning and researching; communication and collaboration; human mobility; and repurposing of material objects such as manufacturing equipment. Across all three energy technologies, technology spillovers were often supported by undirected public R&D, mission-driven RD&D funding, demand-pull incentives for technology deployment, and industry coordination programmes.

A deeper dive into the history of SSL showed how progress in it was driven by recurring cycles of technoscientific research and development in blue light-emitting diode (LED) technology. In those cycles, new forms and functions of LEDs initially developed by engineers often led to the discovery of new scientific facts and their explanations by researchers that eventually enabled further advances in LED technology. Importantly, in this case, engineering often led science, not the other way around, as is commonly implied in a traditional linear innovation model. Two factors were essential in this process, which were also posited as being relevant for innovation in many other technologies. First, exaptation, which in the context of technological innovation is the adoption of novel and often unexpected functions and applications of technology, e.g., when LEDs originally intended for displays or optical storage were used in lighting applications. Second factor was surprising, unexpected findings resulting from serendipity, curiosity and outsider perspectives on technology. For example, the key breakthrough in the development of blue LEDs in the 1990s was made by an 'outsider' to an LED R&D community working in a chemical company rather than a semiconductor firm who was not restricted in his work by 'common knowledge' in the community that gallium nitride-based LEDs 'should not work'. Ultimately, both novel exapted applications that drove the technoscientific cycle of discovery and development in LEDs and surprising outsider perspectives that enabled key breakthroughs in LED technology were only possible because of the links between SSL and other industries, actors, and knowledge domains in a wider innovation system. This case also highlights the inextricable link between science and engineering, which goes contrary to the common view of these activities being separate, as progress in technology is not possible without simultaneous progress in underlying science.

Another deep dive into the history of technological progress in solar energy cautioned against a bias caused by the retrospective view taken by historical analysis. When technology develops, it often exists in many competing versions and alternative designs. It is not possible to predict which technology design will eventually be chosen by the market based purely on the known characteristics of technology at that time. In the case of solar energy, silicon-based PV has been developing simultaneously with other types of PV technologies based on cadmium telluride (CdT), copper indium gallium selenide (CIGS), and lead halide perovskites, among others. Among these types, silicon solar PV has been dominating the market recently because it has managed to achieve better manufacturability, long-term stability, higher efficiency (driven by R&D and innovation) and remarkable cost reductions (driven by the reduced cost of capital, better engineering practice, and learning-by-doing resulting from continuously increasing deployment of solar energy on a global scale). The next contender to capture the growing solar energy market seems to be the perovskites, where a very rapid progress in PV cell efficiency took place over the past decade. The UK is a major player in this area, with Oxford Photovoltaics developing one of the most promising variants of this technology. However, as was the case in the past with other promising solar technologies, the future success of perovskite solar cells on the market is not guaranteed both globally, and specifically in the UK, which lacks incentives and policy support for the deployment and manufacturing of solar PV.

Participants further focused on the role of imagination, serendipity, surprise, and risk-taking in the innovation process. As innovation is inherently uncertain, these factors are often needed to shift innovation in unpredictable but productive directions. However, as several participants noted, the current institutional structure of innovation ecosystems is not very conducive to risk-taking and freedom of search and experimentation. The following factors contributing to difficulties in conducting imaginative and high-risk research were discussed.

- Under the pressures of public accountability, public agencies and publicly funded academic and research institutions are often discouraged from funding and conducting 'risky' R&D that may result in a loss of public funds or having certain organisational or funding redundancy/slack that would cover for the uncertainty of R&D and encourage experimentation.
- Funding flexibility can increase the chances that high-risk research will be supported. For example, the US has multiple funding agencies with overlapping mandates (e.g., NSF, DOE, DOD), DARPA-style agencies that specifically fund high-risk, high-reward research, and various sources of significant charitable funding outside of the health space. In contrast, the UK has a broad mix of different funding and policy support programmes, but it has some notable gaps and is not flexible enough. For example, if

a proposal to a UK research council is unsuccessful, there is often no other funding body or agency where it could be submitted again.

- Another source of discouragement of risk-taking behaviour by researchers is the structure of academic incentives and evaluation systems, such as the Research Excellence Framework (REF) in the UK. Young researchers, in particular, are under constant pressure to publish, which discourages them from 'risky' research or technology development that may not result in quick 'wins' and publications.
- Institutions that are seemingly better equipped to deal with risk-discouraging pressures of public accountability in the US are national laboratories that have flexible block funding from the federal government, and private universities such as MIT, Harvard or Stanford. However, national laboratories are not very good at exaptation, being bound by their missions, and serendipity, mired in 'tedious' paperwork with proposals, while researchers in private universities are also not free from publication pressures.
- A similar situation discouraging risk-taking and experimentation in R&D has been observed in industry, driven by the pressures of 'shareholder capitalism' that encourage outsourcing, cost-cutting, and short-term gains over long-term vision of where future value lies. These pressures make the straightforward replication of the success of past industrial R&D institutions, such as Bell Labs, highly unlikely.
- In the past, innovation in critical areas and public policies that support it were often driven or enabled by crisis. Notable examples include World War II, the oil crises of the 1970s, or the Great Recession of 2008, which all spurred innovation in energy technologies. Can risk-taking, creativity, and institution-building, which were characteristic of innovation activities in the periods of crisis, be replicated under different economic conditions?
- Another important source of creativity and serendipity in innovation is the diversity of skills and backgrounds of researchers and engineers in the innovation process.

Overall, this discussion concluded that the negative pressures of public accountability, academic incentives, and shareholder capitalism on risk-taking behaviour and creativity necessary for rapid progress in energy innovation can be at least partially mitigated by increasing funding flexibility, mission-oriented institutions such as national laboratories, mechanisms enabling interactions across different disciplines, firms, and sectors, and nurturing a diversity of talent and skills base.

Panel 2: Links between energy innovation and broader innovation ecosystem

The second panel of the Workshop continued to explore the links between energy innovation and the broader innovation ecosystem, guided by the following questions:

- What are the key interactions between the innovation ecosystem and energy technology research, development, and deployment activities?
- What is the role of energy deployment and demand-pull policies, early-stage financing, and a broader science and education policy landscape in energy innovation?
- What are the implications of the Energy Technology Spillovers project findings on the importance of technology spillovers for R&D management, policy, and education?

On the latter question, a framework of 'knowledge commons' was used to summarise the Energy Technology Spillovers project findings regarding the mechanisms and enablers of technology spillovers. In this framework, access to and excludability of knowledge both within and beyond the boundaries of particular knowledge domains in the commons are collectively managed and negotiated by actors and institutions in the innovation system. This framework was used to demonstrate the importance of managing knowledge boundaries across the value chain of clean energy technologies, i.e., across science, engineering, and manufacturing, and indicate that technology spillovers can be productively stimulated by:

- increasing absorptive capacity of actors to identify and incorporate external knowledge, e.g., through interdisciplinary hiring and training, interdisciplinary or mission-oriented public and private R&D;
- cross-domain and cross-sectoral collaboration and talent mobility;
- technology demonstration projects enabling new external applications; and
- deployment policies generating 'demand pull' for technology from new user environments and novel applications.

An important conceptual clarification was made on the use of the concepts of innovation systems and ecosystems. The original concept of the innovation system emphasised the links between actors and institutions involved in innovation processes. It has been extensively used in policy research and practice, e.g., in OECD, since the 1990s. The innovation ecosystem approach, emerging later in the 2000s, is more focused on firm innovation and how it can benefit from the openness of the system. However, narrow interpretation of this approach as a focus on 'outsourced' open innovation, practised by many firm strategists and policymakers, may result in firms getting out of R&D activities, which is harmful for the overall innovation performance of the system. Instead, an (eco)systems approach to firm strategy and government policy should encourage a diversity of actors rather than their substitution and exit; embrace long-term strategic thinking and consistent policy support, rather than the pursuit of short-term profits and political gains; and emphasise openness to interdisciplinary collaboration and knowledge exchange, including in regional clusters.

A prominent example of recent success in energy innovation is the ongoing rapid deployment and cost reductions in key clean energy technologies, such as wind or solar PV, that defied all expectations and have already reached a tipping point, making these energy sources cheaper than traditional fossil fuel-based sources in many contexts. A sustainability transitions perspective on this case helps elucidate the importance of societal interactions and systemic feedback loops in facilitating such tipping points. Some of the factors that clearly affect these dynamics, such as the techno-economic cycle of cost reductions and technology deployment represented by technology learning curves, are more or less well understood, but not fully leveraged in policymaking and energy-economic modelling. Other factors that are not yet well understood and thus require further attention include the societal acceptance of new energy technologies, changing social practices and norms, the role of green finance, and policy feedback loops. For example, deployment policies often target positive feedback loops represented by learning curves, but much less attention is given to the effect of balancing feedback loops that represent inertia, path dependency, and lock-in that keep the system in a dominant fossil fuel socio-technical regime.

Another important but often overlooked factor contributing to the success of energy innovation ecosystems is how policy support for clean energy innovation is designed and implemented. The links between many energy technologies and the wider economy, often embedded in different types of infrastructure, require cross-sectoral policy making with a broad participation of experts from different related fields. Particularly challenging is the design of support for technology testing and demonstration, though the UK is testing novel approaches to supporting technology demonstration based on indemnity and liability. Much more could also be done to leverage public procurement to sign-post pre-commercial success of particular innovations. Overall, speakers highlighted the importance of the whole-system approach to policy making across all stages of innovation and policy processes.

The discussion moved on to the importance and limitations of mission-oriented policymaking and its possible effect on energy innovation. The challenge-oriented approach to complex technical problems notably achieved great successes in the past, with Manhattan Project among its most striking examples. The analysis of such cases shows that long-term thinking, cross-sectoral coordination and an entrepreneurial, risk-taking approach to leadership and policymaking—all previously noted in the discussion as important factors in the success of innovation—were critical for the mission's success in these cases as well. However, a mission-oriented approach seems to work better for clearly outlined complex but purely technical problems, rather than society-wide socio-technical challenges, or technical problems where no clear pathway to a solution exists. Particularly in the latter case, undirected 'blue-sky' research to find potential solutions is crucial.

However, beyond the usual resource and funding constraints, undirected research comes with its own unique set of challenges. How to 'keep skies blue' by encouraging open knowledge exchange, open science and open innovation in the ecosystem, while balancing this openness with the demands of national security and intellectual property (IP) rights? IP, in particular, is needed in certain industries with long-term investment horizons (e.g., pharmaceuticals), and for startups to attract investment. The recent example of the COVID-19 vaccine development shows that relaxing IP regimes in areas of strategic importance to the public can accelerate innovation. Is it possible to achieve the same effect in other strategically important areas, such as energy and climate? Finding the right balance between industry needs and demands in the environment of shareholder capitalism, on one hand, and public good expressed through mission orientation, on another hand, thus remains a challenge in general and for IP management and regulation in particular.

Panel 3: New institutions and organisational capabilities for energy innovation

The third and final panel of the Workshop focused on the gaps in the energy innovation ecosystem and how these gaps can be closed through new or improved institutions and organisational capabilities. The discussion was guided by the following questions:

- What is the ongoing thinking on new institutions and reforming old ones to advance energy innovation?
- What are some key open questions and challenges that policymakers / researchers need to think through for what is missing in energy innovation ecosystems?
- How can lessons from history be applied to the current context with a growing prominence of green industrial policy and an ever-changing technology frontier?

The discussion started with the notion that the nature of the technoscientific method requires the institutions in the innovation system to be updated based on a holistic view of innovation, since "doing cannot be separated from understanding." In essence, research is an unscheduled quest for new knowledge and inventions, and its outcome cannot be predicted in advance. Development is a scheduled activity with a well-defined outcome in a specified time frame. Science and engineering are essential ingredients in both processes, feeding off each other in cycles of invention and discovery.

Both Vannevar Bush's linear model of innovation and Carl Popper's theory of the scientific method focused on hypothesis testing do not fully capture the complex cyclical nature of the technoscientific method. However, in the past, they were often used to structure institutions in the innovation system. For example, the Department of Energy (DOE) R&D activities in the US are split into separate basic and applied research accounts, thus creating institutional barriers to the technoscientific cycles of research and development. In contrast, successful industrial R&D institutions of the past, such as Bell Labs, did not distinguish organisationally between different types of R&D and were not isolated from manufacturing and customers, ensuring the vertical integration through the full life cycle of innovation. Novel institutions for energy innovation could be built upon a similarly holistic and integrated view of innovation, reimagining industrial labs of the past through structures that span academia, industry, and government. In the US, the CHIPS Act can be viewed as a first step in this direction, as are the relatively recent DOE constructs such as ARPA-E, Energy Frontier Research Centers (EFRC), Energy Innovation Hubs (EIH), and Office of Clean Energy Demonstrations. However, further institutional design is needed, guided by a new industrial strategy appropriate for the technological frontier and economic competitiveness, national security, and resilience. This design must ensure a clear mission; stable funding; broad, flexible authority and accountability; strong leadership; and a culture of technical excellence and willingness to take risks on uncertain but potentially high-payoff ideas.

There are similar ongoing debates in Germany about how novel public institutions to complement its universities and public research organisations can be structured in terms of their role, scope, and functions. Proposals include an innovation council, special emissary, dedicated mission agencies, and an ARPA-style agency for disruptive innovation (SPRIND). However, in many cases, their intended working mode can conflict with existing regulations (e.g., payment schemes).

Further key issues and challenges for the development of novel institutions or reforming existing institutions in the innovation system include:

- establishing the credibility of novel or reformed institutions against the background of long investment horizons and security concerns;
- establishing functioning coordination and communication mechanisms, particularly when new actors across different sectors that do not share common language are involved;
- answering questions regarding the extent to which the mandates of these institutions should go beyond resource allocation for R&D, particularly against the backdrop of established competencies and positions of existing ecosystem actors, and the need for democratic accountability;
- addressing the tension of time constraints in setting up new actors against the urgency of challenges these actors are intended to address; and
- fostering capacity development in novel and reformed institutions and balancing administrative experience with new perspectives in staff recruitment.

A comparison of existing institutional and funding initiatives to address innovation needs of the battery industry (including the issues of grid-scale storage, resource constraints, and fundamental limitations of LIB technology) in the UK, US, and EU highlights how different approaches taken by different countries resulted in different outcomes achieved. Who initiated and implemented a particular initiative (e.g., industry vs. academia vs. cross-sectoral coalition) and how it was designed (top-down vs. bottom-up) strongly shaped emerging institutional structures, goals, and measures of success (e.g., by outcomes vs. the focus on process or capacity-building). For example, the Faraday Battery Challenge in the UK was designed in a top-down way, driven by industry incumbents, and its direction was determined by stakeholders, without necessarily reflecting the best science available or most creative solutions. In contrast, EFRCs in the US and, to a degree, the EU BATTERY 2030+ initiative were bottom-up and more creative, but much more focused on research rather than on industry needs, resulting in some questionable choices for the technologies of focus. Balancing both approaches to institution-building remains a challenge.

Workshop participants also discussed that wider socio-technical, economic, and political dynamics (e.g., the presence of cheaper incumbent technologies, differences in state subsidies, global competition) should be taken into account when designing support for deploying and scaling up technological innovations. These dynamics and their outcomes for the energy innovation ecosystem in the UK were further discussed in detail in the context of the history of UK energy policy. In the first phase, around 1945-1985, there was a centralised, state-run power system largely based on coal, and, later, nuclear energy, with the grid system optimised for it. The nuclear programme, in particular, was driven by the UK's military needs, as well as energy security concerns in the wake of the 1970s energy crisis. By the end of the second phase (ca. 1985 - late 2000s), the UK ended up with an energy system heavily reliant on gas and shaped by privatisation, which in turn led to a systematic underinvestment in energy R&D, with the government withdrawing from funding anything beyond basic science. The ongoing third phase, characterised by a more mission-oriented UK energy policy and driven by the urgency of decarbonisation, included a range of different market interventions (framed as "nudge-driven policy"), which resulted in an effective offshore wind rollout, but failed to re-launch nuclear energy, and kept the UK reliant on (now, largely imported) gas. Multiple energy innovation institutions were created and then often closed or reformed in a rapid succession in this phase, resulting in a lack of continuity and predictability in the UK energy innovation policy, as well as notable gaps remaining in the UK energy innovation ecosystem landscape. For example, the Catapults play a significant role in technology commercialisation, but their narrow mandate keeps them disconnected from what is going on at the R&D or manufacturing stages. The need for novel institutions which are more collaborative and provide integrated support for innovation across all its stages and capacity building for translation and manufacturing in the UK thus remains.

In the concluding discussion of the third panel, participants focused on the problem of different timescales on which different entities in the energy innovation ecosystem (e.g., industry, government, utilities, or academic institutions) operate (e.g., due to different funding, evaluation, planning, investment, procurement, or election cycles), while the whole ecosystem faces the increasing urgency of addressing climate change and other energy system challenges. The main challenge is to enable temporal coordination within an ecosystem where all actors are supposed to engage over sustained time frames to create innovation, while bridging their short- and long-term tensions. The uncertainty in the outcomes of innovation processes and the time needed to bring innovations to the market, as well as unpredictability of serendipity that is sometimes needed to achieve technological breakthroughs, add extra layers of complexity to the problem.

As a way to address this coordination challenge, participants highlighted the importance of visionary leadership; the need for changes in national industrial strategies with different mindsets and cultures based on the integrated understanding of the technoscientific method, system-wide thinking, and a higher sense of urgency; as well as adapted funding and accountability mechanisms that are directional, yet flexible, allowing for creative risk-taking environments. Recent examples of successfully coordinated innovation activities through common strategy in other fields include a public-private NASA / SpaceX partnership. Similar public-private partnerships are expected to emerge in the semiconductor industry from the bipartisan CHIPS Act in the US. As a counterexample, the recent proliferation of ARPA-style agencies in different countries or reforms in existing agencies such as NSF without coordination between these agencies or their missions may fail to deliver the promise of accelerating innovations relevant to advancing societal goals.

Concluding discussion

The Workshop concluded with a synthesis of the main points across the three panels, highlighting a number of factors contributing to the success of clean energy innovation. Based on these factors, participants of the Workshop formulated **recommendations for action** by national or regional policy makers in the UK and beyond to **accelerate energy innovation through improvements in the energy innovation system**. These recommendations, summarised in the Executive summary on pages 2-3 of this report, are grouped into four overarching themes:

1. Filling the gaps in the energy innovation system.
2. Strengthening the linkages in the energy innovation system and beyond.
3. Facilitating conducive government policy.
4. Changing organisational and leadership culture.

In addition, in a final round of comments, Workshop participants highlighted the following topics as both relevant to the success of energy technology innovation and requiring further research. These topics should be explored in future conversations:

- How can long-term thinking about innovation be done in a liberal shareholder capitalist system that discourages knowledge exchange and positive knowledge spillovers?
- What is the role of creativity and serendipity in innovation, and how it works in (or against) existing institutional structures?
- How can digital technologies contribute to accelerating energy innovation and the energy transition?
- How to organise international cooperation on energy innovation, particularly with developing countries, against the background of geopolitics and national security?
- What should risk-taking in the Government mean? For example, what should government accountability look like in a risk-taking mode?
- How can risk-taking and creativity, characteristic of innovation activities and policymaking in the periods of crisis, be replicated in regular economic conditions?
- When to create new institutions and when to adapt existing institutions in the innovation ecosystem?

The Workshop concluded with reflections on the need to continue such conversations, extending them across different expert fields and internationally, given the importance of the topic and the research gaps identified.

List of participants

- **Professor Floor Alkemade**, Full Professor and Chair of Economics and Governance of Technological Innovation, Eindhoven University of Technology, Netherlands
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- **Dr Ian Brotherston**, Head of Government Levers, Innovate UK
- **Dr Gabriel Chan**, Associate Professor, Humphrey School of Public Affairs, University of Minnesota, USA
- **Professor Sir Richard Friend**, Director of Research, The Cavendish Laboratory, University of Cambridge
- **Professor Dame Clare Grey**, Geoffrey Moorhouse Gibson Professor in Materials Chemistry, University of Cambridge
- **Dr Mengyao Han**, Associate Professor, Institute of Geographic Sciences and Natural Resources Research CAS, China; Visiting Scholar, Department of Land Economy, University of Cambridge
- **Professor Richard Jones**, Chair in Materials Physics and Innovation Policy & Associate Vice-President for Innovation & Regional Economic Development, University of Manchester
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- **Dr Sergey Kolesnikov**, Research Associate, Deputy Director of Centre for Environment, Energy and Natural Resource Governance, University of Cambridge
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- **Dr Evan Michelson**, Program Director, Alfred P. Sloan Foundation, USA
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