Beyond A single stimulus: How to leverage the federal government to advance clean energy innovation?

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SUMMARY
There is a critical need to accelerate and improve the innovation process for clean energy technologies. In order to stem the most-dire effects of the climate crisis, there will need to be increased research, development, demonstration, commercialization, deployment, and adoption of clean energy technologies. The innovation process for energy technologies is especially challenging compared with other technological sectors, and can be strengthened through better use of the unique capabilities of the federal government. Recently, the focus of efforts to enhance clean energy innovation has been on what a stimulus bill and/or single piece of legislation can achieve. However, the federal government possesses numerous other means for strengthening the energy innovation process: (1) taking on a greater quantity of risk in the federal government’s RD&D portfolio; (2) extending the federal government’s support for clean energy technologies through its purchasing power; (3) drawing on the full scope of the federal government; and (4) putting energy innovation in the context of societal transformations. Insights on how to draw on the federal government’s resources to support clean energy innovation through these means are described and discussed with an eye toward applicability and actionable steps.

INTRODUCTION
In order to deploy clean energy technologies at the rate and scale needed to avoid the most-dire effects of the climate crisis, the innovation process for these technologies must be accelerated and strengthened. Clean energy technologies include those that generate low-to-zero greenhouse gas (GHG) emissions, and/or support energy generation contributing low-to-zero GHG emissions (e.g. energy storage technologies). Despite the effects of COVID-19 suppressing energy demand in 2020, global energy-related carbon dioxide emissions were forecasted to increase nearly 5% in 2021, to 33 billion tonnes per year (IEA, 2021). Attaining net-zero emissions by mid-century is consistent with meeting the Paris Agreement goal of limiting future warming to under 2 degrees Celsius. While this will require the elimination of almost all direct emissions, net-zero emissions means any remaining greenhouse gas emissions are offset by an equivalent amount of emissions removal and sequestration (NASEM, 2021a). Attaining this emissions target will not be possible without the increased research, development, demonstration, manufacturing, commercialization, deployment, and adoption of clean energy technologies. Innovation is necessary to lower the cost, improve the performance, and rapidly scale existing technologies; as well as to develop new solutions for low-carbon firm generation, energy storage, and clean power for hard-to-decarbonize sectors of the economy.

Underscoring the essential role of innovation in mitigating climate change, the 2022 Intergovernmental Panel on Climate Change (IPCC) report included an entire chapter on innovation, technology development and transfer. This report noted with high confidence that the cost declines and adoption rates seen for several low-emissions technologies have been enabled by innovation-supporting policies, and that this technological innovation is strengthened through a combination of technology-push (including R&D and demonstration) and demand-pull policies (Intergovernmental Panel on Climate Change, 2022). Relative to other sectors, innovation in energy technology is particularly challenging because of high capital costs, long rates of return on investment, and uncertain commercial potential. The World Economic Forum grouped systematic barriers for energy innovation into four key categories: regulatory risks, financing, enabling infrastructure and market access, and social and cultural barriers (World Economic Forum, 2022).
These challenges faced by the energy sector are especially pronounced when compared with industries such as software and consumer electronics, which have attracted a great deal of investment, attention, and financial returns in part because of holding many properties dissimilar to energy technologies: relatively low initial costs, faster scaling, and shorter product life cycles.

Historically, impactful innovation efforts have benefitted from the informed use of the federal government’s hand: for example, the establishment of the National Aeronautics and Space Administration for space technologies, and the Defense Advanced Research Projects Agency (DARPA) for Cold War-era defense technologies (Bonvillian, 2014). Following in this legacy, the U.S. government continues to support the development of technologies critical to national security as well as those advancing its economic and political interests. In addition, many of the innovations that started within the space and defense sectors have found broad applications in the public sector.

In recent years, a great deal of attention has been directed toward what a one-time economic stimulus package can accomplish to enhance clean energy innovation. This focus stems from the legacy of the American Recovery and Reinvestment Act of 2009, which substantially increased Department of Energy (DOE) funding for research, development, and demonstration (RD&D) projects. The 2021 Bipartisan Infrastructure Law provided substantial quantities of funding for the development and demonstration of clean energy technologies, notably $21.5 billion for clean energy research and demonstration hubs (Department of Energy, 2021a). In addition, this legislation recast DOE’s Undersecretary for Science and Energy position to be the Under Secretary for Science and Innovation; allocated funds to further-develop and deploy numerous energy technologies; expanded the authority of DOE’s Loan Program Office; and also established a new Office of Clean Energy Demonstrations (Department of Energy, 2021b). These recent announcements have underscored how the current means for improving the clean energy innovation process have often occurred within the framework of a single legislative proposal as the key vehicle for action.

However, the federal government’s resources can be leveraged to enhance the innovation process outside of the framework of a stimulus package or one-time piece of legislation. This article draws on novel insights from a recent National Academies of Sciences, Engineering, and Medicine (National Academies) workshop series: Enhancing Federal Clean Energy Innovation (NASEM, 2021b). This series featured presentations from luminaries on the energy innovation process, the capabilities of the federal government, and the specific means the federal government has at its disposal to leverage its capabilities to improve the energy innovation process. A planning committee was convened to determine the key topics to be addressed in this workshop series, determine the experts who would be invited to provide their insights on the federal energy innovation process, and moderate the sessions – asking questions to facilitate discussion and draw out the key insights which inform this paper. Planning committee membership as well as full video and written proceedings of the workshops series are available to the public at https://www.nationalacademies.org/our-work/enhancing-federal-clean-energy-innovation-a-workshop.

Key methods the federal government possesses to bolster clean energy innovation outside of a single stimulus are:

1. Taking on a greater quantity of risk in the federal government’s RD&D portfolio
2. Extending the federal government’s support for clean energy technologies through its purchasing power
3. Drawing on the full scope of the federal government
4. Putting energy innovation in the context of societal transformations

Strategies and insights on how to engage the federal government’s resources in these ways are discussed as follows.

**TAKING ON A GREATER QUANTITY OF RISK IN THE FEDERAL GOVERNMENT’S RD&D PORTFOLIO**

The federal government provides unique value in fostering innovation when it takes on an investment portfolio containing a number of higher-risk, higher-reward ventures. The federal government invests over $140
annually in research and development and is free from some of the constraints facing private capital regarding rates of return for investors – namely, allowing the government to pursue investments in technologies which may otherwise be deemed too risky to attract a sizable amount of private capital, but have the potential to yield substantial societal benefits (NASEM, 2017a).

The federal government already recognizes the gains which can be obtained from taking on high-risk, high-reward projects in the defense space, especially through DARPA. DARPA has noted that program managers reject projects for not being ambitious enough, mitigating the cost of failed projects by only funding projects for a limited period of time, and being willing to reallocate funds away from projects which underperform (Congressional Research Service, 2020). An estimated 85–90% of DARPA projects fail to meet their full objectives (Piller, 2003). Yet, DARPA has initiated many of the technological breakthroughs common throughout society today, including GPS (Alexandrow, 2010), the internet (Waldrop, 2015), as well as cyberattack detection and security systems applied in the energy sector (Weiss, n.d.). This approach can realize substantial benefits if applied to the energy sector, and the Advanced Research Projects Agency–Energy (ARPA-E) has applied much of the essence of this model in its program.

Current federal investments in energy technologies are often made on lower-risk ventures – those that are more likely to yield financial returns. This approach reflects U.S. political concerns over the potentially wasteful use of government funds and government involvement in otherwise-private markets. The political backlash from the government’s investment in failed solar cell company Solyndra is a high-profile example (Weiner, 2012). In the workshop series, Tanya Das (House Committee on Science, Space, and Technology) emphasized the need to improve communication regarding the level of risk in government investments (NASEM, 2021b). Improved communication with the public regarding the government’s intentions with its investment portfolio, and the benefits which can be obtained from the government supporting higher-risk ventures, could help to foster an environment where political leaders and voters are less-sensitive to government investment failures when they do occur. Despite the substantial public and political attention paid to that investment’s failure, Das noted that – even including Solyndra – failed projects only comprise 3% of the funds from DOE’s Loan Program Office (NASEM, 2021b).

The federal government’s research programs pertaining to clean energy would also benefit from greater recognition of the results obtained from investments. The National Academies report Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000, concluded that DOE’s evaluations of RD&D programs tended to focus on economic benefits from technology deployment, and not the broader set of benefits stemming from these investments. Examples of these public benefits include public health benefits from improved combustion from engines, as well as reduced electricity bills from more-efficient refrigerators. Additionally, this assessment found that there were substantial realized benefits found for areas where public funding was likely to have strong leverage – for instance, in the fragmented buildings sector (whose incentive structure does not incentivize innovation), and nitrous oxide emissions reductions (where private markets do not easily capture benefits) (NASEM, 2001). This report also noted the uneven nature of benefits from research funding, with the majority of benefits concentrated in a few technologies that sustained major breakthroughs. The benefits from DOE’s energy research spending over this period being concentrated in a handful of investments is consistent with a high-risk, high-reward outcome from federal investment.

The approach of cautious investing runs contrary to the unique properties and advantages the federal government can offer in the innovation space. As discussed by Dan Arvizu (New Mexico State University), the energy innovation system is capital-intensive and risk-averse (Arvizu, 2020). The federal government, by nature of the institution, has the capacity to support a number of riskier ventures that are not be supported by private capital and that could present meaningful innovations for society (Cunliff and Ngyun, 2021). This is due to the size of the federal government, the full extent of its expenditures and purchasing power, as well as not being established as a profit-seeking entity. This is especially true in comparison to private energy sectors such as the electricity sector – which is traditionally understood to be risk-averse (O’Boyle, 2020), with 46% of utility executives and influencers responding that the sector’s risk-averse culture is the key obstacle to improvements in business models and corresponding investments (Funicello-Paul, 2020).

A helpful concept for understanding the private sector’s appetite for risk is the “hurdle rate” for a project. The hurdle rate is the minimum rate of return on an investment or project expected in order for the project...
to be undertaken. The hurdle rate is generally understood to be equal to a firm’s cost of capital (Lioudis, 2021) and according to a recent survey, the median hurdle rate for U.S. companies is 12% (Hyatt, 2017). The federal government can raise capital and financing through the sale of bonds among additional other revenue-raising activities which can support investments in projects which may benefit the public but do not clear these private sector hurdle rates. For comparison, the Office of Management and Budget applies discount rates of 7 and 3% in its analyses, reflecting effects on investment and business, and a return received by consumers, respectively (Li and Pizer, 2021). This ability allows the government to take a longer-term perspective on when an investment may yield benefit, and assess a broader scope of who is attaining future benefits.

There is also an argument to be made regarding the efficiency of the federal government leading investment efforts. A federal-directed investment effort has the opportunity to view the entire energy investment landscape of its participants. This centralized perspective is conducive to information-sharing that benefits the public at large and informs private sector investment decisions to reduce duplication in RD&D efforts (Breakthrough Energy, n.d.).

Adding additional nuance to the role of the federal government, David Victor (UC San Diego), remarked during this workshop series that the government is more-apt to take on “soft risks,” especially those stemming from regulatory risks faced in highly-regulated industries (NASEM, 2021b). Soft risks are ones that are not easily quantifiable – including risks resulting from subjective, partisan, or emotional factors (Swierstra and te Molder, 2012). In part because the federal government is both influential and is the key decision-maker regarding regulation, federal investment can support projects viewed to have too much unquantifiable regulatory risk, and/or to imbue confidence in an innovative technology and that the market for that technology will continue to exist and be supported.

Simply choosing to take on higher-risk investments does not negate the benefits – and some would argue, imperative – of strategic and informed management of these investments. Projects which contain higher levels of risk still need to be strategically and skillfully managed. Victor highlighted programs like ARPA-E and DARPA as programs with proven processes that identify potential successes and failures and manage projects accordingly. ARPA-E has funded projects on processes ranging from engineered biofuel crops to the conversion of CO2 to liquid fuel (ARPA-E, 2017), and a National Academies evaluation of ARPA-E found that ARPA-E-recipients were approximately 60% more-likely to publish than those receiving funding from DOE’s Office of Science, and 13% of ARPA-E awards had resulted in a patent, compared with 5% of projects receiving funding from DOE’s Office of Energy Efficiency & Renewable Energy (NASEM, 2017b). A recent quantitative analysis found ARPA-E to be fulfilling its objective of supporting the development of innovative energy technologies – ARPA-E-funded start-ups file patents at twice the rate of comparable clean energy technology companies (Goldstein et al., 2020). Noting that the success of programs cannot be determined by one single metric, a National Academies evaluation assessed the agency from a more holistic perspective including patents, publications, follow-on funding, and the foundation of new firms. Using a combination of these metrics, the evaluation determined ARPA-E is fulfilling its statutory mission and goals (NASEM, 2017b). The National Academies evaluation also noted that many of the successful ARPA-E projects have attracted follow-on funding from the private sector that is critical on the path to commercial deployment.

One of ARPA-E’s defining characteristics is the involvement of the Program Director in the technology’s development. This involvement allows for increased and involved feedback between the Program Director and the funding recipient working to develop and further the innovative technology which has been sponsored. During the workshop, Lou Schick (Clean Energy Ventures) noted that when learning is involved and success isn’t guaranteed, the ability to adjust course in a project is valuable (NASEM, 2021b), and Ernest Moniz (Energy Futures Initiative) advocated for applying the rigorous project management regimes found in entities like ARPA-E to demonstrations in the later-stages of the innovation process (NASEM, 2021b).

A common element of the DARPA and ARPA-E models is project managers with limited tenures. In the case of DARPA, this combats risk-averseness, as these individuals understand themselves to be there to accomplish an objective, not build a career (DARPA, 2016). Additionally, a regular influx of new expertise keeps technical knowledge and views on the cutting edge, as also noted by ARPA-E itself (ARPA-E, n.d.-a).
Jacquelyn Pless (MIT) highlighted the need for evidence-based evaluations of government investments in energy technologies, of which there is currently a limited literature (NASEM, 2021b; Pless et al., 2020). It is important to be able to evaluate which projects are working well and which are not. The project management structure from entities such as ARPA-E can be employed to oversee and manage investments in projects which have true potential for success, but carry a meaningful risk of failure.

One key motivation behind the federal government increasing the level of risk in its investment portfolio is that the government can go where the private sector will not. In addition to RD&D investments, the federal government can also leverage its sheer size as a means for supporting energy innovations.

**EXTENDING THE FEDERAL GOVERNMENT’S SUPPORT FOR CLEAN ENERGY TECHNOLOGIES THROUGH ITS PURCHASING POWER**

The government can provide support for innovative, emerging technologies through the engaged use of procurement. Utilizing its vast purchasing power, government purchase orders can allow for the manufacturing of innovative technologies to scale, can be used by firms to attract additional investment, and can help technologies avoid “valleys of death” — areas of development where firms have difficulty raising necessary funding to bring their product to the next stage in research and development, demonstration, and deployment/commercialization (Murphy and Edward, 2003; Hart, 2018).

Prominent examples of where government procurement could create demand for innovative energy technologies include the composition of government vehicle fleets. This is already underway; USPS recently announced a $482 million contract with Oskkosh Defense to add up to 165,000 electrified delivery vehicles to its fleet (Frum, 2021). Procurement policies may also extend to energy resources in government facilities, energy sources and resources on military installations such as resilient microgrids (Holbrook, 2020), energy-efficient appliances for federal buildings (Lawrence Berkeley National Laboratory, 2019), and technology requirements for contractors. A “buy clean” standard applied to the federal government’s procurement, as well as purchases of those doing business with the federal government, would foster additional demand-pull for clean energy technologies.

A concrete example of the federal government driving down costs and providing market certainty for products can be seen for biofuels and bioenergy crops through the U.S. Department of Agriculture (USDA)’s BioPreferred program. Under the BioPreferred Program, the federal government utilizes purchasing requirements for federal agencies and contractors and voluntary product certification and labeling to increase the development, market expansion, and adoption of bio-based products (USDA, 2016). During the workshop, Mary Maxon (Lawrence Berkeley National Lab) also highlighted DOE’s Biological and Environmental Research program, whose Joint BioEnergy Institute research reduced the cost of producing isopentenol from $300,000/gallon to $35/gallon over 10 years (Maxon, 2020). This demonstrates the capability of the federal government to create demand pull for clean technologies and support technology innovations to improve performance and reduce costs.

The Department of Defense (DoD) is another example of part of the federal government which has a substantial procurement budget and uses these purchases to provide demand-pull. The DoD supports numerous successful technological innovations (ranging from technologies pertaining to photography, satellites, and the internet, among others), a mechanism highlighted by Dorothy Robyn (Boston University) and Norman Augustine (Lockheed Martin, Retired) (NASEM, 2021b).

While the federal government has a substantial ability to advance the innovation process through the use of financial resources (e.g. investments, procurement), it also has a number of unique properties pertaining to its mission and the expansive scope of the federal government apparatus which can provide support for clean energy innovations.

**DRAWING ON THE FULL SCOPE OF THE FEDERAL GOVERNMENT**

Given the scale of the climate crisis and the structure of the federal government, enhancing the clean energy innovation process will require innovative thinking and approaches. The federal government has a vast array of resources and capacities at its disposal in addition to RD&D support and its purchasing power. Public-private partnerships, not-for-profit bridge organizations, agency staffing and funding models,
regulatory capabilities, and targeted regional approaches can all be leveraged to strengthen clean energy innovation.

Developing an agency culture that prioritizes innovation and knowledge sharing can be integral to enhancing innovation. Cherry Murray (Arizona State University) identified practices she witnessed during her career at Bell Labs that fostered an environment conducive to the development of novel ideas and approaches. Murray highlighted mission-oriented goals and/or “Grand Challenge” problems as key elements which could be adopted from the Bell Laboratories model (NASEM, 2021b). This approach to innovation identifies key objectives to reach and spurs technology development with the stated aim of achieving these goals. The benefits of lower friction for employees to move between organizations, and the merits of alternative staffing and/or funding models as a means for enhancing the innovation process were also noted.

Another means for enhancing demand-pull is improved public-private partnerships between the federal government and industry. These partnerships provide value by de-risking technologies earlier in their development stages. National laboratories and the government provide means for testing and validating technologies, which supports innovations much earlier in their development cycles. During the workshop, Walter Copan (National Institute of Standards and Technology (NIST)) discussed the success of NIST’s partnership models to establish demand (Copan, 2020). Christopher Gould (Exelon) described Exelon’s unique venture fund evolving from a partnership with Argonne National Laboratory and Arun Majumdar (Stanford University) highlighted SEMATECH (a not-for-profit consortium between the federal government and private companies for chip manufacturing) as a model for government-industry partnership in critical energy sectors (NASEM, 2021b). The DOE laboratory complex is increasingly involved in the technology transfer and commercialization space. One prominent example is the consortium model, launching M²FCT between Los Alamos and Lawrence Berkeley National Laboratories focusing on hydrogen fuel cells, and H2NEW with the National Renewable Energy Laboratory and Idaho National Laboratory focusing on hydrogen production (Department of Energy, 2020). Federal agencies and programs can be poised to aid in the innovation process if they possess manufacturing and business knowledge on their own, without requiring industry involvement. In addition, it is important to note that technology development at national labs also benefits from partnerships and funding to academic institutions, whose expertise – particularly at the early stages of the innovation process – is quite valuable. National laboratories have a history of predominantly focusing on scientific discovery and research, with programs such as Tech to Market at ARPA-E providing support directly connected with commercialization (ARPA-E, n.d.-b).

Norman Augustine (Lockheed Martin, Retired) proposed creating an organization similar to In-Q-Tel (for defense) for energy technologies. In this creative approach, the organization would be a private, not-for-profit bridge organization funded by the government with the ability to quickly award grants and contracts for demonstrations of promising energy technologies (NASEM, 2021b). Another potential strategy involves learning from the National Institutes of Health’s (NIH) staffing and foundation funding model. NIH is led by career civil servants and scientists, with directors often carrying over across administrations, and with appropriated funds allocated at the institute level, a structure discussed by Robin Millican from Gates Ventures (NASEM, 2021b). Both Paul Dabbar (Department of Energy) and Tanya Das (House Committee on Science, Space, and Technology) contemplated the benefits of a foundation funding model for DOE, which would allow the agency to raise private-sector funds and create partnerships with public and private institutions. A related proposal for a DOE foundation has been developed by David Hart (Information Technology and Innovation Foundation) and Jetta Wong (JLW Consulting) (Wong and Hart, 2020).

The federal government can also advance clean energy innovation through the measured use of regulations. One key approach is using regulation to predictably phase-out carbon intensive energy sources and practices. DOE contributing RD&D funds alongside private sector investment to phase out the use of hydrochlorofluorocarbons in refrigeration is one historical example. As a result, notable gains in appliance energy efficiency were obtained (NASEM, 2001). However, regulations are not only limited to reducing the use of products. The Renewable Fuel Standard mandates quantities of renewable fuels (e.g. biomass-based diesel, cellulosic biofuel, advanced biofuels) to replace or reduce petroleum-based fuels consumed for transportation (EPA, n.d.). This regulation, in effect, increases production and consumption of an energy source by setting a requirement. A similar regulation proposed for the electricity
PUTTING ENERGY INNOVATION IN THE CONTEXT OF SOCIETAL TRANSFORMATIONS

To be successful, it is essential that efforts to enhance clean energy innovation effectively integrate equity and justice considerations into decision-making, as well as account for the implications of an increasingly-globalized world. Incorporating these considerations will be integral to building coalitions and societal acceptance necessary for successfully decarbonizing the U.S. energy system (NASEM, 2021a). This transition will touch every aspect of the economy: fundamentally altering the workforce, how people consume energy, and the technologies used. Careful planning is necessary to ensure support and guarantee that benefits and hardships are shared equally across geographies and populations. The essential need to integrate equity and justice in the energy transition was stressed in particular by Ernest Moniz (Energy Futures Initiative), Dan Arvizu (New Mexico State University), George Crabtree (Argonne National Laboratory), and Arun Majumdar (Stanford University). These workshop participants highlighted how the development of a clean energy workforce is a key dimension in the space connecting innovation with equity. The transition to clean energy presents the opportunity to address historical injustices in energy access and affordability (Bednar and Reames, 2020), as well as reduce the disproportionate pollution burden borne by communities of color and low-income communities (Tessum et al., 2021). It also presents the potential opportunity for inclusive economic growth (NASEM, 2021a). Arvizu noted that the clean energy industry has created approximately four million jobs, and is expected to add 3.4 million jobs in the next few years (Arvizu, 2020). Moniz laid out the case that systemic change does not happen without broad coalition-building,
including labor, and that regional innovation ecosystems which feature strong social justice agendas will be critical to a successful climate action plan (NASEM, 2021b).

Another essential consideration for successful clean energy innovation efforts is navigating the shifting tides of increasingly-global and connected supply chains. Strategies and considerations for navigating clean energy innovation in the globalized world were discussed by Laura Diaz Anadon (University of Cambridge), Willy Shih (Harvard University), John Melo (Amyris), Varun Sivaram (Columbia University), and David Hart (Information Technology and Innovation Foundation). These workshop series participants presented the need to balance cooperation and competition between the United States and other nations. In terms of competition, the relationship between the United States and China is a clear example, with Diaz Anadon acknowledging both countries trying to capture markets for clean energy technologies. However, the benefits of cooperation are also quite tangible: Shih noted the interdependence between the United States and China for basic supply chain components, and Sivaram discussed Mission Innovation, where 24 nations committed to doubling their clean energy R&D spending over five years (NASEM, 2021b; Moniz, 2015). Melo also emphasized the role of integrating local talent and skills into international efforts. The changes to the energy system necessary for decarbonization are vast enough that many global actors will be involved and connected. The effects of Russia’s invasion of Ukraine are a timely example – not only increasing energy prices, but also sparking a wave of discussion regarding supply chain security for energy sources and the components for energy technologies in the West. Recognizing the benefits and challenges of these relationships and creating strategic considerations for how to navigate them will be essential to successful innovation efforts.

Considerations regarding who is included and who benefits from energy innovation and clean energy policy are essential to their success. If the efforts described previously are to effectively create the innovation necessary to reach net-zero emissions on a timeline that mitigates the worst effects of the climate crisis, they must have both equitable inclusion of all groups and be informed as to the global nature of the energy system’s supply chains.

Directly addressing and maximizing who benefits from energy innovations and clean energy policies is essential to realizing the emission reductions needed to stave off the worst effects of climate change. If the country is to have the innovation ecosystem necessary for a net-zero emissions economy, the transition also must meet wider societal aspirations for high quality jobs, sustainable communities, and environmental justice. It is only by satisfying these needs that any federal policy to support clean energy innovation can be successful at the scale necessary over the long-term.

LIMITATIONS OF STUDY
This Perspective paper draws on the presentations and discussions of invited experts participating in a National Academies workshop series. Workshops series participants were selected by a planning committee consisting of respected and qualified experts on federal innovation policy and the energy innovation process. The information in this article draws on the insights provided by this group, but may not be representative of the entire scope of perspectives on the topics discussed.

CONCLUSION
The federal government has an enormous breadth of resources that can enhance the innovation process. In order to create the sustained and effective improvements in the clean energy innovation ecosystem necessary to reach net-zero emissions by midcentury, one must look beyond the framework of one piece of legislation.

It is understandable given recent COVID-19 pandemic economic relief legislation, as well as the historical connection between crisis response and innovation policy-making (Gross and Sampat, 2021), that a great deal of attention has been directed toward how clean energy innovation can be addressed through the single stimulus pathway. However, the federal government possesses means to improve the energy innovation process in ways beyond a single legislative package. Many of these means are actions the government is already undertaking, just in domains other than energy (e.g. defense, health). Other actions involve capitalizing on what an entity with the sheer size, scope, and influence of the federal government can do for nascent and emerging innovative technologies.
One of these means is increasing risk in the government’s investment portfolio. If almost all of the federal government’s investments are paying off and yielding success, then the investment portfolio is not risky enough to stimulate meaningful innovation. As noted previously, DARPA – one of the U.S. agencies with the most-celebrated innovation track record – has had only 10–15% of its projects meet their full objectives (Piller, 2003), illustrating the value of investing in technologies and projects with high risks of failure to spur innovation. The federal government is uniquely positioned as an investor which can invest in a number of high-risk, high-reward ventures, but also as a consumer for technologies. The sheer size of the federal government provides it with purchasing power on a level that can influence markets and technology scale-up. Procurement processes for clean energy technologies from the government can stimulate demand for a product, and be at the size where it could prompt an industry to expand or scale their production of a product. Both federal investments and procurement can also support technologies with the potential to yield large societal benefits in addition to potential financial returns. In addition to the government’s magnitude, it also contains a variety of agencies, organizations, and programs whose resources can be leveraged to bolster clean energy innovation. The variety and breadth of entities that comprise the federal government provide numerous avenues for fostering and enhancing innovation – and the severity of the climate crisis is such that all available resources must be leveraged to meet our emissions goals. Decarbonizing the U.S. economy will prompt societal transformations and is occurring in a shifting international context. Acknowledging that all federal government activities supporting clean energy innovation will happen in this social and global context and proactively managing them accordingly will be imperative for informing proper planning and attaining successful outcomes.

The federal government historically played a key role in spurring technology development, and the potential consequences of inaction on climate change are too serious not to leverage every element of the U.S. government available. Drawing on these resources in an informed and effective way will be an invaluable means for addressing the climate crisis.

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AUTHOR CONTRIBUTIONS

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DECLARATION OF INTERESTS

The authors declare no competing interests.

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