

The Pressing Energy Innovation Challenge of the U.S. National Labs

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Accelerating the development and deployment of energy technologies is a pressing challenge. Doing so will require policy reform that improves the efficacy of public research organizations and strengthens the linkages between public and private innovators. With their US\$14 billion annual budget and unique mandates, the U.S. National Laboratories have the potential to critically advance energy innovation; however, reviews of their performance find several areas of weak organizational design. Here, we discuss the challenges the Labs face in engaging the private sector, increasing their contributions to transformative research, and developing the culture and management practices to better support innovation. We also offer recommendations for how the Labs can address these challenges.

1. Introduction

The importance of the public sector's role in shaping innovation systems in general, and in the U.S. national innovation system in particular, is well-known^{1,2}. In the U.S., the Federal Government has a distinct role in funding research and development (R&D), which has been articulated in terms of a responsibility for developing new scientific insight³, conducting mission-oriented research in the national interest^{4,5}, correcting market failures^{6,7}, and enhancing economic competitiveness⁸. It follows then, that in 2011, of the US\$424 billion spent in the U.S. economy on R&D, 30% was funded by federal agencies. Less appreciated however, is that 12% of total R&D (US\$49.4 billion in 2011) was not only funded by

the Federal Government but was also conducted by federal agencies and the 42 federally-funded R&D centers (FFRDCs)⁹. Among these FFRDCs are 16 of the 17 Department of Energy (DOE) National Laboratories (the Labs). Collectively, the 17 Labs have an annual budget of US\$14 billion¹⁰ and are often referred to as the nation's "crown jewels of innovation"¹¹.

However, while there is wide agreement that the Labs play a critical role in the U.S. innovation ecosystem, they face increasing pressure to rapidly develop and deploy new energy technologies, a more restrictive fiscal climate, and an increasingly complex bureaucratic organization. In this context, the DOE has recently completed two parallel processes reviewing how the Labs are performing in the national interest: the report from the Commission to Review the Effectiveness of the National Energy Laboratories (CRENEL)¹⁰, and the interim report from the Secretary of Energy Advisory Board (SEAB) Task Force on DOE National Laboratories¹². These reports broadly examine Lab activities in basic science, nuclear weapon management and cleanup, and energy R&D (see Box 1 for a brief summary of the two reports). In this Perspective, we focus on the last of these activities and present important trends and recommendations pertinent to the Labs' mission to advance innovation in energy technologies. This mission is a significant area of focus for the five multi-mission Labs and the three energy Labs and is also relevant for the energy-related work of the three Labs managed through the National Nuclear Security Administration (NNSA). Box 2 provides detail on the organizational context of the National Labs as it relates to the mission of advancing energy innovation.

2. Key trends in Lab activity and needed areas for reform

2.1 Declining Lab engagement with the private sector

Much of DOE's mission in energy-related research can only be considered successful if private actors adopt new technologies. Fundamentally, private companies must adopt energy technologies invented with public funds that support energy R&D if those funds are to create social value. This is in contrast to other

areas of notable government R&D where the government is both the producer and “consumer” of new technologies, such as military R&D and the weapons and space-travel technologies developed under the Manhattan and Apollo Projects¹³. The design of public energy R&D institutions in the energy context is challenging because mission fulfillment is intertwined with evolving trends in private energy innovation, production, and use, raising the question of what the most appropriate and effective forms of engagement are between the Labs and the private sector.

One way to evaluate Lab engagement with the private sector is by examining formal interactions under the umbrella of technology transfer activities. DOE and the Labs have developed metrics to assess outcomes of technology transfer that provide insight into the level of engagement between the Labs and the private sector. Still, interpreting technology transfer metrics is challenging, as technology transfer may be differentially relevant for different types of R&D (i.e., technology transfer is more likely for applied energy and less likely for fundamental science and weapons activities). Further, the common metrics reported by DOE and the Labs focus on the volume of technology transfer activity, which is an imperfect measure of the effectiveness of such activities. Nevertheless, analyzing the metrics that DOE and the Labs rely upon over time shows that technology transfer activity per R&D dollar invested has declined on average from 1997 – 2012 and from 2001 – 2012, although there have also been periods of increasing activity (Figure 1). In particular, we note that all five metrics we assess—new Cooperative Research and Development Agreements (CRADAs), invention disclosures, patent applications, patents granted, and invention licenses—were at higher levels in 2006 than in 2012 and yet at even higher levels in 1997. Figure 1 also shows that the most recent 3 to 4 years of data suggest upward trends for all metrics but patent applications. Of note, Congress gradually eliminated funding for DOE CRADAs in the late 1990s, leading to a notable decrease in CRADA activity⁸, an important mechanism for enabling collaborations between the Labs and the private sector. The important role of CRADAs as an input into the technology transfer process is suggested in the data: the decrease in funding for CRADAs in the late 1990s preceded a decrease in other technology transfer measures.

The general decrease in technology transfer productivity over the most recent 15 years of data^{14,15} suggests an increasing disconnect between the Labs and the private sector. The CRENEL and SEAB reports make extensive comments about the need to clarify the importance of the Labs' technology transfer mission and to improve the infrastructure and policy architecture that facilitates translation of DOE research for private sector application. However, in terms of specifics, the SEAB and CRENEL reports' recommendations emphasize different directions. Whereas the CRENEL report argues for clear and consistent messaging about the importance of standardization of policies and practices while retaining some flexibility to adapt to contextual factors at the Labs, the SEAB Task Force identifies centralization as an obstacle to technology transfer. We argue that effective technology transfer requires both central coordination—in the form of standardization in practices to reduce the transaction costs of prospective commercial partners to engage with the Labs—and decentralized engagement—to translate the technical details of inventions based on a close understanding of the technology. The centralized coordination will require the dedication of funding at DOE Headquarters for this specific task; the recently created DOE Office of Technology Transitions can serve in this role. Decentralized engagement at the laboratory level will require policies that incentivize Lab scientists to seek partners and engage with the private sector. These policies may include allowing entrepreneurial leave and rewarding scientists whose technologies result in the formation of a spin-out company.

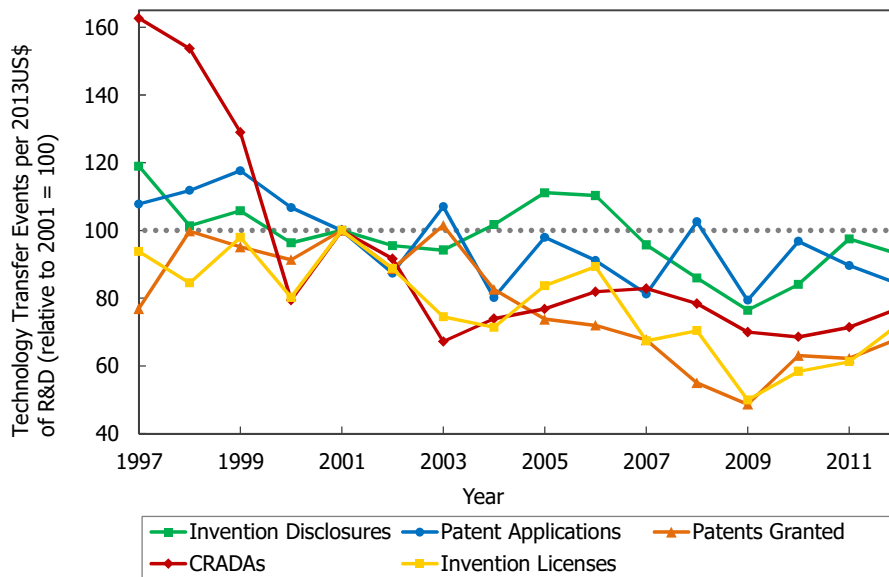


Fig. 1. Technology transfer outcomes over time. DOE technology transfer metrics (new CRADAs, invention disclosures, patent applications, patents granted, and invention licenses; data for all five metrics from Department of Commerce¹⁴) per 2013US\$ of R&D invested (data from National Science Foundation¹⁵), normalized to 2001 rates, shown for the period 1997 – 2012. Technology transfer outcomes are drawn from all DOE-owned facilities, but R&D spending data represents only DOE Government-Owned Contractor-Operated (GOCO) Labs (e.g., including physics and NNSA Labs but excluding the National Energy Technology Laboratory). All metrics exhibit overall decreasing trends and are lower in 2012 than in 2001. The source data and calculations underlying this figure can be found in [the Supplementary Data 1](#).

2.2 Constrained Laboratory-Directed R&D

Innovation outcomes materialize over long time horizons, often decades, but political pressures have created annual review and budgeting cycles for Lab research that undervalue potential long-term impacts.

Successful R&D management requires the institutional capability to make high-risk, high-reward investments, which implies the need for tolerance to failure and more lengthy review cycles.

One tool that Lab directors have to broaden the time horizon of Lab R&D activity and engage in high-risk, high-reward work is laboratory-directed research and development (LDRD). LDRD is funded through Lab overhead costs on other projects and is provided to Lab directors to flexibly fund projects proposed by Lab scientists. As a strategic tool, LDRD has unquestionable value in engaging and retaining

early career scientists by giving them the flexibility to pursue their own “passion projects” at the scientific frontier¹⁶.

Whether LDRD advances the energy innovation mission of the Labs is less clear. The SEAB report argues that “LDRD has been responsible for some of the most important ideas coming from the laboratories,” and DOE itself claims that at least two Nobel Prizes have resulted from LDRD work^{17,18}. However, rigorous evaluation of the overall effectiveness of LDRD in advancing energy innovation is challenging due to a lack of appropriate metrics (see Box 3). Useful proxy measures for understanding the relative effectiveness of LDRD compared to DOE-directed R&D are provided by the rate of disclosure of new inventions and the development of patentable inventions scaled by R&D investment. Our analysis in Figure 2 displays these invention rates, revealing that LDRD funds are significantly more productive in these two metrics.

Two important caveats apply. First, our proxy measures of DOE-directed R&D includes all R&D funding at the Labs, some of which could not reasonably be expected to contribute towards new inventions or patents; instead some of this work leads to findings that are not disclosable (e.g. for security reasons), funds high-energy physics facilities which do not disclose many individual inventions, and supports physical facilities (which do not translate into innovation outcomes in the same year those funds are reported). Second, these metrics do not capture the full range of important services the Labs provide that do not result in invention disclosures and patents. For example, not included are the inventions and patents resulting from the services Labs provide through their user facilities, a major source of private-sector engagement.

With these caveats in mind, the higher rate of invention disclosures and patents granted and filed from LDRD funds compared to DOE-directed funds is consistent with policies aligning LDRD with early-stage

research that engages newer and riskier ideas¹⁹. Thus, we argue that LDRD is also an important policy tool in the DOE and Labs' toolbox for furthering their energy technology innovation mission.

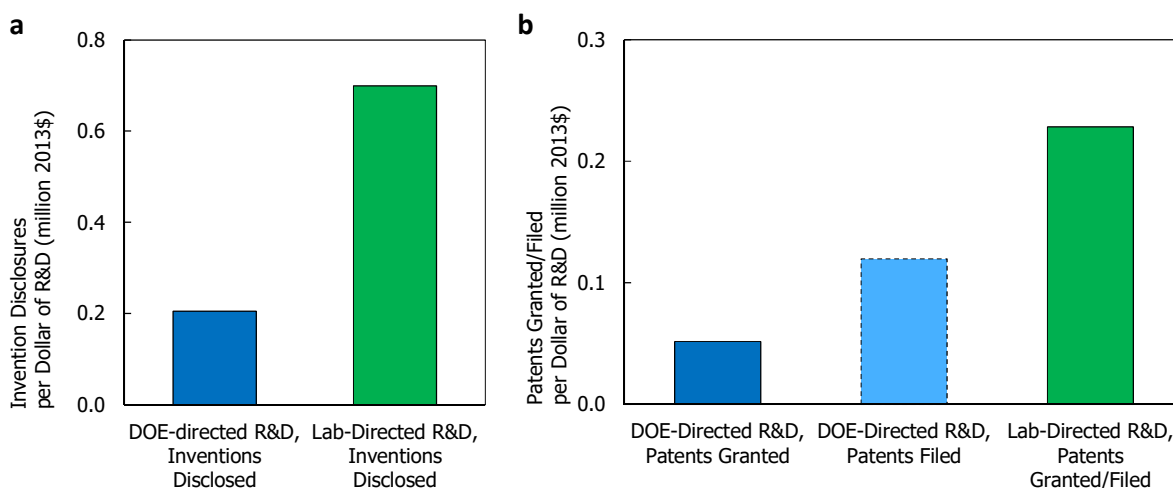


Fig. 2: DOE-directed and Lab-directed technology transfer outcomes. (a) Number of inventions disclosed and (b) patents granted/ filed per million US\$2013 at the Labs for DOE-directed R&D funding (blue) and Laboratory-Directed R&D (LDRD) funding (green) averaged over the period 2007-2012. For LDRD leading to patents, some Labs report granted patents and some report filed patents; the sum of reported granted/ filed patents is included in the LDRD bar. For completeness, DOE-directed R&D leading to patenting is displayed both in terms of granted patents (dark blue) and filed patents (light blue). There are no notable trends in these ratios over this period. Data from the U.S. Department of Commerce on technology transfer outcomes,¹⁴ National Science Foundation data on DOE R&D obligations,¹⁵ and DOE spending data on LDRD^{50†}. Data for technology transfer outcomes includes the several non-National Lab DOE facilities with relatively small R&D budgets, while data for R&D obligations covers only 16 of the 17 National Labs (The National Energy Technology Laboratory is not included). The source data and calculations underlying this figure can be found in [the Supplementary Data 1](#).

Despite the demonstrable value of LDRD in comparison to DOE-directed R&D, there has been a declining trend in funds used for LDRD. Congress has effectively lowered the allowable spending limit for LDRD two times over the past 10 years. Originally set at 8% of the total Lab budget, the LDRD cap was effectively lowered in 2006 when LDRD funds were required to cover their own indirect costs (despite the fact that LDRD programs are themselves funded through the indirect costs of other projects). Further, in 2014, the LDRD cap was lowered to 6%, indicative of the eroded trust between the Labs and Congressional decision-makers. We argue that increasing the limits to LDRD funding should be

considered in light of the evidence presented above and LDRD's unique role in giving more autonomy in selecting R&D projects to the decision-makers closest to the technical expertise in the Labs.

Simply adjusting the statutory limits to LDRD would be insufficient to drive more high-risk, high-return energy R&D. In the 2014 fiscal year, energy, science, and environmental management Labs dedicated only 2.7% of their budgets to LDRD, well below the limit (this is compared to around 5.6% for NNSA Labs²⁰; this difference is explained in Box 3). In exploring why LDRD levels have been below statutory limits at one Lab, the National Renewable Energy Laboratory (NREL), interviews we have conducted reveal that DOE site offices and intense programmatic pressures on shorter term deliverables make Lab managers wary of initiating new high-risk R&D projects through the LDRD program²¹. We argue that the use of LDRD funds could be increased if Lab managers built a case for more LDRD projects as a way to fulfill DOE and the Labs' innovation mission rather than focusing on LDRD's role in personnel recruitment and retention and the nucleation of new programs. With this refocusing of the LDRD program, LDRD projects should be selected in part based on their prospective ability to address some of the short-termism and risk-aversion at the Labs and to increase Lab tech-transfer activities. We also support the SEAB's recommendation to experiment with more creative approaches to unleashing the potential of LDRD.

2.3 Rising project direction and management costs

The bureaucracy managing and providing oversight of the Labs has grown in recent years, in large part due to changes in accounting and other management processes^{21,22}. As a result, an increasing fraction of Lab funding is devoted to overhead and other non-research activities. Reviewing the 2009 budget, the DOE Inspector General found that approximately 35-40% of National Lab budgets were allocated to administrative overhead and indirect costs, describing this allocation as "unsustainable"²². In response, the Secretary of Energy recently established a Laboratory Operations Board to improve the "effectiveness and efficiency of the Labs and of the relationships among Labs, DOE, and contractors"¹². However, as the

CRENEL report points out, a major challenge in understanding the efficiency of Lab research management remains, in that Lab overhead costs are not publicly reported, even though this information has been collected since 2010¹⁰.

Nonetheless, other indicators are available. In Figure 3, using budget data for energy-related programs at DOE Headquarters (distinct from Lab budgets), we show that expenditures in program direction and management have nearly doubled as a fraction of DOE program budgets from 1990 to 2015. This upward trend in program direction and management shows that public funds to advance energy innovation at DOE have increasingly been used for non-research activities.

The CRENEL report¹⁰ highlighted the high ratios at several Labs of site office employees (who provide oversight) to Lab employees (who conduct research and manage Lab operations). Our own work, including interviews with past and present high-level decision makers at the Labs²¹ and other testimonies²³, confirms that increases in program management and direction costs at least partly reflect the increasing reporting requirements and oversight the Labs are subject to. Reducing overhead costs can be accomplished by shifting the oversight model to require fewer DOE approvals and utilizing modern auditing techniques, such as expanding the use of a “Contractor Assurance System” (CAS), as recommended by the National Academy of Public Administration²⁴ for ex post facto verification of effective management by Lab contractors.

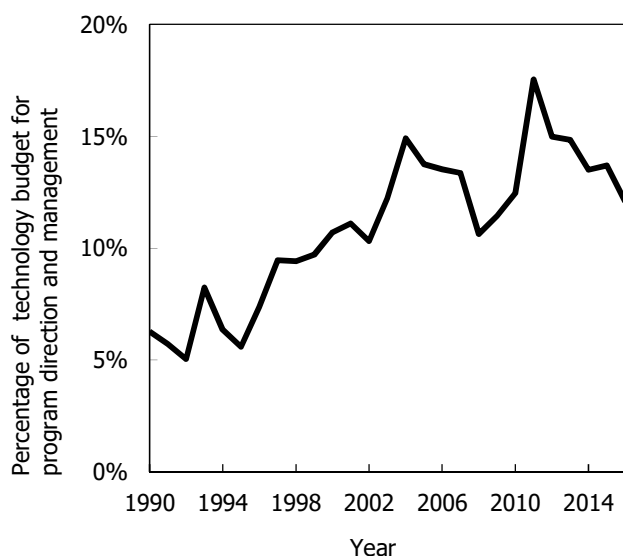


Fig. 3: Percentage of DOE technology funding for program direction and administration.

Percentage of DOE funding for technology programs devoted to “program direction and management” (PD&M) at DOE Headquarters (HQ) as per official DOE budget justification budgets. Fiscal Year 2014 and 2016 budgets are as enacted and the 2015 budget is current appropriations. The 2009 stimulus package has been omitted for comparability. Note that the figure does not include expenses or PD&M in non-energy programs such as environmental remediation and NNSA. It only encompasses R&D expenses and DOE HQ costs in PD&M in 5 technology areas: fossil energy, renewables, energy efficiency, transmission and distribution, and nuclear power. Data from official DOE budget justification documents, collected by Gallagher and Anadon in ref. ⁵¹². Calculations divide the PD&M budget line in each of the 5 program areas by the total R&D expense in the corresponding program area and averages the results. Program direction and management funds provide “resources for program and project management, administrative support, contract administration, human capital management, Headquarters and field site non-laboratory facilities and infrastructure, and contractor support”⁵²³. The source data and calculations underlying this figure can be found in [the Supplementary Data 1](#).

3. Next steps in reforming the Labs’ energy innovation mission

We now focus on three areas that we believe are particularly important to improve the Labs’ contribution towards advancing energy innovation: strengthening interactions with the private sector, removing the separation between basic and applied research, and increasing Lab flexibility while building trust. Our choice of these three areas for recommendations stems from the trends we document above and what we believe are the most crucial areas for politically feasible reform. Our recommendations build on the findings pertinent to the Labs’ energy innovation mission described in the CRENEL and SEAB reports

and other recent work focused on particular Lab activities (e.g. advancing nuclear energy²⁵, increasing local economic benefits of Lab activity in their regional and metropolitan clusters²⁶, and increasing the impact of user facilities as full-scale test beds²⁷). A common theme from these studies is the need to improve the interface between the Labs and the private sector, and we turn to recommendations in this area first. Our second and third sets of recommendations pertain to how theory and experience in the organization and management of research can apply to the National Labs. Here we build on a wide range of reports beyond the CRENEL and SEAB reports (e.g.^{28, 29}), our own work, and our own personal experience: one of us previously served as Sandia National Laboratory's Director of Research and has sat on several advisory committees for DOE research bodies. There are many other important areas to critique and suggest improvements beyond the three we discuss below that we are unable to examine in detail due to space constraints, (e.g., whether the evolution of funding for different technology areas over time reflects the various challenges the nation faces³⁰).

3.1 Strengthening interactions with the private sector

There is a prominent view that the growing disconnect between DOE and the private sector is to some extent intentional and necessary. This view is grounded in the argument that the Labs first purpose is to serve the needs of basic research and enhance the public scientific knowledge base (i.e. that “the proper role of the Federal Government is to support basic research”³¹), thus making it inappropriate for the Labs to provide support for private sector firms interested in acquiring proprietary knowledge with privately appropriable benefits. This view implicitly supports the notion that the basic research that the Labs conduct will eventually lead to public benefits through a gradual process of knowledge diffusion that does not require specific efforts to engage the private sector.

The reality is that even without the existing legislative mandates to engage the private sector³², limited forms of Lab interactions with the private sector are necessary to increase the effectiveness and public

value of Lab research and to contribute to meeting DOE’s goal to “catalyze the timely, material, and efficient transformation of the nation’s energy system”³³ (see Box 2). Managing close interactions with the private sector raises its own set of issues, including managing conflict of interest, ensuring fair access to Lab resources to private partners, and balancing interactions with foreign and domestic partners. A recent Congressional Research Service report explained this difficult balance as follows: “The federal laboratories have received a mandate to transfer technology. This, however, is not the same as a mandate to help the private sector in the development and commercialization of technology for the marketplace. The laboratories were created to perform the R&D necessary to meet government needs, which typically are not consistent with the demands of the marketplace”³⁴. An inappropriately close relationship between private interests and the Labs threatens to displace R&D performed in the public interest. However, a too distant relationship between the Labs and industry also threatens the effectiveness of the Labs by disconnecting R&D from it from its potential applications.

Engagement with the private sector can make Lab-sponsored research more effective by building in iterative feedback between scientific research, applied research, and practice. Research on innovation systems has shown that the linear model of innovation, which assumes that the fruits of basic research will automatically diffuse in the market without additional intervention³, does not represent how the process of innovation works in practice. Exploiting scientific and technical information is costly³⁵, and innovation is iterative, requiring multiple linkages and interactions³⁶. In fact, many devices and technological applications are discovered before fundamental understandings of underlying natural phenomena are developed, and the development of new devices has in many cases facilitated the development of deeper scientific understanding³⁷. In the energy sector, Labs conducting energy technology innovation have limited capacity to engage with practical energy systems without private sector engagement. We believe that engaging the private sector in publicly-supported R&D not only makes public sector R&D more effective (e.g. by drawing attention [onto](#) the commercial viability of

newly developed technologies), but can also accelerate the pace of innovation in the private sector (e.g. by injecting new scientific ideas into practice in a way that stimulates innovation spillovers)³⁸. Moreover, our view, supported by broader work on the nature of scientific research^{39,40}, is that private sector collaboration as one tool in a larger toolkit to advance the Labs' energy innovation mission would contribute to (and not be in conflict with) further advancing fundamental science efforts by providing additional avenues for external feedback and collaboration.

Exploiting linkages between basic and applied research in innovation systems requires developing greater and deeper interactions across actors and organizations that span the public and private sectors^{4,40,41}. Improving Lab interactions with the private sector will require developing stronger linkages that capitalize on the R&D strengths of the Labs without compromising the Labs' fundamental science mission. In our view and that of SEAB, there are already several good examples of strategic partnerships between the Labs and other actors to accelerate the transfer of knowledge between the Lab and the marketplace (e.g. Sandia's Entrepreneurial Separation to Transfer Technology program, Lawrence Berkeley's Cyclotron Road, Argonne's Chain Reaction Innovations program⁴², DOE's initiatives to engage small businesses through the Small Business Vouchers Pilot¹², and the creation of a new DOE Office of Technology Transitions). However, we believe that sustained Congressional support and more work at DOE Headquarters and at the Labs are needed to facilitate partnerships for technology licensing and to accelerate contracting mechanisms for collaborative R&D. In addition, the Labs can also accelerate the commercialization of ideas outside the Labs through other forms of engagement, including a greater role and improved access to their user facilities²⁷. The feedback between the market and government research could also be strengthened by providing the Labs with a greater share of the rewards of their own commercialized innovations.⁴

3.2 Removing the separation between basic and applied research

Lab funding streams are classified along the dichotomous distinction of “basic science” and “applied research,” as codified in government budget lines and statistics. This separation of funding streams has been justified on the principle that basic science should be protected from the political pressures that the technology programs face. This line of thinking has deeply influenced the design of the U.S. national innovation system⁴³. We believe that this separation of funding streams is justified by a false choice between stable, protected funding and funding for research that blends the quest for scientific understanding and practical application. Effective R&D investment requires both stable funding and close integration of the activities that currently fall under “basic science” and “applied energy” distinctions⁴⁴.

The stovepiping of Lab funding streams along basic and applied lines is compounded by the organizational management of Lab funding at DOE. Management of DOE’s research activities (in areas other than nuclear security) is separated into DOE’s Office of Science and its four technology offices (see Box 2). This separation is reinforced by the Congressional appointment of Assistant Secretaries and Directors for these different offices that occupy horizontal positions in DOE’s bureaucracy. Because of the long institutionalization of a strong separation in the management of different “types” of DOE research, DOE’s management of investments under different funding streams has been stovepiped^{21, 28}. This affects the Labs that conduct energy R&D, as they receive funding from the Office of Science and the energy technology offices, making the Labs accountable to multiple offices.

This stovepiping has led to the perception that some of the Labs managed by the Office of Science should primarily operate as “science Labs” (e.g. Lawrence Berkeley National Lab), while others managed by the technology offices should operate as “engineering Labs” (e.g. National Renewable Energy Lab). Even in the newly developed DOE Energy Frontier Research Centers (EFRCs), which were designed to overcome distinctions between basic and applied research, once implemented in practice, we have observed through personal experience that DOE managers have often reverted to outmoded oversight practices and

discouraged researchers from developing proof-of-concept prototyping that combines so-called “basic” and “applied” activities.

Addressing the history of siloes between basic and applied research requires changes in how DOE is organized and managed and in the culture at DOE and the Labs. The 2014 appointment of a joint Undersecretary for Science and Energy Research at DOE is one step in the right direction. In addition, the SEAB Task Force recommends the piloting of a project in which scientists at the Labs are given greater discretion to build interdisciplinary and inter-Laboratory teams¹². In addition to this recommendation, which we support, we believe that counterproductive divides between the historic umbrella of basic and applied research activities could also be addressed by increasing funding allocated under the LDRD program; and by moving some of the funding decisions from the program offices up to the Under Secretary level and leaving lower-level operational details of programs to the Labs.

3.3 Increasing Lab flexibility and building trust

The original government-owned, contractor-operated (GOCO) concept for Lab management was designed to provide autonomy to the Labs. This autonomy, which was created because the government had neither the personnel nor the skills to run large labs, gave Lab operators insulation from political pressures, allowing them to focus on fulfilling the technical mission of the Labs. However, this autonomy has been gradually eroded⁴⁵. Current implementation of the GOCO model makes the Labs less effective in realizing their missions through increased burdens (e.g. the need for a parent company guarantee), misaligned incentives (e.g. a greater emphasis on the contractor award fees), and a fundamental cultural shift away from the service-to-the-nation mantra that motivated Lab operators in the past. Increased reporting pressures under the GOCO model are reflected in the growing share of DOE headquarters project management and direction costs (Figure 3) and further documented in the CRENEL report¹⁰. Operating a National Lab has become a less attractive opportunity, as distrust and micromanagement

from DOE (as discussed in the CRENEL and SEAB reports) and budgetary instability has become commonplace^{46,47}.

In principle, large innovative companies and technology-focused research universities are strong candidates to operate Labs under the GOCO model, as they can contribute connections and insights from the marketplace and the frontier of R&D. Over time, however, these organizations have been displaced by non-profit Lab operators who specialize in federal facility operation. This shift is partly due to the increased micro-management and bureaucratic procedures imposed by DOE Headquarters.

Despite the key role played by the Lab contracting partner in executing the Labs' energy innovation mission, there has been little study or DOE-guidance on the characteristics that make an effective operating partner for the Labs. We believe it important to determine whether industrial firms and large universities would benefit from greater independence in running Labs compared to specialized contractors whose business model depends on retaining Lab contracts. An additional key question in our view is whether DOE contracting mechanisms and annual review procedures for Lab operators can be reworked to be made consistent with the Labs' R&D mission²³, enabling the Labs to focus on riskier and more long-term work that may yield greater public benefits. Such contracting mechanisms and review procedures should also serve to increase the attractiveness of Lab management to increase competition for Lab operator contracts.

4. Broadening the discussion

The National Labs have several unique capabilities and features that can greatly accelerate energy innovation and make the U.S. national innovation system more effective overall: they own unique scientific facilities; provide widely accessible expertise and software; can make available scientists, engineers, and equipment to support national goals on a short time-frame (for example, responding to the

Deepwater Horizon oil spill or providing the analytic capabilities enabling the Iran nuclear deal); and can dedicate resources to long term projects that exceed the capabilities of most universities and industry. These and other comparative strengths, make the National Labs vital pieces of the U.S.'s national innovation system. In addressing DOE's energy innovation mission, the Labs are uniquely positioned to take on difficult long-term energy challenges that require multi-disciplinary capabilities and the engagement of a diverse set of actors.

Growing concerns about global competitiveness and the pressing challenge of reforming the energy sector in response to environmental and security concerns are creating a policy window for an expansion of energy innovation policies and National Lab reform. While the present focus is directed towards the U.S. National Labs, the challenge of improving the contributions of publicly funded research organizations toward meeting national goals is not unique to the United States. The growing importance of technological innovation in meeting societal challenges and improving national competitiveness has increased interest about the role of publicly funded labs in other countries⁴⁸. The importance of public research organizations to national innovation systems may be even greater in other countries, as over 30% of all R&D is conducted by the government itself in at least 68 other countries⁴⁹.

In this Perspective, we have highlighted several key issues and offered recommendations for the U.S. National Labs that can be addressed under existing authority or with politically feasible DOE and Congressional reforms. We hope that this Perspective will inform the implementation of policy responses in the continuing debate surrounding the Labs.

Box 1 - The CRENEL and SEAB Reports

CRENEL is a congressionally mandated board appointed by the Secretary of Energy and the President's Council of Advisors on Science and Technology¹⁰. The SEAB Task Force on DOE National Laboratories, in contrast, was established by the Secretary of Energy for two main purposes. The first was to review past studies, Congressional reports and direction, and Departmental deliberations to identify key areas concerning laboratory management and operations. The second was to remain informed about the deliberations of several studies underway at the DOE laboratories, including the CRENEL report.

The SEAB report¹² proposes experiments within DOE authority in the areas of the management and operation contracting system, technology transfer, and Laboratory Directed Research and Development (LDRD). The CRENEL report provides extensive recommendations on recognizing value by providing more resources; rebuilding trust between DOE and the Labs based on increased flexibility and accountability; maintaining alignment and quality; maximizing impact by increasing external collaboration; managing effectiveness and efficiency by improving facilities and project management; and ensuring lasting change by creating structures to push for implementation.

Box 2 – The U.S. National Laboratories and their energy innovation mission

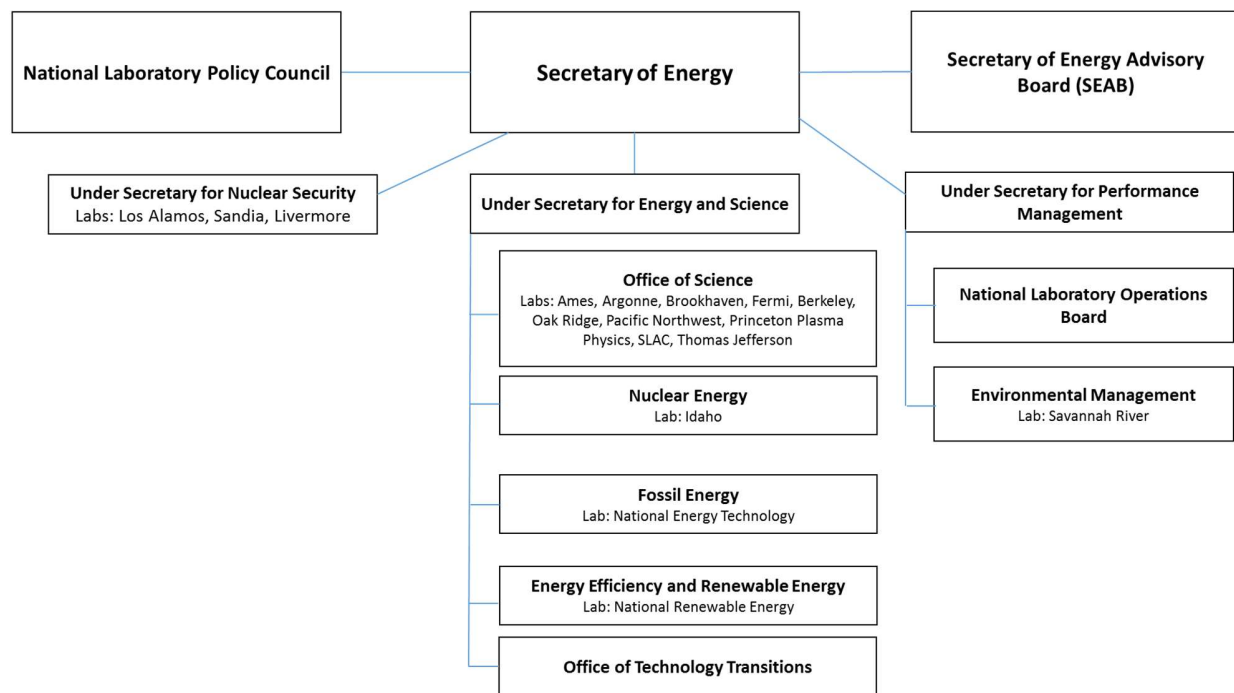
The U.S. Department of Energy (DOE) has the mission “to ensure America’s security and prosperity by addressing its energy, environmental, and nuclear challenges through transformative science and technology solutions.”³³ This mission is broken down into four goals, the first of which is “to catalyze the timely, material, and efficient transformation of the nation’s energy system and secure U.S. leadership in clean energy technologies.”³³ This goal is the most tightly linked to energy innovation.

The Lab system plays an important part in fulfilling the missions of the DOE. It is rooted in the atomic weapons work of the Manhattan Project during the Second World War, but over the last 70 years the mission of the Labs has broadened significantly⁵³. Today, the mission includes supporting national security, advancing fundamental science, promoting innovation in energy and other technological domains, and providing researchers with some of the most advanced tools of modern science.

There are 17 National Labs, 16 of which are FFRDCs. FFRDCs are externally operated entities that conduct research sponsored and funded by a government agency on a long-term research and development need that could not be accomplished with internal agency resources alone⁵⁴. The 17th National Lab is the National Energy Technology Laboratory, which is a government operated laboratory, making it the only non-FFRDC National Lab.

The 17 National Labs vary in their mission and the organization of their management within DOE. There are five multi-mission Labs mainly managed by the Office of Science (Ames, Argonne, LBNL, Oak Ridge, PNNL), three energy Labs managed by the specific technology offices for Nuclear Energy, Fossil Energy, and Energy Efficiency and Renewable Energy (Idaho, NETL, and NREL), three multi-mission Labs managed through the National Nuclear Security Administration (NNSA) (Sandia, LLNL, and Los Alamos), five physics Labs managed by the Office of Science (Fermi, Princeton Plasma Physics, SLAC, Brookhaven, and the Thomas Jefferson National Accelerator Facility), and one Lab focused on hazardous nuclear materials and national defense managed by the Office of Environmental Management (Savannah River). The specific Labs and their management structure within DOE are illustrated below.

Our work in this Perspective is pertinent to the energy Labs and the energy-related work of the multi-mission Labs and the Labs managed through the NNSA. Although the three NNSA Labs have a primary mission related to nuclear security, they are also multi-mission laboratories with an important energy mission. The five physics Labs face different challenges from the other Labs, as their primary mission is to advance the frontier of science. The Savannah River National Laboratory only receives a small amount of its funding from the DOE technology offices¹⁰.



DOE Management Structure for the National Labs: The Department of Energy manages the Labs through a complex bureaucracy. This figure shows a modified organizational chart of DOE that illustrates the relationship of entities involved in Lab management. In addition to DOE offices with management responsibilities for specific Labs, DOE Leadership has reinvigorated two panels of advisors on Lab issues: the National Laboratory Policy Council, which addresses high level strategic issues, and the National Laboratory Operations Board, which addresses day-to-day management issues to drive efficiency. This figure illustrates that Lab management is spread across DOE’s organization.

Box 3 – Understanding LDRD at the National Labs

LDRD is explicitly tasked to support “high-risk, potentially high-value R&D,”⁵⁶ which we argue should be one of the defining characteristics of government investments in energy innovation. However, measuring the social impact of public R&D investment for its high-risk and high-value characteristics is challenging. There are several metrics that one could use. One of them is patent citations, which has been used as a proxy for knowledge flows and economic impact⁵⁶, although recent work suggests this metric may underestimate the benefits of public research⁵⁷. Another approach would be to quantify the market

value of firms that use technologies that have benefitted from Lab R&D. However, this information is available only in a highly limited form. Other metrics, such as scientific publications and the awarding of Nobel Prizes may provide useful measures of scientific advancement but may be less appropriate for understanding the social impact of energy innovation.

LDRD and similarly structured mechanisms play an important strategic role in the management of scientific labs in the public and private sector. Managers of labs use scientist-directed funding mechanisms to aid recruitment and retention of scientists who value opportunities to pursue self-selected passion projects. For example, industrial R&D labs use rules of thumb for researcher-driven work: Bell Labs allocated approximately 10% of all R&D funds as block funding, with the researchers having considerable freedom to pursue new directions, but cognizant of the broad mission of Bell Labs and AT&T,⁴⁰ while Google has encouraged employees to devote 20% of their time to projects outside of their regular job; even as this practice evolves, the company retains a commitment to giving teams considerable discretionary time to pursue ideas distinct from their regular job⁵⁸. In the context of the National Labs, the NNSA Labs have tended to have higher LDRD utilization rates when compared to the energy, science and environmental management Labs. This may be a reflection of the attitude that LDRD is primarily a tool for the recruitment and retention of scientists, rather than an aid for continued innovation. (NNSA Laboratories have more difficulty with workforce quality and retention, partially because scientists would not have as many regular opportunities for purely scientific pursuits in the context of NNSA programs without LDRD²⁰). While LDRD may be quite effective as a strategic personnel management tool, its potential to support high-risk, high-value innovation suggests the need for a broader view of LDRD's place in the missions of DOE and the Labs.

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