The Department of Energy National Laboratories

ENVIRONMENT AND NATURAL RESOURCES PROGRAM

SCIENCE, TECHNOLOGY, AND PUBLIC POLICY PROGRAM

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Organizational design and management strategies to improve federal energy innovation and technology transfer to the private sector

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for Science and International Affairs

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An overhead image of Brookhaven National Laboratory in Upton, NY, May 2016.

Executive Summary

This report recommends policies and actions to improve the return on investment the United States government makes in sponsoring research and development (R&D) at the Department of Energy's (DOE) seventeen National Laboratories ("Labs"). While the Labs make a unique and significant contribution to all of the Department of Energy's missions, we develop the idea that for the Labs to fully support DOE's energy transformation goals, their R&D management practices need to be updated to better reflect current research into innovation systems and management. We also highlight the necessity of Lab interactions with industry in order to impact the nation's energy infrastructure investment, which is, for the most part, privately held.

The dominant DOE model for its Labs, where day-to-day operations at the Labs are conducted by a non-government contractor, is inherently more flexible and independent than intramurally preformed research and even other Federally Funded Research and Development Centers (FFRDC). Dating back to its formative years during the Manhattan Project, this government-owned, contractor-operated (GOCO) model is responsible for many of the key characteristics of the Labs.[1] Our recommendation is that while Labs should increase engagement with the private sector , the central role of DOE in setting Lab priorities and managing the disbursement of funds should not be compromised. At the same time, we recognize that some important historical elements of the GOCO model have been eroded in recent decades. Consequently, some oversight practices should be revised to promote a greater level of trust and independence for the Labs to execute their technical missions, which in many cases require enhancing the interactions with the private sector. This report is structured as follows:

In Chapter 1, we introduce the role of the Labs within the context of U.S. energy policy. This includes a review of the formative history of the Labs, their organizational structure, and the long history of legislation and studies meant to improve Lab operations.

1 Westwick, P. J. (2003). *The national labs: science in an American system, 1947-1974*. Harvard University Press

In Chapter 2, we highlight management and research portfolio allocation challenges facing the Labs. Management and structural issues include fundamental organizations questions such as the correct operating model, choice of operating partner, delegation of research agenda, and overhead costs. Research portfolio issues include redundant funding, the division of research into "basic" and "applied" varieties, and Laboratory planning processes.

In Chapter 3, we review the rationale for government participation in technology transfer activities and offer several recommendations for improving the technology transfer activities at the Lab, including i) giving the Labs resources and tools to assess the value of internal inventions, ii) creating a more integrated approach to identifying commercialization partners for Lab inventions, iii) facilitating the transfer of tacit knowledge from the Labs to the private sector and iv) structuring licensing agreement in a form that maximizes incentives for licensees to pursue follow-on innovation.

In Chapter 4 we present our recommendations to address the challenges highlighted in Chapters 2 and 3. Distinct recommendations are offered for both Lab management and technology transfer policy.

The high-level recommendations for Lab management policy are:

- Maintaining the essential role of the National Labs in executing DOE's multiple missions, but restoring the original intent of the GOCO framework to allow the system to better serve its energy innovation mission.

- Creating incentives to engage a broader range of private sector researchers and private contractor partners to impact Lab culture and enhance the transfer of competencies directly relevant to its energy innovation mission.

- Encouraging DOE to give greater authority to Lab scientists and scientific leadership in the research decision-making process.

- Creating a program within the Office of the Secretary to design high-level objectives for energy innovation and coordinate activities across the entire Lab complex.

- Reorganizing the Department of Energy to reduce inefficiencies resulting from the current separation of "basic" and "applied" research divisions.

- Consolidating funding so that some particular areas of technical competency are concentrated within fewer Labs.

- Putting greater emphasis on technology transfer as a component in Labs performance review, which includes developing additional metrics that go beyond patents, publications, and invention disclosures.

The high-level recommendations for technology transfer policy are:

- Providing Lab technology transfer offices with additional resources to maximize the public value of their portfolio of existing inventions by increasing private competition for commercialization partnership opportunities.

- Increase the capacity of DOE to span the boundary between Lab technologists and political management to create cross-Lab strategies for engaging the private sector.

- Adopt new practices and policies to incentivize Lab scientists and engineers to meaningfully engage with technology commercialization partners.

- Develop new creative technology transfer contracting mechanisms that strengthen the incentive for commercialization partners to invest their own resources in follow-on innovation that builds on Lab inventions.

- Track and improve on metrics measuring how well Labs transfer technologies and exploit the potential of their invention stockpile

Introduction

The National Laboratories ("Labs") are 17 Laboratories owned by the Department of Energy (DOE). The Lab "system", as it is often referred to, has a long and storied history. It has its origin as an outgrowth of the Manhattan Project during World War II, and the Labs remain active in executing key policy objectives of the United States' science and technology enterprise.

The management of these Labs is, in and of itself, a major issue of public policy. With a budget of $14.3 billion in 2014 and employing over 55,000, the Labs are a key source of national scientific capability. Indeed, Nobel Prizes have been awarded to over 60 scientists affiliated with the Labs. The scope of the mission of the Labs, their management structures, their ties to the academic and private sectors, and even their future existence as a public institution has been continually debated almost since their inception. A recent study noted that over 50 reports on the topic of Lab management have been written in the last four decades.[2]

This report contributes novel analysis through a specific focus on the Labs' energy innovation mission. With our combined experience as researchers steeped in the academic literature in energy policy and innovation systems, we bring a different perspective than those advanced in other Lab reports. Rather than address an exhaustive list of policy questions that fall under the rubric of Lab management, we look at Labs through the lens of energy innovation, one of the Labs' key missions. Specifically, we ask how the pathway between the Labs and the private sector can more effectively be traversed—energy technologies which are not commercially deployed have no impact. Our report is aimed at the 13 Labs which perform significant applied energy work and we do not address the nuclear security, cleanup, or physics facility mission that is a core part of many Labs.

There is a great deal of momentum towards enacting substantive management changes at the Labs. First, non-defense R&D funding has been nearly stagnant for almost 15 years, reflecting political pressures against spending; broader

2 Glauthier, T.J., Cohon, J.L., Augustine, N.R., Austin, W.M., Elachi, C., et al. (2015). *Securing America's Future: Realizing the Potential of the DOE National Laboratories. Final Report of the Commission to Review the Effectiveness of the National Energy Laboratories* (CRENEL). *Volume 1: Executive Report.* U.S. Department of Energy. Available at: http://energy.gov/labcommission/downloads/draft-final-report-commission-review-effectiveness-national-energy (Accessed November 27, 2015)

headwinds could result in the significant fraction of R&D spending represented by the Labs coming under even greater pressure. The DOE has already launched initiatives and changed its management structure in ways that are consistent with some of the ideas in this report. Further change is expected with the issuance of two high-level panel reports regarding the future of the Lab system in the last several years.[3] While the current administration has been largely unsupportive of applied energy R&D funding, it has shown interest in leveraging the sort of public private partnerships that could offer opportunities for innovative management structures and technology transfer practices at the Labs.

Given the centrality of energy technology innovation in solving pressing national issues related to climate change, economic competitiveness and security, we would like to contribute our perspective to this debate. We bring perspectives earned from time serving as a Vice President of a Lab, working on Lab issues as Congressional staff, and from knowledge of innovation systems and policy analysis and evaluation gained from years of academic research. The remainder of the report is organized as follows:

In Chapter 1, we contextualize the National Labs within the broader national innovation system and efforts to promote energy innovation through policy. We then discuss the organizational history of the Lab system as well as a timeline of key policy developments and recent attempts by the Executive Branch and Congress to address its management issues.

In Chapter 2, we discuss several major issues with Laboratory management and operations, with an emphasis on how it might impact technology development and transfer.

In Chapter 3, we introduce a theoretical framework for technology transfer and why market failures point to the need for a large role in this area by public innovation institutions. The chapter will identify technology transfer policy design issues and recommend solutions to improve outcomes at the Labs.

In Chapter 4, we recommend several courses of action to improve the status quo for each issue raised in Chapters 2 and 3.

3 Glauthier et al. (2015); SEAB (2015). Report of the Secretary of Energy Task Force on DOE National Laboratories. (Draft Report of the Secretary of Energy Advisory Board, U.S. Department of Energy, March 2015). Department of Energy.

1. The National Labs as an Energy Innovation Organization

1.1 Why energy innovation?

One of the key goals of the National Laboratory system is to execute the DOE's mission to engage in the "transformation of the nation's energy system" through "transformative science and technology solutions" and securing its "leadership in clean energy technologies."[4] The need for this mission derives from several factors:

- **Innovation and Economic Growth:** Developing new technologies is a key driver of economic growth, as over half of the economic growth of the United States in the last few decades can be attributed to technological progress and intangible, knowledge assets.[5] Even absent other positive impacts, such as mitigating climate change, improving energy security, and others, the creation of new technologies can increase public welfare through economic growth.

- **Expense:** Energy continues to be a major expenditure for U.S. industries and consumers. In 2013, U.S. energy expenditures were $1.4 trillion nominal dollars and 8.3% of U.S. GDP; energy expenditures were as high as 9.6% of GDP as recently as 2008.[6]

- **Global Competitiveness and Energy Security:** Energy also contributes to the U.S. trade deficit; despite declining since its 2005 peak of 3.7 billion barrels, the U.S. imported 2.9 billion barrels of

4 DOE mission statement: http://energy.gov/mission (accessed: 1/18/2015)

5 Bernanke, B. (2011). "Speech at the Conference on 'New Building Blocks for Jobs and Economic Growth,': Promoting Research and Development: The Government's Role." http://www.federalreserve.gov/newsevents/speech/bernanke20110516a.htm (Accessed 11/25/2015)

6 U.S. Energy Information Administration (2015). *December 2015 Monthly Energy Review*. http://www.eia.gov/totalenergy/data/monthly/ (Accessed 1/17/2016)

oil in 2016, with net imports at 1.8 billion barrels.[7] As recently as 2011, oil imports represented 66% of the U.S. trade deficit. Though oil contributes to only 13% of the trade deficit in July 2016, a rise in petroleum prices could easily reverse some of these gains.[8] The continued volatility of oil prices and the underlying geopolitics make the reduction of oil dependence a national priority.

- **Threat of Climate Change:** The impacts of climate change are already being felt. The U.S. energy system was responsible for 97% of the U.S.'s 5.4 billion metric tons of CO_2 emissions in 2014.[9] [10] Largely due to transitions of power generation sources from coal to natural gas and other power sources, CO_2 emissions from energy use have declined 9% from 2008 to 2012.[11] Regardless of this progress, the U.S. will not be able to reach its goals of 17% reduction of CO_2 from 2005 levels by 2020 and 26-28% below 2005 levels by 2025 without further measures.[12] [13] In particular, its goal of an 83% CO_2 reduction from a 2005 baseline by 2050 is very likely beyond reach without aggressive policy intervention.[14]

The National Research Council estimated that the negative side effects ("external costs") of energy consumption totaled over $120 billion in 2005, noting that many external costs were not quantifiable.[15] Governments have several tools at their disposal for fostering energy innovation to address the

7 Energy Information Administration (2015). *U.S. Imports of Crude Oil (Thousand Barrels).* http://tonto.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MCRIMUS1&f=A (accessed on 1/17/2016)

8 United States Census Bureau (2016). *U.S. Imports of Petroleum*. https://www.census.gov/foreign-trade/statistics/graphs/PetroleumImports.html (accessed on September 9, 2016).

9 Melillo, J. M., Richmond, T. T., & Yohe, G. W. (2014). Climate change impacts in the United States. *Third National Climate Assessment*.

10 U.S. Energy Information Administration (2015). U.S. Energy-Related Carbon Dioxide Emissions, 2014. http://www.eia.gov/environment/emissions/carbon/ (Accessed 11/25/2015)

11 Melillo et al. (2014)

12 2014 U.S. Climate Action Report, http://www.state.gov/e/oes/rls/rpts/car6/index.htm. Accessed (1/18/15)

13 UN Framework Convention on Climate Change (2015). *U.S. Cover Note INDC and Accompanying Information.* http://www4.unfccc.int/Submissions/INDC/Published%20Documents/United%20States%20of%20America/1/U.S.%20Cover%20Note%20INDC%20and%20Accompanying%20Information.pdf (Accessed June 13, 2017)

14 Anadon, L. D., Bunn, M., & Narayanamurti, V. (Eds.). (2014). *Transforming U.S. Energy Innovation*. Cambridge University Press.

15 National Research Council (U.S.). Committee on Health, Environmental, and Other External Costs and Benefits of Energy Production and Consumption. (2010). *Hidden costs of energy: unpriced consequences of energy production and use*. National Academies Press.

current shortcoming in our energy systems, and the Labs should be seen within the context of broader energy innovation policies.

1.2 Energy innovation policies

Many policies shape the rate and direction of energy innovation. Mowery and Rosenberg[16] usefully classified them into policies that increase demand for technologies (market pull), such as tax subsidies and regulations, and those that reduce the cost for researchers (technology push), such as funding support for research and development and demonstration (R&D).[17] While the U.S. government is active in both areas, we focus on R&D.

Research, Development, and Demonstration

R&D creates new technological capabilities through scientific advancement. According to the American Association for the Advancement of Science (AAAS), the federal government spent $2.1 billion in energy related R&D in 2013 and $2.8 billion in 2015.[18] This is likely using a narrow definition of energy that excludes science and environmental R&D which can be energy related. Another estimate of Energy R&D spending at DOE alone was $3.2 billion in 2013.[19] This number includes funding for demonstration projects at DOE, representing a broader metric than R&D alone.

16 Mowery, D. C., & Rosenberg, N. (1991). *Technology and the pursuit of economic growth*. Cambridge University Press.

17 See also: Dew, N., & Sarasvathy, S. D. (2016). Exaptation and niche construction: behavioral insights for an evolutionary theory. *Industrial and Corporate Change*, dtv051.

18 AAAS (2016). *Historical Trends in Federal R&D*: *By Function: Defense and Nondefense R&D, 1953-2017*. https://www.aaas.org/page/historical-trends-federal-rd (accessed October 24, 2016)

19 Gallagher, K. S., & Anadon, L. D. (2016). DOE budget authority for energy research, development, and demonstration database. Cambridge, MA: Harvard University. http://belfercenter.ksg.harvard.edu/publication/26391/doe_budget_authority_for_energy_research_development_demonstration_database.html (Accessed October 24, 2016)

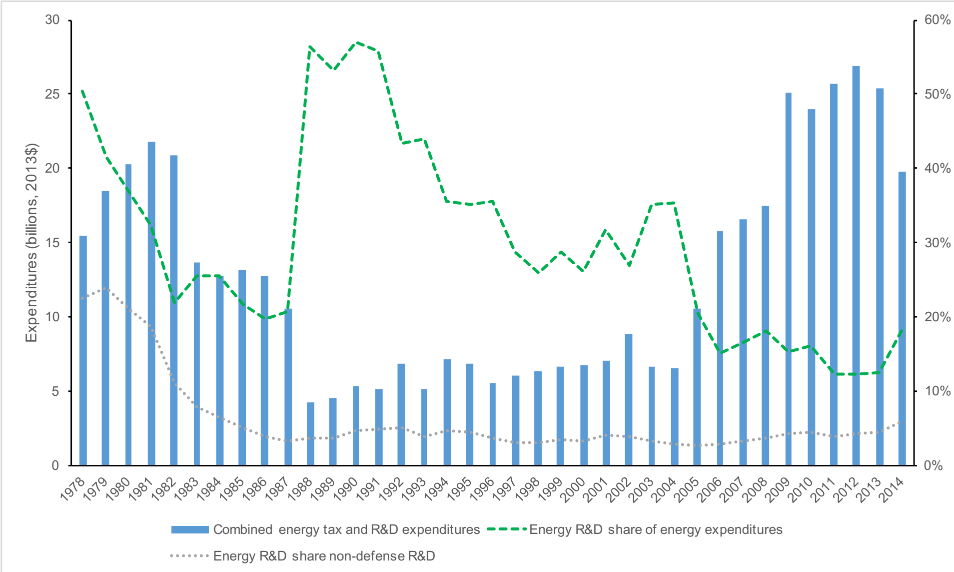

Figure 1.1: Key trends in federal energy policy: Provisions of the tax code aimed at energy usage and spending on energy R&D at DOE (blue bars). Since DOE is the primary federal executor of energy R&D, we use this as a proxy for total federal energy R&D. Over time, these expenditures have varied greatly, and the balance between spending on energy R&D and tax policies has shifted as well. While energy expenditures in recent years have surpassed levels in the late 1970s, recent policies lean more on tax expenditures and less so on energy R&D. Additionally, when DOE energy R&D is considered as a fraction of the non-defense R&D budget, recent levels have not come close to the federal emphasis on energy R&D in the late 1970s and early 1980s.

(Sources: AAAS Budget program, DOE Budget Authority for Energy Research, Development, & Demonstration Database[20]; Congressional Joint Committee on Taxation)

Using support for R&D to alter the U.S. energy supply turns out to be challenging[21] for a wide variety of reasons, most centrally the sheer number and diversity of corporations engaged in energy innovation. According to the National Science Foundation's Business Research and Development and Innovation Survey, about 11,200 companies self-funded $18.4 billion of internal R&D with energy applications in 2011.[22]

There is consensus regarding the important role of R&D to support U.S. energy policy goals.[23] It is noteworthy that the income that the U.S. forgoes due to energy related tax provisions ("energy tax expenditures"), is almost

20 Gallagher and Anadon (2016).

21 Anadon, L.D. et al. (2014)

22 National Center for Science and Engineering Statistics. *Business Research and Development and Innovation Survey (BRDIS) 2011, Table 45* (2014). National Science Foundation. Available at http://www.nsf.gov/statistics/2015/nsf15307/ (accessed on 9/20/2015). Note that the survey counts companies which self-fund R&D and those which receive external funding separately, without specifying the overlap

23 Anadon,L.D. et al. (2014)

an order of magnitude greater than energy R&D expenditures,[24] as shown in Figure 1.1. This is especially noteworthy given findings that experts believe that large increases in energy RD will be necessary to meet the nation's energy goals.[25] [26]

One of the core missions of the National Labs is to execute the long-standing government policy to support ERD&D. In the next section, we consider the rationale for government involvement, first in the context of general R&D, and then in the specific case of energy R&D.

1.3 **The role of government in R&D and technology transfer**

The benefits of R&D do not just accrue to the actors who perform R&D, but often deliver unintended benefits ("positive spillovers") whose further application areas are often unanticipated. Actors in the market are likely to underinvest in R&D since they do not anticipate or capture the full benefits delivered by the R&D, which results in a loss to society. Additionally, the uncertainty of R&D outcomes deters risk-averse investors in many technological areas. This combination of reasons leads to the conclusion that public support for R&D is an economically attractive investment for governments.[27]

However, the economic benefits of a new invention are only realized after a large amount of complementary investment in downstream commercialization is also made in addition to R&D.[28] Society, as a whole, only benefits when those inventions are developed into products that create benefits for consumers (e.g., as goods in the marketplace). Public research

24 Metcalf, G. E. (2008). *Using tax expenditures to achieve energy policy goals* (No. w13753). National Bureau of Economic Research.

25 Anadon, *et al.* (2014)

26 Nemet GF, Kammen DM (2007) U.S. energy research and development: Declining investment, increasing need, and the feasibility of expansion. Energy Policy 35: 746–755. doi: 10.1016/j.enpol.2005.12.012

27 Arrow, K. (1962). Economic welfare and the allocation of resources for invention. In *The rate and direction of inventive activity: Economic and social factors* (pp. 609-626). Princeton University Press.

28 Green, J. R., & Scotchmer, S. (1995). On the division of profit in sequential innovation. *The RAND Journal of Economics*, 20-33.

organizations are often not equipped to invest in downstream commercialization, particularly when commercialization requires physical manufacturing and production.[29] Thus, creating alternative incentive schemes to drive private investment into the commercialization of publicly-sponsored inventions is important for unlocking the full value of public R&D investment. These incentive schemes take the form of technology transfer policy, among other types of policies that can include demonstrations and the creation of niche markets, and are one of the important sets of policy tools that can be used to help "cross the valley of death."

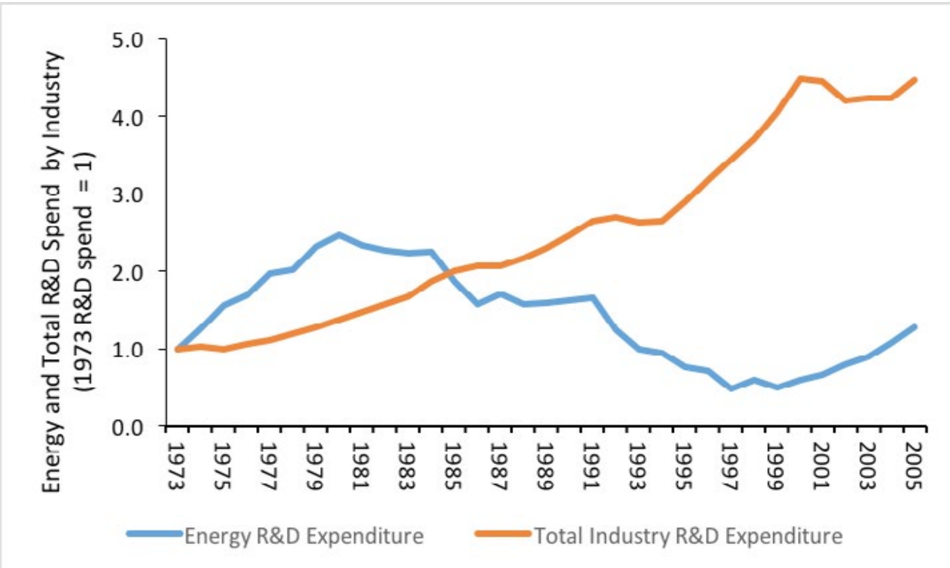

Figure 1.2: Industrial energy R&D expenditures: According to the NSF's Survey of Industrial R&D, inflation-adjusted energy R&D performed by industry rose throughout the 1970s and declined from 1980 to around 2000. In the early 2000s to the end of the data set in 2007, industrial energy R&D finally surpassed its 1973 level, but lagged far behind the near-continual rise of total industrial R&D.[30] Industry energy R&D expenditure was not available in 2006. This figure charts reported industry R&D expenditure and the amount of R&D expenditure that was energy related, normalizing both to their 1973 level. Data is available from 2008 and on, but from a new survey employing a methodology that does not allow direct comparison with earlier data sets.

29 Public organizations rarely manufacture products, as it is not typically in their mandates due to rent creation and the potential crowding out of more efficient private activity. An important exception exists in military activity, as the government may play a more active role in production, including through procurement policy.

30 National Center for Science and Engineering Statistics (NCSES). *Survey of Industry Research and Development*. National Science Foundation. Accessed through Industrial Research and Development Information System (IRIS) at http://www.nsf.gov/statistics/iris/

1.3.1 **The specific case of energy innovation**

The previous section argues that technology transfer is a necessary government function to increase the returns to society of R&D at government institutions. In the particular case of energy technologies, the externalities of energy utilization related to 'hidden' costs such as health damages or contributions to climate change justifies an even stronger role for government R&D and technology transfer. The external costs of energy suggest that the government should support innovation efforts in new energy technologies with lower external costs because current utilizers of energy do not factor in the external costs of energy when they choose to deploy certain energy technologies in their energy deployment strategies. In general, governments have over time supported mission-oriented research in various areas, including energy.[31] [32]

In addition to these theoretical economic reasons for government investment in energy technology innovation, there is also an empirical reality that the market characteristics of large parts of the energy sector are responsible for the fact that the growth in industry investments in energy R&D has not kept pace with the broader industrial R&D investments (see Figure 1.2). Although the data for energy R&D in the private sector available to construct a time series has important limitations (it largely includes oil and gas companies, nuclear and electric utilities and until 2008 it only included about 100 'known large R&D performers'),[33] the trend in R&D expenditure in energy has lagged the trend in total R&D expenditures.

While data does not exist to make a comparison between this historical data and developments in the last 10 years, the recently published NSF Business R&D and Innovation Survey has a more comprehensive indicator for recent private energy R&D expenditures in the U.S. This allows us to compare the R&D intensity (industry domestic R&D expenditure divided

31 Foray, D., Mowery, D. C., & Nelson, R. R. (2012). Public R&D and social challenges: What lessons from mission R&D programs?. *Research Policy*, *41* (10), 1697-1702.

32 Anadón, L. D. (2012). Missions-oriented RD&D institutions in energy between 2000 and 2010: A comparative analysis of China, the United Kingdom, and the United States. *Research Policy, 41* (10), 1742-1756.

33 Jones, C., Anadón, L.D., and Narayanamurti, V. (2014). Encouraging Private Sector Energy Technology Innovation and Public-Private Cooperation. In *Transforming U.S. Energy Innovation* (pp. 125-168). New York, New York: Cambridge University Press.

by total sales) of the pharmaceutical industry (11.8% in 2011) and the computer and electronics sector (9.9% in 2011) with the 2010 value for energy applications, for which we estimate an upper bound of 1.4%. The bound is derived from EIA estimates of U.S. energy expenditures ($1.2 trillion in 2010) and the BRDIS estimated R&D expenditures for energy applications across all industries of $16.5 billion - a ratio of 1.4%. Total R&D intensity across all industries was 3.2% in 2011.[34]

This confirms historic studies of low R&D intensity for energy. [35] [36] An important subsector of the energy industry, electric utilities, historically have a very low research intensity; according to a recent industry presentation, utilities have a research intensity of about 0.1%.[37]

This reality can be attributed to several factors: much of the energy sector is driven by large capital facilities, such as power plants, that have long lifetimes, leading to technological lock-in.[38] Further, energy systems rely on large infrastructure, such as pipelines and the electric grid, which creates natural monopolies. As a natural monopoly that has been historically regulated, many electric utilities have insufficient authority to invest in R&D. Traditional energy companies have relatively low ability to create differentiated products (e.g., electricity generated from different generating technologies functions identically) that will allow them to charge more than incumbents. A contrasting example can be found in telecommunications sector during the 1940s to the 1970s, before the breakup of natural monopolies like AT&T. During that era, higher investments in R&D were facilitated by the fact that such investments would lead to the ability to grow the market and offer new types of differentiated services and that AT&T was a vertically integrated monopoly able and willing to make such investments.

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34 National Center for Science and Engineering Statistics (2014).

35 Margolis, R. M., & Kammen, D. M. (1999). Evidence of Under-investment in Energy R&D in the United States and the Impact of Federal Policy. *Energy Policy*, *27*(10), 575-584.; Nemet, G. F., & Kammen, D. M. (2007). U.S. energy research and development: Declining investment, increasing need, and the feasibility of expansion. *Energy Policy*, *35*(1), 746-755. Nemet, Gregory F., and Daniel M. Kammen.

36 National Center for Science and Engineering Statistics (2014); NCSES, IRIS database (http://www.nsf.gov/statistics/iris/).

37 Costello, Ken (2015). "Research and Development by Public Utilities: Should More be Done?". http://nrri.org/wp-content/uploads/2016/04/2015-Nov-Ken-Costello-Research-and-Development-by-Public-Utilities.pdf (Accessed June 13, 2017).

38 Unruh, G. C. (2000). Understanding carbon lock-in. *Energy policy*, *28*(12), 817-830.

Taken together, the current challenges facing the energy sector suggest the particular importance of federal R&D policies and private sector engagement in this space.

1.3.2 The "original sin" of U.S. public R&D?

One of the key obstacles to realizing the gains from federally-funded research is the structure of the U.S. government R&D. During World War II, the U.S. defense innovation efforts were established as a "connected science" enterprise, where breakthroughs in fundamental science were closely integrated with the subsequent stages of product development, production, and deployment, all with heavy government involvement. Vertically-integrated approaches to R&D have also been used to great effect by AT&T and Bell Labs in the telecommunications sector and IBM in the computer industry in the era after World War II.[39]

In the aftermath of World War II, Vannevar Bush dismantled this model and instead advanced a pipeline approach in the influential essay "The Endless Frontier".[40] In this model, the federal government primarily funds exploratory basic research and the private sector is supposed to take the products of this basic research through the later stages of the technology development pipeline. Additionally, despite Bush's wishes to centralize government R&D funding at what would become the National Science Foundation, political developments ensured that R&D funding spread out across several agencies. Bush himself likely realized the problems inherent in the disconnected model, but believed that focusing public funding on basic research would be more resistant to political pressures.[41] This linear model of innovation has long been criticized.[42] [43] Recent scholarship

39 Rao, C. P. (Ed.). (2001). *Globalization and its managerial implications*. Greenwood Publishing Group.

40 United States Office of Scientific Research, Development, and Bush, V. (2001). *Science, the endless frontier: a report to the President by Vanevar Bush, Director of the Office of Scientific Research and Development. July 1945*. UMI.

41 Bonvillian, W. B. (2009, April). The Connected Science Model for Innovation-The DARPA Role. In *21st Century Innovation Systems for Japan and the United States: Lessons from a Decade of Change: Report of a Symposium* (pp. 206-37).

42 Kline, S. J., & Rosenberg, N. (1986). An overview of innovation. *The positive sum strategy: Harnessing technology for economic growth*, *14*, 640; Mowery, D. C., & Rosenberg, N. (1991). *Technology and the pursuit of economic growth*. Cambridge University Press.

43 Narayanamurti, V. and Odumosu, T. (2016). *Cycles of Invention and Discovery*. Harvard University Press.

has further elaborated on the particular damage inflicted by separating research into "basic" and "applied" classifications and proposed the alternative interconnected concepts of discovery and invention.[44]

Another major trend which has exacerbated the shortfalls in the pipeline or "linear" model has been the reduction in emphasis on fundamental research in the private sector. A recent report by the President's Council of Advisors on Science and Technology (PCAST) observed "that a growing corporate emphasis on short-term returns has eroded private-sector support of basic and early-applied research, resulting in a research gap."[45] As this trend has grown, the national innovation system is left with few actors engaging in what has been termed "long-term basic research."[46] A survey found that only 11% of industrial Labs considered "basic research" to be a major mission.[47] Thus, private actors are generally not developing technologies with a long term vision, nor are they effectively making use of research emanating from federally-funded institutions.

Short of a radical reorganization of public research institutions into a connected model, which is difficult in areas such as energy where end use in largely in the hands of the private sector (as opposed to defense and space exploration), realizing the benefits of federally-funded research can be accomplished through policies better connecting public research at Labs with industry needs. One of the ways this can be accomplished is with restructuring initiatives and the promotion of "technology transfer" activities to bridge the basic-applied divide.

44 Narayanamurti, V., Odumosu, T., & Vinsel, L. (2013). RIP: The Basic/Applied Research Dichotomy. *Issues in Science and Technology*, *29*(2), 31.

45 Gates, S. J. (2013). Transformation & Opportunity: The Future of the U.S. Research Enterprise--PCAST Report. https://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_future_research_enterprise_20121130.pdf (Accessed October 24, 2016).

46 Rosenbloom, R. and Spencer, W. (1996). *Engines of Innovation: U.S.Industrial Research at the End of an Era*. Harvard Business School Press

47 Crow et al. (1998)

1.4 **Federal Laboratories**

In 2013, $456 billion of R&D was performed in the United States. Of this amount, 27% was funded by federal government and 41% of that amount ($49.9 billion in 2013) is conducted either intramurally by federal agencies or by the 42 federally-funded research and development centers (FFRDCs), as depicted in Figure 1.3.[48 49]

This research is conducted in a group of about 700 federal laboratories (including the 42 FFRDCs), with broad diversity in their properties including size, focus, industry ties, and mission. Researchers have had difficulty in establishing a reliable count of federal laboratories and classifying them into a useful taxonomy; in general, there is not a great deal of literature on the organization of the federal research system.[50] Our focus is on a subset of seventeen federal laboratories known as "The National Laboratories" which operate within the Department of Energy. The role of the National Labs can be best understood with a schematic that differentiates federal laboratories based on the management framework, particularly the degree to which the federal government controls day-to-day decision making.

48 NSB. Science and Engineering Indicators 2016. Chapter 4: Research and Development: National Trends and International Comparisons. U.S. National Science Foundation, *National Science Board*. Washington D.C. (2016). Available at: http://www.nsf.gov/statistics/seind16/

49 This represents an update of an analysis performed in Anadon et al. (2016).

50 Crow, M., & Bozeman, B. (1998). *Limited by design: R & D laboratories in the U.S. National Innovation System*. Columbia University Press.

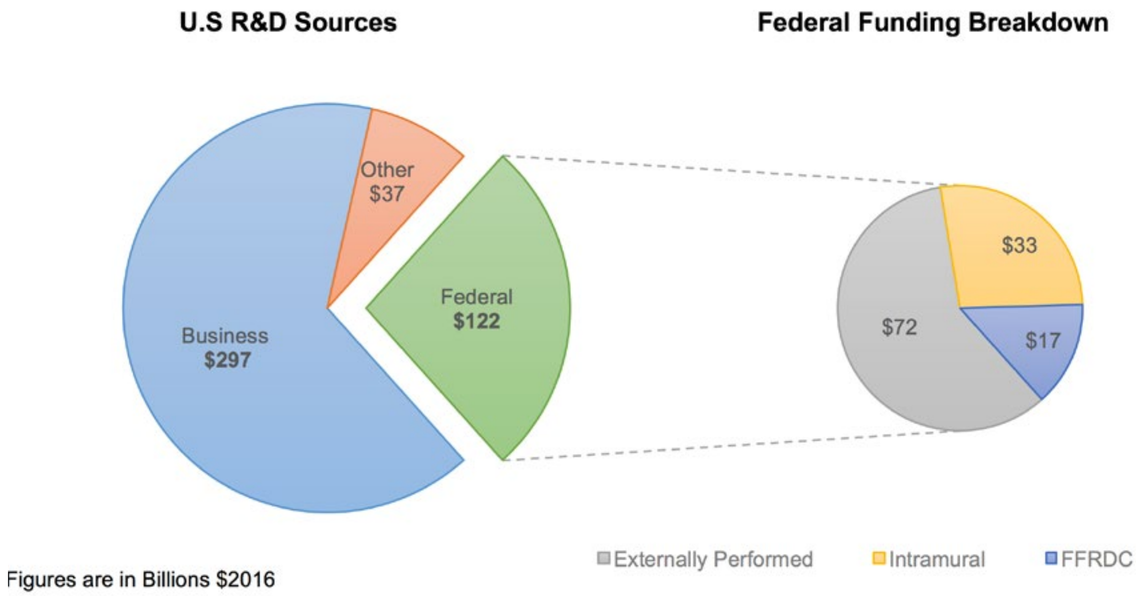

Figure 1.3: Context and Distribution of Federal R&D Funding (2013): The federal government is a major contributor to the U.S. R&D enterprise. The pie chart on the left visualizes the sources of R&D funding in the U.S. economy in 2013. The federal government funds 27% of R&D performed in the U.S., while the private sector funds 65% of R&D. Other sources of funding include state governments, nonprofits, and universities. The pie chart on the right displays where the $122 billion in federally funded R&D funding is performed. The majority of the funding is spent by other parties (predominantly universities and businesses). Of the 41% of federal R&D funding that is spent within the government, about two-thirds is performed intramurally by federal employees at federally operated facilities, while one-third is performed at the FFRDCs.

One useful heuristic for classifying Federal Labs is dividing them into two paradigms, government owned, government operated (GOGO) and government owned, contractor operated (GOCO). In the GOGO model, laboratories are operated by a federal agency, and all management and staff are considered government employees and subject to constraints from that status. For example, the Air Force Research Laboratory is a large, multi-site GOGO research facility which employs around 10,000 people and has a science and technology budget of $4.6 billion.[51]

51 Howieson, S. V., Clavin, C. T., & Sedenberg, E. M. (2013). *Federal Security Laboratory Governance Panels: Observations and Recommendations* (No. IDA-P-4940). Institute for Defense Analysis, Washington DC, Science and Technology Policy Institute.

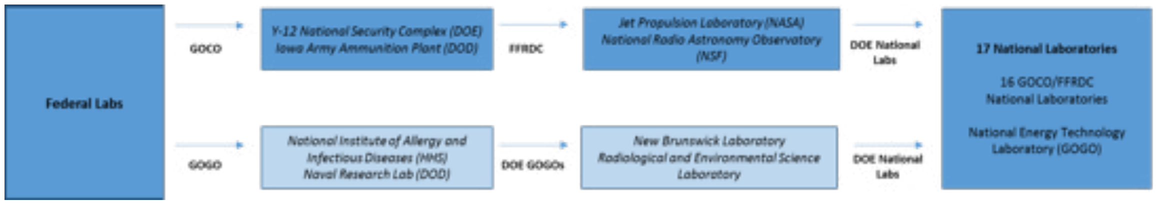

Figure 1.4: Classification Scheme for Federal Laboratories and Facilities, with a focus on DOE-related institutions at the right-hand-side of the chart: Although there is no official or dominant classification scheme for Federal laboratories, we have created an illustrative hierarchy to provide context for the National Labs.

On the far left is the entire set of federally laboratories. Federal Labs and facilities can broadly be divided into GOCO (top) and GOGO (bottom) facilities, which reflect differences in both broad operating procedures and applicable regulations. On the top half and proceeding to the right, some examples of GOCO facilities are enumerated. Not all GOCO facilities are research-heavy Labs; for example, the DOD operates several ammunition production plants as GOCOs. Moving to the right, GOCOs that are research-oriented and meet certain conditions are FFRDCs. The FFRDCs at DOE represent 16 of the 17 National Labs.

A "GOGO facility" (bottom) is a center or facility within a federal agency that has a specific technical or R&D mission, of which several examples are enumerated. The DOE has several GOGO facilities, one of which has a particularly heavy emphasis on R&D and energy technology development and is considered a National Lab (NETL). Only one of the seventeen National Laboratories is a GOGO facility.

Note that this classification is not exhaustive—it does not include, for example, University Administered Research Centers (UARCs).

Source: Federal Laboratory Consortium, NSF List of FFRDCs.

A GOCO facility is owned by the federal government, but the management is contracted to a non-governmental third party, either a university, nonprofit organization, or private firm. The contractor is responsible for delivering the contracted work to the government; management and scientists in GOCO Labs can have considerable more flexibility in personnel rules and decision-making. This makes it easier for GOCO facilities to initiate research activities as well as attract and retain senior scientists and executives.[52] The downside of increased flexibility is that the federal government has less control over day-to-day operations and policies such as personnel pay, but is still open to criticism and the impacts of suboptimal policies and execution.[53] [54] An example of a GOCO facility is the Y-12 Security Complex, a DOE facility responsible for the maintenance and

52 Crow et al. (1998)

53 DOE Inspector General (2012). *Inquiry into the Security Breach at the National Nuclear Security Administration's Y-12 National Security Complex*. Department of Energy.

54 For example, see this letter from the Los Alamos Study Group, an outside group that is vocally critical of DOE's management of the NNSA Labs: http://www.lasg.org/documents/CRENEL_26Sep2014.pdf

production of nuclear weapons parts amongst other nuclear security work. It employs over 8,000 individuals and has an annual budget of $1.5 billion. It is managed as a GOCO by Consolidated Nuclear Security, which recently took over the contract from Babcox & Wilson.[55]

A subset of GOCOs are known as Federally Funded Research and Development Centers (FFRDCs), which are "designed to meet a special long-term research and development need that could not be met as effectively by existing in-house or contractor resources."[56] The number of FFRDCs has risen and fallen, mostly as Congressional opinion supported or questioned the need for such organizations, particularly within the Department of Defense (DOD). DOD has closed many FFRDCs, claiming that their mission has been accomplished, the nation's needs have changed, or that the expertise was better maintained within a more tightly controlled government environment.[57] An example of an FFRDC is NASA's Jet Propulsion Laboratory, which executes part of NASA's space exploration mission. It has a workforce of about 5,000, a budget of about $1.6 billion as of 2011, and is operated by the California Institute of Technology.[58]

It is within this context that the U.S. Department of Energy owns sixteen FFRDCs, a number that has been stable since 1984. These sixteen FFRDCs/GOCOs and one GOGO Laboratory are collectively known as the National Laboratory System ("National Labs" or "Labs").

55 National Nuclear Security Agency (2014). Transition for Pantex and Y-12 Contract Completed [Press release]. Retrieved from: http://nnsa.energy.gov/mediaroom/pressreleases/npotransition (accessed on October 9, 2015)

56 Snyder, B. and Thomas, J.W (undated). "GOGOS, GOCOS, and FFRDCS…Oh my!" Federal Laboratory Consortium. Available at http://globals.federallabs.org/pdf/federal-laboratory-designations.pdf (accessed February 8, 2015)

57 Neal, H. A., Smith, T., & Mccormick, J. (2008). *Beyond Sputnik: U.S. science policy in the twenty-first century.* University of Michigan Press.

58 National Aeronautics and Space Administration (undated). Jet Propulsion Laboratory. Available at: http://www.jpl.nasa.gov/news/fact_sheets/jpl.pdf (accessed on October 9, 2015)

1.5 Organizations for energy innovation: DOE National Labs

The Labs play an important role in executing the DOE's mission of transforming the nation's energy use. The Labs also work towards DOE's other missions of supporting nuclear stockpile stewardship, environmental cleanup from nuclear-related contamination, and fundamental science research. This report studies how Lab design and policies interact with their energy innovation mission and builds upon other recent work.[59] This requires an understanding of the context of the Labs within the broader federal innovation system, how they came to occupy their current role at the Department of Energy, and the current state of Lab engagement with the private sector for its energy innovation mission.[60]

1.5.1 Brief history of the Labs

Origins of the National Labs

The National Labs evolved in part from the facilities constructed for and involved in the successful U.S. effort to build a nuclear weapon during World War II ("The Manhattan Project"). This origin explains a great deal about the system as it is constructed today. The GOCO model emerged from the reality that leading scientists during World War II resisted being subsumed into the military command structure. In response, major elements of the project were managed by, among others, the University of California, the University of Chicago, AT&T, the E.I. du Pont Company, and the Monsanto Company. The requirements, including secrecy, for the Manhattan Project led to the remote siting of several facilities (for example, what today are the Los Alamos, Oak Ridge, and Pacific Northwest National Labs in Los Alamos, New Mexico, Oak Ridge, Tennessee, and Richland, Washington respectively).

59 Anadon, L. D., Chan, G., Bin-Nun, A. Y., & Narayanamurti, V. (2016). The pressing energy innovation challenge of the U.S. National Laboratories. *Nature Energy*, 1, 16117.

60 Anadon *et al.* (2016)

As the war ended, the sponsoring organizations proposed that the sites continue to operate under similar management structures and that additional, regional sites be added to house large elements of scientific infrastructure, giving rise to several more laboratories. The Labs continued to operate in both cooperative and competitive modes; **cooperative** in that the Lab system as a whole covers a broad range of research beyond the capabilities of a single facility. The Labs are **competitive** in that, for many Labs, their areas of expertise overlap with other Labs and they compete for funding from DOE and other sources. Large overlap in Lab functions can be traced an early vision of the Lab system as a network of regional labs in an era before commercial jet travel made a national system plausible.[61]

Stewardship of the nation's nuclear weapons stockpile continues to reside with the Department of Energy and its "weapons" Labs (Los Alamos, Sandia, and Lawrence Livermore National Laboratories) and this work continues to represent the largest category of expenditures at DOE and the Labs. Over time the mission of the laboratories has expanded, from building nuclear weapons during World War II, to health studies of the effects of radiation and nuclear energy research in the decades afterwards.[62] With the energy crises of the 1970s, the Labs began to focus more extensively on alternative sources of energy as part of a national shift in priorities towards reducing energy consumption and increasing domestic energy production.[63] This occurred in concert with the formation of the DOE and the rise in ERD&D funding documented earlier.

With the end of the Cold War in the early 1990s and the current posture against nuclear weapons testing, the Labs have had to reconsider their role. Labs with a strong focus on nuclear weapons increasingly diversified, particularly by engaging in energy-related research.[64]

The role of the Labs in connection with the industrial innovation system has fluctuated over time. During the 1980s, Congress passed several laws

61 Westwick (2003)

62 Ibid.

63 Seidel, R.W (1993). Science Policy and the Role of the National Laboratories. *Los Alamos Science*, Los Alamos National Laboratory 21: 218-226. Available at http://library.lanl.gov/cgi-bin/getfile?21-39.pdf (accessed November 27, 2015)

64 Neal et al. (2008)

facilitating increased interactions between federal Labs and the private sector,[65] and these interactions continued to grow well into the 1990s. The late 1990s saw criticism of programs marshaling Lab resources in partnership with the private sector and there was a resultant de-emphasis of such partnerships.[66] The last decade has seen rapid growth in the deployment of clean energy technologies, which has brought renewed attention to how the Labs address energy innovation challenges. In response, the federal government has continued investigating and refining Lab policy, as well as created new organizations and programs with designs that would be difficult within the Lab system, such as ARPA-E and the Energy Innovation Hubs.[67] As the commercialization of clean energy technologies accelerated in the last few years, it has given rise to increasing understanding of the important role that private sector partnerships can play in overcoming challenges inherent to technology deployment in this area.[68]

1.5.2 **Organization of the Labs**

Each of the Labs has its own history and unique characteristics; a formal taxonomy does not fully exist for classifying the Labs. Given our focus on energy innovation, we set forth several organizing characteristics and key statistics that situate each Lab within the DOE's energy mission.

Sponsoring Program: Each individual Lab is overseen by a "program area" or a specific area of concentration within the U.S. Department of Energy (DOE). DOE can change focus or emphasis within specific programs as political actors change and policy priorities shift, but the distinct areas of management making up the Department's portfolio are more stable and require Congressional approval for significant changes.[69]

65 Total Technology Inc. (2013). *The Green Book: Federal Technology Transfer Legislation and Policy*. The Federal Laboratory Consortium for Technology Transfer.

66 Neal et al. (2008)

67 Narayanamurti, V., Anadon, L. D., & Sagar, A. (2009). Transforming energy innovation. *Issues in Science and Technology, National Academies*, *26*(1), 57-64.

68 Anadon et al. (2014)

69 The current Departmental Organization Chart is visible here: http://energy.gov/leadership/organization-chart (accessed November 27, 2015)

The major organizational structures involved in Lab management are the National Nuclear Security Agency (NNSA), which is responsible for weapons stockpile management, Environmental Management (EM), responsible for cleaning up sites contaminated by nuclear activity, the Office of Science, responsible for fundamental science research (e.g., high-energy physics) and "basic energy research", and Energy, which included applied energy programs such as Energy Efficiency and Renewable Energy, Fossil Energy, and Nuclear Energy. The programs oversee different Labs, as shown in Figure 1.4, coordinate the division of funding amongst their Labs, and oversee the implementation programs within the Labs. For almost all the Labs, the bulk of their funding comes through Congressional appropriations that are allocated to their sponsoring organizations.

The below figure is a schematic of the current Laboratory-related management of the Department of Energy.

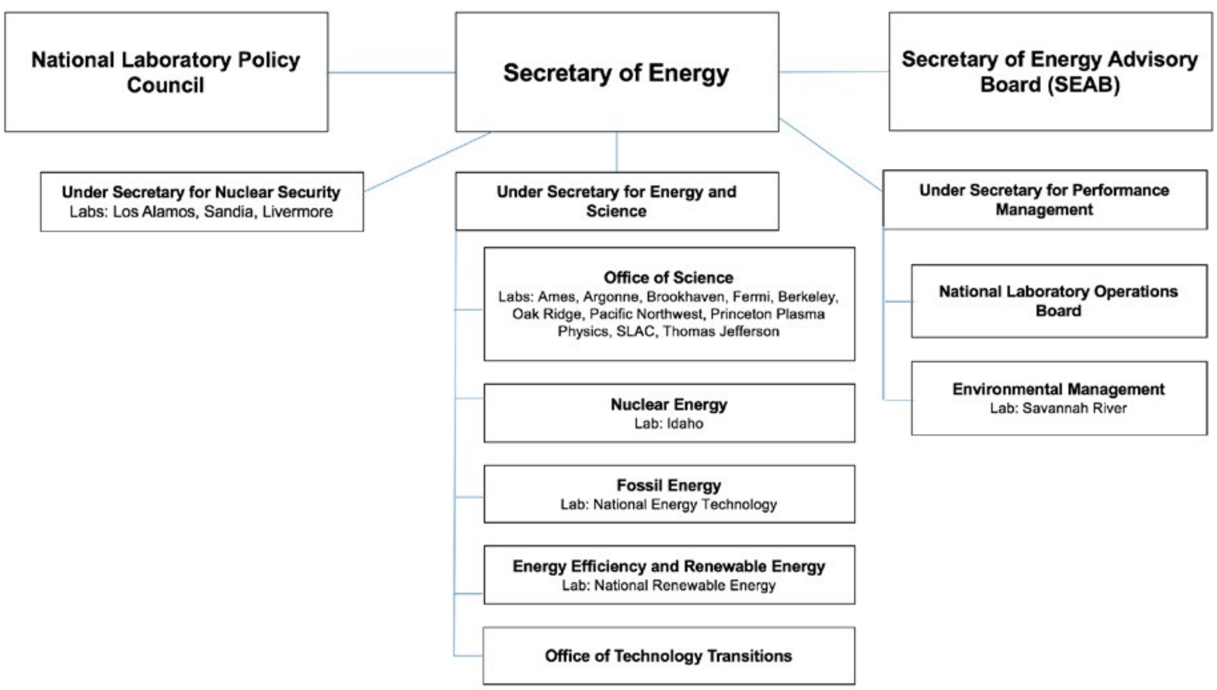

Figure 1.5: DOE Management Structure for the National Labs: The Department of Energy manages the Labs through a complicated bureaucracy. This figure is a modified organizational chart meant to illustrate the relationship of entities involved in Lab management. DOE Leadership has reinvigorated two panels of advisors on Lab issues—the National Laboratory Policy Council addresses high level strategic issues, while the National Laboratory Operations Board addresses day-to-day management issues to drive efficiency. This figure, reproduced from Anadon *et al.* (2016), illustrates that Lab management is spread across the organization, presenting obstacles to strategic management of the system as a whole.

Mission Alignment: Labs support one or more of DOE's missions and are primarily aligned with the mission supported by its main sponsoring program. However, many Labs support multiple missions and receive significant funding from programs aside from their sponsor. For example, EERE funds a significant amount of research at Oak Ridge National Lab (ORNL) even though ORNL is an Office of Science ("Science") Lab. Further, a significant portion of Lab funding comes from government agencies outside the DOE, mainly the U.S. Departments of Defense and U.S. Homeland Security.[70] Additionally, about 2% of Lab funding comes from outside of the federal government.

Though no formal definition exists, for the purposes of this report, we have defined a "single mission" Lab as one that received less than $10 million from energy-related programs outside its sponsoring office in FY2014. The multi-mission Labs all perform significant energy work. The "single mission" Labs are the four Science Labs which focus on high-energy physics facilities, Brookhaven National Lab (which does significant "basic energy science" work for the Office of Science, but little work for applied energy programs) and the Savannah River National Lab.

Total DOE Funding: This column identifies the portion of the overall DOE budget that was appropriated to each Lab in FY2014.

Energy Related Funding: For each Lab, we calculate the total funding in FY2014 from the following programs: Electricity Delivery and Energy Reliability, Nuclear Energy, Energy Efficiency and Renewable Energy, Basic Energy Sciences, Biological and Environmental Research, and Fusion Energy Sciences.

Largest Applied Energy Funder: While each Lab's primary mission is supporting the goals of their sponsoring office, 14 Labs received at least some funding from an applied energy program. As seen in the organizational chart (Figure 1.5, there are several energy technology programs within the applied Energy office. This column identifies the largest applied energy funder of each Lab.

70 Department of Energy Office of Science (2014). "Work for Others: Interagency Work, a presentation before the Committee to Review the Effectiveness of the National Energy Laboratories". U.S. Department of Energy. Available at: http://energy.gov/sites/prod/files/2014/10/f18/Work%20for%20Others%20Program%20Interagency%20Work.pdf (Accessed on November 27, 2015)

Contractor: The 16 GOCO Labs operate under a maintenance and operation (M&O) contracting structure. Established by the 1946 Atomic Energy Act ("McMahon Act"), it enabled the Atomic Energy Commission, the forerunner of the DOE, to enter into contracts with nongovernmental entities to advance research supporting its mission.[71] This contract is seen as a key feature of the Lab system; while the scale and scope of the work at the Labs may not be suitable in an industry, non-profit, or academic setting, these sectors are seen as valuable partners in managing the Labs.

The M&O contractor, identified in Table 1.1, is responsible for hiring senior Lab personnel, helping to establish advisory and governance boards with scientific and business expertise to direct Labs, deliver the promises made in the contract, and seek to extract greater value out of Lab personnel and resources.[72] Although not without restrictions, the GOCO structure allows Labs to bypass federal employment guidelines and the involvement of an external, known contractor can serve as a recruitment tool to attract personnel. Over time, as we discuss in Chapter 2, reduced competition for Lab management contracts, as well as other management issues, have reduced the ability of the Labs to effectively deliver on their innovation mission.

In response to criticism of "fraud, waste, and abuse" in the DOE's management practices through the M&O contract,[73] a commission recommended that DOE more rigorously compete its M&O contracts.[74] This has led to increased competitiveness in awarding the M&O contract and the emergence of "consortiums" of partners, sometimes across sectors, to manage Labs.[75] Additionally, the threat of M&O competition has increased DOE leverage in negotiations and led to greater oversight of M&O contracts; DOE has demonstrated increasing willingness to switch operators at the end of the contract period (usually 5 years).

71 Neal et al. (2008)

72 Interview with executive at Lab M&O contractor

73 U.S. General Accounting Office (2002). *Report to the Secretary of Energy: Contract Reform—DOE Has Made Progress, but Actions Needed to Ensure Initiatives Have Improved Results*. U.S. Government Printing Office. Available at http://www.gao.gov/assets/240/235299.pdf (accessed on November 27, 2015)

74 Blake, F.S. and Brinkman, W.F. et al. (2003). *Competing the Management and Operations Contracts for DOE's National Laboratories: Report of the Blue Ribbon Commission on the Use of Competitive Procedures for the Department of Energy Labs*. U.S. Department of Energy. Available at http://www.breckenridgeinstitute.com/2003-SEAB-S-BLUE-RIBBON-COMM-RPT.pdf (Accessed 2/12/2015)

75 Neal et al. (2008)

Mission	Lab	DOE Sponsoring Organization	Total DOE Funding 2014 ($M)	Energy Funding FY2014 ($M)	Largest applied energy funder FY2014 ($M)	Contractor
Applied Energy (Multi-mission)	National Energy Technology (NETL)	Fossil Energy	$731	$671.1	Fossil Energy ($492.2)	GOGO—(Department of Energy)[A]
	Idaho	Nuclear Energy	$1,073	$435.7	Nuclear Energy ($407)	Battelle
	National Renewable Energy (NREL)	Energy Efficiency and Renewable Energy	$270	$291.5	Solar Energy ($61.7)	Battelle/MRI Global
Science (Multi-mission)	Oak Ridge	Science	$1,050	$799.1	Nuclear Energy ($80.7)	Battelle/ University of Tennessee
	Lawrence Berkeley		$566	$383.3	Building Technology ($27.8)	University of California
	Argonne		$559	$356.9	Vehicle Technologies ($38.1)	University of Chicago
	Pacific Northwest		$566	$229.3	Bioenergy Technologies ($30)	Battelle
	Ames		$33	$49.7	Advanced Manufacturing ($9.3)	Iowa State
NNSA (Mulit-mission)	Sandia	NNSA	$1,694	$128.3	Solar Energy / Nuclear Energy ($14.7/$14.8)	Lockheed Martin[B]
	Los Alamos		$1,932	$96.1	Nuclear Energy ($13.5)	UC/Bechtel
	Lawrence Livermore		$1,130	$42.8	Advanced Manufacturing ($2.5)	UC/Bechtel
Science (Single Mission)	SLAC	Science	$398	$286.1	Solar Energy ($0.2)	Stanford University
	Brookhaven		$503	$256.0	Nuclear Energy ($2)	Battelle/SUNY Stony Brook
	Princeton Plasma Physics		$77.4	$85.5	None	Princeton University
	Thomas Jefferson National Accelerator Facility		$163	$1.0	None	Southeastern Universities Research Association/ Computer Sciences Corporation
	Fermi		$423	$0.05	None	University Research Associates/University of Chicago
Environmental Management (Single Mission)	Savannah River	Environmental Management	$14.2	$6.2	Nuclear Energy ($3.8)	Fluor/Newport News Nuclear/Honeywell

Table 1.1: Key characteristics of the National Labs in relation to the DOE energy mission

A NETL was absorbed into the Lab system as a GOGO Lab because it was originally a U.S. Department of the Interior GOGO facility. In Congressional testimony, Ernest Moniz, the current Secretary of Energy, states that NETL remains a GOGO laboratory because it performs a significant amount of federal contract management, a function which requires federal employees and not contractors.

B Shortly before publication, the management of Sandia National Lab was transferred from Lockheed Martin to National Technology and Engineering Solutions of Sandia (NTESS), a wholly-owned subsidiary of Honeywell International. The current contract will be supported by Northrop Grumann and Universities Research Association.

1.6 National Lab key policy design issues

Over the last 70 years, even as the nation's technological needs have evolved and the stewardship of the Labs passed from the military to the Atomic Energy Commission (AEC) to the Energy Research and Development Administration to the DOE, many of the unresolved tensions that were present at the system's inception still remain. Additionally, as the mission of the Labs has evolved and broadened, new questions have arisen. The next chapters of this report will address a subset of these issues.

Role in Innovation Pipeline: The Lab system was formed to address specific technology development issues. In the aftermath of World War II, it was not clear whether "basic science" research would be within the scope of the Labs' mission. An AEC advisory panel advocated for a strong basic science mission on the grounds that it would help train future scientists for the Labs' missions. Over time, the AEC repeatedly resisted attempts to consolidate basic research funding under the control of the NSF; basic research remains a major part of the research mission for DOE and the Labs. Today, the question remains how, and to what extent, research at the Labs should be coordinated with the remainder of the government's R&D budget.

Challenge/topic areas scope: In executing the DOE's missions of security, environmental management, science, and energy, the Labs are involved in vast areas of science and engineering, so there is a natural question as to the extent of appropriate challenges for the National Lab program. For example, the DOE and Labs were the initial leaders of the Human Genome Project and worked on it until its completion.[76] After the Cold War, Labs began to rapidly diversify their work to position themselves to capture a broader range of funding streams, with some Labs obtaining significant portions of their funding from outside the DOE. This raises the question: What restrictions, if any, should there be on Lab ability to pursue scientific research?

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76 Gisler, M., Sornette, D., & Woodard, R. (2010). Exuberant Innovation: The Human Genome Project. *Swiss Finance Institute Research Paper*, (10-12). Available at: http://arxiv.org/ftp/arxiv/papers/1003/1003.2882.pdf (accessed on September 7, 2015)

Systemicity vs. Independence: Many of the Labs have overlapping missions. When considering this from a systems perspective, how prescriptive should the DOE be in promoting the development of specific capabilities at each Lab? Should any competitive work be awarded to any Lab? How should the wide body of work and broad set of necessary competencies best be divided across a Lab system that is geographically diffuse?

Relationship to DOE: 16 of the Labs are FFRDCs, are operated by non-governmental contractors, and have a certain degree of independence from DOE. One Lab (NETL) operates under the more restrictive GOGO model. A key question continues to be where the Labs belong on the continuum between privatization and independent operation on one hand, and ceding decision-making abilities at all levels to DOE on the other. What is the correct balance that ensures both effective Lab operation and that Lab actions advance public interests? Does it depend by mission or technology area?

NNSA Separation: While beyond the scope of this report, Congress created the National Nuclear Security Agency in 2000 as a semiautonomous agency within DOE with responsibility for nuclear weapons, nonproliferation, and the naval reactors program, with stewardship responsibility for three of the National Labs. This was done largely in response to several security incidents at NNSA Labs. However, it is far from clear that this reorganization has improved security management—a recent report designated it as a "failure" and some have suggested that Labs focusing on security work best be managed within the Department of Defense's R&D apparatus.[77] Additionally, policymakers face questions on the future of the significant energy work that takes place today at the NNSA Labs and how to best balance security and non-defense R&D.

Connection to Industry: Particularly in its mission to transform the U.S. energy system, the ultimate client for DOE and Lab work is the private sector, which owns the vast majority of the U.S. energy infrastructure. There are a diverse range of potential energy sector clients for DOE and Labs. National

77 Augustine, N.R., and Mies, R.W., et al. (2014). *A New Foundation for the Nuclear Security Enterprise: Report of the Congressional Advisory Panel on the Governance of the Nuclear Security Enterprise.* Congressional Advisory Panel on the Governance of the Nuclear Security Enterprise. Available at htttp://www.lasg.org/budget/NSE_Governance_Panel-Interim_Rpt.pdf (access February 22, 2015)

policy towards Lab technology transfer activities has vacillated, but recent years have seen a strong shift towards greater engagement with technology transfer. This question will be a key element of our report, and one that has taken on additional import since the start of the Trump administration.

1.6.1 Historical reviews of the Labs (literature survey)

Major Studies

Given the centrality of the Labs to the execution of U.S. R&D policy and the unusual circumstances of its founding, it is not surprising that considerable effort has been expended in studying the system and its management. Indeed, a recent presentation by the Science and Technology Policy Institute claims that a non-exhaustive review found 55 studies in the previous 20 years.[78] Prior to this, Crow and Bozeman[79] counted 19 "blue ribbon" reports on the Labs from 1975-1994.

Some of the early reports can be seen as a reaction to the energy crises of the 1970s, the formation of the DOE, and the subsequent reduced federal prioritization of energy innovation in the 1980s (see Figure 1.1). A wave of reports were written in the wake of the collapse of the Soviet Union and changing U.S. security needs, prompting further debate on the future of the Labs and consideration of legislation which would have significantly altered the organizational structure of the Labs.

One of the most noteworthy reports in this period was the "Galvin report",[80] chaired by Robert Galvin, the former CEO of Motorola. Among other conclusions, the Galvin report expressed concern that the balance of power between DOE and Lab operators have shifted too far towards the DOE. In particular, the panel recommended a quasi-privatization of

78 Mark Taylor, et al. "Introduction to Current & Prior Studies of the DOE Laboratories". Science Technology Policy Institute, July 18, 2014. Accessed on 10/25/2015: http://energy.gov/sites/prod/files/2014/08/f18/Intro%20to%20Current%20%20Prior%20Studies%207_15_2014.pdf)

79 Crow and Bozeman (2013)

80 Galvin, R. (1995). Alternative Futures for the Department of Energy National Laboratories (The Galvin Report). *Prepared by the Secretary Of Energy Advisory Board, Task Force on Alternative Futures for the Department of Energy National Laboratories, Department of Energy, Washington, DC.*

the Labs, modeling their operation after private, for-profit research organizations and having Lab directors report to a board appointed by the President. Ultimately, significant changes to the M&O contracting process did not result from the Galvin Report, although in the early 2000s, after much criticism,[81] DOE began to more aggressively compete the M&O contracts for Labs operation.[82]

The mid-1990s saw several attempts at restructuring or even closing the Department of Energy; a Budget Resolution passed by the House of Representatives in 1995 would have closed the Department. Various fates were proposed for the Labs, including privatization and closure. These attempts continued throughout the late 1990s, and found a partial resolution in the creation of the NNSA.

1.6.2 **Recent developments and the current policy window**

The last several years has seen a renewal of intense interest and a number of major reports on the management and future of the National Laboratories. Some of this may be attributable to the increased recognition of the role of technology innovation as a source of national competitiveness, as well as to the maturation of renewable energy technologies such as wind and solar power and the growth of associated industry. These developments have renewed the question of how Labs can best interact with the private sector to advance energy innovation.

There have been a large number of recent reports related to the structuring of the NNSA and its Labs.[83] In a June 2013 report, an ideologically diverse range of think tanks jointly released a report with recommendations to move the Labs towards greater autonomy and away from strict DOE oversight, as well as simplify the process by which the Labs to execute

81 U.S. General Accounting Office (2002)

82 Blake and Brinkman, et al. (2003)

83 Augustine, N.R., and Mies, R.W., et al. (2014).; National Research Council (2015). *Aligning the Governance Structure of the NNSA Laboratories to Meet 21st Century National Security Challenges*. National Academies Press; Secretary of Energy Advisory Board (2015). *Interim Report of the Task Force on Nuclear Nonproliferation* (Washington, DC: DOE, 2014); NRC, *Peer Review and Design Competition in the NNSA National Security Laboratories* (forthcoming).

technology transfer agreements with the private sector.[84] The same year saw the release of a report commissioned by Congress and written by the National Academy of Public Administration that examined oversight mechanisms and recommended less intrusive forms of oversight.[85]

Legislation related to the National Labs continues to be considered by the Congress, and several changes have been passed into law as part of larger annual appropriations bills. The Consolidated Appropriations Act of 2014 required the creation of an independent panel charged with answering a broad set of questions regarding the function, future, management, and size of the Labs system.[86] The panel, the Commission to Review the Effectiveness of the National Energy Laboratories (CRENEL) delivered a final report in October 2015. [87]

The DOE has not been passive during this time. In the second term of the Obama administration, under Secretary Ernest Moniz, Lab management issues became a major focus. Some key developments led by DOE during this time frame include:

- Commissioning a report from the Secretary of Energy's Advisory Board (SEAB) Task Force on the National Laboratories. The Task Force released a draft final report in March 2015 proposing a series of experiments in key areas related to management, including M&O contracting, creating value for the private sector using technology transfer, and Laboratory Directed Research and Development, with the aim of improving management at the Labs.

- Combining the leadership of the Office of Science with the leadership of the applied energy offices—until 2013, the Office of Science and

84 Stepp, M., Pool, S., Loris, N., & Spencer, J. (2013). *Turning the Page: Reimagining the National Labs in the 21st Century Innovation Economy.* The Information Technology and Innovation Foundation, The Center for American Progress, and The Heritage Foundation, Washington, DC.

85 Breul, J.D., Ink, D.A., et al. (2013). *U.S. Department of Energy— Positioning DOE's Laboratories for the Future: A Review of DOE's Management and Oversight of the National Laboratories*. National Academy of Public Administration.

86 Consolidated Appropriations Act of 2014, H.R. 3457, 113th Congress. (2014). Retrieved from Congress.gov

87 Glauthier, T.J., Cohon, J.L., Augustine, N.R., Austin, W.M., Elachi, C., et al. (2015). *Securing America's Future: Realizing the Potential of the DOE National Laboratories. Final Report of the Commission to Review the Effectiveness of the National Energy Laboratories* (CRENEL). *Volume 1: Executive Report*. U.S. Department of Energy. Available at: http://energy.gov/labcommission/downloads/draft-final-report-commission-review-effectiveness-national-energy (Accessed November 27, 2015)

its Labs ultimately reported to the Under Secretary for Science, while the applied energy offices and their Labs have reported to the Under Secretary [for Energy]. A recent reorganization has consolidated these two roles, an important development allowing the integration of multiple stages of the research and development pipeline.[88] There has been some indication that the Trump administration would undo this change,[89] although that had not occurred by time of publication.

- The creation of an Under Secretary for Performance and Management, responsible for the Laboratory Operations Board and creating more uniform policies for Lab management.[90]

- The creation and prominent role of a National Laboratory Policy Council, reporting directly to the Secretary of Energy.[91] [92]

- The creation of a pilot Lab Technology Innovation Corps at six Labs to train Lab researchers how to successfully commercialize technologies.[93]

- Funding the Office of Technology Transitions, which will centralize technology transfer policy at the Department of Energy.[94]

- In FY 2016, DOE requested, for the first time, funding for six coordinated, crosscutting initiatives. The areas of focus were grid modernization, subsurface technology and engineering, supercritical

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88 Malakoff, D (2014, December 4). "U.S. Senate approves new DOE science undersecretary", *Science*. Retrieved from http://news.sciencemag.org/people-events/2014/12/u-s-senate-approves-new-doe-science-undersecretary

89 Bravender, Robin (2017, January 31). "Trump team overhauls Obama-era energy shop", *Greenwire*. Retrieved from: https://www.eenews.net/greenwire/stories/1060049294

90 Dixon, D (2013, July 22). "Moniz to reshape Energy leadership", *Politico*. Retrieved from: http://www.politico.com/story/2013/07/ernest-moniz-to-restructure-top-leadership-at-energy-94527.html

91 Department of Energy Organization Chart. Available at http://energy.gov/leadership/organization-chart (Accessed March 1, 2015).

92 Malakoff, D (2013, July 12). U.S. Energy Secretary Moves to Create Two New Panels Focused on National Laboratory Reform," *Science*. Available at: http://news.sciencemag.org/2013/07/u.s.-energy-secretary-moves-create-two-new-panels-focused-national-laboratory-reform

93 Department of Energy (2014). Energy Department Announces New Lab Program to Accelerate Commercialization of Clean Energy Technologies [Press release]. Retrieved from: http://www.energy.gov/articles/energy-department-announces-new-lab-program-accelerate-commercialization-clean-energy

94 Department of Energy (2015). Energy Department Announces New Office of Technology Transitions [Press release]. Retrieved from http://energy.gov/articles/energy-department-announces-new-office-technology-transitions

carbon dioxide technology, the energy-water nexus, exascale computing, and cybersecurity. A total of $1.2 billion was requested.[95]

- DOE has responded to the CRENEL report and offered specific actions it will take in response.[96]

As this report was being edited in the early days of the Trump administration, it seemed likely that considerable restructuring of DOE and the Labs could occur, but few concrete organizational changes had occurred.

1.7 Role of this report

Given the volume of historical and ongoing activity around National Lab policy, it would be natural to be skeptical of the marginal benefit of any particular report. Indeed, the lack of impact from major efforts in this area has been a major cause for pessimism in our conversations during the course of research for this report.

We have chosen to write this report because the existing literature does not consider the Labs within the framework of energy innovation. We focus specifically on the Labs' energy innovation mission, and see issues of Lab management policy and technology transfer engagement as important elements in the design of energy innovation organizations. As researchers steeped in the academic literature in energy policy and innovation systems, we bring a different perspective when compared to other Lab reports. We use our understanding of energy innovation systems as well as policy analysis and evaluation, to build upon quantitative analysis, interviews, and the experience of the authors to make specific recommendations for improving management and technology transfer effectiveness at the Labs.

95 Department of Energy (2015). *Department of Energy FY 2016 Congressional Budget Request: Budget in Brief.* Accessed March 14, 2016. Available at: http://energy.gov/sites/prod/files/2015/02/f19/FY2016BudgetinBrief.pdf

96 Department of Energy (2016). *Departmental Response to the Final Report of the Commission to Review the Effectiveness of the National Energy Laboratories*. Accessed March 14, 2016. Available at: http://energy.gov/sites/prod/files/2016/02/f29/CRENEL%20Response%20-%20FINAL%20COMBINED_0.pdf

2. National Laboratory Management and Culture

2.1 Introduction

In Chapter 1, we placed recent and ongoing reviews of the National Lab system within the broader context of energy innovation policy as well as the historical and political forces that have shaped the Labs. In this chapter, we discuss key areas of concern around management and culture at the Labs and recommend concrete steps for improvement.

A vast number of reports over several decades have put forth recommended reforms for the Lab system. Many of the recommendation sets overlap and, some argue, have not had a significant collective impact. This chapter builds upon the experiences and research of the authors to advance a single thesis upon which our recommendations are predicated: **To the greatest extent possible, control over research agendas should be close to scientists and research managers conducting and managing front-line research at the Labs.** This will require building a sense of trust and organizing funding decisions in a way that reflects significant buy-in from the Lab scientific community, with the ultimate end of devolving significant decision-making authority to the Labs. Additionally, rather than rely on qualitative efforts such as interviews, experience, and surveys, we have used quantitative data and existing results in peer-reviewed, academic literature to support our recommendations.

In Section 2.2, we discuss several issues related to the intersection of research culture and management at the Labs. We discuss the merits of the GOCO model and contractor operation, Laboratory Directed Research and Development funds (LDRD), and the future of the Lab/DOE/Congress/Contractor relationship. In Section 2.3, we identify and discuss the structure of the Department of Energy's Lab management organization. Later, in Chapter 4, we offer recommendations specifically tailored to address the issues we identify here. In our view, much of the history of the Lab-DOE relationship is driven by the struggle over the decision-making role and appropriate degree of delegation to scientific organizations. In the latest round of discussion over the Labs' future, this has not changed.

2.2 **Management issues**

Both the CRENEL and SEAB Task Force reports cited a "breakdown in trust" between the DOE and the Labs, which has led to increasing DOE regulation of the Labs.[97] The Galvin report identified excessive Congressional oversight as a major force driving high overhead costs at the Labs and DOE and a contributing factor towards the erosion of the DOE-Lab relationship. Collectively, this dynamic has a broad range of negative consequences for the effective operation of the Labs.

A breakdown in trust places constraints on the ability of the Labs to implement changes and programs, for fear of jeopardizing contract renewals. Additionally, the increasingly prescriptive management resulting from mistrust between Congress, DOE, the Labs, and the broader industrial and scientific community has reduced the ability and desire of organizations, particularly private corporations, to play a role at the Labs through either collaborative projects or by serving as Lab operators.[98]

Addressing this reality requires a multi-faceted approach, as it is not clear how to directly implement a recommendation of "increasing trust". Rather than focus directly on more nebulous, cultural and trust building measures, we offer several examples of how decreased trust manifests itself in reduced Lab effectiveness. Addressing these points will signal a shift towards a more productive alignment between contractors, the Labs, DOE, and Congress.

97 Cohon, et al. (2015) and SEAB (2015)

98 Madia, W. (2014). Stanford's input to the Commission to Review the Effectiveness of the National Energy Laboratories. (Presentation to the Commission to Review the Effectiveness of the National Laboratories in Washington D.C. on its Meeting of October 6, 2014). Available at: http://energy.gov/sites/prod/files/2014/10/f18/Stanford%E2%80%99s%20input%20to%20the%20Commission%20to%20Review%20the%20Effectiveness%20of%20the%20National%20Energy%20Laboratories.pdf

2.2.1 **National Lab operating model**

The plethora of recent reports on the National Lab system, of which we cite just a small subset,[99] [100] [101] is a clear indication of the widespread sentiment that major reforms are necessary at the Labs. However, some proposed reforms would be destructive to the Lab system. In the mid-to-late 1990s, in the wake of the end of the Cold War, a variety of proposals were floated to privatize, consolidate, and/or close some Labs, some of which gained traction in Congress.[102]

Moving the Labs to the private sector or consolidating them may result in negative consequences. The Labs, even performing at less than optimal efficiency, fill an important role within the U.S. National Innovation System, executing a significant portion of federal R&D and maintaining important user facilities.[103] If the Labs, as a system, were to be downsized, it would likely reduce the overall Federal spending on R&D, particularly critical energy-related R&D. Similarly, if the Labs were to be privatized, the system could evolve to one where long-term, high-risk research is disincentivized in favor of more short-term horizon, incremental research. In the last few years, federal investment in energy technology research and development has been at its highest point since the formation of DOE,[104] even as private sector research in the energy industry has remained low.[105]

As discussed in Chapter 1, there are multiple models for the operation of federal laboratories; in many cases, the particular management structure used follows from the intended functionality of the laboratory.[106] The Labs were intentionally designed to carry out missions directed by the federal government while devolving key cultural elements and decision-making

99 Cohon, et al. (2015)

100 SEAB (2015). Report of the Secretary of Energy Task Force on DOE National Laboratories. (Draft Report of the Secretary of Energy Advisory Board, U.S. Department of Energy, March 2015). Department of Energy.

101 Breul, et al. (2013)

102 Boesman, W.C. (2000). RL30588: Restructuring DOE and Its Laboratories: Issues in the 106th Congress." U.S. Congressional Research Service. Available at http://fas.org/spp/starwars/crs/agency-29.htm (accessed on May 5, 2015)

103 See Cohon et al. (2015)

104 Gallagher and Anadon (2015)

105 Nemet and Kammen (2007)

106 Crow and Bozeman (1998)

capabilities to technical leadership,[107] a key characteristic for successful technical organizations.[108]

While the GOCO model remains in place in 16 out of 17 National Laboratories, some have suggested that the current operation of the Lab complex may more closely reflect the GOGO, or civil service institute, model than has been historically the case.[109] Frustration with the rigid management of the Labs led to the recommendation by the 1995 Galvin report that the Labs should be “de-federalized” to the greatest extent possible.[110] Contemporary observers have indicated that while the Labs technically remain GOCO, their management model evolved to become much closer to that of a civil service institute.[111]

2.2.2 **Choice of management and operations (M&O) contractor**

As explained in Chapter 1, the GOCO model emerged from the need to bring in contractors (primarily private companies and large universities) with expertise in managing complex R&D projects and with a research profile attractive to prospective scientists. Entities that are or have been DOE contractors in the past include industrial firms such as DuPont, Union Carbide, and AT&T and universities such as University of California, University of Chicago, and University of Tennessee. In the last several decades, a number of Labs have been managed by non-profit organizations such as the Battelle Memorial Institute, or a consortium of multiple partners, often coming from different sectors (e.g., University of California / Bechtel at Los Alamos and Battelle / University of Tennessee at Oak Ridge).

107 Westwick (2003)

108 Narayanamurti, V., Anadon, L. D., & Sagar, A. (2009). Transforming energy innovation. *Issues in Science and Technology, National Academies, 26(1)*, 57-64.

109 Madia (2014)

110 Secretary Of Energy Advisory Board (1995). *Alternative Futures for the Department of Energy National Laboratories*. U.S. Department of Energy

111 Narayanamurti, V., Anadon, L. D., & Sagar, A. D. (2009). Institutions for energy innovation: a transformational challenge. *Energy Technology Innovation Policy research Group, Belfer Center for Science and International Affairs, Harvard Kennedy School, USA. Available at: http://belfercenter.ksg.harvard.edu/files/Institutions-for-Energy-Innovation-A-Transformational-Challenge.pdf*

The original model for private sector collaboration was a no-fee/no-liability agreement with the private contractor.[112] Companies often committed to this arrangement out of a sense of duty to contribute to the national interest. For example, DuPont's involvement with the Savannah River Site (which today encompasses the Savannah River National Laboratory) began with a request directly from President Truman to the CEO of DuPont.[113] Similarly, AT&T's management of Sandia National Lab was considered vital at both the highest levels of the company and the U.S. government.[114]

A Lab executive recently argued that corporations have been losing interest in serving as Lab managing contractors over the last several decades as stronger regulations, tight oversight, and increased liability have heightened the drawbacks of serving as a Lab contractor.[115]

In the past two decades, management of both the Idaho National Lab, a large applied energy Lab, and Oak Ridge National Lab, a multi-mission Lab, has moved from the private sector, where it had been since each Lab's inception, to the nonprofit and academic sectors. Only one Lab with significant energy-related activities remains under the management of a single industrial firm (as opposed to a consortium): Sandia National Lab is managed by National Technology and Engineering Solutions of Sandia (NTESS), a wholly-owned subsidiary of the Honeywell International. Until May 2017, Sandia was managed by the Sandia National Corporation, a wholly-owned subsidiary of the Lockheed Martin Corporation. An interviewee affiliated with Sandia stated that Lockheed Martin's motivations for operating Sandia were an ethos of national service and the prestige of operating the Lab.[116] [117] Over the past ten years, industrial firms have joined

112 SEAB Task Force (2015).

113 E.I. du Pont de Nemours & Company (1990). *History of Dupont at the Savannah River Site*. E.I. du Pont de Nemours and Co.

114 Gertner, J. (2012). *The Idea Factory*. Recorded Books.

115 Madia (2014)

116 Interview with Sandia government relations official

117 The strong investment Lockheed Martin has in operating Sandia is reflected its aggressive attempts to renew its contract with DOE, which have attracted the attention of the DOE Inspector General;
DOE Inspector General (2014). Special Inquiry: Alleged Attempts by Sandia National Laboratories to Influence Congress and Federal Officials on a Contract Extension. U.S. Department of Energy. Available at http://energy.gov/sites/prod/files/2014/11/f19/IG-0927.pdf (accessed on 5/5/2015) and resulted in a $4.7 million settlement with the Department of Justice (http://www.justice.gov/opa/pr/sandia-corporation-agrees-pay-47-million-resolve-allegations-related-lobbying-activities, accessed 9/19/2015)

consortiums at the other two NNSA Labs (Los Alamos and Livermore), a nod to the expertise that private companies can bring to the immense scale of the NNSA Labs (the 3 NNSA Labs represent just under half of DOE's Lab budget). However, some have pointed at the large contracting fee DOE pays contractors at NNSA Labs (about $60 million annually)[118] and the move to a corporate contractor has generated some criticisms within the scientific establishment of these organizations.[119]

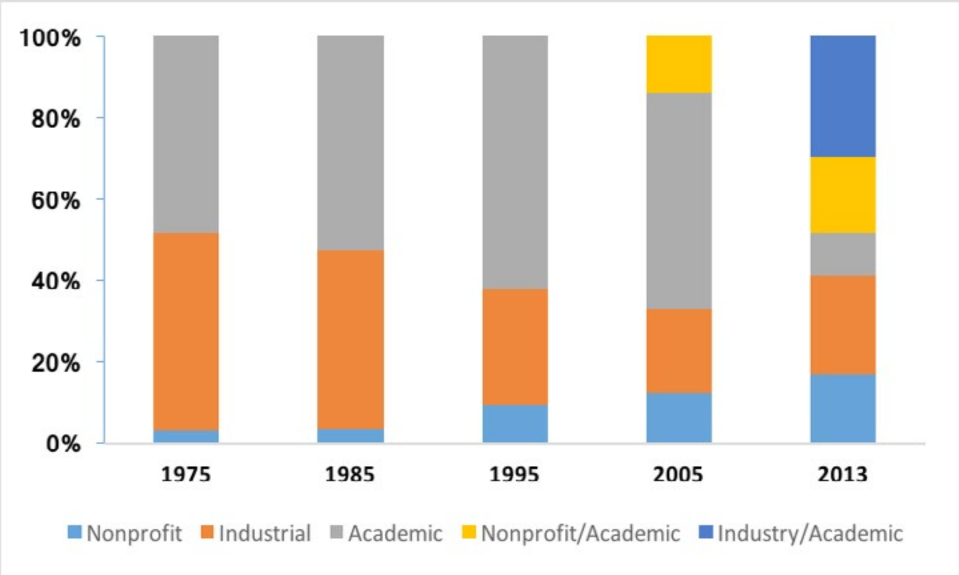

Figure 2.1: The evolution of National Lab M&O Contractors: This figure illustrates the proportion of the Lab research budget controlled by M&O contractors classified as industrial, academic, nonprofit, or consortium. For the records before 2005, we used data from the NSF Survey of Federal Funds. For the 2005 and 2013 years, we used Lab level budgets from the DOE Lab Tables. In the early years of the Lab system, Labs were run by universities or large industrial firms. Since the mid-1970s, nonprofit firms have managed an increasing proportion of Lab budget, whereas non-consortium industry and academic partners have shrunk considerably. Source: NSF Survey of Federal Funds for Research and Development (1975-1995) and DOE Laboratory Tables (2005-2015)

The shift of the Los Alamos and Livermore contracts from university managed to a consortium model with joint academic/private management raises the question of why private management no longer exists at the applied energy (NREL, INL) and multi-mission (ORNL, ANL, LBNL, PNNL) Labs.[120] In particular, the topic of whether the Labs may benefit

118 United States Government Accountability Office (2013). *National Nuclear Security Administration: Laboratories' Indirect Cost Management Has Improved, but Additional Opportunities Exist*. GAO. Available at: http://www.gao.gov/assets/660/655651.pdf

119 Committee to Review the Quality of the Management and of the Science and Engineering Research at the Department of Energy s National Security Laboratories (2013). *Quality of Science and Engineering at the NNSA Laboratories*. National Research Council.

120 An academia-industry consortium is in place at the Thomas Jefferson National Accelerator Facility, a single purpose National Lab facility.

from the greater operational and market expertise of the private sector—or if industrial leadership can be detrimental to Lab operation—has not been well addressed in the literature.

On the one hand, there may be concerns that private interests do not line up with the broader societal mission of the Lab system, a gap that has grown over time as corporations have increasingly tended towards shorter planning horizons.[121] [122] Additionally, there are multiple potential conflicts of interest for private entities managing public research dollars, giving deserved pause to consideration of such an arrangement. Moreover, a partial analysis of patents and licensing in the Lab system did not find a significant differentiation between Labs operated by different types of contractors.[123] [124]

The argument for considering a more prominent role for industrial firms is the presumption that they can bring greater skill in managing large, research-intensive enterprises such as the Labs. A survey found that industrial Labs were able to hire and fire personnel, informally circulate research results, and publish research on timetables considerably shorter than government or academic labs.[125] When examining the Labs through the lens of technology transfer, which by definition requires a conduit between the Labs and the private sector, private sector management may be an effective channel for improving performance.

Interviews with senior Lab officials have reinforced the idea that long-standing contractors create a culture at the Labs. Labs with a long history of private sector management have helped to create a culture more amenable to collaborating with the private sector and generating commercializable outcomes. By contrast, Labs with a history of academic

121 MIT Committee to Evaluate the Innovation Deficit (2015). *The Future Postponed: Why Declining Investment in Basic Research Threatens a U.S. Innovation Deficit*. Massachusetts Institute of Technology.

122 Myhrvold, Nathan (2016). "Basic Science Can't Survive without Government Funding". *Scientific American*. Available at: http://www.scientificamerican.com/article/basic-science-can-t-survive-without-government-funding/ (accessed 1/25/2016)

123 Chan, G. (2014), "The Commercialization of Publicly Funded Science: How Licensing Federal Laboratory Inventions Affects Knowledge Spillovers (Draft)", accessed at: http://isites.harvard.edu/fs/docs/icb.topic1459278.files/CHAN-Gabriel_11-21-14_JMP%20-%20National%20Lab%20Patent%20Licensing.pdf on 5/5/2015

124 Lab-level technology transfer statistics were provided by a former DOE employee.

125 Crow et al. (1998)

management tend to emphasize "fundamental" science and have less emphasis on early stage technology research and development. It should be noted that a Lab culture can take decades to create, and is not as simple as putting a contractor with the desired competencies in place.

A recent study of University of California research outcomes showed that privately-funded projects at the university led to more patent citations, licensing, and knowledge spillovers than federally-funded research.[126] Within the National Lab system, the Lockheed Corporation instituted an aggressive and successful approach towards spinning out lab technologies in the mid-1990s when it operated what is now the Idaho National Laboratory.[127] The effort strongly leveraged Lockheed and their partners' knowledge and connections within the private sector ecosystem. Though this effort was largely seen as successful, Lockheed was removed as the operator of the Lab after 5 years for unrelated reasons.[128] Lockheed utilized a scaled down version of this approach at the Technology Ventures Corporation associated with Sandia National Lab. While support for spinoffs is not unique to industry-operated labs,[129] recognizing and realizing market value is a function that caters well to the particular strengths of industrial companies.

While some Lab operators have been in place for the duration of the National Lab system (University of Chicago at Argonne, Iowa State University at Ames, and University of California at Lawrence Berkeley), the instability of industrial contractors can be seen in the short average tenure of industrial operators visualized in Figure 2.2. Their shorter tenure is evidence of obstacles faced by industrial firms in securing and maintaining M&O contracts. If absorbing a culture from a contractor takes decades, the continual churn amongst industrial Lab partners points to a reality that DOE Labs have not been able to sustain relationships with the sort of contractors who might better promote a technology transfer mission.

126 Wright, B.D., Drivas, K., Lei, Z, and Merill, S.A. (2014). Technology transfer: Industry-funded academic inventions boost innovation. *Nature* 19 (March 2014). Retrieved from http://www.nature.com/news/technology-transfer-industry-funded-academic-inventions-boost-innovation-1.14874

127 Jaffe, A.B. and Lerner, J.. Reinventing public R&D: Patent policy and the commercialization of national laboratory technologies. *Rand Journal of Economics*, 167-198. (2001)

128 Ibid.

129 Examples include Cyclotron Road, a technology incubator hosted at Lawrence Berkeley National Lab.

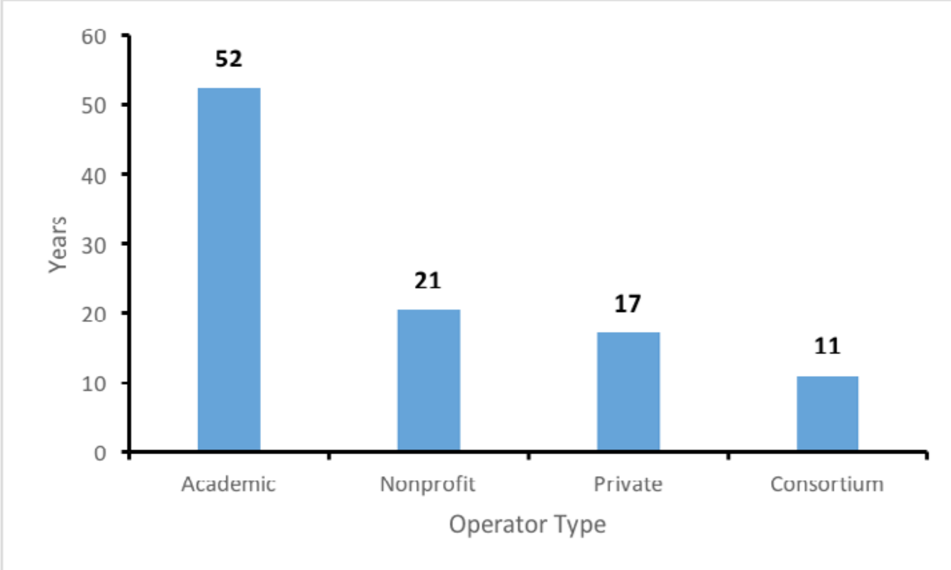

Figure 2.2: Average tenure type by type of Lab operator (1940—2015): Average tenure type by type of Lab operator (1940—2015). Consortium and nonprofit operators tend to maintain M&O contracts longer than industrial firms. The figure actually understates the effect, as consortiums and nonprofit operators have only been used in the last few decades, while academic institutions and industrial operators have been contractors since the Lab system started.

2.2.3 Laboratory directed research and development (LDRD) at the Labs

As mentioned in Chapter 1, LDRD is a funding stream within each Lab (as of FY2015, all 16 GOCO Labs have an LDRD program) that is managed by the Labs instead of being centrally-directed by DOE. While the details of LDRD fund disbursement differ from Lab to Lab, the general methodology is that the Lab directorate publishes a call for proposals within some general guidelines. For example, LBNL asks for LDRD submissions aligned either with major areas of Lab focus, or specific strategic initiatives.[130] Scientists submit proposals which are competitively reviewed. Selected projects are funded for a limited time and budget.[131] The proposals are generally small-scale (well under a million dollars, often just tens of thousands) and are reported in great detail to the DOE for an annual review

130 Lawrence Berkeley National Laboratory LDRD Program (2015a). *Call for Proposals: FY 2016 Laboratory Directed Research and Development (LDRD) Program*. Lawrence Berkeley National Laboratory. Available at: http://www2.lbl.gov/DIR/LDRD/assets/docs/FY16_LDRD_Call_for_Proposals.pdf (Accessed November 27, 2015).

131 Lawrence Berkeley National Laboratory LDRD Program (2015b). *Lawrence Berkeley National Laboratory LDRD Program*. Lawrence Berkeley National Laboratory. Available at http://www2.lbl.gov/DIR/assets/docs/LDRD_Guidelines_10-09-c.pdf (accessed November 27, 2015)

to ensure that these “investments reflect highly innovative and the highest quality research projects.”

Projects funded by LDRD have led concretely to many advances[132] and enabled a Noble Prize-winning research effort.[133] Some have argued that giving more discretion to Laboratory directors and scientists in setting research direction will ensure better long term evolution of research priorities.[134] Research has shown that discretionary funds at federal laboratories, such as LDRD, have considerable potential to increase effective engagement with industry if they are deployed to build portfolios of collaborative activity. Discretionary funds are a particularly important policy tool because the diversity in federal lab skillsets and relevance to industry missions makes it difficult to craft across-the-board policy options.[135]

We studied whether LDRD funds are more effective than funds allocated through the typical DOE process by examining technology transfer metrics reported by DOE. Our analysis demonstrates that LDRD projects are considerably more effective in creating new intellectual property when compared to Lab funding as a whole.

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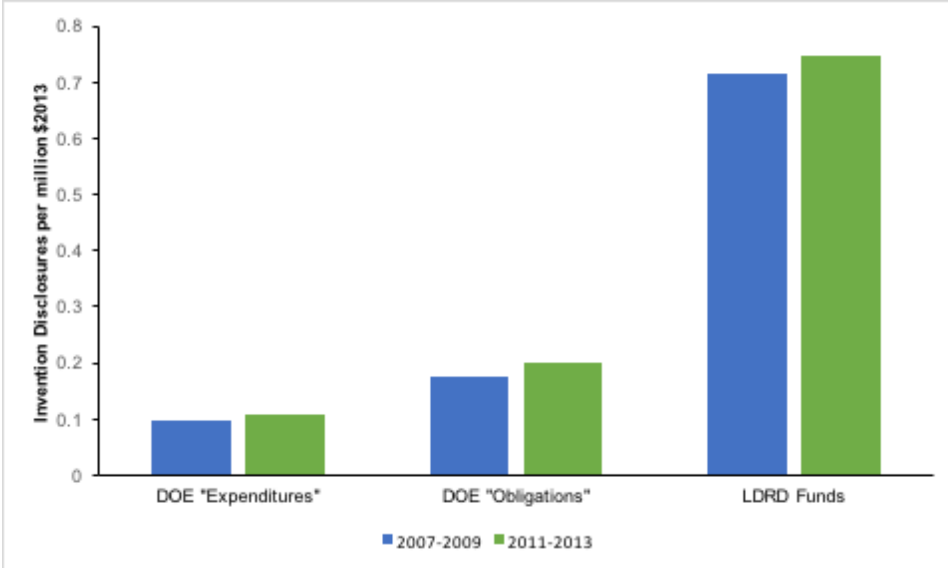
132 U.S. Department of Energy (2011, June). *LDRD Highlights*. Department of Energy. Available at http://science.energy.gov/~/media/lp/pdf/laboratory-directed-research-and-development/impact/brochures/DOE_LDRD_Brochure_June-28_FINAL.pdf (accessed November 27, 2015)

133 Bashor, J (2011, October 4). Nobel Laureate a Computational Cosmology Pioneer [Press release]. Lawrence Berkeley National Laboratory. Available at http://www.crd.lbl.gov/news-and-publications/news/2011/nobel-laureate/ (accessed on November 27, 2015).

134 Committee on Criteria for the Management of Los Alamos and Lawrence Livermore National Laboratories (2004). *Maintaining High Scientific Quality at Los Alamos and Lawrence Livermore National Laboratories.* National Research Council.

135 Crow et al. (1998)



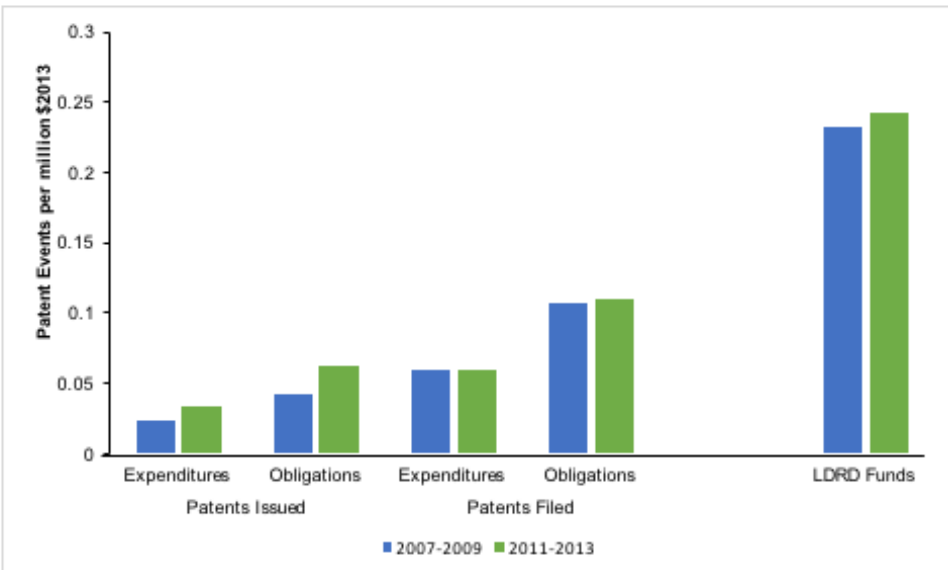


Figure 2.3: Invention disclosures and patents for LDRD and DOE-directed funding: Using data published by the NSF, Department of Commerce, and Department of Energy, we calculated technology transfer outcomes per dollar of R&D spending for both LDRD funds and total DOE-directed funding. Total DOE-directed funding is represented by the "Expenditures" and "Obligations" categories, which represent two different methods of calculating total DOE-directed research funding at the Laboratories. A full explanation of terms used and methodology for this figure is included in Appendix A. This figure represents a more granular analysis of a data set presented in Anadon et al. (2016).

Figure 2.3 compares the rate of inventions and patents per million dollars of R&D funding at DOE[136] and what those metrics look like when isolating LDRD funding. Because of ambiguity in how LDRD patents are reported, we compare LDRD figures with both DOE patents granted and patents filed (even though our analysis indicates that the vast majority of LDRD patents reported are actual patents granted). Some disparity between outcomes from general R&D funding and LDRD funding is to be expected, as LDRD funds represent marginal expenditures on new research projects, while general R&D funds also supports a broader range of activity that does not produce research outcomes, such as the construction of new facilities. However, the notably high level of LDRD productivity relative to general R&D funds suggests that ceding some degree of research autonomy to Lab scientists translates to more IP-related outcomes.

This is consistent with the practice of some leading private corporations who have seen the value of encouraging independent contributions from employees. Google has highlighted its program to allow employees to devote 20% of their time to independent projects[137], and, much like LDRD, Royal Dutch Shell incubates internal ideas from employees through its Gamechanger program.[138]

Yet, LDRD has been politically controversial and been underutilized by the Labs. As recently as January 2014, Congress cut the maximum amount of funds eligible to be spent on LDRD projects from 8% to 6% of the Labs budget. This follows changes in 2005 that required LDRD to pay a significant amount of overhead fees—effectively cutting the impact of a given amount of LDRD funding almost in half.[139] In a recent fiscal year (2014), all Labs aside from the NNSA Labs used less than half the maximum allowable LDRD under the old, 8% cap. Most came considerably beneath even that amount, as seen in Figure 2.4.

136 Technology Partnerships Office. Federal Laboratory Technology Transfer Summary Reports to the President and the Congress (1987—2013). U.S. Department of Commerce. Available at http://www.nist.gov/tpo/publications/federal-laboratory-techtransfer-reports.cfm (accessed November 27, 2015)

137 Schrage, M. (2013). Just How Valuable Is Google's "20% Time"? *Harvard Business Review*. Available at https://hbr.org/2013/08/just-how-valuable-is-googles-2-1 (accessed November 27, 2015)

138 Al-Hakim, L. (Ed.). (2010). *Innovation in Business and Enterprise: Technologies and Frameworks: Technologies and Frameworks*. IGI Global.

139 DOE Office of Science (2014). LDRD Legislative history. Department of Energy. Available at: http://science.energy.gov/lp/laboratory-directed-research-and-development/legislative-history/ (accessed April 18, 2015)

One potential reason for the higher utilization of LDRD at NNSA Labs is that Congress sees scientist recruitment as one of the primary objectives of LDRD funding (as it allows scientists the possibility of directing a project strongly related to their interests and less constrained by Lab mission and needs). A Government Accountability Office (GAO) report found that LDRD was most important for recruitment at the NNSA Labs and less important for Labs with a focus on basic research[140] and an NRC study stressed the importance of a robust LDRD program for "recruiting science and engineers".[141] This strategy aligns with the distribution of LDRD in the above figure—greatest for NNSA Labs, followed by multipurpose and applied energy Labs, and with single-purpose Labs utilizing the least amount of LDRD.

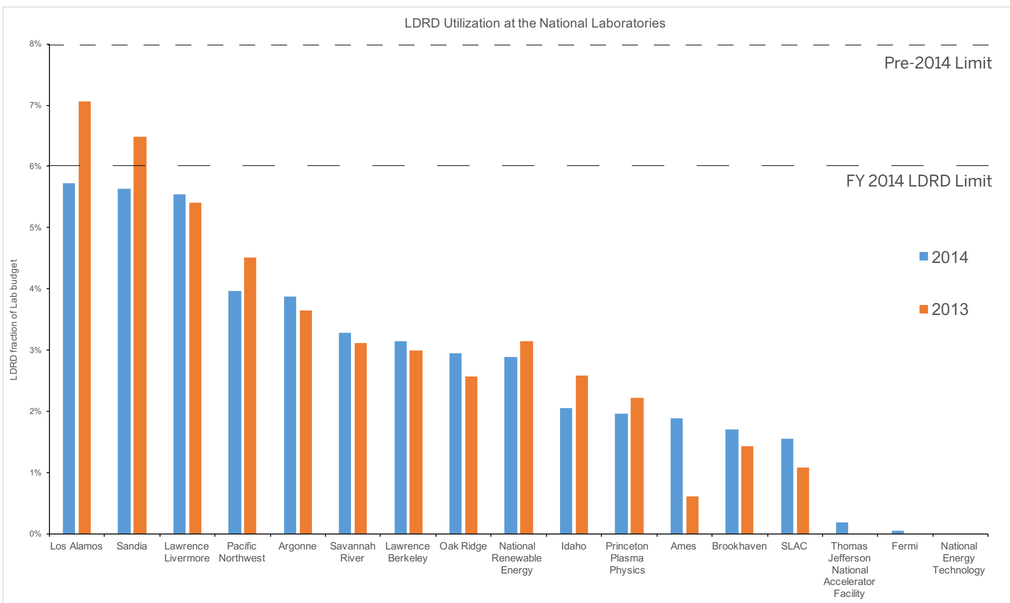


Figure 2.4: LDRD utilization by Lab (FY2013-2014). While Los Alamos and Sandia were affected by the decreased LDRD limits and significantly decreased their LDRD spending, most other Labs spend far less than the statutory ceiling. Data obtained from annual DOE reports to Congress on LDRD spending (http://energy.gov/cfo/reports/laboratory-directed-research-and-development-annual-reports).

140 United States General Accounting Office (2004). *Information on DOE's Laboratory-Directed R&D Program.* (2004). U.S. Government Printing Office. Available at: http://www.gao.gov/assets/250/242213.pdf (accessed April 18, 2015).

141 Committee to Review the Quality of the Management and of the Science and Engineering Research at the Department of Energy's National Security Laboratories (2013)

2.2.4 **Increasing program direction costs at DOE**

Over the past 25 years there has been increased spending on program direction at DOE headquarters, which can be seen as an indicator of an escalating level of oversight at the Labs.[142] Funding for research is now distributed in smaller amounts and with less flexibility as to how funds can be spent.[143]

Overhead costs at the Department of Energy and the National Labs can also present obstacles for the efficient use of R&D funding. Private companies are less likely to pursue collaborations with Labs burdened with high overhead rates, presenting an obstacle to partnerships and the diffusion of technologies resulting from such partnerships. A 2011 Inspector General report documented that approximately 35-40% of total laboratory operating costs are "support costs", which is particularly worrisome in an adverse budget climate.[144] The figure applies to the Laboratory side of the budget and does not count program direction costs, which come out of DOE headquarter funds. Over time, headquarter overhead costs have increased. Figure 2.5 illustrates the portion of each program's budget dedicated to program direction and management. Composite program direction and management expenditures as a fraction of DOE's total budget have nearly doubled from 1990 to 2015, although the share of expenditures has decreased since peaking in 2011.[145] The CRENEL and SEAB Task Force reports attributed overhead to the large number of distinct entities at DOE, the Labs, and the M&O contractor involved in Lab management with duplicative roles and without clear delineation of authority.

One major contributor to Lab and DOE headquarter overhead is "budget atomization."[146] In this process, every small package of funds distributed at the Labs has distinct reporting and compliance requirements, necessitating

142 Anadon *et al.* (2016)

143 NAPA (2013)

144 DOE Inspector General (2011). *Management Challenges at the Department of Energy*. U.S. Department of Energy. Available at http://energy.gov/sites/prod/files/IG-0858.pdf (accessed May 5, 2015).

145 Anadon *et al.* (2016)

146 Johns, C. (2015). Budget Atomization of DOE Funding (Presentation to the Commission to Review the Effectiveness of the National Laboratories in Washington D.C. on its Meeting of April 22, 2015). Department of Energy. Available at: http://energy.gov/sites/prod/files/2015/04/f22/Budget%20Atomization%20-%20DOE.pdf

large staffs for both the Lab and DOE headquarters. This overall trend suggests that public funds allocated to research at the Labs are increasingly used for non-research activities, potentially due to added oversight resulting from increasing political pressure. The CRENEL report noted anecdotes of Laboratory personnel having been laid off due to increasing overhead costs. The report also highlighted the high ratios at several of the Labs of site office employees (who provide oversight) to Lab employees (who conduct research and manage Lab operations). Our own interviews with past and present high-level decision makers at the Labs and other testimonies confirm that increases in overhead costs have been due to DOE and Congress increasing reporting requirements and oversight. This ultimately curtails scientific freedom and erodes the primacy of the Labs' technical mission.

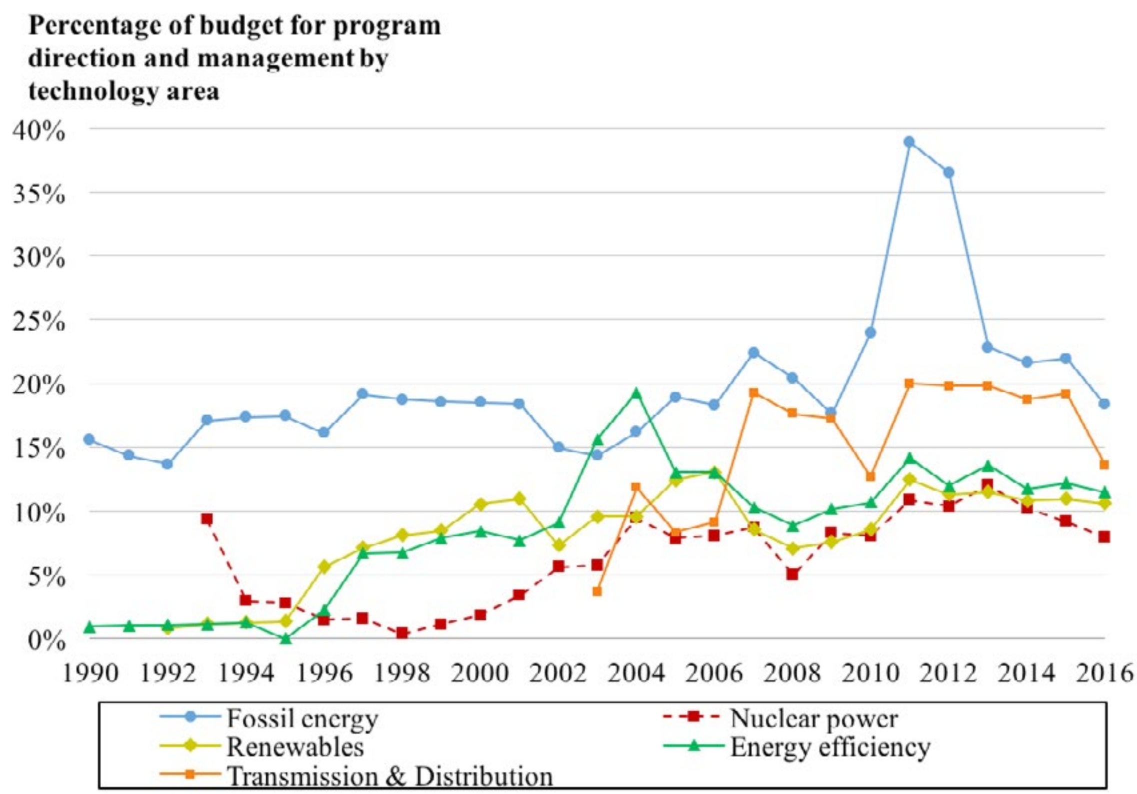


Figure 2.5: Program Direction and Management spending at DOE: This figure plots the percentage of DOE funding for technology programs devoted to "program direction and management" (PD&M) at DOE Headquarters. This figure is adapted from Anadon et al. (2016) which calculates the average fraction of budget dedicated to PD&M across technology areas, demonstrating that the aggregate total is trending upwards, albeit peaking in 2011. Source: official DOE budget justification documents, collected by Gallagher and Anadon,[147] and Anadon et al. (2016).

147 Gallagher and Anadon (2016)

2.2.5 **Barriers between Labs and the private sector**

In Chapter 3, we will go into greater detail on a variety of mechanisms available to Labs for collaboration with the private sector. One mechanism receiving considerable attention is the Cooperative Research and Development Agreement (CRADA). As will be discussed in Chapter 3, the number of CRADAs initiated has declined steadily since the late 1990s, as have many of the other tech transfer indicators tracked by DOE. As mentioned in Chapter 1, CRADAs became the subject of negative Congressional attention in the late 1990s but have been looked upon with more favor as of late. In response, DOE has shown interest in facilitating greater use of CRADAs and other tech transfer mechanisms. However, in a recurrent theme, external firms perceive DOE as slow to engage private sector partners, with agreements requiring many levels of approval before execution.[148] [149] The lengthy CRADA approval process may itself be partially the result of DOE over-cautiousness in the wake of Congressional oversight.

In FY2012, the Labs performed $250 million worth of work for non-federal partners (non-federal WFO). This represents under 2% of the Lab's budget, with an unknown proportion of this sum representing work done with state or local government and academia, as opposed to the private sector.[150] DOE has recently signaled that it would like to "integrate the needs of the private sector into DOE's work, though the work and mission will be directed by the federal government."[151] There have been proposals to increase the usage of collaborative mechanisms through delegating full legal authority on cooperative R&D agreements to Laboratory Directors,[152] but some experts have commented that this authority would only be

148 Harrer, B.J. and Cejka, C.L. (2011). *Agreement Execution Process Study: CRADAs and NF-WFO Agreements and the Speed of Business*. Pacific Northwest National Laboratory (2011). Available at http://www.pnl.gov/main/publications/external/technical_reports/PNNL-20163.pdf (accessed May 5, 2015).

149 Ham, R.M. and Mowery, D.C.. "Improving the effectiveness of public–private R&D collaboration: case studies at a U.S. weapons laboratory." *Research Policy* 26.6 (1998): 661-675.

150 U.S. Government Accountability Office (2013). *DOE Needs to Improve Oversight of Work Performed for Non-DOE Entities*. United States Government Accountability Office. Available at: http://www.gao.gov/assets/660/658585.pdf (accessed on May 5, 2015).

151 Ling, K (2015, March 17). New office will oversee $25M fund, push innovation to market. *Energy and Environmental News*. Available at http://www.eenews.net/greenwire/2015/03/17/stories/1060015214 (accessed May 5, 2015).

152 Council on Competitiveness (1992). *Industry as a Customer of the Federal Laboratories*. Council on Competitiveness.

effective if the Directors had broader authority on research direction for the Lab which generally is not the case.[153]

2.3 Optimizing the Lab's research portfolio

As described in Chapter 1, the history of the Labs has seen a constant tension between the Labs as independent entities and a network acting in concert. The current management configuration institutionalizes a divide between different Labs, even if there is substantial overlap in the work they do.

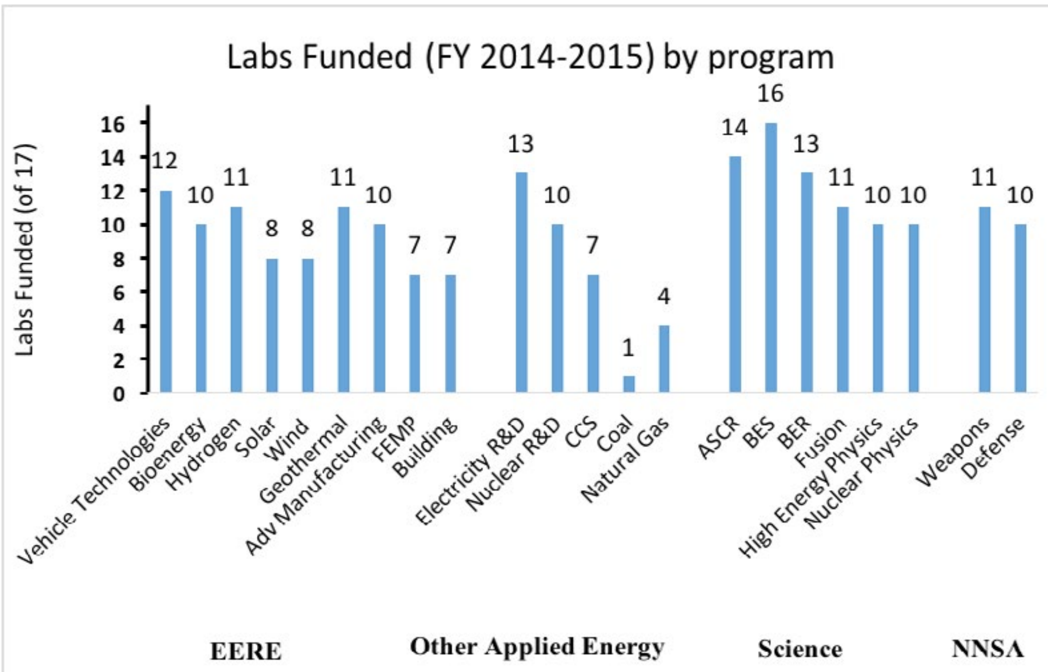


Figure 2.6: Labs funded by DOE programs (FY2014-2015): A Lab was counted if it received any funding from a program in either FY2014 or FY2015. We list major funding categories from EERE, Energy, and Science programs. A major funding category is defined as one where more than $25 million was requested for that program across all Labs in the FY2016 DOE Budget Request.

Despite recent reforms, such as reviving the National Laboratory Operations Board, creating a National Laboratory Policy Council,[154] forming a position of Under Secretary for Performance Management, and the consolidation of the former Under Secretaries of Energy and Science into one

153 Crow, et al. (1998)

154 Malakoff, D. (2013)

position,[155] the organization chart (Figure 1.5) makes it clear that the DOE management of the Laboratories can be challenging because of the dispersion of managerial responsibility for Lab functions across the organization.

2.3.1 **Redundant funding**

When technology offices fund work across many Labs, this can produce an operational environment in which the effective coordination of investments becomes difficult. To a certain extent, the Labs were structured from the beginning to create competition for the best approach in a particular subject matter, which requires a certain degree of redundancy.[156] However, as can be seen in Figure 2.6, almost all major energy and science related programs fund a large number of Labs, which can reduce efficiency. One study noted that the disbursement of funding can be driven by "particular individuals and leaders of particular labs" rather than a rational process.[157]

A portion of the Labs' mission is to serve as a key storehouse of knowledge and technical skill in critical areas. A recent survey at a conference hosted by the American Council on Renewable Energy (ACORE) indicated that private companies have very low awareness of the Labs as a source of innovation.[158] We believe that the Labs' ability to serve in this role is hampered by the diffusion of individual program funding across too many Labs. This prevents Labs from creating distinct identities for expertise in specific areas of technology. This echoes findings that unfocused diversification leads to reduced valuations for corporations.[159]

The Labs have long battled a tension between central planning and allowing duplication for the sake of engendering competition and creating multiple pathways for progress.[160] Since Lab programs receive funding

155 As noted earlier, the Trump administration might consider separating these positions again.

156 Westwick (2003)

157 Crow et al. (1998)

158 Correspondence with Michael Brower, former President of ACORE

159 Lang, L.H.P. and Stulz, R.M. (1994). Tobin's Q, Corporate Diversification and Firm Performance. *Journal of Political Economy, Volume* 102, Issue 6 (Dec., 1994), 1248-1280

160 Westwick (2003)

from both their sponsoring office and other offices, it can be difficult to coordinate the development of related programs at Labs.

To a certain degree, competition between different Labs for funding is positive. It fosters the development of multiple approaches and may spur improved performance. However, excessive diffusion of funds can create challenges in funding capital-intensive initiatives and can actually encourage Labs to become excessively conservative to preserve their portion of overall funding.

The proliferation of research areas at each Lab also leads to difficulty in tracking expertise and research at the Labs. Interviews with researchers at one Lab highlighted that when managers receive invitations to conferences, they sometimes are not able to identify and engage the correct Lab personnel to attend, as the unfocused organization of research efforts does not allow the easily identification of researchers who are leading efforts for a specific topic.

Part of this dynamic emerges from the Labs' transition to a post-Cold War reality. Particularly in the NNSA Labs, there has been concern that the decreased need for weapons development would result in consolidation or downsizing, so the Labs have been proactive about broadening their scope and competing for more of the funding streams available from DOE, even if it is far from their Lab's main mission.[161] This dynamic has moved beyond the NNSA Labs; many other Labs are increasingly seeking other sources of funding further from their traditional mission.[162]

The diffusion of funding makes it more difficult for the Labs to create coherent identities as leaders within specific technologies. This, in turn, makes it difficult for potential industrial partners to identify the right partners within the Lab system. A study found that CRADAs were more likely to be successful when Lab engineers are familiar with the use case for the technology they are developing,[163] which is more likely when considerable experience and resources for a specific area of technology are concentrated

161 Neal et al. (2008)

162 NAPA (2013)

163 Ham and Mowery (1998)

at a few Labs. Additionally, aligning the Labs with specific areas of inquiry and development may make it easier to find an appropriate Lab operating contractor with the relevant area of expertise. A study once described many Labs as "a community of loosely attached research units"[164] each vying for funding from program leaders at headquarters. Better, and more strategic, alignment of research competencies at the Labs and funding distribution from DOE headquarters may result in a more effective utilization of limited DOE resources.

2.3.2 **Disciplinary boundaries and the "basic/applied dichotomy"**

In Section 1.4, we noted that the separation of "basic" and "applied" research is partially an artifice of a decision by Vannevar Bush rooted in political calculation. The DOE serves as a case study on the impacts of relying on the "linear model of innovation" for organizational design.

As indicated by Figure 1.4, management of DOE's energy research activities is separated into DOE's Office of Science and the energy technology offices (i.e., of Fossil Energy, Nuclear Energy, Energy Efficiency and Renewable Energy, and Electricity Delivery and Energy Reliability). These offices have extensive bureaucracies (for example, EERE is led by an Assistant Secretary, a Principal Deputy Assistant Secretary, and three Deputy Assistant Secretaries; below this leadership structure, there is a Director for each technology office such as wind, solar, vehicles, etc.). Some of this separation is encouraged by Congressional appointment of separate leadership for the Office of Science and the energy technology offices. Because of this strong separation in the management of different "types" of DOE research, DOE's investments have been stovepiped in management and in funding streams.[165] [166]

164 Crow et al. (1998)

165 PCAST (1997). Federal Energy Research and Development for the Challenges of the Twenty-First Century (Report of the President's Committee of Advisors on Science and Technology). Executive Office of the President. Chapter 4:7.

166 N. Logar, V. Narayanamurti, L.D. Anadon, in *Transforming U.S. energy innovation,* L.D. Anadon, M. Bunn, V. Narayanamurti, Eds. (Cambridge University Press, Cambridge UK, 2014), Chapter 3.

The separation of management in DOE's organizational structure also affects energy R&D program areas (e.g., wind, solar, etc.) in a similar manner. Arbitrary distinctions of "basic" and "applied" research within a technological area can divide a research program into parts that would fall under the purview of two different managers on the same organizational level, but in disparate parts of the organization with little ability to coordinate.

Because activities classified as "basic research" are separated from applied thinking, the resulting research becomes disconnected from use and does not benefit from the essential learning that takes place when ideas are translated into practice.[167] [168] This separation makes it difficult for "siloed" R&D organizations to meet the needs of the energy community and employ more open innovation methods.

Recent thinking on technology innovation has moved away from the "pipeline" model and replaced it with "invention"/"discovery" phases which inform each other and do not have a uni-directional progression between the two phases.[169]. This philosophy has informed suggestions that links between the science and applied energy programs should be carefully constructed, and underpinned recent action in both Congress and the previous Administration to create a joint Undersecretary position for energy and science programs.[170] Some have proposed entirely eliminating the distinction between basic and applied programs by creating programs based on broad areas of innovation (e.g., energy, computing, biology) that would encompass funding streams currently divided between the Office of Science and applied energy programs.[171]

In addition to the organizational barriers created by erecting boundaries between "basic" and "applied" research activities, such distinctions create cultural barriers that can prevent effective programs from taking root. A

167 Narayanamurti, et al. (2009)

168 Currall et al. (2014)

169 Narayanmurti et al. (2013)

170 U.S. Department of Energy (2014, December 4). Dr. Franklin Orr Confirmed as Under Secretary for Science and Energy [Press release]. Department of Energy. Retrieved from http://www.energy.gov/articles/dr-franklin-orr-confirmed-under-secretary-science-and-energy (accessed on November 27, 2015)

171 Stepp et al. (2013).

recent report on DOE funding for technology maturation projects noted that expectations of the role of "basic science" Labs has encouraged the mindset that they should not be engaged in technology maturation, despite evidence that such programs help advance DOE's mission.[172] Even in the newly developed Energy Frontier Research Centers (EFRCs), which were designed to overcome distinctions between basic and applied research, once implemented in practice, DOE managers reverted to outmoded oversight practices and discouraged researchers from developing proof-of-concept prototyping.[173]

2.3.3 **Laboratory planning processes**

The recent CRENEL report noted that the Office of Science, which operates 10 Labs, has well developed mechanisms for incorporating Laboratory feedback into long-term planning. The report recommended standardizing the review process and using this process in all offices that manage Labs. [174]Another innovative approach to improving coordination with Labs is one taken by the Nuclear Energy program, which co-locates of much of its staff near Idaho National Laboratory.

Research on Bell Labs[175] and DARPA[176] indicates that devolving some decision-making authority to researchers can lead to better results, suggesting increasing feedback between Labs and DOE headquarters might enhance long-term planning of Lab priorities. This is consistent with previous research arguing that effective mission-oriented R&D organizations have strong leadership that is empowered to pursue a core agenda, an entrepreneurial culture which rewards initiative, and an organizational structure

172 Howieson, S.V., Sedenberg, E.M., Sergi, B.J., and Shipp, S.S.. (2013). *Department of Energy Technology Maturation Programs*. Science and Technology Policy Institute. Available at https://www.ida.org/~/media/Corporate/Files/Publications/STPIPubs/ida-p-5013.ashx (accessed November 27, 2015).

173 The senior author has sat on several EFRC advisory committees and observed this on multiple occasions.

174 Cohon et al. (2015)

175 Gertner (2012); Logar, Narayanemurti and Anadon (2014); Naryanamurti and Odumosu (2016)

176 Bonvillian (2009)

that gives institutional leadership flexibility in allocating funds and directing research (while maintaining a level of oversight). [177] [178] [179]

As mentioned earlier, the current structure of DOE organizes resources around the development of specific technologies. A review found that while incremental advances are facilitated by strict disciplinary approaches, key breakthroughs are more common in teams bringing together multiple disciplinary backgrounds.[180] This highlights the importance of collaborations both within and across Labs.

DOE has already taken steps towards organizing funding around multi-disciplinary, multi-Lab efforts such as Crosscuts, initiatives which are addressed on a broad, strategic basis, and the Energy Innovation Hubs. Established under Secretary Steven Chu, the Hubs are a "challenge model" approach to innovation, which are organized around a particular technological goal and reach across disciplinary and institutional boundaries. The premise of the Hubs has been well-received, although some have criticized their execution.[181] Along these lines, the SEAB Task Force has recommended the formation of a pilot project in which scientists at the Labs are given greater discretion to build interdisciplinary and inter-Laboratory teams.[182]

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177 Currall, S. C., Frauenheim, E., Perry, S. J., & Hunter, E. M. (2014). *Organized innovation: A blueprint for renewing America's prosperity*. Oxford University Press.

178 Damanpour, F. (1991). Organizational innovation: A meta-analysis of effects of determinants and moderators. *Academy of management journal*, *34*(3), 555-590.

179 Narayanamurti et al. (2009)

180 Fleming, L. (2004). Perfecting cross-pollination. *Harvard Business Review* 82.9 (September 2004)

181 House Committee on Science, Space, and Technology. "Subcommittee on Energy Hearing - Department of Energy Oversight: Energy Innovation Hubs." June 17, 2015. Accessed at: https://science.house.gov/legislation/hearings/subcommittee-energy-hearing-department-energy-oversight-energy-innovation-hubs

182 SEAB Task Force (2015)

3. The Role of Government in Technology Transfer

Chapter 1 explored the government's role in facilitating the development of new energy technologies. While government activities, including R&D at the National Labs, have historically led to many important innovations in the energy sector and beyond, these activities are also "limited by design."[183] Fundamentally, much of DOE's mission in energy-related research can only be considered successful if private actors in the energy sector adopt the new energy technologies the public sector helps develop. This stands in contrast to government research in many other areas, such as defense-related technologies or mission-driven space research (e.g., the Apollo Project), where success can be measured by technical progress and public sector adoption of technologies by government bodies.

Success in innovation of new energy technologies requires technology adoption by energy producers and consumers, the majority of whom are in the private sector. Therefore, government investment in energy R&D cannot by itself deliver the broad social value enabled by government-supported innovation without engaging private sector actors. The requirement of private sector activity in making public sector energy technology research successful raises difficult questions about the appropriate role of public actors and how deeply they should engage with the private sector. In particular, public-sector engagement with the private sector may require tradeoffs between making newly developed technologies equitably accessible to all actors and accelerating new technologies into deployment rapidly by working with a limited number of targeted partners.

Public energy R&D activities are complemented by a wide array of public and private sector actions and policies that together shape technological advancement. Functions complementary to public sector energy R&D and National Lab R&D in the U.S. National Innovation System[184] include the human capital and research training performed by universities, the enforcement of intellectual property, the provision and maintenance of

183 Crow and Bozeman (1998)

184 Atkinson (2014)

infrastructure systems, and private sector investment in technology development and deployment. In this section, we focus on a specific set of such complementary functions, those that perform the key translation between government-supported R&D at the U.S. National Labs and private sector investment in technology development and deployment. Specifically, we examine the set of actions termed "technology transfer," which are the focus of public policies that facilitate Lab-private sector engagement. This Chapter explores the role of the government and public policy in technology transfer and considers the many forms of actions that fall under the heading of technology transfer. Section 4.2 suggests a number of reforms to technology transfer policy and practice to increase the impact of U.S. National Laboratory innovation.

Definition: **Technology transfer** is any exchange that involves a technological idea through which the right or ability to use the idea is transmitted from one agent, typically the idea's creator, to another agent, typically one who will use the idea for practical application. Technology transfer agreements may be informal (e.g., interpersonal communication of an idea) or formal (e.g., a legally binding patent license agreement).

3.1 The economics of technology transfer

Fundamentally, technology transfer involves a transaction (contractual, or not) over an intangible technological idea. This poses a unique set of problems for the markets built around these types of transactions. In transactions over ordinary tangible goods (e.g., the sale of a physical product from a firm to a consumer), "sellers" lose their ability to exploit the sold good once the transaction is complete (the fact that a good can only be consumed by one actor is referred to as its "rival" nature). Further, in transactions over ordinary tangible goods, there are well-accepted norms and laws that prevent non-paying third-parties from using the good in the transaction (the ability to prevent non-paying third-parties from using a good is referred to as its "excludability"). In contrast, transactions over technological ideas are significantly more complex. Absent public policy, "sellers" of technological ideas do not somehow forget their idea or lose access to exploiting the idea once sold (ideas are non-rivalrous). Nor are there straightforward mechanisms to prevent third-parties not involved in the transaction of the idea from exploiting it once they understand it (ideas are non-excludable). This is problematic for transactions over technological ideas because sellers cannot market their ideas to potential consumers without revealing the idea itself (thus diminishing the sale-value of the idea) as potential consumers would already have received the full value of the idea just through the process of attempting to strike a deal.

Intellectual property law helps to mitigate the concerns described above by making the right to utilize a technological idea excludable for a limited period of time. Intellectual property also seeks to facilitate the disclosure of new technological ideas through public repositories of filed patents. Taken together, these two fundamental functions of systems for intellectual property suggest that patent protection is a necessary tool for enabling transactions over technological ideas. Once codified and protected by intellectual property, a technological idea gains many of the properties of a tangible product that can be marketed, bought, and sold. Patent systems and their supporting legal structures create a system of rules and norms by which the exploitation of formalized technological ideas can be controlled to a significant extent. Thus, while the patent system plays a well-known and highly debated role in incentivizing innovation (through the financial incentive derived from the rents of a limited patent monopoly)[185], the patent system also plays a distinct and fundamental role in enabling transactions over technological ideas. In the realm of technology transfer, this means that patents, and to a lesser extent, other forms of intellectual property, form the foundation for enabling the markets by which technology "sellers" can form contracts with technology "buyers."

Between two private firms, market forces will encourage at least some degree of technology transfer, as the comparative advantage to develop new inventions does not always align with advantages in product development and commercialization. Therefore, technology transfer between private

185 The role of patent systems in incentivizing innovation is controversial. No comprehensive studies have definitively established whether patents encourage more or less innovation in the private sector. For a historical review see Moser (2013); for international evidence, see Lerner (2009); for theoretical treatment of patents compared to other innovation incentive schemes, see Wright (1983); for detailed empirical work in specific contexts see Murray and Stern (2007) and Williams (2013); for a discussion of improvements to the patent system see Jaffe and Lerner (2004) and Bessen and Meurer (2008).

actors can be mutually beneficial when the inventing firm lacks—but the using firm possesses—the complementary assets and skills required to develop a technology for commercialization. As in any private transaction, there are "gains from trade" with technology transfer, as the user of the transferred technology gains access to a new technology that it can commercialize and profit from, and the inventor party can demand compensation for granting access to the invention it has developed (e.g., through royalty payments).

Yet, when the *government* has invented a technology, technology transfer can be expected to be more difficult, as the profit-motive that drives private technology transfer is substantially weakened. Further, the practices and focus of government-funded R&D may deviate strongly from those of a private firm engaged in technological innovation. Private R&D is conducted in the context of a profit-motivated organization where organizational dynamics create strong incentives to identify application areas and then commercialize nascent inventions. This drives how private organizations select the type of R&D projects to invest in, the technologies to develop into products, and the products to commercialize. Whereas private R&D projects are likely to be selected on the merit of potential commercial applications, the motivation for government R&D project selection is more varied. For example, government R&D projects may be selected on the basis of government missions—such as national defense, environmental protection, or otherwise advancing the public good, on the basis of political benefit,[186] or even to fulfill scientific curiosity.[187] Further, government innovators almost never possess the complementary assets nor the strategic mission to scale up and market socially valuable inventions. Thus, in the absence of the driving incentive of mutually beneficial gains from trade, technology transfer of publicly discovered inventions requires an additional set of functions to incentivize socially beneficial transfer of technological assets from public inventing organizations to private commercializing actors.

Technology transfer also has a distinct benefit of bringing new information into government labs from commercializing private actors with close

186 Cohen, L. R., & Noll, R. G. (2002). *The Technology Pork Barrel*. Brookings Institution Press.

187 49% of federal R&D is classified as "basic," indicating at least some component of curiosity-driven R&D Source: AAAS. "Historical Trends in Federal R&D." 2015.

ties to technology users. Technology transfer requires close engagement of government lab scientists, engineers, and managers with private actors pursuing technology commercialization. These interactions, ostensibly driven by transferring technology out of the Labs can also inform how government labs set research direction for future innovation. These interactions provide a channel for critical feedback from the private sector users of technology back to the government labs setting future research priorities.

3.2 The role of government in technology transfer

This section reviews the legislative authority for technology transfer activities at the U.S. National Laboratories as well as the conceptual foundation for how these agreements work, highlighting the important role for government actions and law.

3.2.1 Mechanisms of technology transfer

The complexities of technology transfer between government labs and private firms has led to the creation of many policy mechanisms to develop lab-industry commercialization strategies. These mechanisms range in the types of problems they address (e.g., technology value uncertainty, R&D cost-sharing, etc.) and the depth of engagement between public labs and private firms, from deep partnership in technology development through arms-length contractual technology licensing arrangements. The table below presents definitions and examples for the most prominent mechanisms of laboratory commercialization and technology transfer.

Table 3.1 Technology Transfer Mechanisms (based on U.S. Federal Laboratory Commission's definitions[188])

Mechanism	Description	Example
Licensing	A Licensing Agreement transfers less than ownership rights in intellectual property, such as a patent or software copyright, to permit its use by the licensee. Licenses vary from commercial, noncommercial, and government use. Licenses can be exclusive, for a specific field of use or for a specific geographical area, or non-exclusive.	Argonne National Lab entered into an exclusive licensing agreement with AKHAN Semiconductor, granting rights to use a suite of breakthrough diamond-based semiconductor inventions developed by a Lab scientist.
Cooperative R&D Agreement (CRADA)	A CRADA is a collaborative agreement that allows the Federal Government and non-federal partners to share technical expertise in a protected environment, access intellectual property emerging from the effort, and advance the commercialization of federally developed technologies.	Lawrence Berkeley National Lab entered into a CRADA with CalCharge, a coalition of stakeholders working on energy storage, allowing members to pursue joint research with the Lab.
Work for Others (WFO)	A WFO Agreement is a fee-for-service contract that enables industry, non-profit institutions and other non-federal entities to pay the Laboratory to perform a defined scope of work or tasks that draws upon the facilities, equipment, and personnel of the Laboratory. Closely related to sponsored research (which could be for research already planned)	About 88% of WFO work at the Labs is done for other federal agencies, mostly the Department of Defense. One project used laboratory expertise in laser decontamination to facilitate removal of chemical agent residues from equipment. The remainder of WFO is sponsored by non-federal governments and the private sector.[A]
User Facilities and Agreements	National Lab scientific user facilities provide researchers with the most advanced tools of modern science including accelerators, colliders, supercomputers, light sources and neutron sources, as well as facilities for studying the nanoworld, the environment, and the atmosphere.[B] Specialized and standard agreements are available to expedite user access to these facilities.	The National Synchrotron Light Source (NSLS) at Brookhaven Laboratory supported research on neuronal ion channels, leading to the 2003 Nobel Prize in Chemistry.[C]
Spin-Out	A spin-out is a new company formed specifically to develop technology arising from within the Lab, with the direct involvement of founding researches from the Lab as shareholders.[D]	In 2015, Descartes Lab raised venture capital and became an independent company. The company was based on years of work by its founders at Los Alamos National Lab using new machine learning techniques for image analysis.[E]
Informal mechanisms	Mechanisms facilitating the flow of technology knowledge through informal communication processes. In contrast to formal technology transfer mechanisms which often aim at transferring a specified research outcome like a patent, informal mechanisms do not, and there is usually no expectation that they will.[F]	Personal communication, conferences, consulting, publications, and educational activities are examples of informal technology transfer mechanisms
Other technology transfer mechanisms not included in this table include cost shares, personnel exchanges, consortia, and entrepreneur in residence programs.		

A GAO (2013).
B Office of Science. "User Facilities." Accessed May 21, 2016 (http://science.energy.gov/user-facilities/)
C Brookhaven National Lab. "The Nobel Prize: Chemistry of a cell." Accessed May 21, 2016 (https://www.bnl.gov/bnlweb/history/nobel/nobel_03.asp)
D Hockaday, Tom. "Spin-out versus Licence." Isis Innovation Ltd. Available at: http://isis-innovation.com/wp-content/uploads/2014/10/Licence-or-Spin-article.pdf (Accessed May 21, 2016)
E Crunchbase (2016). " Descartes Labs." Accessed May 21, 2016 (https://www.crunchbase.com/organization/descartes-labs)
F Grimpe, C., & Hussinger, K. (2013). Formal and informal knowledge and technology transfer from academia to industry: Complementarity effects and innovation performance. *Industry and Innovation*, *20*(8), 683-700.

188 For more detail on these other mechanisms see https://www.federallabs.org/T2-Mechanisms

3.2.2 **Technology transfer legislative history**

In the early 1980s, major legislation was adopted to increase the flexibility of the disposition of intellectual property (IP) produced by federal grants (the Bayh-Dole Act of 1980) and to require federal laboratories to actively participate in technology transfer activities by setting aside funds and personnel for that purpose (the Stevenson-Wydler Act of 1980). Since 1980, the role of technology transfer has been highlighted as an area for increased policy focus to fulfill the National Labs' and the Department of Energy's scientific and technological missions in energy and other sectors. Technology transfer is seen as a key area because it can directly or indirectly lead to private sector development and deployment of government-sponsored inventions. Absent private sector investment, many technologies developed in the public sector would lack the necessary resources and incremental follow-on innovation to achieve their maximum benefit to society.

The Federal Technology Transfer Act of 1986 (Public Law 99-502) required scientists at federal laboratories to consider technology transfer an individual responsibility. It also permitted GOGO laboratories to enter into CRADAs and to negotiate licensing arrangements for patented inventions made at the laboratories. An executive order further encouraged laboratories to engage in licensing and CRADAs to the fullest extent of the law.

The National Competitiveness Technology Transfer Act of 1989 (Public Law 101-189) allowed GOCO laboratories to enter into CRADAs, created provisions to protect information shared with the Laboratory, and provided a technology transfer mission for the nuclear security Labs. The flexibility to enter CRADAs is particularly important, as some have credited the liberalization of CRADA rules in the late 1980s to increased IP generation at the DOE Labs in the late 1990s.[189]

Further legislative tweaks to the CRADA mechanism were made in 1995 and 2000. In the meantime, a shift in the political climate saw increased questioning of federal agency involvement in technology transfer (and specifically CRADAs) as "corporate welfare". Along with a variety of other

189 Jaffe and Lerner (2001)

factors, such as a lack of an advocate for technology transfer at DOE or a set commercialization budget, technology transfer activities at the Labs dropped sharply in the early 2000s (see Figure 3.1). As a prominent mechanism to create more fluid interactions between the Labs and the private sector, CRADA activity is an important input into the technology transfer process, making it unsurprising that the decrease in funding for CRADAs preceded a decrease in other technology transfer measures.

By the mid-2000s, technology transfer became a higher priority item, and provisions in the Energy Policy Act of 2005 (Public Law 109-58) required the creation of a Technology Transfer Coordinator and created a Technology Commercialization Fund to work with private partners in promoting energy technologies. However, execution of the legislative mandate to appoint the Coordinator and develop a plan for the Fund were severely delayed until 2016[190] when the Office of Technology Transitions was formed within the DOE to coordinate the agency's technology transfer work.

3.2.3 **Trends in DOE technology transfer activity**

The U.S. Department of Energy is one of the largest performers of technology transfer in the U.S. National Innovation System. In this section, we present trends in key technology transfer metrics for activity at DOE. Figure 3.1 displays trends in five metrics.[191] These trends are scaled by the total amount of R&D funding spent in that year and all variables are scaled to 1997 levels for comparability. Publicly available data allows us to present trends from 1997—2014. Variables shown are invention disclosures, patent applications and grants -- which indicate the number of inventions with potential commercial application, new CRADAs executed, and invention licenses.

Previous analysis of these metrics has shown that technology transfer activity per R&D dollar invested declined consistently from 1997—2012 and from 2001—2012.[192] Incorporating additional data for 2013 and 2014 paints a

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190 U.S. Department of Energy Inspector General (2014). Audit Report: Technology Transfer and Commercialization Efforts at the Department of Energy's National Laboratories. OAS-M-14-02." Department of Energy.

191 Anadon et al. (2016)

192 Anadon et al. (2016)

slightly more nuanced picture. While invention licenses, invention disclosures, and CRADAs all fell from 2012-2014, patent applications and patents granted rose sharply during this period. However, both remained at or below the high-water mark which occurred in the early period of this analysis.

The general decrease in technology transfer metrics over the most recent 15 years of data suggests an increasing need to understand the effectiveness of public policies shaping technology transfer activities. In the remainder of this chapter, we present a broad-ranging conceptual discussion of the policies shaping government technology transfer, with a particular focus on improving understanding to reform policies shaping National Lab and DOE technology transfer.

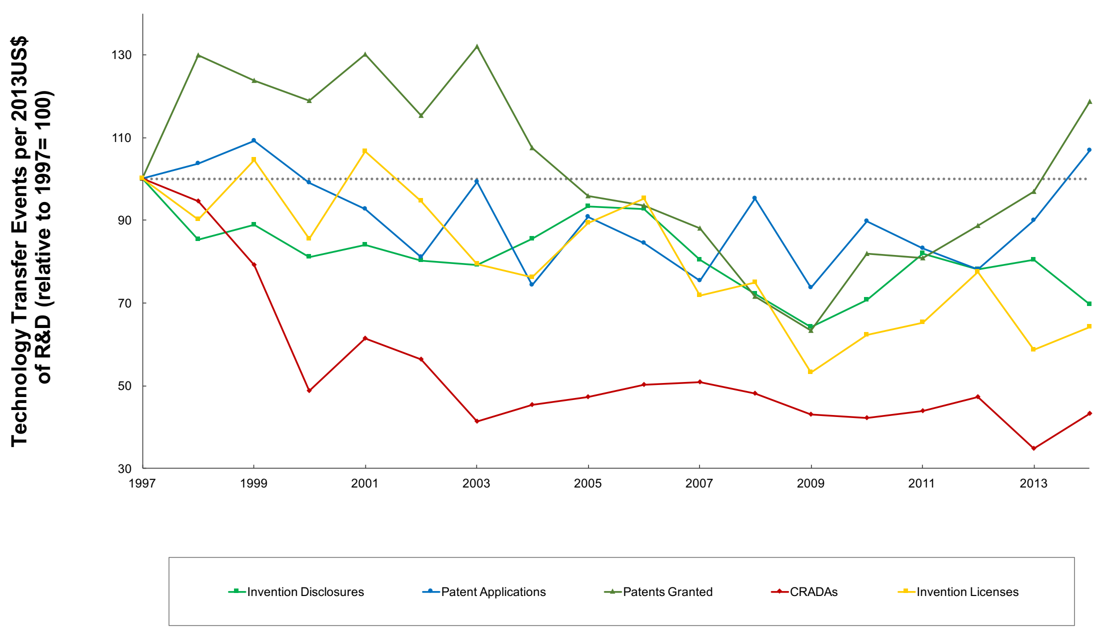

Figure 3.1 DOE technology transfer metrics (new CRADAs, invention disclosures, patent applications, patents granted, and invention licenses) per dollar of R&D invested, normalized to 1997 rates, shown for the period 1997—2014. Technology transfer outcomes are drawn from all DOE-owned facilities, but R&D spending data represents only DOE GOCO Labs, including physics and NNSA Labs but excluding NETL. Several metrics exhibit an overall decreasing trends and all are lower in 2014 their high point in the 1997-2003 period. Source: own analysis of data from the Department of Commerce and the National Science Foundation.[193 194]

193 Technology Partnerships Office (2015).

194 NSF. Federal Funds for R&D. U.S. National Science Foundation. Washington D.C. (2013) Available at: http://www.nsf.gov/statistics/fedfunds/. Last updated: 06/2013. Accessed on 07/2015.

3.3 Reforming National Lab technology transfer policy

Realizing the potential economic value of government-funded inventions from the National Labs requires targeted efforts to encourage complementary private sector investment in the commercialization of these technologies. Driving private investment into technology commercialization requires a mechanism by which private actors can partner with government labs or obtain title to government inventions. As detailed in Section 3.2.2, since the 1980 Bayh-Dole and Stevenson-Wydler Acts, a suite of policies have provided a framework by which National Labs can partner with private sector actors or patent their inventions and transfer title of these inventions to private actors. These two Acts, later reformed through incremental acts of Congress and changes in practices, lay the foundation for National Lab technology transfer. However, additional challenges remain. In this section, we introduce five categories of policy challenges for technology transfer policy at the National Labs. For each challenge, we present the theoretical insights undergirding the challenge. We explain important findings from a broad range of theoretical and empirical research and our own experience in this area and then draw out implications for policy. In Chapter 4, we identify existing policies or gaps where additional reforms may be needed for each challenge. We also propose metrics for evaluating progress towards addressing each challenge.

3.3.1 The challenge of invention value discovery

One of the most important difficulties in negotiating transactions over technological ideas is establishing the fair value of the idea. The uncertainty in the value of a technology at an early stage of its development is great, typically much greater than that of other investments, such as houses, bonds, etc. Uncertainty in the value of technology is due to the unknown properties of a technology and how it might shape or be shaped by other technologies and social institutions. Further, value uncertainty of an invention is increased by the potential for an invention to lead to follow on inventions, an issue we return to in Section 3.3.4. Value uncertainty makes investing in innovation and purchasing the intermediate outcomes of innovation extremely challenging. Ordinary financial tools for managing investment risks can be unhelpful when confronted with large technology risks, increasing the cost of doing business with technological ideas. Assessing the fair value of a technological idea in technology transfer agreements is challenging, but market forces (i.e., competition) can greatly help "discover" fair values for technologies. For example, auctions are regularly used to discover prices of goods with highly uncertain value, such as fine art, and more recently, auctions and other market platforms have been applied for price discovery in markets for patent rights.[195]

The National Labs have created a large portfolio of disclosed and patented inventions that could be highly beneficial to society, but determining what those benefits might be is also incredibly challenging. While some efforts have been made to estimate the economic value of Lab activity,[196] comprehensive measures and patent-level estimates do not exist. Without value estimates, the potential of transferring Lab inventions to the private actors who can deliver the value of such inventions remains highly uncertain. This could erode the political support to strengthen technology transfer activity. Further, the challenge of estimating the benefits of Lab inventions increases the transactions costs of forming partnerships with the Labs. For example, the fair market-value of licensing a lab invention depends on what private actors who can develop the technology for various applications are willing to pay for the right to license. However, if technological uncertainty limits the number of firms that actually engage the Labs in negotiations to license a technology, firms may exploit the Labs and offer to pay an amount below their willingness to pay (decreasing royalties that accrue back to the Lab). Conversely, Lab technology transfer offices may be wary of this problem and demand exorbitant licensing fees if they believe that firms are underbidding for the right to license a technology. By decreasing competition, technology uncertainty creates second-order effects that may inhibit technology value discovery. Improving the robustness of competition for Lab inventions could go a long way towards ameliorating these effects.

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195 Hagiu, Andrei and David Yoffie. 2013. "The New Patent Intermediaries: Platforms, Defensive Aggregators, and Super-Aggregators." *Journal of Economic Perspectives*, 27(1).

196 CBRE Consult (2007). *Berkeley Lab: Economic Impact Study*.

3.3.2 **The challenge of aligning expertise across Lab management**

A well-functioning intellectual property system and market forces can help facilitate the difficult process of price discovery for technological assets.[197] However, when the government holds title to an invention and seeks to market access to the technology to other actors, distinct challenges arise. First and foremost, public research organizations and their researchers are not equally motivated to commercialize technologies. The motivation of government actors to transfer technologies stems primarily from policy-mandated objectives (see Section 3.2.2 of this chapter), which have had limited associated resources for implementation. Therefore, there is limited political incentive associated with exerting higher effort to transfer technologies. Across government laboratories, operating contractors may vary in their enthusiasm for supporting technology transfer activities. However, even if properly motivated to transfer a technology, there are few incentives in place to ensure that the government receives a fair return for the public investment it has made in inventing a new technology. Whereas market forces help the discovery of the fair price of a technology in private sector technology transfer (firms theoretically face a tradeoff between developing a technology in-house and licensing it to others), when the government holds initial title to an invention, there are few mechanisms in place by which the government can negotiate the most favorable terms (financial or otherwise) for the public interest. Unlike a private-sector innovator, the government does not have an option to develop a technology in-house, and therefore there is no "floor price" to licensing revenue that private innovators have.

Technology transfer agreements with government laboratories are also challenging to strike because the government's available opportunities for partnerships and technology transfer are not broadly known by private actors. However, efforts to publicize government-sponsored inventions available for licensing have improved over the last several years (e.g., the

197 Arora, Ashish, Andrea Fosfuri, and Alfonso Gambardella. 2001. "Markets for Technology and their Implications for Corporate Strategy." Industrial and Corporate Change, 10(2): 419-451.
Gallini, Nancy, Suzanne Scotchmer. 2002. "Intellectual Property: When Is It the Best Incentive System?" Innovation Policy and The Economy 2: 51-77.

DOE's Energy Innovation Portal[198]). While private actors are naturally incentivized to seek out government technologies that may be useful to them, there are limited resources by which specialized private firms can search for technologies (owned by the government or a private firm) relevant to their line of business. Further, due to the fundamental difficulty of codifying a technology for its application as a marketable product, private actors may require a large degree of individualized information exchange in order to understand whether a government-sponsored technology is of interest. Because government labs vary in their motivation and requirements for technology transfer, these large set of informational hurdles in identifying lab technology-private partner pairs can be large or small, but are generally larger than those in the case of privately owned technologies.

In addition to the challenge of identifying the right partner for the right technology, government laboratories also face the large challenge of internally identifying which technological ideas are best suited for commercialization at any given moment. While the decision to promote a technology for commercialization will always be an uncertain process, government labs tend to lack the capabilities to identify commercial opportunities that seasoned private companies tend to possess. Within the DOE laboratory system, layers of organization hold different levels of technological information that can feed into a decision about whether or not to promote a technology for commercialization (e.g., actively seeking private sector partners through personal networks, pursuing a patent application, or publicizing an invention disclosure on the Internet).

The Lab scientists who interact directly with technologies have the highest information and tacit know-how to inform commercialization decisions, but they also tend to have the lowest level of authority to make such decisions. On the other end of the management structure, DOE headquarters is ultimately responsible for complying with technology transfer legislative requirements, and therefore has broad authority to implement technology transfer activities. However, DOE headquarters is removed from the technological details that are most relevant to interested commercial partners. Between the Lab scientists and DOE headquarters are the Lab managers and technology transfer offices. These layers of organization create

198 https://techportal.eere.energy.gov/

potential informational divides that are crucial to overcome for effective technology transfer activity. For example, if DOE headquarters does not have clear information even on which Lab technologies are available for commercialization, they will fail in maximizing the commercial potential of DOE R&D investments. This is likely to be particularly important when inventions from multiple laboratories can be usefully pooled in a single licensing agreement. Further, if Lab scientists hold key information relevant to the commercialization of a technology but do not have a channel to communicate this information, technologies can languish in the early stages of development without full engagement of commercial partners.

3.3.3 **The challenge of transferring tacit knowledge**

A key issue that arises in understanding the disclosure of a technology is that formalized codification of an idea, such as in a patent, can only feasibly encompass a fraction of a technological idea's functions, applications, and potential for follow-on innovation. All technologies have some degree of complementary knowledge that cannot be codified, referred to as "tacit knowledge." While inventors who file for intellectual property are encouraged to disclose the details of a technology, they may also purposefully keep secret the details that would allow competitors to circumvent or "leap-frog" the invention's protection. More problematically, many insights into how a technology can be most effectively implemented in practice that are known to the inventor may be too detailed or too embedded in the inventor's experiential knowledge to be included in codified intellectual property.

While the codification of Lab-discovered inventions can occur through intellectual property, codification is always incomplete and Lab scientists and engineers (just like those in the private sector) retain tacit knowledge that is required by commercial partners to extract the full value of a technology. This suggests that in order to be effective, technology transfer must be a "contact sport,"[199] wherein inventors and commercial partners frequently interact and exchange tacit knowledge.

199 Dubois, Lawrence. "DARPA's Approach to Innovation and Its Reflection in Industry," in *Reducing the Time from Basic Research to Innovation in the Chemical Sciences*. National Research Council. 2003.

3.3.4 **The challenge of facilitating incremental product innovation**

In Chapter 1, the economic rationale for government investment in R&D was presented. Because positive spillovers accrue from the unanticipated benefits from new knowledge creation, free markets undersupply new inventions and government support in R&D is welfare-improving. Here we discuss the economic rationale for broader government involvement in technology commercialization. Academic research has demonstrated that there are often positive spillovers from learning-by-doing associated with the process of developing technologies from inventions (codified into patents, for instance) into technologies for the marketplace.[200] Thus, technology transfer can also lead to additional positive spillovers that accrue in the form of follow-on or incremental innovation that occurs through the process of learning as a technology is commercialized and used. As long as these positive spillovers accrue beyond the appropriable range of the technology user, technology transfer will again be underprovided among private actors.

Licensing Lab inventions leads to substantial follow-on invention. These follow-on, or "spillover" inventions, have large economic benefits and would never be realized without the initial government invention and subsequent transfer and commercialization of the invention. To a large extent, these follow-on inventions create benefits that are not appropriable by the licensee, as a majority of these spillovers accrue outside of the licensing firm.[201]

Under current practice, Labs and the DOE do not systematically monitor the technologies that are licensed. Without comprehensive records of technology transfer agreements that enable analysis and comparisons, understanding of Lab impact is diminished. Tracking of all Lab licensed technologies and records of products and their sales derived from Lab-sponsored inventions is required for evaluating Lab activity. But useful tracking doesn't stop there. DOE and the Labs could also track the spillover

200 Chan, Gabriel. "The Commercialization of Publicly Funded Science: How Licensing Federal Laboratory Inventions Affects Knowledge Spillovers." Unpublished Manuscript. 2015.
Drivas K., Z. Lei, and B. Wright (2014). Academic Patent Licenses: Roadblocks or Signposts for Nonlicensee Cumulative Innovation? *SSRN Working Paper*.

201 Chan, Gabriel. "The Commercialization of Publicly Funded Science: How Licensing Federal Laboratory Inventions Affects Knowledge Spillovers." Unpublished Manuscript. 2015.

benefits of Lab-sponsored inventions by tracking citations to licensed patents and by qualitative efforts to track next-generation products that build on the products developed by the licensing firm. This kind of tracking would go a long way toward understanding the broader impact of Lab inventions and technology transfer policies.

The potential for incremental innovation to increase the value of an initial invention creates large uncertainty in the value of forming a new commercialization partnerships. This uncertainty poses barriers to identifying interested commercial partners with the capability to conduct follow-on, incremental innovation and to the government's ability to negotiate for the most favorable terms in the public interest. This uncertainty is closely related to fundamental technological uncertainty described in Section 3.3.1. Recognizing the additional uncertainty in the value of follow-on invention reinforces the recommendations described there. In some scenarios, uncertainty can be mitigated by diversifying a portfolio of risky investments (e.g., investing in R&D in multiple technological areas). In the context of reducing the uncertainty in the value of follow-on innovation, invention title-holders may also pursue diversification strategies, such as issuing multiple non-exclusive license agreements for a single patent.

3.3.5 **The challenge of formally codifying and protecting inventions**

A key challenge in a technology transfer agreement is agreeing on the explicit boundaries that define the technology in question. Because technologies are embodiments of abstract scientific ideas and practices, "codifying" the exact definition of the technology is challenging and often requires formal documentation, such as a patent, copyright, trademark, or published paper. Although in some cases, codification can take the form of a mutual understanding of a technology's boundaries arrived at through oral communication, relying on informal codification mechanisms makes establishing formal agreements more difficult. Therefore, formal agreements on technology transfer more typically rely on formal documentation of a technology in the form of codified intellectual property. Codification of a technology is central to creating effective technology transfer agreements because it defines exactly what the agreement transfers (see Section 3.1).[202]

Public labs typically face distinct incentives compared to private firms when filing intellectual property. A private inventing firm may file for IP protection to derive greater profit from products based on an invention or so that its further R&D work can freely build on previous inventions in the protected space afforded by IP protection. In contrast, the Labs primarily file for IP protection to fulfill their legislative obligation to facilitate technology transfer (see Section 3.2.2). Filing for IP at the Labs poses an important institutional challenge because IP does not ostensibly directly affect the future productivity of the Labs. Incentives for the Labs to file for IP protection are directly related to how Lab management translates legislative requirements and normative goals into routine practices.

Nevertheless, because the primary Lab motivation for filing IP is derived from policies to facilitate technology transfer, the Labs typically file for patents and copyrights in ways that are detailed and explicit so that potential commercial partners can understand the technology. In contrast, many private inventing firms file IP in ways that obscure and broaden technological details to cover a wider set of technologies for litigation purposes. Developing IP that covers the intricacies of a technology in a way that makes the technology most attractive to potential commercial partners requires significant resources at the Labs to develop legal and commercialization expertise that complements the Labs' scientific technical expertise.

Inventions, once formalized in IP, are protected through the judicial system. In private sector technology transfer agreements, profit-maximizing firms who license technologies are incentivized to litigate patents that are infringed or license agreements that do not follow terms. National Labs are not profit maximizing and may not have the resources or mission to enforce their intellectual property and license agreements. In a technology transfer agreement, the party receiving a technology receives a larger part of the value of the agreement upfront after gaining access to knowledge it

202 Arora, Ashish, Andrea Fosfuri, and Alfonso Gambardella. *Markets for Technology: The Economics of Innovation and Corporate Strategy*. MIT Press. 2001.
Gallini, Nancy, and Suzanne Scotchmer. "Intellectual Property: When Is It the Best Incentive Scheme?" *Innovation Policy and the Economy* 2:51-77. 2002.

did not previously have. Enforcement of intellectual property is required to avoid exploitative use of licensed inventions. Yet Lab technology transfer offices have very limited resources for pursuing IP infringement litigation, and example infringement cases are very rare (this mirrors a similar problem faced by university technology transfer offices[203]). National Labs must develop alternative norms for enforcing their intellectual property (both patent infringement and license agreements). This would improve the integrity of their agreements and give future licensing partners confidence that they are playing under fair rules.

Finally, while the role of IP is critical in enabling partnerships between the Labs and commercialization partners, the creation of IP derived from publicly funded R&D raises equity concerns. The research conducted by the Labs that does not lead to commercialization outcomes is typically made available to the public for free in the form of disseminated information (e.g., publications) that advance the collective frontier of science. Yet inventions developed at the Labs that lead to commercial products are more frequently codified as IP and transferred to specific private partners. In effect, this process privatizes a share of the value of publicly funded R&D. This process of privatization may be necessary in some cases for the public to derive any value at all from publicly funded inventions (lest inventions languish as ideas never turned into products that can be bought and sold in markets). Nevertheless, privatization raises important equity concerns about which private actors benefit from publicly funded R&D. More research is needed to understand how National Lab policy and practice can be reformed in this domain to serve the public's interest, particularly with respect to the fair transfer of IP rights developed from public funds to a limited number of private sector firms.

203 Rooksby, 2013. http://digitalcommons.law.yale.edu/cgi/viewcontent.cgi?article=1084&context=yjolt

4. Policy Recommendations

4.1 Research management recommendations

4.1.1 National Lab operating model

Recommendation 1: Reforms should restore and protect the historical operating model of the Labs

There is broad consensus that significant changes are needed to improve the management of the National Laboratories and their ability to effectively execute the DOE's mission, particularly around advancing energy technologies. However, some proposed actions would, on net, harm national welfare.

Although proposals to consolidate research streams across a more limited set of Labs could have benefits in terms of operational efficiencies and increased ease in forming interdisciplinary teams and centers, there are significant concerns that it would inevitably lead to reduced levels of federal R&D funding.

We recommend that major cultural changes be made to the Labs within the framework of the current system. In particular, we emphasize that the Labs need to be understood as a major player within the larger energy and technology innovation ecosystem. Many issues with Lab management stem from views of senior government officials in both Congress and the Executive Branch that the Labs should concentrate on a narrow execution of the DOE and Congressional agenda. This is exacerbated by the transient status of political leadership. Amelioration of Lab governance culture will contribute greatly to better performance at the Labs; this culture is the sum total of relationships between the major players in energy R&D: DOE, Congress, the Labs, Lab contractors, and other industrial, academic, and non-profits entities engaged in R&D activities.

As such, we strongly recommend that the outcome of any reform process should preserve the current high-level framework for Lab management, including DOE stewardship and the initial intent of the GOCO model, while introducing important cultural changes. Most of our recommendations to follow revolve around changes that will help restore the balance and independence that were historically features of the GOCO model, while maintaining a healthy degree of Executive Branch and Congressional oversight.

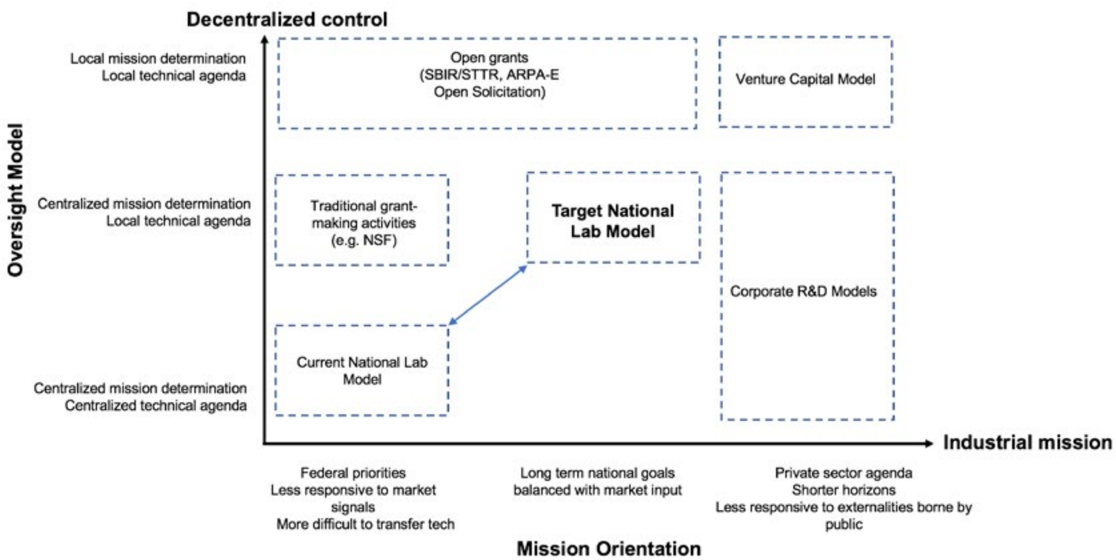


Figure 4.1: Oversight and Mission Setting Cultures for Innovation: Schematic sketch of different potential R&D and where Labs would ideally be situated. Several other organizations are placed on this schematic to provide context.

The left side of the continuum represent public missions and the right side represents private innovation agendas. The bottom of the continuum represents organizations where the research agenda is centrally managed, and the top represents mission determination by funding recipients. For the Labs to advance energy innovation that both achieves federal policy goals and is tied to market signals, balance will be required in both dimensions.

4.1.2 **Achieving technology transfer goals in a research-focused culture**

Recommendation 2: Broaden the universe of potential Lab Contractor/Operators

The culture of each Lab is impacted by its management, particularly if that management is stable over a significant period of time. One interviewee commented that, to this day, Sandia retains significant elements of its culture from AT&T, which managed the Lab from 1948 to 1993. Despite a history of industrial firms operating National Labs out of a sense of civic responsibility, this tradition is waning and in danger of extinction. As demonstrated earlier, there has been as a significant trend towards non-profit firm and consortium-based management at Labs in the last few decades. We interpret the shift away from private Lab operators as evidence of a Lab climate less hospitable to public-private partnerships.

While it is clear that industrial firms possess a greater understanding of market needs and have greater competencies at the final stages of the commercialization, evidence is inconclusive as to whether this translates into superior performance when employed as Lab managers. Given the size of the budget and degree of influence Lab contractors have, we have found surprisingly little literature addressing this topic.

On the one hand, there are legitimate concerns that industrial partners do not obtain undue benefit from operating a Lab; however, there are also concerns about the independence of entities whose business model depends on retaining Lab contracts. Labs with different missions require different relationships with the private sector; Labs with a "fundamental" science mission would likely benefit less from close industrial associations. However, Labs with a mission to accelerate new energy technologies may well benefit from closer association with companies with a track record of research excellence, whether those relationship are the M&O contracting mechanism or through other organizational structures.

We recommend that Congress and DOE strive to expand the M&O competition to more potential bidders. Further, DOE and Congress should strive to create a reality at the Labs where service to the nation through Lab operation is seen as a feasible choice for a broader range of partners. This will likely include restructuring the M&O relationship to allow Lab operators more autonomy.

Recommendation 3: Devolve more decision-making to lab researchers through expanding and protecting the Laboratory Directed Research and Development program

LDRD is often seen as a personnel recruitment and retention tool, particularly at the NNSA Labs. Certainly, the retention of quality scientific personnel is necessary for executing the Labs' mission. However, given our finding of increased technology transfer metrics through LDRD funding, DOE should view of LDRD as a key element of its innovation strategy. This finding parallels the increasing recognition of the power of "bottom-up" innovation, which uses ideas originating with researchers to complement a research agenda driven by centralized management. As noted earlier, private firms have created programs that solicit input from scientists and employees at the front lines of innovation, often dedicating considerable funds and personnel time to these ideas.

Our recommendation is that DOE and Congress recognize LDRD as a key tool in rapidly developing ideas from the scientists and engineers at the Labs and encourage increased use of this funding mechanism at the multipurpose and applied energy Labs.

We recommend that Labs look for additional creative funding mechanisms similar to LDRD funding. One example is Oak Ridge's Seed Money Fund, a subset of LDRD which disburses funds on a more frequent basis than the annual LDRD process (with a shorter, peer-centered review and smaller grants), which can be valuable in capturing ideas that might not be funded in a more traditional LDRD funding process. Some elements of this recommendation can be captured by reducing or eliminating prospective DOE headquarters review of LDRD grants, which is often conducted by local site offices. Revitalizing the LDRD program would recapture the intent of the GOCO model, where technical decision-making rests appropriately with local-level experts.

We also recommend raising the cap on LDRD funds, either by reducing its overhead burden, raising the cap outright, or both. The CRENEL report recommended eliminating the LDRD overhead cost requirement Congress added in 2014. We support that proposal and recommend, as well, that the LDRD cap be raised to 10%. Additionally, at the multi-mission and applied energy Labs that today do not come close to the LDRD cap, a minimum amount of protected LDRD funding should be required.

Recommendation 4: Reducing program direction costs at DOE

The percentage of the budget for program direction costs at DOE has increased in recent decades, reducing funds available for research and development.

To reduce spending on direction costs, Labs, DOE, and Congress should implement a leaner management structure with longer, less frequent review cycles and greater reliance on measures that create ex-post accountability rather than ex-ante justification. Our recommendations to consolidate "applied" and "basic" research (Recommendation 6) would also have the benefit of reducing overhead. Additional measures that can reduce overhead include greater budgetary flexibility for Labs, thereby reducing the amount of money spent on reporting and compliance, decreasing the number of approvals needed to spend designated funds, and the use of more uniform contracting mechanisms.

Recommendation 5: Encourage a cultural shift around private sector engagement

The decline of frontier-expanding and vertically integrated corporate R&D Labs has created a deficiency in the National Innovation System, namely, a de-emphasis on long-term focused research. The National Labs, in appropriate partnerships with private firms and science and technology focused research institutions, can play a key role in filling this hole. Fulfilling this role requires a significant commitment to cooperative research.[204]

204 Crow et al. (1998)

Cooperative research and other activities with the private sector should be seen as enhancing Lab understanding of market needs and providing an avenue for Lab technologies to reach consumers. To enhance and expand cooperative activity, resources and incentives should be put in place to encourage Lab engagement with the private sector. Appropriate measures should include:

1. **Create a collaboration strategy:** Currently, DOE collaborations with the private sector are largely *ad hoc* arrangements. Just as DOE leadership actively seeks to identify promising areas for new investments in R&D, domains where public-private partnerships have significant potential should be identified and collaborations proactively encouraged.[205] This can complement building specific expertise at individual Labs which would serve as a nexus for private sector collaboration.

2. **Evaluate Labs based on technology transfer outcomes:** Evaluation frameworks for Labs, known as Performance Evaluation and Measurements (PEMPs), do not include technology transfer as a significant contributor to evaluations. Since PEMPs affect the level of Lab operator fee, tying its outcome to appropriate technology transfer metrics, efforts and qualitative assessments, as a supplement to existing metrics, sends a clear message of their importance. Evaluations should be designed to go beyond simply tallying technology transfer activities and should recognize measurable impacts.

3. **Delegate legal authority to sign cooperative agreements to Laboratory Directors:** In the context of increased autonomy for Laboratory Directors (including measures such as the increase of LDRD funds and allowing Directors to shape the long-term Lab planning process), allow Directors to enter into cooperative R&D without DOE headquarters approval. If necessary, this authority could be granted for a trial period of appropriate length and/or only apply for cooperative agreements below a certain limit.

205 Anadon *et al.* (2014)

The Labs are well-placed to serve as an important nexus between sectors. Policies should encourage this role, but not at the expense of the Lab's missions of scientific and engineering excellence.

4.1.3 Energy innovation management recommendations

Recommendation 6: Reorganize DOE and alter policies to eliminate artificial distinctions between basic and applied research

Vannevar Bush's separation of basic and applied science was done in part to create political insulation for basic research, which remains less controversial and subject to funding instabilities as "applied research." This distinction has persisted at great cost. The DOE organizational chart reflects this divide and, as documented, creates unnecessary divisions and political boundaries between "basic science" and "applied" Labs.

Our recommendation is to re-order the status quo where program managers observing strict boundaries (e.g., solar energy, basic energy sciences) are responsible for the vast majority of funding decisions at the Labs. Another report has suggested a complete merger of the applied energy offices and the Office of Science, with funding organized around broad areas of innovation (e.g., energy, computing, biology).[206] The Office of Science has a planning process that coordinates across the Labs it manages, but the value of that process is limited because of the separation between the applied energy and Office of Science Labs.

We propose a more modest reorganization of Lab reporting authority that avoids needlessly separating "basic" and "applied" research activities. In our taxonomy, there are currently three groups of Labs managed by the Office of Science and the applied energy offices: applied energy Labs, multi-mission Labs, and single-mission Labs. The multi-mission and single mission Labs are managed by the Office of Science. Although the demarcation is not entirely neat (for example, some single-mission Labs such as SLAC do significant work for the Basic Energy Science office and have important

206 Stepp et al. (2013)

user facilities), it is primarily the multi-mission and applied energy Labs that perform significant energy work. Therefore, we recommend that they be consolidated under a unified management structure.

Current Management	Applied Energy Offices	Office of Science	
Proposed Management	Science and Energy Labs		Single Mission Labs
Labs	Currently applied energy: • NREL • Idaho • NETL	Currently multi-mission: • ORNL • Argonne • Ames • LBNL • PNNL	• Fermi • SLAC • Brookhaven • TJNAF • Princeton

Figure 4.2: Re-organization of DOE: Currently, the applied energy Labs are managed by the applied energy offices, while the multi-mission and single-mission Labs are managed by the Office of Science. In our proposed re-organization, a common management structure is created linking the applied energy and multi-mission Labs.

Recommendation 7: Create a position overseeing energy innovation in the Office of the Secretary with the authority to implement a single planning process for energy innovation across DOE; evolve the funding model to rely more extensively on a challenge model; Lab directorship should have a significant voice in this process

Each year, the Office of Science runs an involved planning process involving the Labs it stewards and their directorates. Each Lab submits a ten-year plan in response to DOE guidance, and DOE consolidates all the plans into a ten-year plan for each of the Science National Laboratories.[207] However, only a portion of DOE energy innovation work occurs at Science Labs. In addition to the consolidation of "applied energy" and "multi-mission" Labs under a joint management structure, we recommend the creation of a Lab energy innovation effort in the Office of the Secretary. The director of this effort should report directly to the Secretary, provide a broad strategic vision for energy innovation activities at DOE, and rationalize the allocation of those activities across the Lab system. A step in this direction has been taken through the creation of the Quadrennial Technological Review that sets strategic objectives. Additionally, a full inventory analysis

207 U.S. Department of Energy (October 2016). *Laboratory Planning Process*. Retrieved from http://science.energy.gov/lp/laboratory-planning-process/. (Accessed December 27, 2016).

of ongoing and recent Lab work as well as a full patent database would be invaluable in coordinating research planning across the complex.

This planning process would be centered on a challenge model, choosing important technical objectives and selecting Labs that would be involved based on capabilities. Ideally, Congress would appropriate directly to this office to coordinate challenges across energy and science offices and offer guidance in selecting priority challenges. The energy innovation office should also take lead on coordinating technology transfer policies across DOE and the Lab Complex.

The role of what is now the DOE Science and Applied Energy offices would be modified to advise the new position, manage the disbursement of funds, and oversee the laboratories. Over time, the Lab energy innovation office would grow to some extent as Lab funding models better align with the challenge model. Parts of DOE's legacy structure would remain to fund smaller projects and areas DOE supports that cannot be easily adapted to the challenge model.

The challenge model has been implemented successfully at DARPA and ARPA-E, organizations which concentrate on transformational challenges. While DARPA and ARPA-E work on shorter grants and with a leaner structure, as they do not manage large R&D organizations like the Labs (making it easier to work on new challenges by simply adding a new program with a new program manager), we believe this change in organizational structure would allow the Labs to better implement challenges that bring together industry and Lab capabilities.

Recommendation 8: Strategically develop targeted competencies by deliberately concentrating funding to specific Labs

Dispersing funding from a single program across many Labs encourages Labs to remain unfocused as they attempt to increase access to DOE funding streams. This, in turn, degrades the ability of individual Labs to consolidate expertise in specific areas. While encouraging a healthy degree of competition, DOE should discourage over-diversification at the Labs by reducing the number of Labs funded by individual programs.

This would occur naturally under the challenge model in Recommendation 7, if challenges were carefully distributed to Labs. Labs with expertise developed through participation in one challenge would naturally attract funding for related challenges. Additionally, Labs leading a challenge in a particular area would have visibility to relevant industry partners.

While a natural focus should emerge from areas of strength and competence for an individual Lab, restrictions on over-diversifying Lab funding should not apply to either LDRD funds or funds brought in through a public-private partnership. Labs should continue to have avenues to explore promising scientific/research leads even if they do not adhere to the boundaries of their traditional disciplinary strength. However, this should represent a Lab-level decision, notwithstanding an overarching DOE policy to avoid overly redundant competencies in the Lab system. As a first step, these changes can piloted at today's applied energy Labs, but should eventually be implemented across the Lab system.

4.2 Technology transfer policy recommendations

Recommendation 1: Maximize the value of Lab invention portfolios

While a large amount of uncertainty in the value of an invention is fundamentally unreducible (see Section 3.3.1), there are several specific measures the Labs could take to improve the process of value discovery as it relates to technology transfer.

1. Lab technology transfer offices should be given additional resources to perform the key role of surveying technological developments internally in their Labs to better understand inventions with the potential for commercialization. The key function of Lab technology transfer offices to look internally into their Labs to identify commercial-ready technologies should be given greater institutional support within the Labs. This is a unique function of technology transfer offices, and they should be given additional resources and access to survey Lab scientific groups to closely

monitor in-house technological developments and make new technological commercialization opportunities more widely known to the public. This type of activity could include more deeply engaging technology transfer offices in the daily activities of the Labs and implementing "rotations" of Lab scientists in the technology transfer offices.

2. Labs should take measures to broadly market their available inventions for technology commercialization partnerships (e.g., by creating online databases of available inventions and bundles of inventions) with the goal of increasing competition to partner with the Labs to develop the technology.

3. When multiple potential partners are interested in developing a single technology (for the same purpose), Labs should auction the right to license an invention to attract the highest desired commercialization goals. Robust markets to develop individual technologies with multiple interested partners would greatly facilitate the process of invention value discovery without greatly increasing the resource demands on Lab technology transfer offices.

Metrics to assess progress

Progress in addressing the challenge of improving invention value discovery could be assessed by the average length of time a licensed patent is available before a commercialization agreement is signed, the degree of competition to license individual patents (e.g., number of interested licensing partners), and qualitative feedback from users on the ease of finding relevant inventions available for developing commercialization partnerships. The effectiveness of different modes of supporting transfer could be evaluated using randomized control trials.

Recommendation 2: Balance and synchronize centralized technology transfer efforts with Lab-based efforts

To overcome the barriers to commercialization that arise from the complexity of Lab management structure (see Section 3.3.2), we suggest a stronger role for the Lab managers and technology transfer officers in their capacities as boundary-spanning actors between the technologists and DOE management. The recent creation of a DOE Office of Technology Transitions and the funding of the Energy Technology Commercialization Fund provide a new strategic opportunity to develop stronger roles for boundary-spanning actors to engage meaningfully between Lab scientists and DOE management responsible for implementing DOE's technology transfer mandate.

1. Several steps could be taken by the DOE headquarters and the Lab technology transfer offices to decrease the barriers to private firms being able to identify commercially relevant Lab technologies. The Labs should coordinate with DOE headquarters to present a single unified front for marketing available technologies. Currently, the Labs have many overlapping streams of research in terms of application areas as seen in Figure 2.6. Therefore a cross-Lab integrated approach to marketing technologies would more effectively bundle complementary Lab discoveries in "patent pools". With this recommendation, we note that there could be a potential bureaucratic tension between the centralized technology transfer effort at DOE headquarters and the Lab technology transfer offices. Reforms to practices in the marketing of technologies must strike a careful balance between preserving Lab autonomy and agency in making technology transfer decisions and the coordinating role of the DOE headquarters. Therefore, clear communication and delineation of authority is essential. A fully decentralized approach, as recommended by some,[208] would miss out on the potentially important synergies between technologies developed at different Labs that can only be captured with a strong but limited DOE role.

2. Labs should experiment with alternative boundary-spanning institutions and experimental initiatives that can increase exposure to their technologies to key industry actors. Drawing inspiration

208 SEAB Task Force (2015)

from university proof of concept centers,[209] such as the Deshpande Center at MIT, the Labs could create "microlabs" right outside of their security border. These institutions could house patented prototypes of lab discoveries that the general public and interested private firms could interact with. Through this hands on experience, and interactions with Lab scientists, interested commercial partners could get hands on experience with a technology and develop some degree of tacit knowledge before choosing to pursue formalized technology transfer. Labs should also expand their programs to bring outside entrepreneurs and technology commercialization professionals from the private sector (such as venture capitalists) into the Labs. Programs like the Entrepreneur in Residence initiative represent important new efforts to integrate the outside perspective of private firms into Lab commercialization decisions. These new programs should be evaluated for their effectiveness and considered for expansion.

Metrics to assess progress

Progress in addressing the challenge of aligning expertise in the Lab-DOE bureaucracy could be assessed by bureaucratic performance metrics, including employee satisfaction with communication and operational efficiency; the formation of invention/patent pools to develop commercialization partnerships around groups of Lab inventions; the development of new experimental approaches to increase outside access to Lab inventions; and overall knowledge of Lab technical expertise and inventions by potential commercialization partners in key domains, such as large industrial firms and venture capitalists.

209 Gulbranson, Christine, and David Audretsch. 2008. "Proof of concept centers: accelerating the commercialization of university research." *The Journal of Technology Transfer*, 33(3): 249-258.

Recommendation 3: Incentivize Lab researchers to work with commercial partners in transferring tacit knowledge

To overcome the challenges of transmitting tacit knowledge from Lab scientists and engineers to commercial partners (see Section 3.3.3), Lab technology transfer offices should play an increased role in facilitating interactions between scientists and partners after a technology transfer agreement is completed. As a complement to other technology transfer mechanisms, scientists should be required (or otherwise incentivized) to dedicate time towards transferring tacit knowledge to commercial partners. This type of interaction should be formalized in some cases, as it would increase the value of a transferred technology to an interested private actor, thus increasing demand for Lab technologies. A possible approach to formalization would be the inclusion of a clause in licensing agreements that the private sector licensing partner pay for a portion of an inventing scientist's salary to have the inventor work as a temporary employee of the firm. In cases where technologies have a very high degree of tacit knowledge, technology transfer offices could encourage spin-outs rather than licensing, as spin-outs retain the initial inventing team in the commercialization team, thus limiting the barriers posed by tacit knowledge.

Metrics to assess progress

Metrics to assess the transmission of tacit knowledge along with codified intellectual property in technology transfer agreements include measures of accessibility of Lab scientists to commercialization partners (e.g., through time logs), the number of personnel exchanges developed in conjunction with other forms of technology transfer, and the number of spin-outs per invention disclosed. Over time, one could also track whether there are differential levels of commercialization depending on the level of personal engagement involved in a particular transfer. Such tracking efforts can help make funding allocation for technology transfer more cost-effective going forward.

Recommendation 4: Better understand and use creative contracting mechanisms to promote follow-on innovation

The challenge of promoting follow on innovation that builds on Lab inventions (see Section 3.3.4) can be partially overcome with four recommended actions:

1. To the greatest extent possible, DOE and the Labs should maintain databases of their technology transfer activities. Further, DOE and the Labs should seek to track follow-on innovations from their commercialization partnerships to highlight the broader impact of their inventions and technology transfer activities. This could be implemented in practice by maintaining a database of new inventions that build on Lab-sponsored inventions; this could be tracked by tracing patent citations; the creation of new inventions building on Lab-inventions could be established with qualitative interviews (including surveys), or quantitative analysis, the strength of which could be facilitated by a priori planning of data collection and follow up.

2. The varying motivation of DOE Labs to engage in technology transfer needs to be better understood. To this end, the Labs should track a more detailed, consistent, and broader set of technology transfer metrics and outcomes (e.g., in terms of technologies in the market place, patents successfully or unsuccessfully tested in large pilots, etc.). These metrics, which include lessons learned from failures and dead-ends, should be reported to DOE headquarters annually and made publicly available. Right now, DOE headquarters is unable to track its Labs' performance along many key dimensions of technology transfer performance.[210] For example, no office with the DOE or Lab system tracks the fraction of license agreements that originate from a CRADA. Such a metric is fundamental to understanding how technology transfer offices should be allocating their efforts across technology transfer mechanisms.

210 U.S. Department of Energy Inspector General (2014). "Audit Report: Technology Transfer and Commercialization Efforts at the Department of Energy's National Laboratories." OAS-M-14-02.

3. To partially overcome the large uncertainty from the possibility of follow-on innovation building on Lab inventions, the Labs should be allowed to utilize more flexible policies with built-in "option" clauses to transfer inventions. Borrowing from principles of financial derivatives used to drive investment in the face of large, incrementally unfolding uncertainty, Labs could be given the option of providing a limited license for a fixed length of time with a built-in clause to allow the licensor to renew the license at an alternative royalty rate at a certain date. Such a tool would reduce the financial risk of licensing a Lab technology and could drive greater experimentation in developing Lab technologies in alternative fields of use.

4. An alternative approach to a limited-duration license would be a scheme of offering many low-cost, short-term non-exclusive licenses followed by an auction to the highest bidder for a single exclusive license. Such a scheme would similarly drive greater experimentation in commercializing a technology while also helping the government more efficiently extract the fair value of its technologies. We recommend that the Labs pioneer explorations of alternative licensing arrangements that provide greater flexibility. Government Labs, unlike private firms, are well positioned to experiment with alternative licensing agreements because they are in a position to actively market a wide range of technologies for licensing and are in a strong position to negotiate commercialization agreement terms. Further, unlike the private sector, the government licenses technologies to broaden the social impact of its sponsored inventions. Therefore, experimentation of alternative arrangements should seek to maximize the diffusion of a technology, rather than the maximization of profits (which is the typically assumed objective of private sector licenses).

In the case of CRADAs, a similar problem manifests itself as a result of high uncertainty in the potential for follow-on innovation. In the case of CRADAs, the cost of R&D is known but, like all R&D, the initial returns and returns from future inspired R&D activity are uncertain and may be potentially large. Because of this high uncertainty, a set of standardized terms for CRADAs should be developed and offered to (but not required of) all potential partners, particularly with respect to the intellectual property that may be created during the execution of a CRADA. Standardized CRADAs could be developed for different R&D cost levels, but are more likely to be useful for smaller, more regular cooperative R&D arrangements. This would have the advantage of lowering transactions costs and approval times for establishing CRADAs, a well-identified issue,[211] and clarifying the allocation of benefits. Offering a standardized contract can lower transaction costs but Labs should also retain the right to re-negotiate CRADA contracts as necessary, particularly for larger CRADAs. Standardized CRADA terms could be based on R&D cost thresholds, such that standardized contracts are offered for R&D projects at different anticipated cost levels; CRADA terms for smaller R&D projects may not be viewed as favorably when costs are higher.

Metrics to assess progress

Progress in addressing the challenge of facilitating incremental product innovation could be assessed by the number of licensing agreements signed per dollar of R&D invested, per invention disclosed, and per patent filed. Progress could also be measured by assessing the degree of experimentation at the Labs with alternative licensing arrangements that build in flexibility into licensing terms and qualitative measures of private sector interest in partnering with the Labs to develop technologies into products, including under flexible licensing or CRADA terms.

211 Harrer, B.J. and Cejka, C.L. (2011). "Agreement Execution Process Study: CRADAs and NF-WFO Agreements and the Speed of Business." Pacific Northwest National Laboratory for the U.S. Department of Energy.

Recommendation 5: Invest in IP expertise throughout the Lab management structure

Intellectual property is critical to the Lab technology transfer mission (see Section 3.3.5). We recommend that DOE improve its understanding of what resources are needed to improve relevant Lab IP expertise. We suggest that effective technology transfer requires both central coordination—to bundle inventions across multiple Laboratories and to actively seek commercial partners on a unified front—and decentralized engagement—to translate the technical details of inventions based on a close understanding of the technology.

Metrics to assess progress

Progress in strengthening Lab activity related to overcoming the challenge of formally codifying IP in ways that enable technology transfer could be assessed by measuring the number of patents and copyrights filed per dollar of R&D funding and per invention disclosed, and by the number of patents and copyrights left idle with no interested commercial partners.

Progress towards addressing the challenge of enforcing intellectual property at the National Labs could be assessed by measuring the number of patent infringement lawsuits or other legal infringement communications (e.g., cease and desist letters) per patent granted (comparing this metric to private entities and universities in similar technological fields). Another proxy measure is the total resources spent on patent attorneys per patent filed.

Finally, progress towards understanding the fairness of intellectual property management at the National Labs could be assessed by the distribution of transferred IP disaggregated by different equity dimensions, such as the firm size of the commercializing partners, the geographic region of commercialization partners, and the socioeconomic levels of consumers purchasing commercialized products.

Table 4.1 Summary of key theoretical insights and policy challenges and their linkage with our policy recommendations and metrics for evaluation.

Challenge Posed for the National Labs	Theoretical Insight	Proposed and Existing Policy Reform	Metrics for Evaluation
3.3.1 The Challenge of Invention Value Discovery The Labs rarely receive multiple offers to develop a commercialization partnership around a single invention and feel fortunate to find even one interested partner in most cases. In the absence of partnerships, Lab inventions can sit "idle on the shelf" for years.	Recognizing the value of an invention to a private firm is challenging. This makes the negotiating process for commercialization partnerships more difficult, because it limits the number of parties that become interested in accessing the technology. Limited interest lowers competition and weakens the process of "price discovery" that could otherwise take place in competitive markets or auctions.	**Recommendation 1:** Maximize the value of Lab invention portfolios Lab technology transfer offices should be given additional resources to perform the key role of surveying technological developments internally in their Labs to better understand technological developments with the potential for commercialization. Labs should take measures to broadly market their available inventions for technology commercialization partnerships (e.g., by creating online databases of available inventions and bundles of inventions) with the goal of increasing competition to partner with the Labs to develop the technology. When multiple potential partners are interested in developing a single technology (for the same purpose), Labs should auction the right to license an invention to attract the highest desired commercialization goals.	Average length of time a licensed patent is available for licensing before a commercialization agreement is signed. Degree of competition to license individual patents (e.g., number of interested licensing partners). Feedback from users on the ease of finding relevant inventions available for developing commercialization partnerships.
3.3.2 The Challenge of Aligning Expertise in a Bureaucracy In the context of the Labs, the required skill sets for building commercialization partnerships are separated in the Lab-DOE bureaucracy and it is challenging to bring these resources to bear in a concerted manner. For example, DOE headquarters has little information about which technologies the Labs have available for commercialization but has some of the strongest information on market potential.	Developing a successful technology commercialization partnership requires many types of expertise, ranging from deep technical knowledge of the invention in question, to an understanding of a technology's potential application areas and market demand, to IPR law.	**Recommendation 2**: Balance and synchronize centralized technology transfer efforts with Lab-based efforts A stronger role should be given to Lab managers and technology transfer officers in their capacities as boundary-spanning actors between the technologists and DOE management, such as through the DOE Office of Technology Transitions. DOE should also facilitate communication across Labs, particularly in areas where multiple Labs are working in the same technical fields where overlapping inventions could be usefully bundled in a single commercialization partnership. The Labs should also experiment with creating new boundary-spanning organizations ("microlabs") and entrepreneur in residence programs that can help facilitate access to Lab inventions and building connections with the private sector.	Bureaucratic performance metrics, including employee satisfaction with communication and operational efficiency. Availability of invention/patent pools to develop commercialization partnerships around groups of Lab inventions. The development of new experimental approaches to increase outside access to Lab inventions. Overall knowledge of Lab technical expertise and inventions by potential commercialization partners in key domains, such as large industrial firms and venture capitalists.
3.3.3 The Challenge of Transferring Tacit Knowledge Patents alone may be unable to demonstrate the full value of a technology without additional tacit knowledge transfer. The value of a Lab patent to a private firm interested in licensing it may be lower without access to additional Lab expertise from the inventing scientists who possess relevant tacit knowledge.	Formal codification of a technology cannot capture all dimensions of an invention. All technologies require some degree of complementary "tacit knowledge" which cannot be codified but that is essential to use the codified part. For example, tacit knowledge may emerge from an inventor's hands-on experience with using the technology.	**Recommendation 3**: Incentivize Lab researchers to work with commercial partners in transferring tacit knowledge Lab scientists should be made available to actors who license Lab inventions those scientists helped develop. This could be through informal exchanges, formal personnel exchanges, and even spin-outs. Lab scientists should be required (or otherwise incentivized) to dedicate time towards transferring tacit knowledge to commercial partners, potentially paid for by the partnering actor.	Accessibility of Lab scientists to commercialization partners (e.g., through time logs). Number of personnel exchanges. Number of spin-outs per invention disclosed.

Challenge Posed for the National Labs	Theoretical Insight	Proposed and Existing Policy Reform	Metrics for Evaluation
3.3.4 The Challenge of Facilitating Incremental Product Innovation The Labs are not in the business of product development and rarely contribute to late-stage technology learning, but in some cases, this learning is critical to creating public value from Lab inventions.	Intellectual property is often filed before a technology is fully mature. Often, additional learning about the technology's function and value occurs as the invention is developed and used in practice. This learning process happens later in product development and inventions that are never developed may never realize their full potential for social value. As a corollary, the value of a newly filed patent is highly uncertain and not a clearly observable value.	**Recommendation 4**: Better understand and use creative contracting mechanism to promote follow-on innovation Labs should improve their tracking of Lab inventions and the spillover inventions they inspire. Overall metrics of technology transfer activity should be improved and used to better understand how incremental product innovation can be spurred by Lab activity. Labs should be allowed to utilize more flexible policies with built in "option" clauses to transfer inventions in light of the uncertain value of those inventions. Labs could be given the option of providing a limited license for a fixed length of time with a built in clause to allow the licensor to renew the license at an alternative royalty rate at a certain date. An alternative approach would be a scheme of offering many low-cost short-term non-exclusive licenses followed by an auction to the highest bidder for a single exclusive license	Number of licensing agreements signed per R&D dollar invested, per invention disclosed, and per patent filed Experimentation with alternative licensing arrangements that build in flexibility in the license terms. Private sector interest in partnering with Labs to develop technologies under flexible licensing terms or CRADA terms.
3.3.5 The Challenge of Formally Codifying and Protecting Inventions Codifying an invention in a legally binding manner requires formally disclosing all relevant aspects of an invention. This requires activity beyond the Labs' typical R&D work and may require restricting full public access to undisclosed aspects of Lab inventions. In private sector technology transfer agreements, profit-maximizing firms who license technologies are incentivized to litigate patents that are infringed or license agreements that do not follow terms. National Labs are not profit maximizing and may not have the resources or mission to enforce their intellectual property and licenses.	Technology transfer requires formalized contracts that transfer the right to use an invention form one party to another. To make a contract enforceable, all relevant aspects of an invention must be defined and formally codified. In a technology transfer agreement, the party receiving a technology receives the full value of the agreement upfront after gaining access to knowledge it did not previously have. Enforcement of intellectual property is required to avoid exploitative use of licensed inventions.	**Recommendation 5**: Invest in IP expertise and distribute appropriately within the organization Labs can file for intellectual property (under the 1980 Stevenson-Wydler Act and subsequent reforms). This allows Labs to file for patents and other forms of intellectual property and then license these patents to other actors. Lab capabilities in filing and managing IP should be supported with adequate resources. National Labs must develop alternative norms for enforcing their intellectual property (both patent infringement and license agreements). This would improve the integrity of their agreements and give future licensing partners confidence that they are playing under fair rules.	Number of patents and copyrights filed per R&D dollar invested and per invention disclosed Number of idle patents and copyrights with no interested commercial partners Patent infringement lawsuits per patent (compared to private entities and universities working in similar technological fields). Spending on patent attorneys per patent filed.

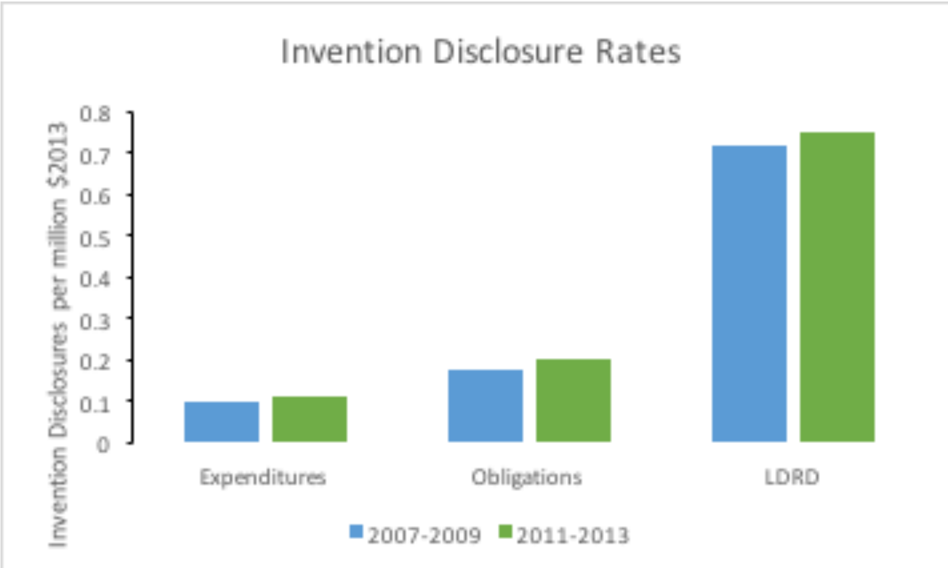
5. Concluding Thoughts

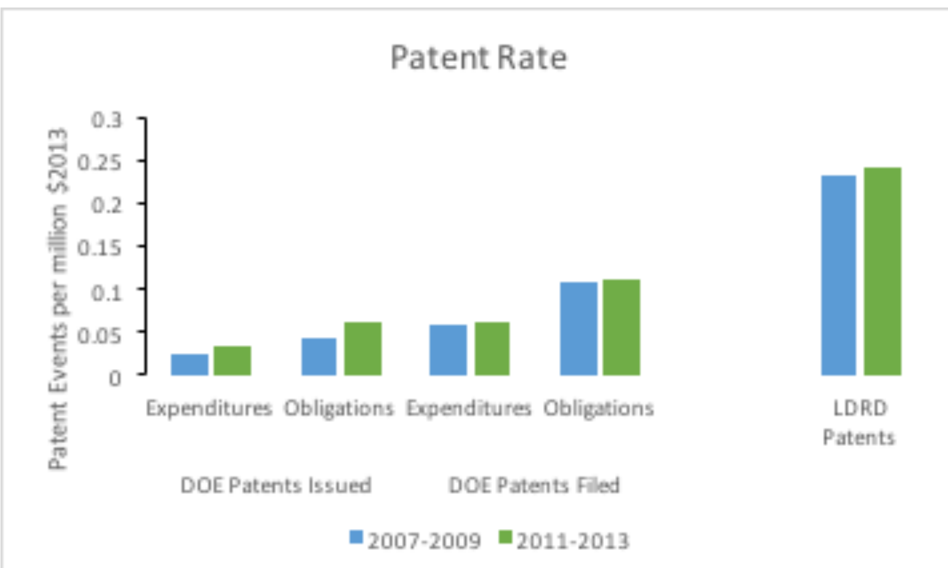
The National Labs have historically played an important role in the National Innovation System, and more specifically, in recent efforts to advance energy innovation. The scale of the Labs' budget offers it the opportunity to significantly impact the development of energy technology. At the same time, the Labs' budget represents a significant portion of the total U.S. investment in non-military R&D and draws significant federal scrutiny over its budget and activities. This tendency has been exacerbated by political realities and perceived high-profile failures of DOE activities, whether security lapses at the Labs or subsidies to companies that ultimately failed. This report has demonstrated that these realities are often in tension with each other. While oversight can improve decision-making, there is a point at which the returns to increased oversight begin to diminish, and we have laid out the case that the current system is beyond that point.

Our recommendations center on a thesis that the key to Lab management lies in the proper internal management of scientific R&D and strengthening appropriate external ties between the Labs and the private sector. Some of the recommendations can be carried out by DOE, whereas others will require the enactment of legislation. It is our hope that our contribution will foster further conversation at DOE, the Labs, and within Congress. While many individuals we have spoken with have downplayed the possibility that inertia on Lab management policy can be overcome, we see a critical mass of conversation at DOE and Congress acknowledging serious issues and the need for timely solutions.

Appendix A

A.1 LDRD and DOE R&D technology transfer outcomes





Documentation for Funding Sources

LDRD funding for each year is reported directly by DOE to Congress (Available at: (http://www.energy.gov/cfo/reports/laboratory-directed-research-and-development-annual-reports).

R&D spending at DOE's FFRDCs (a category which includes all National Labs but NETL) is reported in two different ways by the NSF.

i) "Obligations" refers to DOE-reported R&D obligations at its FFRDCs and is accessed through the National Center for Science and Engineering Statistics (http://www.nsf.gov/statistics/).

ii) "Expenditures" refers to FFRDC-reported R&D expenditures funded from all sources. This is obtained from the NSF's survey of FFRDCs (http://www.nsf.gov/statistics/srvyffrdc/).

There is a large discrepancy between the two—"Expenditures" are nearly double "Obligations" in any given year. This largely due to 1) inconsistencies in defining what consists of R&D and 2) non-DOE funding that shows up in "Expenditures" but not "Obligations".

Both definitions offer insight. Analyzing the broader funding base captured by "Expenditures" is appropriate because tech transfer outcomes emerge from the entirety of R&D expenditures. The metric of DOE "Obligations" is also appropriate because it reflects the ability of DOE to leverage its internal investments into tech transfer outcomes, including from external investments.

For both categories, we subtract LDRD funding to arrive at "DOE-directed" funds, even though it is not clear that these funds overlap, so this would be a conservatively low estimate of "DOE-directed" funds.

Top Figure: Invention Disclosures per million ($2013)

Calculating this figure starts with the total inventions reported by DOE at federally operated Labs and FFRDCs (available here: http://www.nist.gov/tpo/publications/federal-laboratory-techtransfer-reports.cfm). We then subtracted out the inventions reported as earned through LDRD funding (from DOE reports to Congress, available here: https://energy.gov/cfo/listings/laboratory-directed-research-and-development-annual-reports).

To calculate DOE inventions per million 2013$, the total number of inventions for the specified years was divided, separately, by both Expenditures and Obligations. Both of these metrics slightly overestimate DOE's effectiveness, as they count inventions from NETL and other DOE-operated facilities in the numerator, but do not count the R&D obligated/spent at these facilities as part of the denominator.

Bottom Figure: Patents per million ($2013)

"Patents filed" and "patents issued" for the entire DOE organization are reported in the Department of Commerce Technology Transfer reports (http://www.nist.gov/tpo/publications/federal-laboratory-techtransfer-reports.cfm). Patents resulting from LDRD-funded projects are reported by DOE to Congress as "patents issued/filed" without clarifying whether clarifying whether this represents patents filed or patents issued. Based on our study of individual Lab LDRD reports, we extrapolate that the number largely reflects the lower "patents issued" category (as only a subset of patent filings result into an issued patent).

We make the comparison of patents per million dollars spent (indexed to 2013 dollars) using both the denominator of Expenditures and Obligations at FFRDCs. To be able to make the comparison between DOE-funded projects and LDRD projects we performed the following analysis:

To calculate the rate of "DOE Patents Filed", we determined the total amount of DOE patents filed in each period, and subtracted out patents attributed to LDRD funding during the same period. We believe this represents of overestimate of the patent filing rate because the set of LDRD "patents filed/issued" is smaller than the number of LDRD patents issued. We then repeat the analysis for "Patents Issued" by subtracting the LDRD patents from the DOE issued patents over each period. We believe this is a justifiable approximation because the LDRD patents largely reflects issued patents.

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