American Energy Innovation Council

Unleashing Private-Sector Energy R&D

INSIGHTS FROM INTERVIEWS WITH 17 R&D LEADERS

AEIC Staff Report // January 2013

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PRELUDE

AEIC STAFF REPORT // JANUARY 2013

American business relies on innovation as a core driver of success. So, how do our most successful businesses manage innovation, and what is the role of national policy in enhancing private sector R&D?

For this study, we interviewed top R&D executives at some of the largest and most innovative companies in America. Their insights shed light on how to integrate research and development into a successful business model. They also reveal how government and business can work together to accelerate innovation and solve America's energy challenges.

ABOUT US

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American Energy Innovation Council members include: **Norm Augustine**, former chairman and chief executive officer of Lockheed Martin; **Ursula Burns**, chief executive officer of Xerox; **John Doerr**, partner at Kleiner Perkins Caufield & Byers; **Bill Gates**, chairman and former chief executive officer of Microsoft; **Chad Holliday**, chairman of Bank of America and former chairman and chief executive officer of DuPont; **Jeff Immelt**, chairman and chief executive officer of GE; and **Tim Solso**, chairman and chief executive officer of Cummins Inc. The Council is advised by a technical review panel consisting of preeminent energy and innovation experts and is staffed jointly by the Bipartisan Policy Center and Energy Innovation: Policy and Technology LLC. For more information, please visit www.americanenergyinnovation.org.

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Disclaimer

Any views expressed by the interviewees are personal and do not necessarily reflect the views of the interviewees' employers, former employers, or AEIC.

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EXECUTIVE SUMMARY

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Private companies have led technological revolutions that transformed industries such as computers and medicine, but the energy industry remains stuck in the past: our transportation system is 93% dependent on petroleum, and only 3.4% of our electricity is generated by solar, wind, and geothermal sources. America will be far wealthier, more secure, and more competitive with a rich array of sustainable, domestic energy options. U.S. energy companies can be leaders in the development of our future energy technologies, but they must make R&D a central part of their business models, and the government must create a public policy environment that is favorable to long-term, high-risk investments in R&D by private firms.

To learn how these goals can be achieved, we interviewed R&D leaders at 16 large, innovative companies on three topics: how they structure and manage their R&D activities, what government policies are helpful to their R&D efforts, and what are the most serious obstacles they face to greater R&D success.

HOW R&D IS FUNDED AND MANAGED IN PRIVATE COMPANIES

Structure of the Research Group

Most interviewees' companies have a central research group, though all perform product development activities outside of this group (often in business units). Centralized R&D structures tend to promote the sharing of technology across different arms of the company. They also encourage risk-taking and long-term thinking, increasing the likelihood of achieving a fundamental breakthrough. On the downside, there can be a disconnect between centralized research and the company's business needs. A distributed research structure promotes development that is more aligned with business needs and has a shorter time to market. This increases its short-term economic impact but risks lessening long-term success by failing to produce major breakthroughs.

Global Location of R&D

Almost every interviewee's company performs significant R&D overseas, and overseas R&D is generally increasing in importance relative to R&D in the United States. The most common reason for overseas R&D is to work with local clients, understand local markets, and design products for those markets. Many of these countries have large economies with low national R&D intensities, implying that some movement of R&D overseas is not driven by specific policies, but is a matter of R&D in those countries "catching up" to what is merited by the countries' market sizes. Another important driver of R&D movement overseas is a desire to co-locate research with manufacturing facilities. Reversing the decades-long decline in the importance of manufacturing to the U.S. economy would have the co-benefit of promoting more domestic R&D. Inexpensive natural gas, which is used as a feedstock in industrial processes, is starting to drive some manufacturing investments in the U.S. Lastly, companies move R&D overseas to gain better access to talent, an issue discussed in "Obstacles to Greater R&D Success" below.

Gating Mechanisms and Terminating Research Projects

Research is an inherently risky enterprise, and some failed projects are inevitable. Companies typically maintain a portfolio of different projects and routinely terminate failing ones so that funding may be directed to more promising options. The most common reasons for terminating projects are a lack of commercial potential for the innovation and technical issues with the product or the science. An objective "gating mechanism," which requires projects to meet specific milestones, can prevent projects from dragging on for years, consuming staff time and money, without clear progress toward a commercializable outcome.

Research Partnerships

All of our interviewees' companies engage in research partnerships. Some provide unrestricted research grants to universities in order to form relationships with faculty, gain access to graduate students in their fields, and help these students develop their skill sets. Many also sponsor specific projects at universities with a potential product use in mind. In these cases, they desire to own or easily license the IP resulting from the partnership. Although corporate funding for academic R&D increased in the last decade, it declined in importance relative to other sources of funding and now represents just 7% of universities' R&D budgets. Many corporations also partner with national labs, often using a cooperative research and development agreement, or CRADA. Partnering with national labs is considered to be quite expensive, but worth the money, due to the labs' highly specialized facilities and expert staffs. CRADAs are generally well-regarded by participants and are effective at stimulating private research and patents, as they demand commitment and buy-in from both research partners.

POLICIES THAT EFFECTIVELY PROMOTE R&D WORLDWIDE

Grants and Contract Research

By a large margin, direct funding of research through grants and government contracts is regarded as the most helpful policy to promote private R&D. 32% of federally-funded R&D is carried out by businesses. Grants and contracts often require a private company to contribute matching funds to a research project. This can be effective at eliciting much greater levels of private R&D investment than would have occurred without the matching government funds. However, the funds offered by the government must be comparable to the company's own investment in order to affect the company's research agenda.

Regulations to Provide R&D Targets and Justification to Management

Regulations (such as fuel efficiency, safety, or emissions standards) can provide direction to a company's research efforts by giving clear, technical targets to a research team. Regulations also sometimes helped R&D leaders make a business case to corporate management for robust support of research. Regulations need not be a net cost to a firm; a company with a better research organization may find ways to achieve compliance at lower product cost than competitors, enabling them to gain market share once a regulation takes effect. However, in order to support innovation, regulations must give companies the flexibility to choose their methods of compliance and avoid prescribing the use of particular technologies or strategies.

Foreign Economic Support

Foreign governments sometimes provide considerable support for companies' R&D efforts, including generous R&D tax credits, free or subsidized land and buildings, a good education system, and funding local university or graduate students' internships with the company. These supports are most helpful if offered together, as a package. No single factor, like a generous R&D tax credit, is by itself sufficient. For instance, India has the world's most generous R&D tax credit but a low national R&D intensity, while Germany has no R&D tax incentives but manages to be an innovation leader thanks to a variety of other support mechanisms.

OBSTACLES TO GREATER R&D SUCCESS

Lack of Access to Talent

The most commonly-cited obstacle to greater R&D success is a lack of access to talent in the United States. This problem has education- and immigration-related aspects. In international tests, students in U.S. primary and secondary schools score below the OECD average in math and about average in science. The discrepancy can be largely explained by the high U.S. poverty rate, since U.S. schools in low-poverty areas outperform schools in foreign countries with comparable poverty rates. The United States possesses 27-38% of the top 200 universities, but only 9% of the top 100 universities less than 50 years old, revealing a trend toward the increasing quality of foreign scholarship. Additionally, the percentages of U.S. university graduates with degrees in science, technology, engineering, and mathematics (STEM) as well as education have waned since the early 1980s. With respect to immigration, the U.S. has strict quotas on both Permanent Resident Cards (green cards) and work visas, and there is a backlog of green card applications that is many years in length for most workers. Employers must go through a difficult, bureaucratic, and time-consuming process to sponsor workers for visas and green cards, which sometimes drives them to open R&D labs in other nations. Groups across the political spectrum have called for streamlining visa and green card procedures, addressing the application backlog, increasing quotas, and giving green cards to graduates of U.S. universities in STEM fields.

Inconsistent or Insufficient Tax Credits

Interviewees also highlighted the inconsistency of the R&D tax credit and the Production Tax Credit (PTC), as well as the low value of the R&D credit, as a significant barrier to greater R&D success. Each of these tax credits has been allowed to expire repeatedly and been extended, often retroactively, for no more than a year or two at a time. In the wind industry, the irregularity of the PTC has led to a boom-and-bust cycle of sales, with installations down 76-90% during the expirations of the PTC in 2000, 2002, and 2004 relative to the preceding years. Research is a long-term investment, so the irregularity and brief extensions of the R&D tax make it difficult for companies to consider the tax credit when making R&D funding decisions. Thus, the tax credit incentivizes less private-sector R&D than would a long-term credit of equal magnitude. Additionally, the value of the R&D tax credit is on the low side, such that the U.S. ranks 27th out of 42 major countries in terms of R&D tax credit generosity.

Difficulty Licensing IP from Universities

In recent years, schools have been increasingly interested in retaining ownership of IP in hopes of earning royalties through technology licensing, while companies feel they should receive a royalty-free license to any IP they helped to create through funded projects. Disagreements in IP negotiations with universities often prevent companies from partnering with particular schools. Some schools, such as the University of Minnesota and Penn State, are beginning to offer new IP licensing procedures designed to emphasize effective partnerships over the possibility of royalties.

CONCLUSION

Our interviews provide insights for energy-sector businesses, and for any innovation-driven business, on how successful companies structure and manage their R&D. There are also lessons for government concerning which policies are most effective at promoting R&D. Perhaps most importantly, we have found that the current public policy environment poses challenges that businesses cannot solve on their own, and these problems are hindering U.S. technological innovation. This must change. If government and business can work together to foster a climate that promotes innovation, then private-sector R&D can help set us on a path to an affordable, secure, and clean energy future.

INTRODUCTION

AEIC STAFF REPORT // JANUARY 2013

In the last several decades, technological revolutions led by the United States have transformed almost every aspect of our society. Internet-enabled computers and mobile devices boost business productivity and connect us to people across the globe. In medicine, implanted therapeutic devices, robotic surgery, brain-controlled prostheses, and targeted cancer drugs help us to live longer and healthier lives.

However, the commercialization and deployment of clean energy technologies is lagging. It has been a policy goal of the U.S. to free itself from dependence on foreign energy sources since the oil embargo in the 1970s, and scientists have warned us about the threat of climate change for over two decades. America will be far wealthier, more secure, and more competitive with a rich array of sustainable, domestic energy options—and we've had years in which to make progress toward this goal. Yet, today our transportation system is 93% percent dependent on petroleum,[1] 45% of which is imported,[2] and only 3.4% of our electricity is generated by solar, wind, and geothermal sources.[3]

Why the discrepancy? Why hasn't clean energy undergone the same widespread deployment and commercialization that we have seen in other sectors, such as computers and medicine?

One key explanation is found in the nature of R&D investments in each industry. The energy system is driven principally by the private sector. However, the critical national security and environmental benefits offered by energy technology innovation are not always reflected in the market price of energy, which is the primary basis for private sector decision-making. As the AEIC's 2011 report *Catalyzing Ingenuity* points out, investment in energy R&D—from both the private and public sectors—is currently insufficient to meet our national security, economic, and environmental goals. While the private sector has been, and continues to be, a powerful engine of innovation, public policy has the power to either enhance or diminish private sector innovation.

To understand how private sector companies make their R&D decisions, and which government policies help or hinder them, we interviewed 17 R&D

leaders from large, successful companies across many sectors of the economy. We had two central goals: first, we wished to understand the way successful companies in many sectors structure and fund their R&D departments, choose their research projects, and develop those projects into marketable products. We hope that some of these approaches and techniques may provide lessons on how to build a more successful innovation model in energy-sector businesses.

Second, we asked the R&D leaders about the largest obstacles their companies face to greater R&D success. Private companies' decisions regarding how much and what types of research to pursue are strongly influenced by the public policy environment. A stable set of policies that create a favorable environment for R&D investment make a tremendous difference in private companies' ability to conduct research and justify those investments to their shareholders. By identifying the most important obstacles to R&D, we hoped to understand what the government could do to remove those obstacles and unleash private-sector companies to pursue the innovation we need. These findings may help not just firms in the energy sector, but in any innovation-driven sector.

In AEIC's previous reports, *The Business Plan* (2010) and *Catalyzing Ingenuity* (2011), the AEIC principals made the case for robust public investment in energy R&D, and they made a variety of recommendations about how the government could most intelligently structure its programs and thereby spur energy innovation. This staff report complements that previous work by focusing specifically on the needs of the private sector, a force which will be central to our energy future, but only if government and the private sector can work together.

This report, then, reflects the interviewees' views of what is needed to achieve greater R&D success; while we provide historical and policy context for the issues they raise, we have made no attempt offer our own policy recommendations. The R&D leaders' compelling, first-hand accounts speak for themselves. Naturally, AEIC will consider the data in this report when revising and expanding AEIC's own set of policy recommendations in the future.

We greatly appreciate the time and insights of our 17 interviewees, and we believe their ideas can help guide us to a more prosperous and sustainable future.

METHODOLOGY

The data in this paper come from interviews with R&D leaders at sixteen companies. Since interview data are strongly dependent on how interviewees are selected and what questions are asked, we feel it is important to include an explanation of our methodology to provide a framework for interpreting our results.

SELECTION OF COMPANIES

As discussed in the *Introduction*, the goal of this report is to understand how research is done in successful, technologically innovative companies in many sectors, not just the energy sector. Accordingly, we generated a list of companies based on several criteria. We wanted a diversity of industry perspectives, so the list intentionally avoided over-representing any single industry. Since we wished to learn how companies make innovation a regular part of their operations, we focused on "innovation-driven" companies—namely, those whose business models rely significantly on technological R&D.[4] Although start-ups are often highly innovative, their business models may be too flexible and short-term to be easily applied in the energy industry (which is dominated by large, conservative companies that make long-term infrastructure investments), so we chose to focus on larger and more well-established companies in our study. Lastly, if we had a contact at a company that met the criteria above, we were more likely to include that company on our list. This was a practical consideration, since having a helpful contact increases one's ability to secure an interview.

WRITING INTERVIEW QUESTIONS

We devised a set of interview questions covering a range of topics regarding R&D in an interviewee's company (or industry). These topics included: how research is structured and funded, the locations where research is conducted, the nature of obstacles to greater research success, the forms of government support that interviewees felt were or would be valuable, and whether the interviewees' companies engaged in research partnerships. A complete list of the interview questions appears as the *Appendix* in this report.

CONTACTING INTERVIEWEES

We contacted individuals from 29 companies to request an interview with an R&D leader (a CTO, chief scientist, VP of Research, or similar individual who would be able to answer our questions). When we were able to obtain the contact information for a suitable interviewee, we contacted him/her directly. When we did not have this information available, we contacted another individual at that company (usually an executive or media contact) and asked if he/she could put us in touch with a suitable interviewee. While we mostly contacted current employees, we also contacted recently retired R&D leaders in some cases.

Ultimately, R&D leaders from 16 companies interviewed with us, a 55% response rate. The individuals, their positions, and their current or former employers are listed in the Acknowledgements section. We had 17 interviews in total because two individuals from one company (Ford Motor Co) each agreed to an interview.[5]

INTERVIEW PROTOCOL

All interviewees were provided with the list of questions before the interview. Interviews were conducted by telephone and were roughly one hour in length. We did not stick strictly to the written interview questions; we also asked follow-up and clarifying questions based on the particular responses of each interviewee and the unique features of each company.

We obtained permission from the interviewees to record the interviews, and notes were taken based on the recordings. This helped to ensure accuracy and completeness. As a separate check, all interviewees were given an opportunity to review a pre-publication draft of this report, and we agreed to correct or remove any information from an R&D leader's own interview that he/she indicated is inaccurate or should not be made public.

REPORTING OF DATA

Where possible, responses to our interview questions were tabulated. The frequency of different answers, such as the most commonly cited obstacles to greater research success, helped us to determine which topics to emphasize in this report. Tabulated results are presented anonymously. In addition to the tabulated results, interviewees often provided us with stories, anecdotes, and detailed reasoning for their views. Throughout the report, attributed (i.e. non-anonymous) stories, anecdotes, and reasoning are included to help illustrate key findings.

Finally, we include a *Staff Comments* section for each topic. These sections provide a historical and policy context for interviewees' responses, helping readers fit the interviewees' views into a "bigger picture." Staff comments intentionally focus on the most popular responses from interviewees, as this is a reasonably objective way to select what to cover from the large universe of possible analyses that could be done for each topic.

How R&D is Funded and Managed in Today's Private Companies

STRUCTURE OF THE RESEARCH GROUP

One topic we investigated was the nature of the research group (or groups) and how they fit into the overall corporate structure at the R&D leaders' companies. Although the terminology varied from business to business, most of the interviewees' companies possessed a centralized corporate organization and individual business units (sometimes called "departments," "divisions," etc.) focused on various product lines. Some companies' research teams formed an independent organization under the central corporate umbrella, while others divided up their research among the different business units or many small labs, each emphasizing different topical areas. Table 1 shows the breakdown of how companies organized their research departments.

TABLE 1: **R&D STRUCTURE**

ANSWER	# OF COMPANIES
Centralized corporate or independent group (may also do R&D in business units or ancillary labs)	11
Research only done in business units	2
Research distributed among many small labs	2
Research done via external organizations	1

Note that some interviewees broke apart "R&D," indicating that research activities were done in a centralized or independent organization, while development activities were done in business units. Even companies that possessed centralized research groups performed development activities (and often some research) outside of the centralized research group. We found that 11 of the 16 companies had a centralized or independent organization responsible for at least some of the company's research, while five companies had no centralized or independent research organization.

An example of a highly independent research organization is that possessed by Microsoft. Microsoft Research (MSR) is an independent division with roughly 1,200 scientists and engineers. It is not under the purview of any of the business units, and it is funded through central corporate revenues (rather than getting funds from Microsoft's business units to support particular projects). MSR performs a great deal of basic research in computing (often with no specific end product in mind), and they publish and patent much of their work. MSR presents the business units with unified "solutions" to their problems, sometimes combining technology from several different research projects developed over many years. As an example, Craig Mundie, our interviewee from Microsoft, described how MSR was able to bring together "seven research activities from four labs on three continents" to create the Kinect sensor for XBOX, a machine vision and hearing system for controller-less gaming. Almost all of these seven projects had been in progress for over a decade, and at the time those research projects were started, none of them could have anticipated their eventual, combined use in a product like the Kinect.

Southern California Edison (SCE) is an example of the opposite model: research is highly dispersed and divided by topic area. For instance, SCE has separate research groups that handle projects in energy efficiency, battery storage, electric vehicles, electricity distribution, smart meters, etc. SCE runs different laboratories that support different project areas, and most projects are highly applied (not basic) research. For instance, SCE often works with vendors or product manufacturers to test products which are market-ready, or nearly so, to verify their real-world performance characteristics and determine their impacts on SCE's system. SCE also conducts sociological or marketing research. Paul Delaney, our interviewee from SCE, indicated that a "big hurdle" preventing adoption of energy efficiency technologies is selling them to the customer. SCE is "taking a good, hard look" at using social video games to provide extra motivation to save energy. Customers could use their smart meters to verify that they've saved energy, earning them virtual currency to be used in-game.

While businesses' R&D structures fell across a wide range, the plurality of businesses structured their R&D in the following way: most research is done in a corporate or independent group, while most or all product development is done in the business units. Research groups focus primarily on applied research, typically aimed at known needs of the business units and their product lines. However, a small but non-zero percentage of research funds are reserved for basic or "blue sky" research.

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STAFF COMMENTS

Gary Pisano, a professor of business administration at Harvard Business School, points out that R&D structure varies from company to company because "there is no one best model for R&D that is universally superior. There is no 'magic bullet.' R&D performance results from the interaction of many different decisions and choices."[6] Andreas Larsson, head of the Innovation Engineering group and professor at Lund University, notes that the choice of how to structure and manage corporate research "should be seen as a strategic competitive weapon, joining … R&D output with the desired future business strategy."[7] Though R&D structures can take many forms, they can be broadly categorized as centralized, decentralized, or a hybrid of both models.

A centralized R&D structure has several benefits. It "promotes sharing of technology across the whole corporation and capitalizes on economies of scale in R&D."[8] Thomas Tirpak, a professor at Northwestern University who worked for 14 years in Motorola's corporate R&D group, asserts that a centralized structure also "encourages risk-taking and long-term thinking," thereby "increasing the likelihood of fundamental technology advances."[9] It also signals that the company values research, helping to attract top talent. The main downsides are the lack of facilities near to "technology-rich regions" throughout the world, the risk of a "disconnect between R&D and the company's needs," slow product development, and difficulty accounting for the benefits of research in economic terms.[10]

Larsson believes that decentralized R&D "enables a business-oriented approach, which responds quickly to market requirements" and focuses more on development than on fundamental research.[11] This structure is well-suited to companies that wish to focus on incremental improvements to existing product lines, since it promotes development that is aligned with business needs and has a shorter time to market.[12] The biggest risk is that a focus on short-term goals may lessen long-term success by failing to produce major breakthroughs. A study by Josh Lerner and Julie Wulf, professors at Harvard and Wharton Business Schools, found that companies with "centralized R&D organizations generate innovations that have a higher level of impact and affect a broader range of technological areas than do firms with decentralized R&D organizations."[13]

A hybrid R&D structure shares some features of each approach, typically including both a centralized R&D group and smaller R&D divisions within the business units. This model enables incremental innovation to be handled in the business units, while long-term projects and breakthroughs are achieved via central R&D. This approach is most commonly used by large companies, which have enough revenue and personnel to support two R&D structures.[14]

Throughout the early- and mid-20th century, companies tended to favor the centralized approach to R&D. In the 1980s, in response to increasing market globalization and increasing pressure for quarterly financial results, many companies began to decentralize their research facilities. In the last decade, "the pendulum" began to swing back toward centralized R&D, as businesses sought fundamental new ideas and products to sustain their growth.[15]

R&D structure varies from company to company because "there is no one best model for R&D that is universally superior."

GLOBAL LOCATION OF R&D

In our interviews, we asked the R&D leaders where their companies conduct research and development activities, with a focus on how much R&D is done in the United States and how much overseas. We also wished to learn whether the percentage of total R&D done outside of the U.S. is increasing or decreasing, and we asked about the factors which influence the companies' decisions to locate R&D in the United States or in other countries. These data can help us understand whether the U.S. is falling short relative to other countries in supporting private investment in R&D and provide insight into what policies or conditions would be needed to foster R&D growth.

In fact, 14 out of the 16 interviewed companies conduct research overseas. While some interviewees did not mention a trend in either direction, those that did identify a trend uniformly indicated that overseas R&D has been growing in importance relative to U.S.-based R&D. However, for most companies, the amount of R&D done inside the United States still exceeds the amount done overseas. Table 2 shows the reasons for companies' R&D location decisions. (Some interviewees provided more than one reason.)

When asked for the reason for R&D location, only one respondent provided a reason for domestic R&D (a desire to keep money within its own service area). The other respondents all provided to reasons to locate R&D overseas.

We found that the overwhelming driver of overseas research is the desire to provide products or services for overseas customers. Several interviewees described the difficulty of understanding market conditions and needs in far-off countries when working exclusively from a laboratory in the United States. By employing local engineers and scientists, they can more effectively create products that will be successful in markets that are very different from the United States, particularly in developing countries like India, China, and Brazil. Katharine Frase of IBM provided an example: IBM researchers in India are working on ways to make a voice-based equivalent of the internet that works on "dumb" (non-data enabled) phones, to serve India's large population of illiterate people who only have access to ordinary cell phones. Tom Kavassalis of Xerox mentioned that overseas labs can also enable "reverse innovation," or the adaptation of ideas from developing countries for use in developed countries. He told us that GE developed inexpensive MRI machines for the Chinese market, and later started selling them to small, rural clinics in the United States.

TABLE 2: REASON FOR GLOBAL LOCATION OF R&D

ANSWER	# OF INTERVIEWEES
To work with overseas clients or design products for overseas markets	8
To co-locate with own manufacturing facilities or other operations	4
To have better access to talent	4
To take advantage of foreign government support for R&D	2
To avoid U.S.-specific regulatory hurdles	1
A desire to keep money inside own service area	1

There were two other important reasons for locating R&D overseas. The first was the desire to co-locate research facilities with the rest of the company's operations (particularly manufacturing plants), in order to improve efficiency. William Banholzer of Dow Chemical emphasized the value of co-locating one's facilities: "It's ideal when you have an R&D lab sitting next to a pilot lab sitting next to a plant." For some companies, manufacturing plants may have already been moved overseas for reasons completely unrelated to R&D, and now R&D facilities are simply following them abroad.

The last important reason companies chose to open or expand R&D labs overseas was to gain better access to talent. Many interviewees criticized the United States' restrictive visa procedures for skilled, foreign workers (even those educated at U.S. universities), and some also criticized the U.S. public education system for failing to produce a sufficient number of skilled science, technology, engineering, and mathematics (STEM) graduates. Note that "lack of access to talent" was the most commonly cited obstacle to greater R&D success, so this issue is discussed in the *Obstacles to Greater R&D Success* section of this report and will not be discussed here.

STAFF COMMENTS

Our interviewees' companies were not unusual in conducting significant overseas R&D. A recent survey of 1,050 North American companies by Ernst and Young found that 11% currently conduct at least a quarter of their R&D overseas, and they expect that 23% of companies will conduct a fourth of their research overseas by 2015.[16] These comments examine two of the major reasons for this trend reported by our interviewees: access to overseas markets and co-location with manufacturing facilities.

Overseas Markets: While the United States is still the world's largest economy, the importance of the U.S. market relative to overseas markets has greatly declined over the past fifty years. According to inflation-adjusted data from the World Bank, the United States' GDP represented 39% of worldwide GDP in 1960. By 2011, that fraction had declined to 22%. A large portion of world growth in GDP has come from the East Asia & Pacific region, which expanded from 12% of world GDP in 1960 to 27% in 2011.[17]

Most of our interviewees' companies sell products all over the world. As overseas markets grow in importance, it is natural that companies will devote an increasing fraction of their resources to designing products for these markets, as a larger market offers the potential for a greater return on the same R&D investment. So long as performing R&D in-country offers advantages when designing products for the local market (for instance, by providing greater access to local people who understand the culture and needs of a country's residents), this will tend to direct an increasing fraction of R&D growth offshore, particularly to countries with rapidly developing economies.

However, it is important to note that R&D spending is not a zero-sum game. Irrespective of whether other countries grow or shrink in economic importance, the United States can enact policies that boost its own economy and the absolute level of in-country R&D. For this reason, a metric such as R&D intensity (total in-country R&D spending divided by national GDP) may provide a better sense of whether a country affords a favorable economic and policy environment for research and development.

According to data from the National Science Foundation, the United States has an R&D intensity of 2.9%, ranking ninth among the economies tracked by the OECD and UNESCO. Table 3 lists the top 20 countries in national R&D intensity in 2008-2009. Although the U.S. does not lead the world in this

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STAFF COMMENTS (continued)

metric, it is well ahead of the large, developing economies which have accounted for an increasing fraction of the world's GDP over the past fifty years, such as China (1.7%), India (0.8%), and Brazil (1.1%).[18] Thus, even if U.S. companies are primarily opening new R&D labs in large developing countries, this would not, in and of itself, imply that the U.S. has important lessons to learn from those countries' R&D policies. They may simply be "catching up" to the level of R&D merited by their economic size. A favorable policy environment, with potential lessons for the U.S., is more likely to be found in countries with particularly high R&D intensities, such as Israel (4.3%), Finland (4.0%), and Sweden (3.6%).[19]

Co-Locating with Manufacturing Facilities: A number of our interviewees indicated that locating research near their other facilities (usually manufacturing plants) factored into R&D location choices, so the amount of manufacturing in the United States has an indirect impact on U.S. R&D. The United States has a long history as a manufacturing center, having surpassed the UK to become the world's largest manufacturer in 1895, a title it held until the U.S. was surpassed by China in 2010.[21] This is only the latest development in a decades-long decline in the importance of manufacturing to the U.S. economy. In 1960, manufacturing accounted for just over 25% of the United States' GDP. By 2011, it had shrunk to

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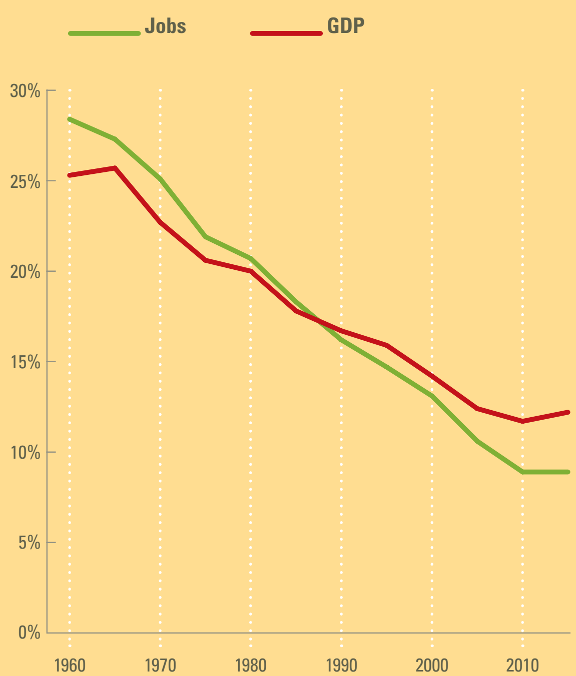
TABLE 3: NATIONAL R&D INTENSITIES, TOP 20 COUNTRIES, 2008–2009[20]

RANK	COUNTRY	R&D INTENSITY	RANK	COUNTRY	R&D INTENSITY
1	Israel	4.28%	11	Austria	2.75%
2	Finland	3.96%	12	Singapore	2.35%
3	Sweden	3.62%	13	France	2.21%
4	South Korea	3.36%	14	Australia	2.21%
5	Japan	3.33%	15	Belgium	1.96%
6	Denmark	3.02%	16	Canada	1.92%
7	Switzerland	3.00%	17	Slovenia	1.86%
8	Taiwan	2.93%	18	United Kingdom	1.85%
9	United States	2.88%	19	Netherlands	1.82%
10	Germany	2.78%	20	Ireland	1.79%

STAFF COMMENTS (continued)

barely more than 12% of GDP.[22] The drop in manufacturing employment has been even more striking: 28% of nonfarm workers were employed in manufacturing in 1960, compared to less than 9% in 2011, as shown in Figure 1.

FIGURE 1: MANUFACTURING AS A PERCENTAGE OF U.S. GDP AND JOBS, 1960-2011[23]



A recent report from the Information Technology & Innovation Foundation argues that "the loss of U.S. manufacturing is due to the failure of U.S. policies (for example, underinvestment in manufacturing technology support policies and a corporate tax rate that is increasingly uncompetitive, among others) and the expansion of other nations' mercantilist policies."[24] ITIF denies that loss of manufacturing is inevitable in a developed economy, pointing out that many other nations (including Austria, China, Finland, Germany, Japan, South Korea, the Netherlands, and Switzerland) have stable or growing manufacturing sectors.[25]

Reversing the decline in U.S. manufacturing would improve the climate for R&D within the United States. The President's Council of Advisors on Science and Technology (PCAST) point out that "Historically, the manufacturing sector has been tightly linked with the nation's R&D activities," accounting for nearly two thirds of all private-sector R&D[26] and, according to Deputy Secretary of Commerce Rebecca Blank, 90 percent of U.S. patents.[27] PCAST makes a number of recommendations regarding how to begin a "renaissance" in advanced manufacturing, including: an Advanced Manufacturing Initiative that would coordinate federal investments to support manufacturing, tax policy reform (including a permanent extension of the R&D tax credit), and support for research, education, and training (to include increased research budgets at federal agencies, improvements to the U.S. education system, and granting green cards to foreign graduates of U.S. universities in the fields of science, technology, engineering, and mathematics).[28]

In a follow-up report on achieving competitive advantage in manufacturing, PCAST points out that manufacturing is dependent on a reliable and sustainable energy system. They recommend that the U.S. incentivize energy efficiency and conservation, increase and diversify domestic energy supplies, accelerate the development of renewable energy technologies, and transition to a low-carbon economy.[29] They also point out that inexpensive natural gas, which is used as a feedstock in various industrial processes, is "driving multi-billion dollar investments" in the U.S. manufacturing sector.[30]

GATING MECHANISMS AND TERMINATING RESEARCH PROJECTS

Research is an inherently risky enterprise, and not every research project will achieve the performance and cost milestones necessary to become a commercial product. Many research organizations have "gating procedures," which are designed to identify unpromising research projects and shut them down before they consume too much time or money. We asked interviewees to describe a research project that was terminated and why, so that we would have a number of examples of how successful companies address this aspect of the research process. We also hope these examples will remind policymakers that failed research projects are inevitable, so no single government-sponsored project's failure will become a political issue or an excuse to shut down broader government support for energy R&D. Table 4 lists the reasons why the failed research projects mentioned by interviewees were terminated. (Some interviewees provided more than one reason.)

Two reasons were equally common: a lack of commercial potential for the innovation and technical issues with the science behind the product. The line between these two issues is not always clear. If a device works but cannot be produced at a competitive price, technical limitations prevent the product from having commercial potential. However, in most cases, either technical or market issues were the driving factor.

Fred Coppersmith of Consolidated Edison described a project that has thus far been unsuccessful for technical reasons. ConEd is a distributor of electricity, natural gas, and steam to end users. One "holy grail" of the steam business is detecting when you might have a water hammer event, a pressure surge that can damage pipes and other distribution equipment. ConEd has been trying to develop sensors to detect precursors to a water hammer event that can survive in the extremely hot, wet conditions of a steam main. So far, they have been unable to develop sensors with the durability and performance necessary for use in their steam system. ConEd more recently partnered with NASA's Jet Propulsion Laboratory (JPL) on this project, as JPL has experience developing technology that operates in high-temperature, hostile environments (such as inside a jet engine), in the hope that a practical water hammer sensor might yet be developed.

TABLE 4: REASONS FOR TERMINATING RESEARCH PROJECTS

ANSWER	# OF INTERVIEWEES
A lack of commercial potential for the innovation	5
Technical issues with the product or the science	5
Poor behavior by another organization in a research partnership	3
Poor internal communication	1
Intellectual property issues	1
A change in business needs	1
Changes in government policy	1
Competition from cheap overseas products	1

George Craford of Philips shared a project which was canceled due to a lack of market demand for the innovation. Craford believed that LEDs had great potential for use in energy efficient, rear-projection television sets. Craford's team was able to produce rear-projection LED TVs with good picture quality no more than 6-8 inches thick. Craford believed that this was thin enough for a television set. It turned out that consumers demanded extremely thin TVs, causing the rear projection technique itself to fall out of favor. This eliminated the commercial potential for energy-efficient, rear projection LED TV sets.

Although less common, several interviewees mentioned projects that were canceled due to problems with a partner organization working on the same project. The three problems cited bore little resemblance to each other: one concerned poor project management by a government agency leading a research collaboration, one concerned the inability of a supplier to deliver promised devices, and one concerned academic institutions attempting to usurp the role of their corporate research partners. The main lesson may be simply that one potential hazard of engaging in research partnerships is the possibility that a partner may not live up to its commitments.

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Technological research is a high-risk, high reward investment, so organizations that fund research are increasingly using a portfolio approach to manage risk.[31] By supporting a diversity of research projects that approach problems from multiple angles, an organization stands a better chance of backing a project that is ultimately successful. However, there is not always a bright line that clearly demonstrates when a project has "failed." Projects can drag on for years, consuming staff time and money, without clearly succeeding or failing. A scientifically robust and objective gating mechanism, which requires projects to meet particular milestones in order to continue to receive funding, can help ensure a private company or government agency continues to direct funding toward the most promising projects year after year.

An objective gating mechanism is particularly important for government-sponsored research, because it can be politically difficult to terminate a funded project or program once it is initiated. In a recent report, the Office of Management and Budget acknowledges that "many Government programs have been allowed to continue or grow even when objectives are unclear and rigorous assessments of effectiveness are lacking. The result has been a profusion of programs that are duplicative, ineffective, or outdated."[32] If research funding decisions are subject to political pressure (from industry lobbying groups or elected officials representing areas where the research is carried out), it is less likely that money will be redirected from mediocre or failing projects to more promising options.

A related problem can result from individuals' personal oversight of funding decisions. No human is perfectly objective; any particular research manager may become attached to certain projects, scientific approaches, or research teams. A manager might fund his/her favorite projects or teams for longer than would be justifiable given a rational evaluation of the project's potential for technical and commercial success.[33] Conscious of this hazard, drafters of ARPA-E's enabling legislation chose to limit the agency's program managers to three-year terms (with the possibility of renewal).[34] This stands in contrast to the essentially permanent hiring in other DOE departments. While this offers a mechanism to ensure research project gating is not hamstrung by any single project manager, it may present challenges in ensuring the long-term preservation of institutional knowledge and expertise within the agency. Temporary hiring is not the only way to address this problem; it is also possible to design gating mechanisms such that no individual decision-maker can unilaterally perpetuate a research project long-term.

RESEARCH PARTNERSHIPS

Another important consideration in the way companies structure and run their R&D programs is whether they engage in research partnerships. We wished to learn what types of organizations our interviewees found it was useful to partner with, and why the work was done with a partner. Partnerships are common in research endeavors, as each partner may have different strengths in terms of expertise, funding, or equipment. Sometimes, the government may seek out and help to fund a partnership in order to focus research attention on a problem that would not be adequately addressed by the private sector alone. Table 5 lists which other types of organizations (or freelancing individuals) worked with interviewees' companies on joint research projects.

The vast majority of the interviewees indicated their companies work with universities on research projects. These partnerships often took one of two forms. On the one hand, it was common for companies to offer small, unrestricted grants to sponsor research in scientific fields of interest. These projects were not aimed at a particular product or end use for the company, tending instead to emphasize "basic science" or "blue sky" research. Companies did not provide unrestricted grants in order to obtain intellectual property (IP) from the university. Rather, they sponsored basic research primarily to form relationships with faculty, to gain access to graduate students in their fields, and to help develop the skillsets of these students, who might eventually become employees.

For example, Paul Citron told us that Medtronic provides research grants to a number of universities. This has enabled the company to form relationships with these universities and have ongoing, collegial interactions with professors who have expertise in areas of interest. Medtronic's grants help to ensure work is being done in the fields that the company cares about, and funded grad students are potential "future researchers and employees." Citron mentioned that Medtronic in fact "gets more bang for their buck" by giving a grant to a university than it would by engaging in a joint project because universities charge different overhead costs for each mode. If Medtronic provides a grant, more of the money goes to fund research and less is taken by university administration.

Dow Chemical also provides grants to universities. William Banholzer indicated that they reserve roughly 1/3 of their university funding for "skills development," helping to ensure a flow of quality chemical engineering graduates. The company may direct its funding toward particular areas, such as catalysis, mass transfer, or fluid mechanics, based on anticipated business needs.

TABLE 5: RESEARCH PARTNERSHIPS

ANSWER	# OF COMPANIES
Universities	13
National labs (or other government labs, e.g. JPL)	9
Other private companies	8
Government-run coalitions	6
Government Agencies	6
Standards and industry bodies	5
Freelancing individuals	2

The second type of relationship between universities and companies involved joint projects or directed projects aligned with companies' near-to-mid-term product needs and objectives. In these cases, companies felt it was important to own or possess an unrestricted license to use the intellectual property resulting from the partnership. Universities' procedures regarding IP licensing proved to be a substantial hurdle, which was mentioned by many interviewees. (It was tied as the second most-commonly mentioned obstacle to overall R&D success, so university-related IP issues will not be discussed at length here. See the *Obstacles to Greater R&D Success* section of this report for the full discussion.)

For example, Tom Kavassalis of Xerox indicated that his company sponsors directed research. They increasingly sponsor this type of research at foreign universities, which avoids problems acquiring IP rights that are common in the United States. David Whelan indicated that defense and aerospace companies sometimes sponsor research at foreign universities in order to satisfy local "offset requirements," laws which require foreign companies to make in-country investments in those industries in which they wish to sell products.

Many of the companies we studied did sponsor research or partner with U.S. universities. Of the companies we examined, UTC had one of the most aggressive strategies for partnering with universities. J. Michael McQuade indicated that UTC works with "close to 100 universities around the world," including many top U.S. schools. UTC focuses on forming deep, long-term relationships with its chosen set of universities, funding programs as an "overall package" rather than funding one specific project or researcher. UTC identifies graduate students early in their careers, tracks them, and sometimes these graduate students choose to complete their academic theses with UTC.

Partnerships with national labs were also common. National labs provide specialized equipment and expertise which companies cannot affordably obtain in-house. John Wall of Cummins provided an excellent overview of the benefits of working with Sandia National Laboratory. Sandia possesses a "wonderful combustion facility with laser diagnostics." This facility is a "fabulous asset" for engine research and design, but even so, Cummins wouldn't be able to justify the expense of building or operating such a facility for itself. "Even the technicians [there] have PhDs," and the entire staff keeps their skills honed by working on projects from a variety of sources. Cummins engages in Cooperative Research and Development Agreements (CRADAs) with national labs, which typically involve 50-50 cost sharing. Wall found that these agreements resolve IP issues, leverage the strengths of both organizations, and help to form a "much more collaborative environment." Many other interviewees similarly spoke highly of their experiences with national labs. Ellen Williams of BP told us that national labs are expensive on a cost basis, but "you're really paying for good quality… You're paying for experienced scientists who know how to do the job," as opposed to graduate students who are learning. This means a company can count on a national lab to get work done in a short timeframe, while it is most often not possible to rely on a university to finish a project quickly.

Joint projects with other companies were reasonably common as well. For instance, the utilities all worked with vendors to test the performance of new products and to determine the impacts of those products on their electrical systems. Bryan Hannegan indicated that EPRI tries to do most work in house, but they will hire consultants to work with them on projects where they lack the necessary in-house expertise (such as sampling power plant stack emissions or conducting exposure tests to understand the impacts of air pollution on cardiovascular disease). Scott Elrod indicated that PARC's business model centers around providing innovative technologies to support the growth initiatives of other companies.

Several companies participate in government-run coalitions with an R&D or technology deployment focus. For example, Paul Delaney of Southern California Edison told us about the Emerging Technologies Coordinating Council (ETCC), a collaborative effort by the California Public Utilities Commission, the California Energy Commission, and a number of utilities throughout California, including SCE. The ETCC's goal is to help energy technologies transition from the laboratory to the marketplace, and it serves as a forum for members to "exchange information on opportunities and results from their Emerging Technologies activities."[35]

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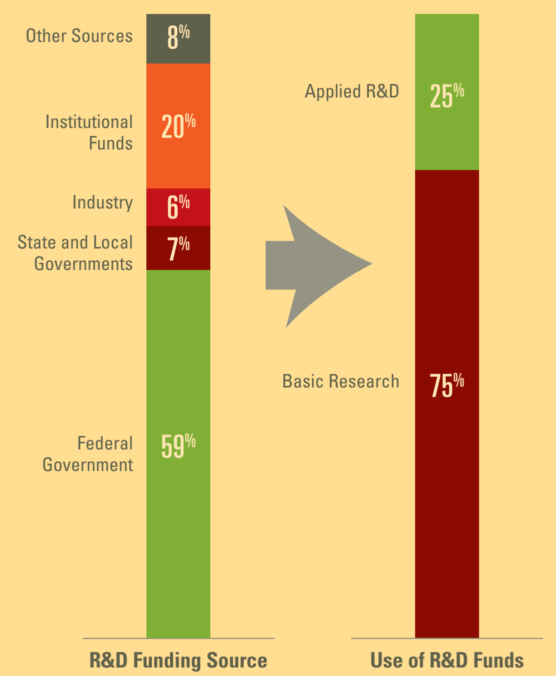
Universities: U.S. academic institutions have played an increasingly important role in technology development over the last several decades, leading to thousands of new products and technologies. In 2010, U.S. universities received 4,500 patents, nearly 40% more than the previous year.[36] Of the total number of patents granted to U.S. owners over the past decade, 4.2-4.7% have gone to universities.[37]

Companies increasingly partner with these schools to gain access to their facilities, knowledge, and talent. Our interviewees' companies provide evidence for this trend, as nearly all of them engage in research partnerships with universities. While corporate funding for academic R&D has increased significantly in recent years, the importance of companies to university R&D efforts is modest and declining in relative terms. In 2009, university R&D in the fields of science and engineering received $55 billion in funding. 59% of the total was from federal sources, while the institutions' own funds provided 20%.[38] Investment by industry comprised only 6% (see Figure 2). Research money from the federal government and internal sources has approximately doubled every decade since the 1960s. In contrast, funding from industry has increased by less than 50% in the last decade.[39]

FIGURE 2: **U.S. UNIVERSITIES' SOURCES AND USES OF R&D FUNDING, 2009**[41]



Universities' forte remains basic research. 75% of total R&D funding goes toward basic research, while the remaining 25% is used for applied research and development, as shown in Figure 2. Since "institutions of higher education [perform] approximately 56% of the nation's basic research," they fill a crucial niche in technology development, particularly by building the theoretical framework to support product R&D.[40]

Federal agencies, such as the National Science Foundation, have created a handful of programs to facilitate collaboration between industry and universities. Partnerships For Innovation (PFI) was introduced in 2005 and has worked to establish and expand university-industry partnerships so that "research from institutions of higher education can be translated into innovation." The program awards $15 million per year to approximately 22 partnerships.[42] Another NSF program, titled Grant Opportunities for Academic Liaison with Industry (GOALI), also funds university-industry research collaborations. Additionally, GOALI assists in funding fellowships and traineeships for faculty, postdoctoral fellows, and students. It provides 60 to 80 awards with a net value of $5 million.[43] Some non-governmental organizations also work to foster

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university-industry partnerships. For instance, the University-Industry Demonstration Partnership "provides a forum for university and industry representatives to meet and discuss contracting and intellectual property policy, publication and technology transfer preferences, and other issues."[44]

A recent trend in private sector-university partnerships is the establishment of research institutes devoted to topic areas relevant to corporate sponsors. This includes centers that focus on energy issues, such as the Global Climate and Energy Project at Stanford University, the MIT Energy Initiative, the Energy Biosciences Institute (a collaboration between BP and several universities), and the Solid State Lighting & Display Center at UC Santa Barbara. Research institutes like these provide a framework for ongoing collaboration between companies and universities, helping to coordinate the efforts of many faculty members and students while reducing the bureaucracy associated with a project-by-project funding approach.

Partnerships between universities and industry significantly contribute to the economy. Roessner et al. conservatively estimate that university licensing contributed $16.8 billion to U.S. GDP and $94.9 billion to industry output in 2007.[45]

National Labs: Prior to the 1980s, it was not a part of the mission of the national labs to transfer their technology to the private sector. The "foundation for technology transfer at the national laboratories" was established by the Stevenson-Wydler Technology Innovation Act of 1980, which established federal Offices of Research and Technology Application and made the transfer of research information to private industry an explicit goal of the Federal government.[46] The Federal Technology Transfer Act of 1986 went a step further, mandating that national labs seek out opportunities to transfer technology to the private sector[47] and establishing one of the most important mechanisms for joint research projects with national labs, the Cooperative Research and Development Agreement (CRADA).

A CRADA is a legal agreement, signed before the joint project begins, that lays out the funding, equipment, and research personnel to be provided by each partner, as well as how the IP resulting from the partnership will be divided up and licensed.[48] Oak Ridge National Lab, for instance, specifies in its CRADAs that each partner owns its own inventions, the commercial partner is granted a "first option to exclusively license any CRADA-generated inventions made by Laboratory staff," and any CRADA-generated information that cannot be protected via a patent may be kept confidential by the lab for up to five years, providing a competitive advantage to the commercial partner.[49]

CRADAs with national labs have generally been well-regarded by both partners. A study of CRADAs between private companies and Los Alamos National Lab found that the main goals of the private partners were to obtain new technology and IP and to save money in developing a new process or product. The main goals of the participating research teams at Los Alamos were different: the lab's project teams hoped to improve the research ability of their laboratory

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Partnerships between universities and industry significantly contribute to the economy.

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(such as by adding new equipment or other capabilities) and to obtain research funding. Despite these different goals, over 90% of the private companies and over 90% of the Los Alamos project teams "considered their CRADA a success."[50] A 2003 study of 220 private laboratories that partner with national labs found that CRADAs successfully "stimulated industrial patents and company-financed R&D… [and] no other channel of technology transfer from federal laboratories… exerts a comparable effect," as CRADAs demand commitment and buy-in from both partners.[51]

DOE has established a number of additional mechanisms to facilitate effective partnerships between the private sector and national labs. The Work For Others (WFO) program enables companies, state and local governments, and other organizations to pay a national lab to perform research and to provide engineering and technical services for their projects.[52] Agreements for Commercializing Technology (ACT) were established in 2011 as an alternative to CRADA and WFO agreements. ACTs allow for greater flexibility in IP rights, payment arrangements, project structure, and other issues. Also, they are more suited than CRADAs and WFO agreements to collaborations that involve more than two parties.[53]

National Labs also offer User Agreements. These are legal documents that address liability, intellectual property, and other financial issues associated with non-lab personnel using national lab facilities. Labs have signed User Agreements with hundreds of institutions, resolving recurring legal issues without the burden of negotiating a unique agreement for each individual project or researcher.[54] As User Agreements are a prerequisite before outside personnel may access national lab facilities, they are complementary to CRADAs, WFO agreements,[55] and ACTs.

Private industry now collaborates frequently with national labs. In 2008, national labs engaged in more than 700 CRADAs, 2,500 WFO agreements, and 2,800 User Agreements.[56] Many energy technologies developed with the help of national labs have been commercialized by the private sector, including energy-efficient windows with low-emissivity coatings, magnetic and methane sensors used to locate abandoned and leaking wells, a process to remove mercury from coal power plant emissions, and inexpensive nanocrystal solar cells.[57]

Many energy technologies developed with the help of national labs have been commercialized by the private sector…

Policies that Effectively Promote R&D Worldwide

To understand what the government might do to promote R&D in private-sector energy companies, it is important to know which policies have been helpful to the R&D efforts of successful companies in the past. Knowing what works today does not provide a complete policy road map—new policy tools may also be needed to help resolve the major obstacles faced by private companies' research departments. However, identifying effective policies is part of the answer, and it may provide information that is valuable when deciding which policies to protect from government budget cuts, to expand from other sectors into the energy sector, or to strengthen in other ways. Table 6 shows the policies (existing and proposed) that interviewees cited as being helpful to their R&D efforts. Only one respondent mentioned a proposed policy; the others discussed existing policies, either in the U.S. or abroad.

To understand what the government might do to promote R&D in private-sector energy companies, it is important to know which policies have been helpful to the R&D efforts of successful companies in the past.

TABLE 6: **POLICIES THAT EFFECTIVELY PROMOTE R&D**

ANSWER	# OF INTERVIEWEES
Grants and contract research	10
Regulations to provide R&D targets and justification to management	4
Foreign economic support	4
Government-funded student research or internships	2
Foreign grants of land, buildings, etc.	2
The U.S. R&D tax credit	2
Excellent schools and universities	1
Loan guarantees	1
Tax/tariff earmarked for R&D (proposed)	1

GRANTS AND CONTRACT RESEARCH

The most important tool for stimulating private R&D is the direct funding of R&D work through grants or contract research. Sources of direct research funding mentioned by interviewees included ARPA-E, other parts of the Department of Energy, the American Recovery and Reinvestment Act (ARRA), the Department of Defense, and foreign governments. Sometimes this money came with requirements for matching investment from the company (e.g. risk-sharing) and/or oversight by the government agency.

The amounts of money provided via direct payments were often substantial for recipients. For example, Don Kopczynski of Avista told us that the company's research budget, formerly $1M annually, has dwindled considerably in recent years. Today, the company's research consists almost entirely of sponsoring projects at the Electric Power Research Institute (EPRI), the Gas Technology Institute (GTI), and universities. However, Avista received a $50M award over three years from the DOE to work on smart-grid R&D projects. This award came with a required 50/50 cost share. Avista redirected $50M of its capital improvements budget to the smart grid initiative in order to secure the DOE funding.

R&D in the defense industry relies heavily on government payments and contracts. David Whelan of Boeing pointed out that the U.S. government typically reimburses companies for 80% of their internal R&D costs for defense projects, and Boeing invests in addition to this reimbursement for certain projects.

The experiences of William Banholzer of Dow Chemical demonstrate the importance of ensuring government support matches the scale of the problem. The Department of Energy gave Dow $2.5M over three years to support Dow's work on solar technologies, but Dow was already investing $30M per year ($90M over three years) in the project. Though Dow "appreciates the money," the government support was so small compared to Dow's own investment that Dow would have pursued that project with or without DOE funding. On the other hand, government support was far more important for batteries. Dow Kokam (Dow's battery business) received a $161M grant, enough to pay for half of a plant's construction cost. Without this grant, Dow wouldn't have pursued work in batteries as quickly or at as large a scale.

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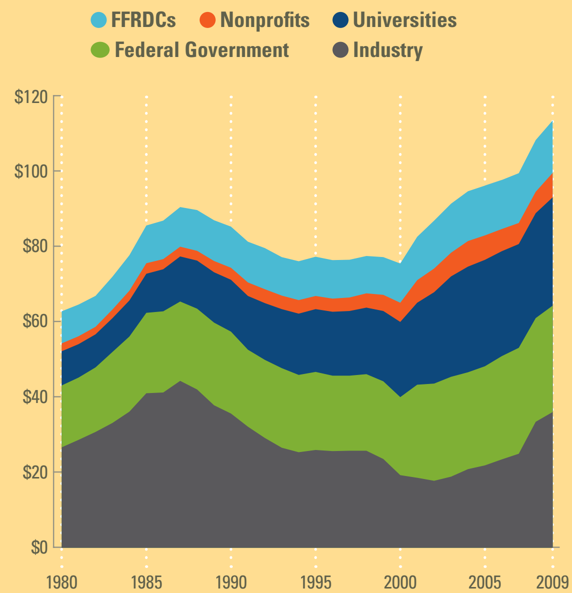
Direct funding, in the form of federal grants or research contracts, is one of the most fundamental ways in which government can promote corporate R&D. Federal grants are given to recipients to provide them with financial assistance during the initial stages of technology R&D. The private company is generally granted ownership of any resulting technologies, though there are often requirements or conditions that must be met.[58] Research contracts differ from grants in that the federal government enters into the contract for the purpose of acquiring "goods or services for the direct benefit or use for the Government."[59] Government typically plays a more involved role in the process of development under a research contract, as they will eventually gain ownership of the developed product.

Figure 3 shows federal government expenditures on R&D activities from 1980–2009, broken down by the type of recipient (in 2005 dollars). In 2009, industry received $36.1 billion, about 32% of the $113.4 billion total.

FIGURE 3: FEDERAL R&D FUNDING BY RECIPIENT, 1980–2009 (BILLIONS OF 2005 $)[60]

Federally Funded Research and Development Centers (FFRDCs) include many of the national labs, as well as a variety of other facilities, operated by industrial firms, universities, and nonprofit institutions.[61]



In 2009, the five most important R&D funders were the Department of Defense ($66.3 B), the National Institutes of Health ($29.6 B), the Department of Energy ($8.1 B), NASA ($5.7 B), and the National Science Foundation ($3.9 B).[62] Each funding source has its own peculiarities and procedures regarding its research funds, so it is hard to speak broadly about the ways in which government research money is secured and used. Instead, we discuss one particular agency in depth—the Advanced Research Projects Agency-Energy (ARPA-E)—due to the agency's emphasis on the creation of ground breaking clean energy technologies and their commercialization, in line with the scope of this study.

The creation of ARPA-E was first proposed by a committee chaired by Norman Augustine in the 2007 National Academies report, "Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future."[63] The report envisioned an energy research funding agency modeled on the Defense Advanced Research Projects Agency (DARPA). DARPA has been famously inventive, playing a key role in the development of breakthrough technologies including stealth aircraft, GPS satellites, packet switched computer networks, and the internet.[64] ARPA-E strives to achieve success through guiding principles similar to those of DARPA, including a rapid review process for research proposals, an emphasis on high-risk, high-payoff technologies with commercial potential, and the requirement for projects to demonstrate progress in order to continue to receive funding.

The Agency was established in 2007 under the America COMPETES Act, but it received no research funding until the passage of the American Recovery and Reinvestment Act

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(ARRA) in 2009. ARRA provided ARPA-E with $389 million,[65] and Congress appropriated $180 million to the agency in fiscal year 2011 and $275 million in FY2012.[66]

ARPA-E's funding opportunities differ from most federal science research funding in several ways. First, ARPA-E supports purely applied research and development projects in an effort to "create real-world solutions to important problems."[67] While they commend basic research, the Agency does not use its money to support research "directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind."[68] Second, ARPA-E seeks out transformative research, or "research that creates fundamentally new learning curves," as opposed to incremental research, which instead "[moves] existing technologies down their learning curves."[69] By introducing new learning curves, ARPA-E recognizes that many of the technologies they fund may be disruptive to the market, either by displacing existing technologies or creating new markets entirely.

Along with ARPA-E, many other branches of the government play important roles in funding energy research. The DOE's Office of Energy Efficiency and Renewable Energy devotes much of its $1.8 billion budget to research in areas including biomass, geothermal, solar, fuel cells, building technologies, and vehicle technologies.[70] Other offices in DOE fund fossil and nuclear research, while the Office of Science funds basic research that sometimes has energy-related applications. A portion of the Department of Defense's large R&D budget is directed toward energy technologies that increase the effectiveness of our military forces, such as improvements in fuel efficiency and reductions in the weight and size of batteries.[71] Additionally, the DOD is uniquely positioned to be an early adopter of new energy technologies, using its bases and facilities as a test bed.[72]

The source of industry funding for R&D has undergone a major transition over the last several decades. Today, only 14% of the funding that private companies receive for R&D comes from federal government sources. This is a drastic decline since the late 1950s and early 1960s, when government funded more than half of industry R&D.[73] A study from the Congressional Budget Office explains that this shift in funding sources is caused by a difference in the type of research that the private sector conducts and the type of research that government wants to fund. "Firms undertake R&D that promises the largest likely profit, which is not necessarily the work that produces the greatest benefit to society."[74] Due to the private sector's emphasis on financial gain, "governments… fund research and development activities… to supplement those private-sector activities," with R&D in the national interest.[75] Still, a large portion of this government-funded R&D is carried out by private firms. In 2009, 32% of federally-funded R&D was conducted by industry, while federal labs and research centers performed 37%, universities 25%, and other non-profit organizations 6%.[76] So, if direct government support for R&D were increased without changing how the money is allocated, about a third of each extra dollar would go to private firms' R&D divisions.

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REGULATIONS TO PROVIDE R&D TARGETS AND JUSTIFICATION TO MANAGEMENT

Several interviewees indicated that regulations (such as fuel, safety, or emissions standards) were helpful to their R&D efforts. These regulations gave direction to their research, providing clear targets to aim for. Additionally, the existence of these regulations sometimes helped R&D leaders make a business case to corporate management for robust support of research. (Our interviewees were not the heads of their companies but specifically managed research activities.)

Bill Powers of Ford Motor Co told us that the CAFE standards (which required improvements in automobile fleet mileage per gallon) and emissions control (which required an order-of-magnitude reduction in particulates, hydrocarbons, and NOx) were important drivers of the team's research efforts. The research division was always "looking down the road," anticipating future tightening of regulations. They knew that as soon as they could "routinely hit target emission levels," the standards would be tightened, so the research team worked hard to keep Ford ahead of the curve.

Ellen Williams of BP provided a similar example. Biofuel blending mandates around the world (laws which require a certain percentage of biofuels to be mixed with gasoline or diesel) are critical for BP's biofuels research. That research program would be much less likely to exist in the absence of blending mandates.

The examples above may make it sound like these regulations cost the researching company money, but John Wall pointed out that this is not necessarily the case. If Cummins knows what standards they have to meet, they can invest in the required technologies, such as hybrid power trains or heat recovery systems. When the standard comes into effect, Cummins gets a return on its research investment, as Cummins is then positioned to offer better or cheaper products that meet the standard than are available from competitors.

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While there is little dispute that grants and contract research promote R&D, regulations used to be an inhibitor of R&D innovation.[77] However, the design of regulations has changed over the last several decades, and now they are routinely structured to incentivize technological development. Jonathan Wiener of Duke University points out that in the 1960s, regulations were seen as a way to "command and control" the market's activities, including the prescription of particular technologies to be used by firms. Beginning in the 1970s, "economic regulations were dismantled in a wave of deregulation," to be replaced by technology-neutral rules that focused on the social impacts of a firm's activity. Techniques developed over the following 30 years, such as performance standards, pollution taxes, and tradable allowances, offered companies the "flexibility to choose [their] methods of compliance."[78] These policies encouraged private-sector R&D by incentivizing companies to develop innovative technologies that lower the cost of achieving compliance.

Lastly, it is important to note that the relationship between technology and regulation is bidirectional: R&D success has the potential to affect regulations. Christine Ng of ENVIRON points out that, beginning in the 1990s, "firms [began to] actively influence regulations, not only through political lobbying, but through technological progress and competitive strategy. There has been increased recognition of the value in treating regulations as endogenous to innovation because influencing regulations can be an integral part of firm strategy."[79] In the energy sector, the government primarily provides funding and support for early (pre-competitive) R&D efforts. Once a technology has been demonstrated and proven to work at reasonable cost, policy makers may have

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the confidence to establish stricter regulations, knowing that industry has a cost-effective way to achieve the new targets. Developing technology that influences regulations can also be "a powerful tool" in demonstrating a firm's technology leadership to potential customers.[80] One example is the development of ultra-low sulfur diesel fuel by BP and Tosco during the late 1990s, which provided support for the EPA's 15ppm sulfur standard by 2006.[81] Another example is provided by efficiency improvements for refrigerators in the 1970s and 1980s. With DOE support, private firms dramatically improved refrigerators' energy efficiency while increasing refrigerators' average size and phasing out ozone-depleting HCFC refrigerants. The existence of these highly efficient models on the market was "a key factor in the development of more demanding efficiency standards," and those standards in turn prompted further efficiency innovations.[82]

FOREIGN ECONOMIC SUPPORT

Foreign governments' tax credits for R&D expenditures, as well as other forms of financial support, were important for several interviewees. (Although the U.S. also has an R&D tax credit that is used by interviewees' companies, its inconsistency and low value were among the most commonly cited obstacles to R&D, so the U.S. tax credit is primarily discussed in the *Obstacles to Greater R&D Success* section of the report.) Some foreign governments had comparatively generous and reliable R&D credits. Additionally, some governments provided grants of land or buildings to entice companies to open research facilities, and they funded university or graduate students to perform research or internships with private companies. Taken together, these supports can form an attractive package of research incentives.

Katharine Frase of IBM provided an example of a set of incentives for R&D offered by the government of Ireland. Ireland has "very attractive" R&D credits. They also have a "great educational system," and the government funds university students and post-docs to do internships at IBM. The Science Foundation Ireland provides funds for particular research projects, and the Irish Development Agency offsets the cost of bringing new jobs into Ireland. Ireland views attracting external companies with high-value jobs as an important part of their growth engine. They believe it "worked in the Celtic Tiger years [and] they are determined it's going to work again." Frase indicates that, due to Ireland's many incentives for R&D, "it is in many ways more attractive to do [R&D] work there."

Paul Citron told us that one reason Medtronic located R&D facilities in the Netherlands, Singapore, and Ireland was because those governments made it "financially attractive to locate there." He found that tax credits, grants, land, buildings, and capital support are all useful incentives. Citron also emphasized the need for policy continuity. Medtronic "has to plan years in advance" to fill their research pipeline. If they don't know what incentives will be in place, or if they can "expire in the middle of a cycle… it becomes hard to plan."

William Banholzer of Dow Chemical pointed out that foreign governments' support for R&D is not solely designed to attract overseas companies. Foreign governments also help their own companies, posing a competitive threat to the United States. "In Korea or China, they'll build a building for you, they'll give you money to buy the equipment… That's who we're competing against." Banholzer indicated that the United States doesn't have the same positive attitude toward manufacturing companies that prevails in some foreign countries. "In Korea, Samsung is like a national hero." He emphasized how critical it is for the U.S. government to understand that big U.S. firms are "not the enemy," and for industry and government to work together to achieve competitive advantage for the United States.

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Foreign governments have a variety of policies to support R&D. One form of support which is readily comparable between different countries is their R&D tax credits. A recent study by the Information Technology & Innovation Foundation evaluated and ranked 42 countries by their R&D tax credit generosity. The study found that the United States ranks 27th, while the most generous countries included India, France, Portugal, and Spain.[83] However, none of these countries have particularly high national R&D intensities: France spends 2.2% of its GDP on research and development, while Portugal spends 1.7%, Spain spends 1.4%, and India spends only 0.8%.[84] (In contrast, the United States spends 2.9%, as shown in Table 3.) This implies that while R&D tax credits may be helpful in attracting some R&D, having a high R&D tax credit is not sufficient to make a country an R&D leader. An OECD comparison of countries' R&D tax incentives has similar findings. The OECD points out that tax incentives alone may not lead to greater innovation output because firms may "relabel" existing expenses as R&D expenses; scientist and engineer wages may rise, thereby increasing the cost of R&D; and the projects that would not have been undertaken but for R&D tax incentives are those with the lowest marginal productivity.[85]

Instead, a whole constellation of policies and traits is needed to effectively promote R&D. Germany provides an instructive case study. Germany has no R&D tax incentives,[86] yet Germany's R&D intensity is almost as high as that of the United States (2.8%).[87] According to the World Intellectual Property Association, in 2010, Germany led the world in the number of protected trademarks and industrial designs and ranked 5th in number of patents.[88] A number of factors contribute to Germany's innovation system. For instance, Germany has a very strong applied research organization, the Fraunhofer-Gesellschaft, which supports both government and private innovation efforts. With 20,000 staff, a €1.8 billion budget, and more than 80 research units, Fraunhofer provides R&D support in almost every area of applied technology.[89] 30% of Fraunhofer's budget is provided as "base funding" by the German government, while the rest comes from research contracts with both private companies and government agencies.[90] Germany's primary education system is significantly above average in science and math; according to the OECD Programme for International Student Assessment (PISA), only six countries reported a greater percentage of students highly proficient in science, while 12 countries led Germany in mathematics.[91] Another factor promoting innovation in Germany is the Central Innovation Program, or ZIM. The ZIM solicits research proposals and funds projects at small and medium enterprises, sometimes done in cooperation with other research partners. Funded projects must aim to develop "new products, processes or technical services … [that] are clearly superior to existing [alternatives]" while increasing the market competitiveness of awardee companies.[92] Germany's ZIM program bears some resemblance to the United States' Advance Research Projects Agency—Energy (ARPA-E), but applied at a larger scale and without a specific focus on energy technologies. All of these factors help Germany achieve R&D success even in the absence of an R&D tax credit.

There is no single country that can or should serve as a model for the United States. A variety of policies, including a globally-competitive R&D tax credit and government support for ground breaking R&D projects with commercial potential, may work together to foster the best possible environment for innovation.

Obstacles to Greater R&D Success

One of the most important ways that government can promote private-sector R&D in the energy sector (and other sectors) is by removing obstacles that stand in the way of greater R&D success. Accordingly, an important part of our project involved gathering data on the nature of the barriers faced by these companies. Interviewees named a large number of different obstacles, the majority of which were only mentioned by a single interviewee. However, a few obstacles arose repeatedly. Table 7 lists the obstacles and barriers to greater R&D success mentioned by interviewees.

TABLE 7: OBSTACLES TO GREATER R&D SUCCESS

ANSWER	# OF INTERVIEWEES
Lack of access to talent	7
Inconsistent or insufficient tax credits (primarily R&D and PTC)	5
Difficulty with IP licensing from universities	5
Lack of stable policy environment (other than tax credits)	4
Too little direct government funding	3
Regulatory approval requirements or delays	3
Quarterly financial pressures/investor impatience or opposition	3
Pressure on universities to do applied work/prototyping/commercialization	3
Difficulty with IP licensing from national labs	2
Need for government to fund more basic research in universities	2
U.S. competitiveness clause or patent waiver requirements in FTTA	1

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TABLE 7: **OBSTACLES TO GREATER R&D SUCCESS** (continued)

ANSWER	# OF INTERVIEWEES
Lack of interest from venture capital	1
Inherent difficulty of the science	1
Government policies that "pick winners"	1
Loss of "research culture" in private firms	1
Unrealistic consumer expectations for products	1
Pressure on national labs to do applied work/prototyping/commercialization	1
Difficulties getting permits for new facilities	1
National lab mismanagement/red tape	1
Universities' failure to commercialize their breakthroughs	1
Economic downturns	1
Risk-sharing and oversight practices of sponsoring government agency	1
R&D is a bad investment vs. spending in proven product areas	1
Inability to keep R&D benefits inside one's own company	1
Concerns about personal injury liability/lawsuits	1
The rapidity of technological progress (outside one's own company)	1
Own business units are threatened by new technology	1
Need for a globally-competitive corporate tax rate in the U.S.	1
Poor/Inconsistent worldwide protections for IP	1
Problems with the legal process for patent lawsuits	1
Global variance in regulatory standards	1
Vendors target others' problems because those markets are larger	1
Inability to bank money for future R&D expenditures	1
Need better coordination/partnering with government agencies	1

LACK OF ACCESS TO TALENT

The most commonly mentioned problem, and a problem interviewees often discussed with considerable passion, is a lack of access to talent in the United States. Specifically, they had trouble finding and hiring enough individuals with top skills in science, technology, engineering, and mathematics (STEM) fields relevant to their research efforts. Interviewees highlighted two contributing factors to this problem. First, some criticized the U.S. educational system for its failure to produce sufficient numbers of talented STEM graduates interested in a career in R&D. Second, they indicated that restrictive policies on work visas and residency prevent them from hiring talented, foreign-born people to work in their labs, even if those people attended university inside the United States.

George Craford of Philips described how his company has grappled with these issues. Craford indicated that among American students, the percentage of degrees issued in non-technical fields has been going up, while degrees in engineering have been going down. He points out that U.S. schools are "getting hammered" by budget cuts and other problems, so that today, the American educational system is "not what it once was." He asserts that jobs are open for skilled workers, but Philips simply can't find enough skilled workers. Visa regulations are a big part of the problem. After foreign-born students get degrees in technical fields at U.S. universities, the U.S. "should be begging them to stay. We should staple green cards to their diplomas." However, the government makes this very difficult. Philips has managed to get green cards for many foreign-born employees, but "it's time-consuming [and] a lot of work" for the company.

Tom Kavassalis of Xerox mentioned that getting H1 visas can be so problematic that Xerox has trouble even bringing new, foreign hires to the U.S. for an extended period of training. They work around these problems, sometimes with the aid of technology such as videoconferencing equipment.

Don Kopczynski of Avista pointed out that there is a linkage between the challenge of finding good personnel and the level of R&D funding going to universities. Avista needs good engineers to run their business, but "you can't have good engineers without good universities. You can't have good universities without good instructors. You can't have good instructors unless you pay them more than their salaries; they need" money to support their research projects as well. Thus, funding basic research at universities can ultimately impact businesses' ability to hire staff with the technical skills they need.

Visa issues can drive companies to open research facilities in other countries instead of the United States. Craig Mundie of Microsoft recalled that several years ago, Microsoft made job offers to many graduating seniors. 600 of these people turned out not to be U.S. citizens. Microsoft determined that the company would not be able to get them visas to work. Rather than rescind the job offers, Microsoft built a new lab in Vancouver, Canada. Canada happily let all of the new hires work there. "They are all super-smart, well-paid people" who contribute to Canada's economy. "You have to shake your head and say, 'How long can this go on?'"

Specifically, they had trouble finding and hiring enough individuals with top skills in science, technology, engineering, and mathematics (STEM) fields relevant to their research efforts.

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These comments will examine two topics that impact the difficulty of finding skilled STEM talent in the United States: education and immigration/visa issues. Three aspects of education are worth considering: primary/secondary school performance, the strength of U.S. universities, and student preferences to go into STEM fields vs. other fields.

Primary/Secondary Schools: While data show that U.S. students score well below the international average in mathematics and roughly average in science, a closer examination of the data reveals that the test score disparity may be explained by the poverty rate, as U.S. schools in low-poverty communities in fact out-perform foreign schools in countries with comparable poverty rates. The OECD's 2009 Program for International Student Assessment (PISA) tested 15-year-old students in every OECD country as well as 30 non-OECD countries in mathematics, science, and reading skill. The average U.S. mathematics score was below the OECD average by a statistically significant margin, placing the U.S. 25th out of the 34 OECD countries.[93] In science, the U.S. was about average, ranking 17th within the OECD. However, these results average high- and low-performing schools within the U.S. The PISA categorizes U.S. schools by examining the percentage of students eligible for free or reduced-price lunches (FRPL) under the National School Lunch Act,[94] which limits eligibility to students whose families make no more than 1.3 or 1.85 times the poverty threshold.[95] Gerald N. Tirozzi, the executive director of the National Association of Secondary School Principals, pointed out that U.S. students in schools with less than 10% FRPL eligibility achieved higher reading scores than students in any country that reported a poverty rate under 10%. Results were similar for the 10-24.9% bracket.[96] (While PISA mathematics and science scores disaggregated by FRPL eligibility were not available, they are likely to show a similar pattern, as studies have shown that performance in math and science correlate strongly with FRPL eligibility rate.)[97] Since schools in the United States are funded primarily by state and local governments (46% by the states and 37% by localities),[98] schools in poorer communities receive less money, even as they serve students who may come from more difficult backgrounds and receive less support at home. These results imply that the United States' unimpressive results in international educational comparisons are primarily due to poverty in the U.S. combined with local and state funding of school systems. Improving STEM performance in primary and secondary schools may require policies that address the growing income inequality[99] and poverty rate[100] in the United States.

Universities: Comparative, multi-nation data on student performance at the university level is difficult to find, although several organizations publish worldwide rankings of universities. The United States possesses many of the world's top universities, including 75 of the top 200 (37.5%) according to Times Higher Education[101] and 54 of the top 200 (27%) according to QS World University Rankings.[102] Subject area-specific rankings of world universities are only available from QS, where the U.S. featured 34 of the top 100 schools in mathematics, 37 of the top 100 in computer science, 41 of the top 100 in the biological sciences, and 26 of the top 100 in electrical engineering.[103] However, these statistics embody an entrenched advantage from older schools. Times Higher Education editor Phil Baty claims that many foreign schools are "rising stars, coming to challenge [older U.S. and U.K. universities] for the best students and the best academic faculty.'" He points out that only 9 of the top 100 universities less than 50 years old are inside the United States.[104] Along with the rise of high-quality foreign universities, another threat facing U.S. post-secondary institutions is the rising cost of tuition. After adjustment for inflation, combined rates for undergraduate tuition, room and board, and required fees at 4-year institutions have risen 138% since 1981.[105] David Feldman, professor of economics and public policy at the

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College of William and Mary and author of the book *Why Does College Cost So Much?* has studied the factors that drive tuition increases. He writes that while many factors have been erroneously blamed (such as competition for prestige, the faculty tenure system, fancy amenities, and administrative bloat), there are only two real drivers: falling support for universities in State budgets and growing income inequality (forcing schools to raise the "sticker price" of tuition, charged to those who can pay, to help fund larger amounts of student aid for those who cannot pay).[106]

Selection of STEM Fields: Some interviewees were concerned with the possibility that fewer students are electing to pursue degrees in STEM fields than in years past. The data bear out this concern. Table 8 shows data from the National Center for Education Statistics indicating the percentage of all bachelor's degrees conferred in the U.S. by field for STEM fields and for education in 1981 and 2010. Degrees in STEM fields declined from 18.0% to 15.4% of the total number of degrees conferred. It is worth noting that education is the single field that suffered the most severe drop, falling from 11.6% to 6.1% of the total. While education is not itself a STEM field, fewer graduates interested in a career in education may negatively impact the teaching quality of STEM subjects. The fields seeing the largest gains were communications/journalism (+1.8%), psychology (+1.5%), parks/recreation/fitness (+1.4%), the arts (+1.2%), and homeland security/law enforcement (+1.2%). Programs that increase student interest in STEM subjects and/or provide financial incentives to enter these fields might increase the available pool of U.S. talent for innovative businesses.

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TABLE 8: **PERCENTAGE OF ALL BACHELOR'S DEGREES CONFERRED BY FIELD IN THE U.S.**[107]

1981 and 2010 (STEM Fields and Education shown)

FIELD	1981	2010	CHANGE
Biological and biomedical sciences	4.6%	5.2%	+0.6%
Computer and information sciences	1.6%	2.4%	+0.8%
Engineering	6.8%	4.4%	-2.4%
Engineering technologies	1.3%	1.0%	-0.3%
Mathematics and statistics	1.2%	1.0%	-0.2%
Physical sciences and science technologies	2.6%	1.4%	-1.1%
STEM Fields Total	**18.0%**	**15.4%**	**-2.6%**
Education	11.6%	6.1%	-5.4%

STAFF COMMENTS (continued)

Immigration and Visas: In order for a foreign national to work in the U.S., that person must possess either a Permanent Resident Card (green card) or a work visa, of which the main type for long-term, skilled workers is the H-1B visa. An employer may sponsor a potential hire for either a green card or a visa, but quotas restrict the number of employment-sponsored green cards and visas which may be issued each year (with the number allotted to particular countries further restricted). This has resulted in a backlog of applications for green cards that, for most workers, is many years in length. It is impractical for a business to wait this long for a new hire, so many businesses will first sponsor a worker for an H-1B visa, then further sponsor that worker for a green card once he/she has the visa and is working in the United States. To secure a visa, a business must certify that a minimally-qualified U.S. worker is not available to fill the prospective hire's position, a bureaucratic process that includes antiquated elements, such as posting a vacancy announcement in a print publication. The business also must endeavor to secure the visa before the annual quota is reached, often early in the fiscal year. If a worker is unable to secure a green card before the H-1B visa expires, he/she will be forced to leave the U.S. and wait one year before applying for a new visa, which may make continued employment with his/her U.S. employer difficult.

The procedures above are very burdensome, not only for foreign workers, but also for U.S. businesses that seek to hire talented people in the sciences, engineering, and mathematics. Liberal, conservative, and nonpartisan groups have all called for streamlining visa and green card procedures. A report by the National Academies claims that "current immigration policies continue to seriously constrain the valuable flow of talent so critical to the economic prosperity of our nation" and recommends that the U.S. expedite visa processing and "consider taking the strong step of granting residency (a green card) to each non-U.S. citizen who earns a doctorate in an area of national need from an accredited research university."[108] The business roundtable, an association of CEOs of major U.S. companies, discusses the tremendous value of immigrants to the U.S. economy, particularly in innovation. The roundtable recommends including eliminating the 20,000 cap for advanced degree holders seeking H-1B visas, increasing the general H-1B visa quota, and providing green cards to "foreign students who graduate from U.S. universities with advanced degrees in STEM fields."[109] The U.S. Chamber of Commerce believes that, "as a nation of immigrants, it's… critical to have a secure and efficient immigration system that welcomes highly educated and talented professionals to our nation," and recommends that current H-1B and green card limits "be significantly raised or reformulated to fluctuate with market demand, and processing delays should be addressed."[110] The President's Council on Jobs and Competitiveness[111] and the President's Council of Advisors on Science and Technology[112] echo similar sentiments. Both President Obama[113] and Republican presidential nominee Mitt Romney[114] have stated that they would support "stapling" a green card to the diploma of students who receive advanced degrees in the U.S.

Current immigration policies continue to seriously constrain the valuable flow of talent so critical to the economic prosperity of our nation.

INCONSISTENT OR INSUFFICIENT TAX CREDITS

Another barrier to R&D success mentioned by several interviewees has been the inconsistent nature and/or low value of U.S. tax credits. Interviewees highlighted two tax credits in particular: the R&D tax credit, for all businesses, and the production tax credit (PTC), for renewable energy businesses. Although these credits are directed toward different ends, they suffer from similar problems: they have been repeatedly renewed for short periods of time and allowed to expire. This prevents businesses from being able to rely on the existence of these credits when making R&D investments, which often must consider a time horizon of many years from project inception to the ultimate launch of a commercial product.

J. Michael McQuade of UTC emphasized that he "need[s] a predictable R&D tax credit," not one that changes "every year or every 18 months." In addition to being long-term, the credit must be "globally competitive." However, the exact value of an R&D tax credit (plus or minus a few percentage points) is not as important as ensuring the credit's long-term predictability.

Tom Kavassalis of Xerox provided a contrasting viewpoint. He indicated that as an individual company, Xerox benefits from very generous R&D tax credits in Canada and France, but not in the U.S. However, from the standpoint of a national government, he questioned whether R&D tax credits are an effective policy tool for increasing a country's nationwide level of R&D. Such tax credits can quickly "become part of the baseline" and lose their impact. Kavassalis pointed out that despite their high R&D tax credits, both Canada and France lag behind the U.S. in terms of R&D intensity (total R&D spending vs. GDP).

With respect to the PTC, Scott Elrod of PARC indicated that the on-again, off-again nature of the credit has been a "total disaster for the renewables industry." Inconsistency introduces considerable uncertainty in the economics of big projects, which is "one of the greatest barriers to driving things to scale." Ellen Williams of BP described how this can work in practice. If a company builds a wind farm at just the right time, they can "lock in" the favorable policy conditions for the expected 20-year lifetime of the equipment. The expiration and renewal of policies that make that investment economical

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In the United States, support for the R&D and PTC tax credits has been inconsistent, leading to market uncertainty and, for renewable energy technologies, boom-bust cycles of investment.

The U.S. Research and Experimentation Tax Credit (the R&D tax credit) "is designed to stimulate company R&D,"[115] but it has been hobbled by frequent expirations and renewals. Since the credit was introduced in 1981, it has been extended by Congress fourteen times.[116] Most of those extensions have been retroactive. This defeats the purpose of the tax credit: a credit that covers a period of time in the past cannot incentivize new research during that time, but merely rewards companies for research that they chose to do in the absence of the credit. The R&D tax credit most recently expired at the end of 2011 and has not yet been renewed, though the credit enjoys bipartisan support, and another retroactive extension is likely.[117]

The R&D tax credit has also been criticized for being globally uncompetitive. Businesses may opt to calculate the R&D tax credit in one of two ways. Under the "regular" method, a company deducts 20% of qualified research expenses (QREs) above a base amount that is calculated by "applying the taxpayer's historical percentage of gross receipts spent

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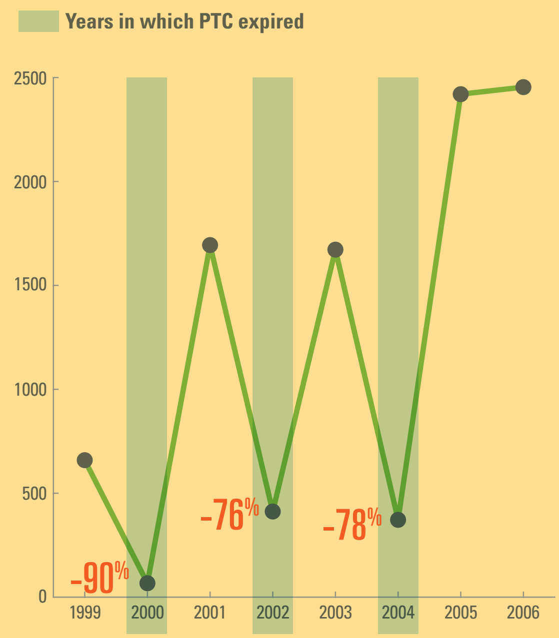
on QREs… to the four most recent years' average gross receipts," where that percentage cannot exceed 16% and the base amount cannot be less than 50% of the current year's QREs.[118] Under the "alternative simplified" method, a company deducts 14% of QREs above a base amount that is the average of the company's QREs over the preceding three years.[119] A comparative analysis of worldwide R&D credits by the Information Technology & Innovation Foundation concludes that the U.S. ranks 27th out of 42 studied countries in terms of R&D tax credit generosity. According to ITIF, the most generous nations, such as India, offered tax credits in excess of 100% of research expenses.[120] ITIF suggests that increasing the alternative simplified method credit from 14% to 20% would cost the government money in the short term, but "after 15 years, tax revenues would begin to exceed the cost of foregone revenues in net present value terms."[121]

Critics have claimed that the definition of qualified research activities under the R&D tax credit is too broad, enabling companies to take the credit for manufacturing and production activities. Although politicians support the credit, there is concern that there is "a real problem with the statutory language," and the credit may need to be rewritten to "define research more specifically."[122]

The PTC was first enacted by President George H. W. Bush as part of the Energy Policy Act of 1992 with an eligibility window of 80 months, ending in 1999.[123] Since then, the credit has been allowed to expire five times, and extensions have been one to three years in length.[124] For wind technology, the principal beneficiary of the PTC, the credit is scheduled to expire at the end of 2012; for other technologies, it will expire at the end of 2013.[125]

Congress allowed the PTC to expire in 2000, 2002, and 2004. In these years, new wind installations fell by 90%, 76%, and 78% relative to the preceding years, as shown in Figure 4. (These precipitous drops occurred even though the tax credit was retroactively extended to cover these three gaps,[126,127] demonstrating that retroactive extensions are ineffective at accomplishing the purposes of the tax credit.) The tax credit's unreliability has also "discouraged long-term planning for complementary investments in manufacturing capacity, transmission infrastructure, and private-sector technology R&D."[128] These large, periodic drops in sales have been a barrier to the development of the wind power industry in the United States, giving advantage to foreign firms that enjoy more stable investment climates.

FIGURE 4: NET. U.S. WIND GENERATION CAPACITY ADDITIONS, 1999-2006 (GW)[129]



"leads to an up-and-down pattern of wind investment," in sync with companies' certainty or uncertainty "about whether government will continue to support the production tax credit."

DIFFICULTY LICENSING IP FROM UNIVERSITIES

The third commonly-cited problem facing R&D organizations was difficulty working with universities due to problems getting the rights to IP produced through funded research or partnerships. Several interviewees told us that if they fund a research project, they deserve to have the right to use the intellectual property that is produced as a result of that project. Once they have valuable IP, the university shouldn't turn around and ask the company to enter negotiations to purchase a license for IP that the company helped to create. As William Banholzer of Dow Chemical put it: universities should want to collaborate, not compete. If a university wants Dow "to license their technology, then they are a competitor."

A few times, we heard from interviewees that some universities informed them that it was impossible to agree to provide them with rights to use IP when forming a partnership because this was incompatible with the universities' tax status. However, other universities were able to make those concessions. Interviewees were uncertain whether this stemmed from differences in tax laws from state-to-state, or whether certain universities were bringing up tax law as a ruse or negotiating tactic.

A couple interviewees described models they use to help manage IP issues in partnerships with other organizations, including universities. George Craford pointed out that a typical research collaboration agreement stipulates that each partner organization owns the ideas generated by its own staff. However, in practice, "everyone is discussing ideas, all intellectual stuff gets co-mingled, and nobody knows whose ideas are whose." Accordingly, Craford proposes a provision which states that while each organization still owns its own ideas, Philips gets a royalty-free license to any ideas generated by other members of the partnership. This has worked for some collaborations, but not others.

Bryan Hannegan indicated that EPRI typically seeks to own all IP from projects it manages, in order to pass as much IP as possible into the public domain. Where this is not possible, EPRI uses a three-box model to define explicitly the IP rights in a partnership. "White box" ideas are made public because all partners want these ideas to be widely known in order to advance the technology. "Black box" items are the "secret sauce" that a partner "cannot give away for fear of reverse-engineering, loss of market share, etc." "Gray box" items are commercially sensitive, but EPRI (and sometimes other collaborators) need access to these data because without it, they could not interpret the project's results. For gray box items, EPRI signs a non-disclosure agreement, or agrees to check with the IP owner before releasing the information.

The third commonly-cited problem facing R&D organizations was difficulty working with universities due to problems getting the rights to IP produced through funded research or partnerships.

STAFF COMMENTS

The role of universities in industry has changed drastically since the middle of the 20th century. During the 1960s and 1970s, the United States began to face new competitive challenges. Having recovered from World War II, the economies of Japan and Germany began to heavily industrialize and innovate, chipping away at the United States' position as the world leader in technology innovation. The number of patents issued in the U.S. steadily declined during the 1970s, while patents granted elsewhere increased.[130]

One reason for the trouble with the United States' innovation system was the lack of an effective R&D relationship between government, academic institutions, and private business. The federal government was the main source of research funding for universities, but universities did not have control over patent rights; they were required to make IP developed with federal funds freely available to the public. Private companies had little incentive to expend the time and money necessary to commercialize these breakthroughs, knowing that their products would have no patent protection (so if their products proved successful in the marketplace, competing companies could rapidly bring similar products to market). This, in turn, had a negative impact on private-sector R&D in these fields. "Cited studies suggest that companies which do not control the results of their investments—either through ownership of patent title, exclusive license, or pricing decisions—tend to be less likely to engage in related R&D."[131]

In the late 1970s, Senators Birch Bayh (D-IN) and Robert Dole (R-KS) recognized these inefficiencies and began drafting legislation that would "[facilitate] collaborative ventures between and among academia, industry, and government."[132] Their efforts led to the Bayh-Dole Act of 1980, which states that "nonprofit organizations… are permitted to retain title to any invention made at that institution under federally funded research and development" programs.[133] The act was designed to give universities flexibility in their choice of IP strategy. It "is very much focused on creating (economic) incentives for universities to commercialize their research output and then allowing them to experiment to find the best means by which to do that."[134] Once universities were able to sell licenses to particular companies, those companies could commercialize products based on this IP with the confidence that their products would be protected by the patent system. The Act also aimed to smooth out the procedure for licensing and patenting, making the entire process more stable and reliable.

Since its passage, universities have been supportive of the Bayh-Dole Act, highlighting its positive economic and social impacts. The Council on Government Relations, an association of research universities, claims that patents licensed under the act "have led to breathtaking advances in the medical, engineering, chemical, computing and software industries, among others. The licensing of new technologies has led to the creation of new companies, thousands of jobs, cutting-edge educational opportunities and the development of entirely new industries."[135] Venture capitalist Jeffrey Baumel agrees with this assessment and credits the act "with the creation of the modern biotechnology industry."[136]

Though the Bayh-Dole Act has helped usher many breakthroughs from universities to the market, it has not been without problems. The initial intention of the Act was to combine the efforts of government, universities, and the private sector: government provides funding for basic research, universities achieve fundamental breakthroughs, and private firms commercialize those ideas and manufacture products. However, universities increasingly desire to maintain control of the IP permanently in hopes of earning licensing royalties. Kristina Johnson, former Provost and Senior Vice President for Academic Affairs at Johns Hopkins University, worries that "more and more businesses are turning to foreign researchers and universities as U.S. universities are

Continued on page 45

STAFF COMMENTS (continued)

unwilling to give up intellectual property."[137] This is potentially problematic for the United States since "success in university/industry technology transfer (UITT) could be a critical factor in sustaining the global competitiveness of U.S. firms."[138]

Critics also argue that by promoting the university as an inventor for the market, "the Bayh-Dole Act is distorting the traditional role of the university [e.g. teaching and basic science research] to the detriment of future technological development."[139] Though Baumel praises the law's achievements, he notes that as universities "seek to maximize and protect the value of their intellectual property, [they] will behave more like competitive private companies in an effort to maximize profitability."[140] Since universities do not have extensive experience commercializing and bringing products to market, there is concern that not only have universities usurped the role of private companies, but that they are doing so inefficiently.[141] However, it can be hard to reconcile this criticism with NSF data that indicate that universities in the 2000s spent a smaller fraction of their R&D budgets on applied research and development than at any time since the early 1970s, before the Bayh-Dole Act.[142] While specific schools or departments may have increased their focus on applied R&D and commercialization, it is likely that most universities protect their IP primarily in hopes of earning licensing royalties.

Some universities are taking steps to address companies' IP licensing concerns. For example, the University of Minnesota recently established the "Minnesota Innovation Partnerships" program, under which "a company sponsoring research at the university will be able to pre-pay a fee and receive an exclusive worldwide license with royalties taking effect only in cases of significant commercial success."[143] VP for Research Tim Mulcahy explains that the university is "transitioning from an approach that focused almost exclusively on the remote probability of royalties to one that values the many tangible and intangible benefits that accrue to the university, our corporate partners and the state from truly effective partnerships."[144] Penn State is also changing the way it handles IP in industry partnerships. Henry Foley, VP of Research at Penn State, writes that his university "has concluded that it is no longer viable to maintain the long-held position that we must own all intellectual property that derives from any and all research that we do.... It is to the benefit of society, and to our students and faculty, to let the ownership of IP developed with industrial funds flow back to the sponsor. This, we believe, will catalyze more commercialization of new technology, help the university build stronger ties to practitioners, and create new adjacencies between theory and practice from which both students and faculty can learn."[145]

More and more businesses are turning to foreign researchers and universities as U.S. universities are unwilling to give up intellectual property.

LESS-COMMONLY CITED OBSTACLES OF NOTE

Several obstacles were raised by 3–4 interviewees. We include brief notes on these below.

Lack of Stable Policy Environment (Other Than Tax Credits)

While the most common complaint about the inconsistency of government policy focused on tax credits, some interviewees mentioned the uncertainty introduced by changes in other policies. For instance, Raj Nair of Ford mentioned that globally, requirements regarding automobile safety features and emissions can be volatile. This makes regulatory trends "difficult to forecast." Ellen Williams of BP mentioned a few areas in which government policy has been variable, including biofuel blending mandates. The uncertainty introduced by fluctuating government policies surrounding newer energy technologies compares unfavorably with the "reliability of return on investment for existing energy sources." For instance, BP carried out a long term development program for an enhanced oil recovery technique called Lo-Sal. The company is now deploying it in the North Sea with confidence that replication of the approach in other fields will continue to yield return on the initial R&D investment for many decades.

Too Little Direct Government Funding

Several interviewees pointed out that there is too little government funding for R&D, often in specific contexts. For example, Scott Elrod of PARC pointed out that ARPA-E had such a small budget that they were only able to fund 37 projects out of 3,500 applicants, about 1%. "Even if 50% or 80% of [the project proposals] are chaff, many good projects aren't being funded." As PARC is not a manufacturer, they have difficulty pursuing high risk research projects like these without some initial government support because their initial investment dollars are limited, and it would require "gambling on the ability to license any eventual IP to someone" who would then commercialize it.

Regulatory Approval Requirements or Delays

A few interviewees mentioned problems caused by regulatory approval requirements. Paul Citron of Medtronic indicated that the FDA has an "overly burdensome regulatory process" that delays the entry of products to the U.S. market for years. This leads Medtronic to locate more R&D overseas, near the clinical sites where their products are first being deployed. Utilities had mixed views of the need to obtain PUC approval for R&D expenditures. While they respected the process (and one pointed out its value as a gating mechanism), sometimes the need for approval could introduce delays or prevent certain projects.

Quarterly Financial Pressures/Investor Impatience or Opposition

The quarterly cycle of budgeting and corporate finances proved to be an obstacle for several interviewees' companies. Katharine Frase of IBM pointed out that it could be unacceptable to tell shareholders, "I might have lower earnings this quarter because I'm placing a big bet on something that won't pay back for a while." In the past, investors used to have more patience. This high-level problem "percolates down, affecting how everything gets reported, budgeted, and managed." This is particularly taxing for research departments, because research is "inherently lumpy."

Pressure on Universities to do Applied Work/ Prototyping/Commercialization

Several interviewees warned that the government is applying pressure on universities to shift from basic science to more applied work, prototyping, or activities supporting product commercialization. This pressure may not always be intentional; it may partially result from a lack of funding for universities. Craig Mundie of Microsoft told us that the government is underfunding basic science at universities, causing them to become more dependent on "cash flows from the business environment." Cash from businesses often comes with a "big set of strings attached" regarding what the school can work on. Mundie believes that the "country's best performance came when basic science was funded at universities by the government." If a university serves as a business "incubator… it's more likely to tilt [the school] toward shorter-term horizons, cutting off the basic science that generates breakthroughs."

Conclusion

Our interviews have provided a wealth of data about how successful, innovative companies structure and manage their R&D operations, the policies they find helpful, and the obstacles they face to greater R&D success. They embody lessons for the energy industry, as well as any company that seeks to understand how to make innovation a part of a successful, sustainable business strategy. In addition, there are key insights here for government, as the current public policy environment poses challenges that businesses cannot solve on their own, and these problems are hindering U.S. innovation. This must change. If government and business can work together to foster a climate that promotes innovation, then private sector R&D can help set us on a path to an affordable, secure, and clean energy future.

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APPENDIX

INTERVIEW QUESTIONS

Background

"Can you provide me with an overview of R&D at your company? What types of research projects does your company engage in? What is your role in the process?"

Funding

"How does your company determine how much money to allocate to R&D? How do you determine the allocation of R&D funding among different existing and potential projects? In your opinion, are funding levels generous, satisfactory, or too low? Has R&D funding been increasing or decreasing in recent years?"

Payback Timeframe

"Over what timeframe does your company think about R&D investments and paybacks? How long it the typical gap between the start of a research project and the use of its outputs in a commercial product at your firm?"

Market Influence

"How does the end market for your products influence your R&D spending? Are customers pushing for new technology, do their expectations increase each year, or are they primarily concerned with the reliable delivery of existing products at affordable prices?"

Global location of R&D

"Does your company primarily conduct R&D inside the United States or overseas? In the future, do you expect that a higher or lower percentage of your R&D will be conducted in the U.S.? What policies or factors are driving this shift?"

Obtain Anecdotes

"Can you tell me about one or two R&D projects that your company successfully completed? How about some that failed or were terminated? Why is a project terminated: is it based on the technical merits of the project, insufficient commercialization potential, a lack of research funding, or some other factor?

Obstacles

"Going forward, what do you see as the largest obstacle to greater R&D success at your company or in your industry? What measures would be most helpful in overcoming that obstacle: changes in government regulations or tax policy, better consumer education, a different economic climate, etc.?"

Government Support

What existing or proposed forms of government support (e.g. tax credits, loans, grants, loan guarantees, etc.) are most important to your company's R&D efforts or would help your company increase R&D? How does government support influence R&D decisions?

INTERVIEW QUESTIONS (continued)

Non-Price Barriers

Are there any non-monetary barriers that influence your company's ability to conduct R&D? For instance, these could be permit requirements, difficulty in hiring suitable personnel, proximity to other firms in your supply chain, etc.

Partnerships

"Does your company ever engage in joint research with academic institutions, national laboratories, or government agencies? [Have you found these partnerships to be helpful? / Do you think establishing such partnerships would be helpful?] What barriers prevent universities, national labs, and government agencies from being more effective research partners for the private sector?"

Freeform

"Is there anything else you would like to tell me related to any of the topics we discussed? Do you have any ideas you would like to share?"

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