Social, political, and technical influences on the past and future of United States energy research and development

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Executive Summary: The United States federal government is a primary provider of research and development (R&D) funding. In the last century, the Manhattan Project and Apollo Programs proved that massive federal R&D investments can rapidly produce technologies that reshape the social, economic, and political systems of the country. Incremental investments can likewise shape technology and society over time. Tracking changes in the Department of Energy's (DOE) R&D funding levels and policies over time show a sensitivity to evolving energy needs in the United States, but also unique challenges in turning R&D investments into technologically sound, politically acceptable, and socially beneficial outcomes to solve complex sociotechnical challenges.

As energy has become ubiquitous in daily life, four broad framings have emerged to define the meaning of energy and the most pertinent energy goals. The commodity framing focuses on free-market energy, the security framing on stable energy supply, the environmental framing on energy-related environmental degradation, and the justice framing on accessibility of energy for all. Changes in energy R&D policy over time reflect real effort and potential to address these dynamic frameworks. Shocks to energy perception, such as the 1970s Arab Oil Embargo, cause rapid changes in both amounts of spending and how the DOE prioritizes and justifies R&D investments. Gradual shifts in energy perception, such as growing concerns about climate change, also influence the DOE's policies as reflected in increased funds for clean energy R&D.

Despite real effort to reflect public energy perceptions, the DOE's R&D policies show the tension between goals that arises from conflicting energy framings. The DOE focuses R&D initiatives on more popular or urgent energy framings. The environmental framing, with its long-term focus, is overshadowed publicly by more immediate concerns regarding energy cost and stability. Moreover, the federal government faces pressure from the commodity framing to not interfere with technologies' market values, making it difficult to justify expensive but socially beneficial R&D spending intended to promote the use of specific energy technologies.

In addition to working within conflicting energy framings, the DOE's R&D funding is shaped by social, political, and technological factors that slow adaptation and constrain public benefits. Energy priorities and willingness-to-pay for federal energy research varies among demographic groups. Appropriations for energy R&D are often used as political tools in the congressional budget. The government must pick and choose among a wide variety of emerging technologies requesting more than the available R&D funding. Together, these factors incentivize the measurement of R&D policies in quantitative terms that fail to capture social impacts of technology.

A common policy proposal to address energy needs is increased federal R&D funding. However, policies that guide the funding process are as important as total funding amounts. Future policies must embrace the government's influence on energy technology, fund social science research on energy through the National Science Foundation and other agencies, and assess R&D proposals on a mix of social, environmental, technical, and economic merit. Through R&D policy, the DOE has proven itself responsive to the dynamic meaning of energy. For future investment to have the most impact, new policies must highlight long-term sociotechnical challenges that energy framings often fail to capture.

I. Introduction: Federal R&D and Sociotechnical Change

The United States government has funded several massive research and development programs that have fostered substantial technological change. During World War II, the Manhattan Project turned $22 billion of federal investment into the first atomic weapons. During the Cold War, the federal government channeled $98 billion into space exploration through the Apollo Program and put a man on the moon.[1] These government-sponsored programs not only advanced scientific understanding, but also demonstrated how deeply federal R&D aimed at technical processes can influence the economic, social, and political aspects of a country. They produced some of the most iconic innovations in the nation's history.

While such concentrated programs produce rapid change, most federal R&D programs persist over many years with more incremental but just as meaningful impacts. The federal government's investment in energy R&D illustrates the need for and limitations of these ongoing federal R&D programs in addressing embedded sociotechnical challenges. Since the creation of the Department of Energy (DOE) in 1977, the US government has since spent, by one estimate, over $118 billion on energy R&D programs.[2] These programs are integral to energy policy. Federal energy R&D correlates with patent activity related to less well-established energy technologies such as wind, solar, and nuclear fusion.[3] Recent years have seen calls for rapidly increased federal investment from policymakers, private actors, and researchers.[4,5] With significant amounts of money spent, the relationship between federal spending and energy innovation established, and the desire for further investment vocalized, federal R&D funding clearly plays a key role in shaping energy systems.

This paper investigates how development of federal energy R&D funding and policy reveals national energy priorities and federal approaches to energy challenges. Over time, energy has become entrenched in American social and economic systems, pressuring the government to provide for increasingly diverse energy needs while adhering to values born from varying energy framings. I argue that funding levels and R&D programs through the DOE reflect real effort by the federal government to support technologies and infrastructure that address these constantly evolving and conflicting framings. The public utility of the programs, however, is shaped by social disagreements over the role of government in energy, political maneuvering in setting the budget, and uncertainty in risk management related to technological complexity. In some cases these factors align energy R&D more closely with public need, but in others they reveal

[1] U.S. Library of Congress, Congressional Research Service, *The Manhattan Project, the Apollo Program, and Federal Energy Technology R&D Programs: A Comparative Analysis*, by Deborah Stine, RL34645 (2009). https://fas.org/sgp/crs/misc/index-2.html.
[2] Ibid.

[3] Gregory F. Nemet and Daniel M. Kammen,"U.S. Energy Research and Development: Declining Investment, Increasing Need, and the Feasibility of Expansion," *Energy Policy* 35, no. 1 (2007): 746–55.
[4] Ibid.
[5] U.S. Library of Congress, Congressional Research Service, *The Manhattan Project, the Apollo Program, and Federal Energy Technology R&D Programs: A Comparative Analysis* (2009).

unique social, economic, and political barriers that limit federal R&D's power as an energy policy tool.

Federal Responses to Changing Energy Framings

Providing for the public's ranging energy needs is a central mandate and challenge for federal energy R&D. American energy needs reflect a complex mesh of values and priorities. These values and priorities can be described within four evolving energy framings based on the National Research Council's (NRC) 1984 publication *Energy Use: the Human Dimension*: commodity, security, environmental, and justice.[6] The commodity framing primarily defines energy as a good to be traded freely; it "emphasizes the value of choice for present-day consumers and producers" and holds that markets, not governments, can and should be allowed to choose and efficiently distribute energy technologies.[7] The security framing highlights our economic dependency on steady, cheap energy supplies, and so sees relying on imported energy or a single energy source as an economic and political liability.[8] The environmental framing centers on addressing the exhaustibility of energy and the environmental impacts of energy such as pollution and climate change.[9, 10] The justice framing recognizes the necessity of equitable energy access for all and attempts to highlight failures to fairly distribute the impacts of energy projects.[11,12] Though not always explicitly used in energy policy debates, the NRC framings show how emphasizing different values lead to different priorities for policy and investment outcomes. Analysis of federal energy R&D investment through these framings reveals instances where different values demand work on common issues, and conflicts where policies addressing an issue emphasized by one framing may contradict the values of another.

The breadth of programs supported by the modern energy R&D budget demonstrates the government's commitment to addressing all the country's energy needs. The DOE distributes R&D funds through five energy programs, twenty national laboratories, and an Office of Science that oversees seven basic research priorities. Each program attempts to address a range of energy needs across the overlap in the energy framings. For example, the DOE justifies funding the Efficiency and Renewable Energy Program by citing goals of "reducing U.S. reliance on oil, increasing energy affordability, ensuring environmental responsibility, enhancing energy security, offering Americans a broader range of energy choices, and creating jobs."[13] In rationalizing just one program, the DOE acknowledges the range of responsibilities within the four energy framings: moving to domestic sources reflects energy security, choosing renewable energy sources reflects environmental concern, reducing the price of energy reflects accessibility justice, and expanded technological choice and competitiveness reflects free-market economics. The appearance of all of the energy framings in the DOE's program description suggests a clear recognition of America's complex relationship with energy. However, while the DOE combines the four framings within its programs, the resultant broad goals raise questions regarding its ability to adapt to and address all of society's energy needs through R&D.

Past changes in federal energy R&D programs reflect awareness that energy framings have and will continue to change; this awareness suggests the DOE can adapt to changing needs as necessary. Since its official founding in 1977, part of the DOE's mandate has been to protect American energy needs after the Arab Oil Embargo shocked the country into linking dependency on energy imports with insecurity of supply and price. Before the oil crisis, energy programs were spread across different federal agencies and focused on nuclear security and fossil fuels for domestic economic growth. After the crisis, many programs were consolidated into the Energy Research and Development Administration, which

[6] National Research Council, "Thinking About Energy," In *Energy Use: The Human Dimension,* ed. Paul C. Stern and Elliot Aronson (New York, NY: W.H. Freeman and Company, 1984), 14–31.
[7] Ibid., p. 15
[8] Ibid.
[9] Ibid.
[10] Clark A. Miller, Alastair Iles, and Christopher F. Jones, "The Social Dimensions of Energy Transition," *Science as Culture* 22, no. 2 (2013): 135–48.
[11] National Research Council, "Thinking About Energy," 1984
[12] Kirsten Jenkins, Darren McCauley, Raphael Heffron, Hannes Stephan, and Robert Rehner, "Energy Justice: A Conceptual Review," *Energy Research & Social Science* 22 (2016): 174–82.
[13] U.S. Department of Energy, "FY 2017 Congressional Budget Request Justification, Volume 3," CF-0121, Office of Chief Financial Officer (Washington, DC, 2016), p. 9

became the DOE, and their scope broadened to include renewable energy and efficiency research for promotion of energy security through source diversification.[14] The embargo also caused the first major spike in energy R&D spending, which doubled between 1973 and 1976 and again between 1976 and 1980, with annual appropriations growing to 10% of all federal R&D funding.[15] While the DOE retained the nuclear and fossil fuel responsibilities of its predecessors, the mergers and expansion reflects federal willingness to incorporate new energy needs in its mandate.

The Arab Oil Embargo shocked American energy systems and rapidly altered energy framings, but federal energy R&D programs have also adapted over time to gradually shifting ideas regarding energy. For example, the link between energy and climate change has connected the environmental framing to environmental aspects of energy justice and created a push for renewable energy that overlaps with the energy security framing's goal of utilizing domestic resources and addresses security concerns over the impacts of climate change. The shift has elevated the importance of those framings' values. Recent research shows the American public would be willing to fund increased R&D for renewable energy "to address supply security and climate change issues."[16] This shift in the meaning of energy has slowly entered federal energy R&D discussions. Funding for renewable energy and energy efficiency made up a greater proportion of total funding for technology R&D from 2005 to 2014 than from 1978 to 2014 (34.3% vs. 31.6%), implying a modest increase in weight given to those technologies.[17] It is important to note that the American Recovery and Reinvestment Act of 2009 stimulus package provided a $12 billion spike in technology funding for FY 2009, much of which went to renewable energy, including wind, solar, smart grid, and vehicle efficiency.[18] While the increases in renewable energy and energy efficiency funding over time have been modest, the effects from the stimulus investment have been significant as it shows the federal government now sees renewable energy as a valid response to environmental and economic issues. From the late 1990s onward, many new R&D programs have also focused on carbon sequestration and other climate change mitigation technologies.[19] The FY 2016 presidential budget request promoted work on renewables, energy efficiency, clean transportation, and climate change.[20] The FY 2016 Energy and Water Appropriations Bill increased funding for research into hydropower and vehicle efficiency by $9 million and $2 million respectively.[21] Overall, more discussion and more funding has centered on addressing overlapped environmental and security implications of climate change and energy systems. The DOE's inclusion of changing energy framings in new funding and programs suggests that future R&D programs will also respond to emerging sociotechnical challenges.

Conflicting Energy Framings in Federal R&D

Despite increased recognition and discussion of the environmental and security impacts of climate change at the federal level, the overall increase in R&D investment for energy efficiency and renewables has been fairly small. Between 1997 and 2014, the funding for renewable energy and energy efficiency technologies grew by about 12% while total funding for DOE R&D, including other technologies and sciences, grew by almost 40%. Furthermore, renewables in 2015 remained a

[14] U.S. Department of Energy, *U.S. Federal Investments in Energy R&D: 1961–2008* by J.J. Dooley, PNNL-17952, National Technical Information Services (Springfield, VA, 2008).

[15] Ibid.

[16] Hui Li, Hank C. Jenkins-Smith, Carol L. Silva, Robert P. Berrens, and Kerry G. Herron. "Public support for reducing US reliance of fossil fuels: Investigating household willingness-to-pay for energy research and development," *Ecological Economic* 68 (2009): 731–42. p. 741

[17] U.S. Library of Congress, Congressional Research Service, *Renewable Energy R&D Funding History: A Comparison with Funding for Nuclear Energy, Fossil Energy, and Energy Efficiency R&D*, by Fred Sissine, RS22858 (2014). https://fas.org/sgp/crs/misc/index.html.

[18] Ibid.

[19] U.S. Department of Energy, *U.S. Federal Investments in Energy R&D: 1961–2008* by J.J. Dooley

[20] Matt Hourihan, "FY 2016 Budget to Again Prioritize Manufacturing, Clean Energy, Climate, Neuroscience," *American Association for the Advancement of Science,* 22 July, 2014, http://www.aaas.org/news/fy-2016-budget-again-prioritize-manufacturing-clean-energy-climate-neuroscience.

[21] Matt Hourihan, "House Energy Floor Amendments: Boosts for Efficiency, Hydropower; Climate Modeling Program Blocked," *American Association for the Advancement of Science.* 4 May, 2015, http://www.aaas.org/news/house-energy-floor-amendments-boosts-efficiency-hydropower-climate-modeling-program-blocked.

relatively small part, only 7.3%, of the total R&D budget.[22] Moreover, the initiatives and requests discussed above are more disjointed than the concerted action taken after the oil crisis. The contradiction between growing public support for environmentally-friendly energy research and the tepid federal response through R&D funding implies that the funding systems may fail to produce publicly supported and, in this case, publicly beneficial outcomes.

The statistics of investment in renewable energy R&D discussed above provide an example of a public failure within energy R&D policy. Using the definition of Bozeman and Sarewitz, "public values" describe tangible and intangible social goals and public failures occur "when neither the market nor public sector provides goods and services required to achieve core public values."[23] In this case, sluggish growth in renewable energy R&D investment comes as the public's willingness-to-pay for R&D to address climate change has increased,[24] a majority of Americans report concern over climate change and support for renewable energy,[25] and the Department of Defense has called climate instability a security threat.[26] This contradiction constitutes failure to use energy R&D funding to provide for the emerging public value of renewable energy use to mitigate the real dangers of climate change. Bozeman and Sarewitz trace public failures to the decision-making processes policymakers use to distribute finite investment resources among the "many competing scientific disciplines, projects, and programs."[27] These decision-making processes raise questions regarding what values the investments are meant to support and what factors shape the potential of federal R&D programs to uphold those values. Within energy policy, the factors stem from a collection of conflicting framings, social disagreements, political maneuvering, and technological complexities.

One of the biggest factors behind public failure in federal energy R&D comes from tensions within the energy framings. Framings related to climate change are growing more prominent, but more immediate concerns, like energy security, reliability, and low cost tend to gain more traction with elected representatives and society. During the George W. Bush administration, programs like the 2006 Advanced Energy Initiative equated calls for "clean, safe, climate-friendly fuels" with reducing oil imports and thus the country's dependency on foreign energy sources.[28] The renewable energy example shows that programs designed around one framing can also address concerns of others, but that framings that address immediate needs can overpower the others. For example, federal funding for renewable energy research has roots less in the environmental framing and more in the security and justice framings as a way to diversify energy supply and address price spikes in fossil fuels. Recently stable fossil fuel prices and the discovery of new domestic hydrocarbons deposits and extraction methods have calmed fears about insecure energy sources and damagingly high prices, muting calls for investment in more expensive renewable energies based on non-environmental values.[29] When energy framings differ in perceived importance, the government and the DOE may address one framing – in this case, environmental – by speaking to it in terms of another – in this case, security and accessibility. While this subtlety works for society in instances where the framings' different values promote similar outcome, it raises the possibility of some energy needs and values being overlooked if they do not overlap with the prioritized framing.

Another frame-based tension that shapes federal R&D funding emerges from conflicts between

[22] "Historical Trends in Federal R&D," *American Association for the Advancement of Science Research Budget and Policy Program*, 2015, http://www.aaas.org/page/historical-trends-federal-rd.

[23] Barry Bozeman and Daniel Sarewitz, "Public Values and Public Failure in US Science Policy," *Science and Public Policy* 32, no. 2 (2005)., p. 122

[24] Li et al., "Public support for reducing US reliance of fossil fuels," 2009

[25] Bjoern Hagen and David Pijawka, "Public Perceptions and Support of Renewable Energy in North America in the Context of Global Climate Change," *International Journal of Disaster Risk Science* 6, no. 4 (December 2015): 385–98, doi:10.1007/s13753-015-0068-z.

[26] U.S. Department of Defense, "National Security Implications of Climate-Related Risks and a Changing Climate," 8-6475571, submitted to Senate July 23, 2015.

[27] Barry Bozeman and Daniel Sarewitz, "Public Value Mapping and Science Policy Evaluation," *Minerva* 49 (2011): 1 – 23., p. 2

[28] Li et al., "Public support for reducing US reliance of fossil fuels," 2009, p.731

[29] Afzal S. Siddiqui, Chris Marnay, and Ryan H. Wiser, "Real options valuation of US federal renewable energy research, development, demonstration, and deployment," *Energy Policy* 35 (2007): 265–79.

the commodity framing and the others. The commodity framing historically dominates energy R&D. Early in the life of the DOE, the now-closed Office of Technology Assessment critiqued energy R&D programs that invested in risky, unknown technology instead of short-term projects that increased use of commercially viable technologies.[30] The Reagan administration slashed the energy R&D budget soon after, claiming, "only in areas where these market forces are not likely to bring about desirable new energy technologies and practices within a reasonable amount of time is there a potential need for federal involvement." [31] In addition, beginning in the 1980s, the federal government began pulling funding from applied technologies research to fund more basic sciences research.[32] Since then, a significant majority of the DOE's R&D budget has always been slated for either atomic defense or the Office of Science; these programs support basic scientific discoveries with potential private applications rather than explicitly changing the market competitiveness of specific technologies.[33]

Because the commodity framing holds so much power, the federal government lends greater weight to economic outcomes in energy policy than in sociotechnical issues less interconnected with the private sector. This practice leads to questionable outcomes for public needs. Researchers use economic models to analyze the benefits of investing in certain energy technologies, but the studies themselves often recognize the models' inability to fully account for the impacts of R&D investment on non-economic energy needs. For example, one study modeling the benefits of federal R&D investment in renewable energies criticizes the current DOE for using a "deterministic approach" that fails to capture "the important options or insurance value of [renewable energy research]" – that is, the stability that would come from fewer fossil fuel purchases.[34] Bozeman and Sarewitz argue that using economic models to make R&D investment decisions "shifts the discourse…away from political questions of 'why?' and 'to what end?' to economic questions of 'how much?'" That question usually pegs short-term, conventional investments as less risky, therefore discouraging investment in emerging technologies that could address long-term concerns. [35] The commodity framing also supports measuring R&D investment outcomes by economic metrics. For example, The Government Performance and Reporting Act requires federal agencies to annually report the progress of their research programs. The DOE boils progress down to "a limited number of performance metrics…such as avoided customer expenditures for energy and carbon emission reductions" that are assumed to benefit the public.[36] These performance metrics provide some useful tracking measurements, but they fail to capture the subtle range of impacts that energy systems have on society and so may guide federal energy R&D away from the most publicly beneficial investments based on values drawn from non-commodity framings.

Social, Political, and Technological Challenges in Energy R&D

Understanding the implications of diverse energy needs clarifies some challenges within federal energy R&D programs, but social disagreements on the role of government in energy systems go beyond competing framings. Different demographics of the American public exhibit different levels of support for federal energy investments. One survey, for example, found that the majority of Americans favor an increase in the use of renewable energy sources and recognize R&D investment as an important development tool. Unsurprisingly, in this survey, citizens' willingness-to-pay for new energy R&D investments dropped as the price tag rose. In addition, a variety of other socioeconomic variables affected willingness-to-pay: higher levels of support for renewable and crop-based fuels, more importance attributed to R&D and energy issues, being female, holding more liberal

[30] U.S. Department of Energy, *U.S. Federal Investments in Energy R&D: 1961–2008* by J.J. Dooley, 2008, p.10
[31] Ibid., p.11–12
[32] Ibid.
[33] "Historical Trends in Federal R&D," *American Association for the Advancement of Science Research Budget and Policy Program,* 2015.
[34] Siddiqui, Marnay, and Wiser, "Real options valuation of US federal renewable energy research, development, demonstration, and deployment," 2007, p. 226
[35] Bozeman and Sarewitz, "Public Values and Public Failure in US Science Policy," 2005, p. 120
[36] Siddiqui, Marnay, and Wiser, "Real options valuation of US federal renewable energy research, development, demonstration, and deployment," 2007, p. 226

beliefs, and higher incomes all indicated a higher willingness-to-pay.[37]

While this represents the results of only one survey, the implications should not be overlooked. Taxpayers fund federal R&D programs. Significant increases in energy R&D thus require the support of the taxpayers. If differences in energy framings and other socioeconomic factors lead to differences among taxpayer willingness-to-pay for energy R&D, this pressures the government to realistically consider the political feasibility of funding new or expanded programs. Bozeman and Sarewitz claim that the failure to define public values due to insufficient consensus is rare in science policy.[38] In the case of energy policy as reflected in federal R&D, the debate over conflicting energy framings and variability among citizens' support for investments suggest this is one of those rare cases. For example, although a majority of Americans support renewable energy, Americans also report stronger levels of disagreement about policies promoting use of renewable energy than other North American countries.[39] Even if much of the public agree on basic energy values like affordability, stability, marketability, and sustainability, the different framings of energy illustrate strong disagreements over how to weight and achieve those values. R&D programs cannot satisfy all public values without clear social agreement on those values and consensus on the purpose and desired size of federal energy R&D and energy policy.

Beyond the social aspects, political maneuvering around the energy R&D budget also affects public outcomes, as it does for every budgetary item. Funding comes from two sources: discretionary spending requested by the Executive Branch and allocated by Congress through annual appropriations, or mandatory spending requested by the Executive Branch and allocated by Congress through non-appropriations legislation. Both types require the two branches of government to compromise, and in recent years funding battles over energy R&D have been fought mostly along party lines. For example, support for research into renewable hydropower was added into the FY 2016 Energy and Water Appropriations Bill by Democratic representatives from Oregon and Tennessee, while broader amendments for renewables and climate modeling were rejected by Republicans in the House.[40] Similarly, The America COMPETES bill passed the House only after Republican lawmakers shifted $5 million away from renewable energy research and cut climate change and low-emission research in the DOE. Within America COMPETES, the House suggested a 30% cut in energy efficiency and renewables research for FY 2016, in contrast to the roughly 40% increase requested by the President.[41] These examples only provide a snapshot of the politics involved in the budgetary process. They do, however, suggest that politically contentious programs may struggle to secure increased R&D funding, regardless of potential public benefits.

Finally, federal energy R&D programs struggle to make investment decisions given the quantity and complexity of the technologies proposed for funding. Each energy source relies on multiple technologies to extract, process, convert, and deliver energy from raw resources to consumers. Technical complexity refers to the wide range of resources and expertise needed to pursue improvements to existing technologies or development of new and emerging technologies. Suggestions for new or improved technologies fall across a spectrum of usefulness and feasibility. Though this paper cannot fully review technological constraints, the existence of technical complexity and budget constraints necessitate decision-making about investments that further demonstrates the inadequacy of purely economic assessments to guide R&D funding.

A look at one emerging technology shows the blurry lines between feasible and useful technologies. Consider a report outlining the security, social, and environmental benefits of continued or scaled-up investment in bioethanol energy technologies which identifies no fewer than five different technological platforms for producing bioethanol that federal R&D has supported.[42] These

[37] Li et al., "Public support for reducing US reliance of fossil fuels," 2009., p.741

[38] Bozeman and Sarewitz, "Public Value Mapping and Science Policy Evaluation," 2011

[39] Hagen and David Pijawka, "Public Perceptions and Support of Renewable Energy," 2015

[40] Hourihan, "House Energy Floor Amendments," May 4th, 2015

[41] Matt Hourihan, "FY 2016 Budget to Again Prioritize Manufacturing, Clean Energy, Climate, Neuroscience," *American Association for the Advancement of Science,* 22 July, 2014, http://www.aaas.org/news/fy-2016-budget-again-prioritize-manufacturing-clean-energy-climate-neuroscience.

[42] John Sheehan and Michael Himmel, "Enzymes, Energy, and the Environment: A Strategic Perspective on the U.S.

platforms encompass many chemical and mechanical requirements, have been in development for different lengths of time, are at different levels of commercialization, and most importantly, require different levels of investments to research the technological possibilities. The technical variability that underlies just one energy source raises questions that apply to almost every emerging energy technology. Federal energy R&D programs must decide which technological path is the most logical to pursue and whether it is better to spread investment across a wide number of technological options or focus on one.

The answers to these questions change depending on the desired outcomes. Sheehan and Himmel believe "policy makers and the public need to… make some rational choices about risk."[43] This appeal, however, falsely assumes that rationality will lead to consensus on which technologies to pursue. Rationality in choosing technologies for investment requires logically selecting technologies with the most potential to provide certain outcomes. As discussed in this paper, favored outcomes vary widely across society. Sheehan and Himmel suggest looking at which technology has the most potential for price decrease and commercial applicability while considering the principles of diminishing returns on investment.[44] That rational process may favor a different technology than a rational process that incorporate Bozeman and Sarewitz's suggestions for maximizing public, not economic, utility.[45] Thus rationality fails to create consensus when minimizing risk in one aspect of a project, like commercial viability, increases risk in another, like failing to address social needs. Just as society lacks consensus on of the public values of energy, the government lacks consensus on values with which to assess sociotechnical risks and rewards when technological variety and the budget limit investments.

Conclusion: Unique Challenges of Scaled-Up Investment and Policy Recommendations

The federal government faces constant calls for more energy R&D spending. Some merely support increased investment in specific technologies or a shift in federal energy priorities, but more researchers and policymakers desire massively scaled-up energy R&D spending, even a five- or ten- fold increase.[46,47] By the numbers, this scale-up seems possible compared to other massive federal R&D projects. Annual funding for energy R&D has never reached the same share of federal outlays or share of the GDP as either the Manhattan Project or the Apollo Program, both often pointed to as proof of the feasibility of massive federal investment programs.[48] However, energy R&D programs face unique challenges that cast doubts on the feasibility of a heavy scale-up and on the ability of such an undertaking to address energy needs.

First, R&D programs already struggle to balance competing long-term goals and values with short-term demands and needs. Increased funding cannot magically solve the tensions within the energy perspectives nor the social failures they cause. Second, federal R&D for energy projects face a more indefinite timeline than previous massive investment programs. Climate change and diversification for energy security seem less urgent given the perceived stable nature of the climate and energy delivery compared to the existential threats of World War II and the Cold War. Lacking urgency, citizens may not support the increased taxes or cuts to other programs necessary to fund the scale-up. Moreover, The Manhattan Project and Apollo Program had clear, relatively independent end goals, while changes in the energy system are multifaceted and may disrupt the infrastructure that underpins much of our social and economic lives. Finally, the importance of energy to American socioeconomic systems combined with continually changing energy needs necessitate a long-term R&D commitment. Federal spending on energy R&D has never reached the same annual levels of spending as Manhattan or Apollo, but cumulative energy R&D spending has already surpassed both.[49] If scaled up, the federal energy R&D program would have to sustain high

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Department of Energy's Research and Development Activities for Bioethanol," *Biotechnology Progress* 15 (1999): 817–827.

[43] Ibid., p. 818

[44] Ibid.

[45] Bozeman and Sarewitz, "Public Value Mapping and Science Policy Evaluation," 2011

[46] Nemet and Kammen."U.S. Energy Research and Development," 2007, 746–55.

[47] U.S. Library of Congress, *The Manhattan Project, the Apollo Program, and Federal Energy Technology R&D Programs,* by Deborah Stine, 2009.

[48] Ibid.

[49] Ibid.

levels of spending for far longer than either example. Looking at massive federal R&D projects of the past does not specify how massive federal energy R&D could address the unique and complex sociotechnical challenges entrenched in American energy systems.

As the calls for increased investments suggest, federally funded R&D will remain a key policy tool for fostering technological innovation and governing through energy challenges. However, without changes to the policies that guide federal investment, future investments of all sizes and purposes will continue to produce results that adapt slowly to change, fail to provide the most public benefit, and struggle with the social, political, and technological complexities discussed in this paper.

Moving forward on energy policy requires more than reaffirmation of the importance of federal funding and better understanding of energy frameworks. Policy must change to address the conflicts among the various framings of energy. An initial step would be a citizen-led, government-supported push for understanding and acceptance of the government's role in the marketability of energy technology and resources. Historically, energy has never been a purely free-market commodity. Initiatives like the Rural Electrification Administration influenced the market price and reach of energy even before the DOE.[50] Focused public outreach through citizen groups, federal agencies, universities, and research centers, and the hopefully resultant change in public support of government influence in energy markets, could over time lower the publics' expectation that the federal government view energy as a commodity and instead focus on the security, environmental, and justice framings wherein more scope for overlapping values and goals exists. Explicit public outreach would not only increase the political feasibility of increased R&D funding through increased public awareness of energy issues,[51] but it could also make that funding more effective by strengthening consensus on public values in the energy framings and, potentially, increase social willingness to bear the cost of the difficult decision-making necessitated by inevitable conflicts.

Changes in policy regarding allocation of energy R&D funding are also critical for increasing the effectiveness of federal investments. This paper has identified political, social, and technological restrictions on energy R&D investments returning social benefits. These restrictions in part stem from a lack of focus on the social aspects of energy, which results in poor incorporation of social science into most energy research. Policy changes aimed at focusing more research on the "socio" half of sociotechnical energy systems could help remove this barrier. A short review of current grants available through the DOE show that most preferred projects are highly technical and very few could be construed to include social science research.[52] To address this, the DOE should expand grant opportunities for interdisciplinary research teams investigating social impacts and trade-offs of current or developing energy technologies. For all funding opportunities, they should also require applicants to discuss broader social and environmental implications in addition to the technological merit and market feasibility of their projects, and then judge applications accordingly. The National Science Foundation's broader impacts criteria could be a model for this approach. Programs outside of the DOE, such as the National Science Foundation Science of Science and Innovation Policy Program and the National Science and Technology Council, should also support this effort. Energy-focused social science research could identify new energy needs, predict outcomes of trade-offs in energy technology and research, track social impacts of past government-supported energy products, and support the review of funding outcomes using qualitative assessment of social impacts of projects in addition to economic models. To use research to solve broad energy challenges, baseline understanding of all aspects of energy must be equally broad.

Since its founding, the DOE has demonstrated the potential to adjust its R&D funding to address emerging energy needs, reflecting a real effort to address long-term issues from multiple angles. The central challenge now is confronting the trade-offs and interdisciplinary influences inescapable in value-laden bureaucratic arrangements. To realize

[50] Tobey, Ronald C, *Technology as Freedom: The New Deal and the Electrical Modernization of the American Home* (Berkeley: University of California Press, 1997)

[51] Li et al., "Public support for reducing US reliance of fossil fuels," 2009.

[52] "Search Grants/ Agency: All Department of Energy," Grants.gov, accessed September 16, 2016, http://www.grants.gov/web/grants/search-grants.html

the potential of federal energy R&D programs, both government and society must tie the disparate energy perspectives into clear goals for investment that recognize contradictions, embrace overlap, and fit within the systems designed to govern complex sociotechnical issues.

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