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Report to Congressional Requesters

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DEPARTMENT OF
ENERGY

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Advanced Research
Projects Agency Could
Benefit from
Information on
Applicants' Prior
Funding

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December 2011



DEPARTMENT OF ENERGY

Advanced Research Projects Agency Could Benefit from Information on Applicants' Prior Funding

Highlights of GAO-12-112, a report to the Chairman, Committee on Science, Space, and Technology, and Subcommittee on Investigations and Oversight, Committee on Science, Space, and Technology, House of Representatives.

Why GAO Did This Study

The Department of Energy's (DOE) Advanced Research Projects Agency—Energy (ARPA-E)'s purpose is to overcome long-term and high-risk technological barriers in the development of energy technologies. Since 2009, ARPA-E has awarded \$521.7 million to universities, public and private companies, and national laboratories to fund energy research projects.

GAO was asked to examine: (1) ARPA-E's use of criteria and other considerations for making awards and the extent to which applicants identify and explain other private funding information; (2) the extent to which ARPA-E-type projects could have been funded through the private sector; and (3) the extent to which ARPA-E coordinates with other DOE program offices to avoid duplicating efforts. GAO interviewed ARPA-E program directors, award winners, and non-winners with characteristics similar to award winners. GAO also analyzed private venture capital funding data and spoke with venture capital firms.

What GAO Recommends

GAO recommends that ARPA-E consider providing applicants guidance with a sample response explaining prior sources of funding, requiring applicants to provide letters from investors explaining why they are not willing to fund proposed projects, and using third-party venture capital data to identify applicants' prior funding. ARPA-E commented on a draft of this report.

What GAO Found

ARPA-E uses four selection criteria, such as the potential impact of the proposed technology relative to the state of the art, and other considerations in awarding funds. Other considerations include balancing a variety of technology approaches and the likelihood the technology would be brought to market. GAO identified 18 out of 121 award winners through ARPA-E's first three funding rounds that had received some prior private sector investment, and ARPA-E took steps to identify and understand how this funding was related to proposed projects. Beginning with the third funding round, ARPA-E began requiring that applicants explain why private investors were not willing to fund proposed projects. However, ARPA-E did not provide applicants with guidance, such as a sample response, to assist them in completing this requirement, and responses were generally limited. Some applicants provided general information about prior research but did not specifically explain why private investors would not support their projects. When applicants provided little prior funding information, ARPA-E's program directors spent time and resources to determine the extent of such funding for proposed ARPA-E projects. One applicant included a letter from its venture capital investor to explain why the investor was not willing to fund the work proposed to ARPA-E, an approach the National Institute of Standards and Technology uses as a check in its funding applications for advanced research but that ARPA-E currently does not use. Also, ARPA-E officials said that they have considered but have not used venture capital data to identify applicants with prior private investors. Examining such data allowed GAO to quickly cross-check applicants' prior private funding.

GAO's review suggests that most ARPA-E projects could not have been funded solely by private investors. Private venture capital firms told GAO that, among other considerations, they generally do not fund projects that rely on unproven technologies and tend to invest in projects that can be commercialized in less than 3 years. Data from ARPA-E on award winners show that 91 out of 121 ARPA-E projects from the first three funding rounds had technological concepts that had not yet been proven in a laboratory setting. Also, nearly all of the ARPA-E award winners and applicants GAO spoke with estimated that their projects were at least 3 years away from potential commercialization. In addition, GAO found that few eligible applicants that were not selected for an award later secured private funding.

ARPA-E officials have taken steps to coordinate with other DOE offices to avoid duplication. For example, ARPA-E program directors told GAO they engage in outreach with officials from related DOE offices in advance of funding announcements to identify funding gaps in research. In addition, program directors have recruited officials from other DOE offices and the Department of Defense (DOD) to review ARPA-E applications. This cross-agency interaction may also reduce the potential for overlap in funding.

View GAO-12-112 or key components. For more information, contact Frank Rusco at (202) 512-3841, ruscof@gao.gov

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[issue date]

The Honorable Ralph M. Hall
Chairman
Committee on Science, Space, and Technology
House of Representatives

The Honorable Paul Broun, M.D.
Chairman
Subcommittee on Investigations and Oversight
Committee on Science, Space, and Technology
House of Representatives

U.S. energy consumption has increased by 20 percent over the past 20 years and is projected to continue to grow.¹ Volatile prices, global supply disruptions, and the impacts of energy use on climate and the environment have driven interest in reducing energy demand, improving energy efficiency, and expanding supplies with both renewable and traditional energy sources. In 2005, members of Congress asked the National Academies what actions federal policymakers could take to enhance the nation's science and technology efforts so that the United States could successfully compete, prosper, and be secure in the global community of the 21st century.² The National Academies compiled their findings and recommendations in a report that identified two key challenges: (1) creating high-quality jobs for Americans, and (2) responding to the nation's need for clean, affordable, and reliable energy.³ The report also highlighted the idea that scientific and technical innovations are key drivers of economic growth in the United States. Among the report's recommendations was the creation of an agency within DOE to sponsor high-risk energy research and development that industry by itself cannot or will not support in which success would provide dramatic benefits for the nation in meeting long-term energy challenges.

¹U.S. Energy Information Administration, Annual Energy Review 2009.

²The National Academies comprise four organizations: the National Academy of Sciences, the National Academy of Engineering, the Institute of Medicine, and the National Research Council that advise policymakers on scientific and technical matters.

³The National Academies, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (Washington, D.C. 2007).

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In 2007, the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (America COMPETES) Act established the Advanced Research Projects Agency-Energy (ARPA-E) within the Department of Energy (DOE) to overcome the long-term and high-risk technological barriers in the development of energy technologies.⁴ ARPA-E borrows from the Defense Advanced Research Projects Agency (DARPA) model, an agency created within the Department of Defense (DOD) in 1958 to direct and perform advanced research and development projects. As specified in statute, ARPA-E's program goals are to enhance U.S. economic and energy security through the development of certain energy technologies and to ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies.

Since first receiving an appropriation in 2009 in the American Recovery and Reinvestment Act of 2009, ARPA-E has awarded \$521.7 million to universities, public and private companies, and national laboratories to fund 181 projects that attempt to make transformational—rather than incremental—advances to a variety of energy technologies, including high energy batteries and renewable fuels.⁵ Award winners must meet cost share requirements, either through in-kind contributions or outside funding sources.⁶

ARPA-E is required by statute to achieve its goals through energy technology projects that, among other things, accelerate transformational technological advances in areas that industry by itself is not likely to undertake because of technical and financial uncertainty. At the same time, the Director of ARPA-E is required to ensure, to the maximum extent practicable, that ARPA-E's activities are coordinated with, and do not duplicate the efforts of, programs and laboratories within DOE and other relevant federal government research agencies. This report responds to your request that we examine ARPA-E awards. Our objectives were to examine: (1) ARPA-E's use of criteria and other considerations for making awards, and the extent to which applicants identify and explain other private funding information; (2) the extent to which ARPA-

⁴Pub. L. No. 110-69, § 5012 (2007).

⁵ARPA-E generally uses cooperative agreements to make funding awards, which involve the transfer of a thing of value to the recipient to carry out a public purpose authorized by law. Cooperative agreements differ from grants because substantial involvement is expected between ARPA-E and the recipient. ARPA-E uses similar funding agreements for national laboratories.

⁶The cost share requirement for award winners is generally at least 20 percent of total allowable costs although, under section 988(b)(3) of the Energy Policy Act of 2005, ARPA-E has reduced the cost share requirement for certain applicants, such as universities, to 5 percent or 10 percent in each funding round. Award winners' cost share must be provided by a non-federal source.

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E-type projects could have been funded through the private sector; and (3) the extent to which ARPA-E coordinates with other DOE program offices to avoid duplicating efforts.

To address these three objectives we reviewed ARPA-E applications and conducted interviews with applicants, award winners, representatives of venture capital firms and other experts, and with DOE and other federal agency officials. ARPA-E has released a total of four funding announcements—meaning the agency was accepting project proposals for a set period of time—in April 2009, December 2009, March 2010 and April 2011. Our review focused on ARPA-E's first three funding rounds, which had closed prior to the start of our review. The fourth funding round did not close until September 2011.⁷ ARPA-E awarded funds for 121 projects out of 4,788 applicants across the three funding rounds we examined. To address these three objectives we reviewed ARPA-E applications and conducted interviews with applicants, award winners, DOE officials, and representatives of venture capital firms, among other activities.

Specifically:

- To examine ARPA-E's use of criteria and other considerations for making awards we selected a nonprobability sample of 20 applications from the 4,788 applications in the first three funding rounds and reviewed these 20 applications. To examine the extent to which applicants identify and explain other private funding information we searched for evidence of prior private funding for all 121 award winners in VentureDeal, a venture capital database.⁸ As a result of our search we identified 18 award winners that had some prior private venture capital funding from the 121 award winners. We then reviewed the applications of these 18 award winners and interviewed their representatives.⁹
- To analyze the extent to which ARPA-E projects could have been funded through the private sector we analyzed data on the state of technology and potential time to commercialization for the 121 award winners from ARPA-E's first three funding rounds. In addition to the 121 award winners, we conducted structured interviews with 22 of 33

⁷In the fourth round of funding, ARPA-E awarded 60 projects out of 427 applicants.

⁸We were not able to verify the completeness of VentureDeal data, and there may have been ARPA-E award winners that had prior private funding that did not appear in these data. To compile data on venture capital funding, VentureDeal uses (1) Securities and Exchange Commission regulatory filings; (2) survey information collected directly from venture capital firms; (3) financial news media announcements and press releases from venture capital firms or recipient companies; and (4) local business journals.

⁹Eight of these 18 companies also appeared in the sample of 20 applicants that we selected to examine ARPA-E's use of criteria and other considerations for making awards.

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"contingently selected" applicants chosen by ARPA-E during its second and third funding rounds. Contingently selected applicants are those applicants that met ARPA-E's selection criteria but were ultimately not awarded funds.¹⁰ We also conducted structured interviews with a nonprobability sample of 13 award winners selected from ARPA-E's first three funding rounds and we spoke with the 18 ARPA-E award winners mentioned above that we identified through the VentureDeal database to discuss key differences between their prior research and their ARPA-E-funded projects.¹¹ We also conducted interviews with a variety of companies and individuals knowledgeable about research associated with ARPA-E-type projects, including six venture capital firms.

- To examine the extent to which ARPA-E coordinates with other DOE programs to avoid duplicating efforts we spoke with the ARPA-E program directors as well as officials from other DOE program offices, DARPA, and the DOE Office of Inspector General. We also asked award winners and contingently selected applicants to discuss their understanding of other potential sources of DOE funding for their projects.

We provide a more in depth discussion of our methods in appendix II.

We conducted this performance audit from November 2010 to December 2011 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

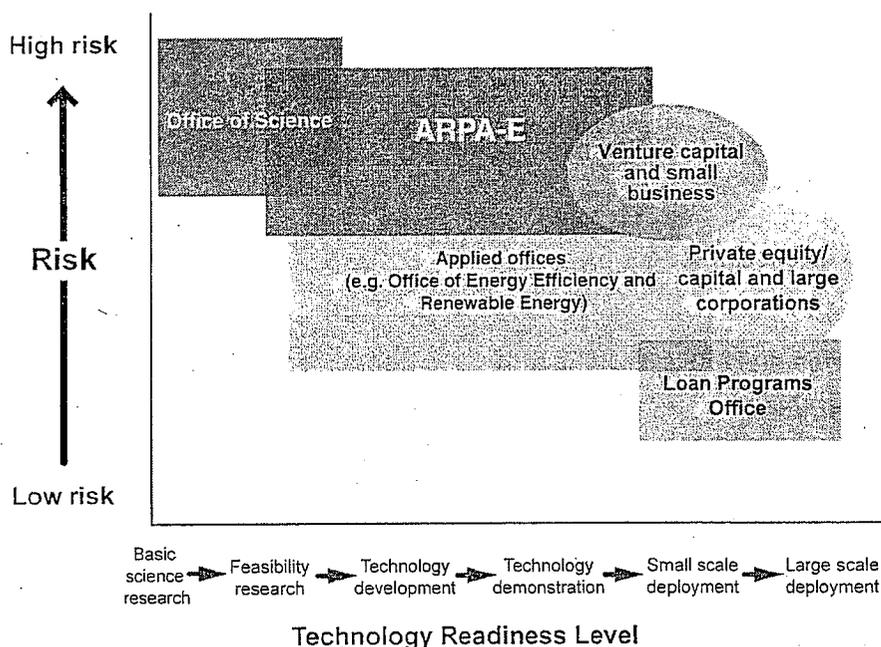
In 2005, the National Academies recommended to Congress the creation of an organization within DOE like DARPA. In 2007, the America COMPETES Act created a new agency within DOE called ARPA-E. In line with the National Academies' recommendation, the America COMPETES Act as amended directs ARPA-E to achieve its goals by identifying and promoting

¹⁰According to ARPA-E officials with whom we spoke, these applicants would have been selected for an award had additional funds been available. The remaining 11 contingently selected applicants did not respond to our requests for an interview.

¹¹Four of these 18 award winners also appeared in our nonprobability sample of 13 award winners.

revolutionary advances in fundamental and applied sciences; translating scientific discoveries and cutting-edge inventions into technological innovations; and accelerating transformational technological advances in areas that industry by itself is not likely to undertake because of technical and financial uncertainty. As such, ARPA-E officials told us that ARPA-E was designed to sponsor research beyond basic science, yet riskier than what the private sector alone or DOE's applied offices would support.¹² (See fig. 1). The National Academies recommended that ARPA-E should not perform research and development itself, but should fund it to be conducted by universities and others in the private sector. In 2009, the American Recovery and Reinvestment Act of 2009 appropriated \$400 million for ARPA-E.

Fig. 1 ARPA-E's Described Role within DOE and the Private Sector



Source: ARPA-E and GAO.

Note: Private sector groups are in ovals and DOE offices are in boxes. According to ARPA-E officials, higher risk research is less likely to be successful in being brought to market but may have greater potential benefits in increasing energy supplies and creating jobs. Technology Readiness Levels are used by DOE to categorize research according to its proximity to basic science or large scale deployment.

ARPA-E is an agency with fewer than 30 federal employees, and its 8 program directors, who are generally scientists and engineers, create and manage funding programs for the agency.

¹²DOE funds the development of energy technologies ranging from basic and applied energy research to loan guarantees for clean energy generation facilities. For example, DOE's Office of Science supports basic scientific research, including chemistry, biology, and materials sciences, as foundational research for a number of energy technologies. DOE's Office of Energy Efficiency and Renewable Energy applies established research to alternative and clean energy technologies, such as improving existing lithium ion batteries for use in electric or hybrid vehicles. DOE's Loan Programs Office offers loans to commercialize clean energy projects, such as wind farms.

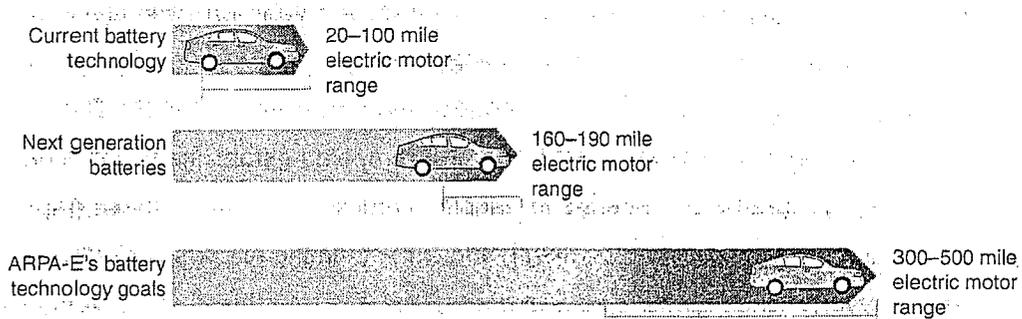
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ARPA-E's program development and award selection process takes 6 to 8 months from start to finish, which begins when the agency hires a program director for a 3-year term and tasks the program director with identifying a gap in energy technology research and developing a program to fill that gap. For example, ARPA-E's batteries for transportation program, called the Batteries for Electrical Energy Storage in Transportation (BEEEST) program, was established to fill a gap in existing federal research programs on batteries for electric vehicles. Identifying these gaps and designing the program involves research, consultation with scientific experts, including a workshop with outside experts, and internal discussion at ARPA-E. From this process, program directors develop funding announcements that describe the technical requirements specific to each program's technology area that applicants have to meet and the four criteria that ARPA-E uses in its selection process.¹³ The four criteria are:

- *Impact of the proposed technology relative to the state of the art.* The applicant must demonstrate the potential for a transformational—not incremental—advancement over current technologies. (See fig. 2.) More specifically, the applicant must demonstrate an awareness of competing commercial and emerging technologies and identify how its proposed concept/technology provides significant improvement over these other solutions.
- *Overall scientific and technical merit.* The applicant must demonstrate that the work is unique and innovative. The applicant must also demonstrate a sound technical approach to accomplish the proposed research and development objectives. The outcome and deliverables of the program, if successful, should be clearly defined. Specific technical requirements that are unique to each individual ARPA-E program funding announcement must also be addressed.
- *Qualifications, experience, and capabilities.* The applicant must demonstrate that it has the expertise and experience to accomplish the proposed project. In addition, the applicant must have access to all facilities required to accomplish the research and development effort.
- *Sound management plan.* The applicant must have a workable plan to manage people and resources. Major technical research and development risks should be identified. The schedule and budget should be reasonable.

¹³ARPA-E program directors developed funding announcements for six program technology areas that made up the agency's second and third funding rounds. (See table 1.)

Figure 2: Current Battery Range for Electric Vehicles and Goals of ARPA-E Research



Source: GAO.

ARPA-E employs the following three-stage application process:

- *Concept paper.* Applicants initially submit a 5 to 7 page abstract of their projects. Scientific experts from industry, government, and academia serve as reviewers.
- *Full application.* After reviews of the concept paper, ARPA-E encourages some applicants to submit full applications using ARPA-E's online application system. ARPA-E's current instructions request that applicants provide, among other things, information about other prior, current, and pending public and private sources of funding, as well as why other funding sources are not willing to fund the projects. Full applications are then reviewed by leading scientific experts in the field, who evaluate them against the four criteria and assign numerical scores.
- *Reply to reviewer comments.* After assessing the full applications, reviewers provide comments and questions to the applicants, who then have the opportunity to respond.

The applications with the reviewers' comments are forwarded to a three-person panel beginning the next three phases of ARPA-E's award funding process, which are as follows:

- *Selection.* The three-person panel, usually chaired by the relevant program director, considers the reviewers' comments and numerical scores, and recommends applications to award. The final decisions on which applicants to select are made by the selecting official, which is usually the ARPA-E Director.
- *Award negotiations.* Negotiations proceed for approximately 2 months. Program directors work closely with the award winners to set up a project plan with technical

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milestones that are to be met during the funding of the award, which are planned to last between 2 and 3 years. Funds are awarded following the negotiations.

- *Monitoring.* ARPA-E monitors and supports the project through quarterly reviews and site visits. After about 1 year, the agency decides whether to continue or terminate the project if the agreed to milestones are not met.

In April 2009, ARPA-E started its funding award process by releasing a funding announcement soliciting proposals to all energy ideas and technologies. Following the review process, 36 projects were awarded funds after being selected from 3,700 applications that spanned the technology areas of 10 programs. ARPA-E released additional funding announcements in December 2009, March 2010, and April 2011. (See table 1.) Money appropriated by the American Recovery and Reinvestment Act of 2009 funded ARPA-E's first three funding rounds. After receiving an appropriation in DOE's fiscal year 2011 appropriations act, ARPA-E announced a fourth round of funding in April 2011.

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Table 1: ARPA-E Funding Announcement Program Technology Areas

	Funding announcements			
	1 April 2009	2 December 2009	3 March 2010	4 April 2011
Program (number of projects)	Biomass Energy (5)	Batteries for Transportation (10)	Grid-Scale Electricity Storage (12)	Advanced Thermal Storage (15)
	Building Efficiency (3)	Materials for Carbon Capture (15)	Building Efficiency (16)	Electricity Network Integration (14)
	Carbon Capture (5)	Electrofuels (13)	Electrical Power Electronics (14)	Plants Engineered to Replace Oil (10)
	Conventional Energy (1)			Rare Earth Alternatives for Energy Technologies (14)
	Direct Solar Fuels (4)			Solar Electrical Power Technology (7)
	Energy Storage (6)			
	Energy Efficient Water Purification (1)			
	Renewable Power (4)			
	Vehicle Technologies (5)			
	Waste Heat Capture (2)			
Total Funding	\$150 million	\$113 million	\$94 million	\$156 million

Source: GAO analysis of ARPA-E data.

Note: The table shows 116 total projects funded by ARPA-E in its first three funding rounds. In August and September 2010 ARPA-E selected 5 additional projects for funding raising total funded projects over these three rounds to 121. These 5 projects were in the following program technology areas: Building Efficiency, Vehicle Technologies, Renewable Power, and Energy Storage. Funds awarded across the four funding rounds totaled \$521.7 million. For further details on ARPA-E's program technology areas, see appendix III.

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In Addition to Its Selection Criteria ARPA-E Also Considers Applicants' Prior Sources of Private Funding, However Most Award Winners We Reviewed Did Not Explain This Information

In addition to its four criteria, ARPA-E gives program directors discretion to use additional considerations to award funds to projects, including whether ARPA-E applicants received private funding. Most ARPA-E award winners did not receive prior private funding, but for those that did, most award winners we reviewed did not explain these funds.

ARPA-E Program Directors Use the Agency's Four Selection Criteria and Other Considerations to Select Projects

Of the 20 applications we reviewed for award selection criteria, all contained supporting information addressing the agency's four criteria. In our analysis of the ARPA-E reviewers' evaluations from these 20 applications, we noted regular assignment of numerical scores rating applicants on the extent to which they met the criteria. All eight ARPA-E program directors told us they considered, or if they were recently hired, will consider all four criteria, but several focused more heavily on two criteria—the impact of the proposed technology relative to the state of the art and its overall scientific and technical merit.

In addition to the numerical scores applicants receive on the extent to which they met the four selection criteria, program directors told us the agency gives them the ability to take other qualitative considerations into account when awarding funds. One of those considerations is to fund a broad range of potential technological solutions with varying levels of risk in solving a given technical problem. Two program directors selected projects to reflect a variety of technologies, and they told us they believe that this approach increases their program's overall chance of success. Specifically, one program director told us he chose projects that employed a variety of new battery technologies, which should increase the likelihood that at least one of them will work. This program director also chose some battery projects with much higher potential storage capacity but with a lower probability of success in achieving project milestones

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and in ultimately being brought to market. In those cases, ARPA-E provided smaller awards to the projects with the lower probability of success.¹⁴

During the selection process, several program directors also told us they considered the applicants' proposed project scope and duration, requested funding levels, and technical milestones and negotiated to revise these, if necessary, to better align applicants' projects with ARPA-E's program goals. Based on our review of ARPA-E data from the first three rounds of funding, the agency reduced requested award amounts by 5 percent or more on 31 out of 121 projects, for a total of \$59 million below total requested award amounts for these rounds. When ARPA-E makes these kinds of adjustments, the agency may also reduce the proposed project scope to fund only what the program directors consider to be the transformational part of the project and to avoid funding applied research or development work that would be outside ARPA-E's program goals. For example, the agency reduced the award amount and proposed project scope for an energy storage technology project designed to improve energy storage on the electrical grid. The project proposal initially requested nearly \$5 million to demonstrate the technology at nearly full scale. During award negotiations, ARPA-E reduced this amount to \$750,000 to focus the project only on smaller scale development and testing of the technology. ARPA-E officials told us the larger-scale demonstration could likely be funded by the private sector.¹⁵

ARPA-E Also Considers Applicants' Prior Sources of Private Funding, but Most Award Winners We Reviewed Did Not Explain This Information

When making award decisions or adjusting the scope of proposed projects, ARPA-E program directors may also consider the identification in applications of sources of private funding and the extent to which that funding might support the proposed projects. This information can help provide program directors with assurance that ARPA-E funds do not overlap with private investment. During the first two funding rounds ARPA-E required that applicants identify

¹⁴All the ARPA-E program directors who had finished their selection process at the time we spoke with them told us that for a project to have a high risk level is not one of their other considerations when evaluating projects, but that the nature of the agency's work has the effect of ultimately funding high risk projects. Several program directors said that a high risk level is inherent in projects with high technological impact.

¹⁵Alternatively, ARPA-E can consider only funding a specific part of research that must be proven before additional work is funded. For example, one applicant's carbon capture project involved a new means of solidifying carbon dioxide. The program director told us he wanted the applicant to first demonstrate that the approach would work, so he reduced the initial amount of funding by over 60 percent.

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relevant private investors if the applicant believed these funds were related to the proposed project. Of the 18 applications we reviewed from award winners that we identified as having received private venture capital, 14 applied during ARPA-E's first and second funding rounds. Most of these award winners did not explain why investors were not willing to fund proposed work. ARPA-E program directors and an ARPA-E official, speaking on behalf of the agency, told us they took additional steps to clarify outstanding prior funding questions when ARPA-E was aware that applicants had received private sector funding. For example, one applicant we reviewed from the first funding round had previously received substantial private funding for work that appeared very similar to its proposed ARPA-E project. ARPA-E officials told us they were initially unable to determine why the private investor was not willing to also fund the proposed ARPA-E project and that the company's application did not include an explanation. ARPA-E officials told us that getting this information required them to draft a series of direct and detailed questions that elicited several pages of written responses from the applicant. ARPA-E officials also told us they conducted multiple rounds of written and verbal follow-up with the applicant and the private investor. Through these efforts, ARPA-E determined that the technological risks of key parts of the project were too high for the private investor and therefore decided to fund the research.¹⁶

Because ARPA-E officials recognized the need for applicants to provide better prior funding explanations, beginning with its third funding announcement, the agency required applicants to explain why proposed work was not sponsored internally if the applicant was a large company, or why private investors were not willing to support the project if the applicant was a small business or start-up company. ARPA-E did not provide guidance on how applicants should respond to this additional requirement by, for example, providing a sample response. Of the 18 ARPA-E award winning companies, four applied during the third funding round, and these companies provided a range of information in response to this new requirement in their funding applications. Two explained how ARPA-E funds would allow them to go beyond currently funded work but did not provide reasons why investors were not willing to support proposed work. Another wrote only that the ARPA-E research was too risky for the company's private investors. One application contained an explanation outlining the specific research its private investors were and were not willing to fund. This applicant explained that private funds were

¹⁶ ARPA-E program directors told us they also conducted review efforts in a number of other cases where it was initially unclear why other entities would not provide additional funds to ARPA-E award winners.

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directed toward lower risk and higher cost technologies.¹⁷ This application also included a letter from the company's venture capital investors that explained which parts of its research the investors were planning to continue funding and which research was too risky for them, although not requested by ARPA-E. This letter provided additional third party support for the funding information in the application. Officials from the National Institute of Standards and Technology's (NIST) Technology Innovation Program told us they request that applicants provide letters from private investors to document why applicants' projects could not be privately funded.¹⁸

When we followed-up with the 18 companies, they were generally able to explain to us why their private investors were not willing to undertake the additional risk and uncertainty associated with the proposed projects.¹⁹ When we examined the data in the VentureDeal database for a number of applicants, it allowed us to quickly cross-check the names of prior private investors that applicants reported to ARPA-E. ARPA-E officials said that they have not used such data for these purposes but that they have considered it. Without an examination of outside venture capital data on its applicants, the agency may be missing a time-saving opportunity to check information on private funding provided in applications, especially in instances where applicants may not have been thorough in their explanations. We found a number of readily available subscription-based venture capital data services that provided company names, transaction amounts, and funding purposes. We found that the web-based VentureDeal database matched formats and data available from other venture capital data services.

Most ARPA-E Projects Likely Could Not Have Been Funded Solely by Private Investors

Our review suggests that most ARPA-E-type projects could not be funded solely by private investors. Private venture capital firms told us that, among other considerations, they generally do not invest in projects that cannot be commercialized in less than 3 years. Nearly all of the 13 ARPA-E award winners and most of the 22 of the contingently selected applicants we spoke

¹⁷ARPA-E officials told us that they funded only the parts of this project that were too risky for the private investors.

¹⁸According to NIST, the Technology Innovation Program funds advanced research in areas of critical national need including healthcare, robotics, and civil infrastructure.

¹⁹Most of these explanations related to the risk or uncertainty associated with the proposed projects.

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with estimated that their projects were 3 or more years away from a potential market-ready product (i.e. commercialization). In addition, we found that only 2 of the 22 contingently selected applicants we spoke with that met ARPA-E's selection criteria but were not selected for an award subsequently secured private funding.

Venture Capitalist Generally Do Not Fund Projects That ARPA-E Looks to Fund

The representatives we spoke with from six venture capital firms identified three factors that limit the general availability of venture capital funding for new energy technologies. These factors were consistent with data we analyzed for the 121 award winners from ARPA-E's first three funding rounds, the sample of 13 award winners we interviewed from these funding rounds, and the 22 contingently selected applicants we interviewed.

First, venture capital firms generally do not fund projects that rely on unproven technological concepts or lack working prototypes demonstrating the technology. A number of venture capital firm representatives told us that they are generally not willing to fund the applied scientific research sometimes required by ARPA-E type projects. Projects they fund generally focus on developing technologies based on known scientific principles. Data from ARPA-E on award winners show that 91 out of 121 ARPA-E projects from the first three funding rounds had technological concepts that had not yet been demonstrated in a laboratory setting.²⁰ According to a recent report from the American Energy Innovation Council, private investors consider these projects too high risk for investment, even for concepts with promising technological potential.²¹ Most of the contingently selected applicants we spoke with—17 out of the 22—told us they were unlikely to receive funding from other sources for their proposed projects because of high levels of scientific uncertainty, an unavailable or undeveloped market, or a lack of a working prototype. For example, one such applicant said that he only had a computer model suggesting that his high-efficiency air conditioning device would work, which was insufficient to convince potential private investors. In addition, many of the ARPA-E award winners we

²⁰These data showed that most ARPA-E award winners were at or below "technology readiness level" (TRL) 3. TRL 3 represents a level where potential technologies are still unproven.

²¹*Catalyzing American Ingenuity: The Role of Government in Energy Innovation* (Sept. 2011). The American Energy Innovation Council is a bi-partisan group of American business leaders.

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surveyed also recognized the inherent uncertainty in their research; 5 of the 13 told us that their projects had a fairly low probability of success.²²

Second, venture capital firms seek more rapid returns on investment and closely analyze a project's potential return on investment over time, which influences their decisions to invest in projects that are in later stages of development and closer to commercialization. Venture capital firm officials told us that they focused closely on the timeliness of investment returns, with one firm noting that the industry tended to invest in technologies that could be commercialized in less than 3 years and that would potentially exhibit exponential market growth in approximately 5 to 7 years. However, we found that nearly all of the ARPA-E award winners and most contingently selected applicants we spoke with estimated that their projects were 3 or more years away from potential commercialization.²³ For example, 12 out of 13 ARPA-E award winners estimated that it would take at least 3 years for their ARPA-E projects to reach the commercialization stage with ARPA-E funding.²⁴ Had they not received ARPA-E funding, most of these award winners—10 out of 13—told us they either would not have pursued their ARPA-E project, or that they would not have been able to develop a commercial product in less than 10 years. At the same time, 18 out of 22 ARPA-E contingently selected applicants estimated it would take at least 3 years for their projects to reach commercialization if they had been able to secure funding for the proposal they submitted to ARPA-E.

Third, venture capital firms may not be comfortable investing in new energy technologies, noting the historical lack of successful venture capital investments in these types of projects. Venture representatives said that venture firms were more comfortable investing in software companies or other businesses with higher potential profit margins and less costly product development than new energy technologies. One venture representative noted that his firm looked to invest in products with potential gross profit margins of 50 percent or more. In addition, these

²²The 18 award winners we identified as having received prior private venture capital told us they were generally able to pursue the development of energy technologies with greater scientific or technical uncertainty with the ARPA-E funding than what they were working on with their private funding. See appendix IV for more detail on these companies' prior privately-funded research.

²³Based on the initial testing of our questions, we determined that these estimates may be optimistic, given that respondents are invested in attempting to bring a technology to market as soon as possible.

²⁴For the 12 award winners, 6 estimated their projects would take 3 to 5 years to reach commercialization, and the remaining 6 estimated their projects would take more than 5 years to do so.

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representatives noted that it is difficult for new advanced energy technologies to compete with well-established and low margin traditional sources of energy like natural gas. Venture representatives also noted that venture firms had become more risk averse and reluctant to fund new energy technologies after lackluster investment returns have made the venture industry more aware of the challenges associated with investing in unproven energy technologies.

While venture capital firms generally do not fund projects that ARPA-E looks to fund, our work suggests that receiving ARPA-E project funding may have a positive effect on some award winners' ability to attract follow-on funding from the private sector for their ARPA-E work. For example, ARPA-E's data indicate that 18 out of 121 ARPA-E award winners from ARPA-E's first three rounds of funding had received private sector funding totaling \$318 million after receiving ARPA-E funding.²⁵ In some cases, award winners received private follow-on funding immediately after receiving ARPA-E funding. A number of the award winners we spoke with stated that, given the highly competitive nature of the program, receiving ARPA-E funding served as a "stamp of approval" to venture capital or other private firms.²⁶ These award winners told us that an ARPA-E award served as a signal of scientific and financial approval for potential investors. Economists call this rapid follow-on private funding a certification effect, which may explain the experiences of some of these award winners.²⁷ This effect suggests that public awards address information gaps that might have otherwise precluded private investment. Some award winners and economists we spoke with told us that the government was suited to identifying technical risks because of its ability to draw on the expertise of many scientific reviewers, while venture firms may not have the scientific expertise on hand to fully understand potential investments. Furthermore, economic literature suggests that the certification effect may be particularly relevant in the high-technology industries where the venture capital community plays an important role and in which traditional financial measures of risk and

²⁵A number of these 18 award winners with follow-on funding were part of the 18 companies we identified as having received private funding prior to ARPA-E.

²⁶These award winners included those that had prior venture funding as well as the others we interviewed.

²⁷See Andrew A. Toole, Calum Turvey. "How does initial public financing influence private incentives for follow-on investment in early-stage technologies?" *Journal of Technology Transfer*, 34: 43-58 (2007). See also Josh Lerner. "The Government as Venture Capitalist: The Long-Run Impact of the SBIR Program," *Journal of Business*, vol. 72, no.3, 285-318 (1999).

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returns on investments may prove insufficient.²⁸ Appendix IV has more information on the difference between research funded by selected award winners' prior investors and ARPA-E funded work.

Few Contingently Selected Applicants Found Funding From Private Investors or Public Sources

Eighteen of the 22 ARPA-E contingently selected applicants we interviewed sought funding after being turned down for ARPA-E funds. Of the 18 that sought funding elsewhere, 13 submitted project proposals to government sources, such as other DOE offices, the National Science Foundation, or nonprofit academic research institutes, and the remaining 5 submitted proposals to private investors such as venture capital firms.²⁹ As of September 2011, we found that 2 out of the 22 contingently selected applicants secured funding from venture capital firms for work that was very similar to their ARPA-E project proposals.³⁰ We also found that 4 contingently selected applicants secured funding from a government or nonprofit source for their projects.³¹ In addition, we found that most contingently selected applicants modified their ARPA-E project proposals to attract subsequent funding for their projects by reducing the scope of their proposal or by focusing on more basic science research. For example, the 4 contingently selected applicants that secured funding from a government or nonprofit source modified their APRA-E proposals to be more focused on basic science research, rather than on developing a commercial technology. In addition, one of these applicants told us that the funding will allow them to continue exploring fundamental materials science rather than developing a product. Also, many contingently selected applicants and award winners said that other government sources were limited. Some noted that Small Business Innovation Research (SBIR) grants would not allow them to make as much progress as larger ARPA-E awards.³² Finally, a number

²⁸Lerner 1999.

²⁹One of the 5 contingently selected applicants that sought funding from a private investor also sought public funding.

³⁰In addition, our review of venture capital funding data for the other 11 contingently selected applicants with whom we did not speak did not show that any had received venture capital funding since not being awarded ARPA-E funds.

³¹Three contingently selected applicants that submitted proposals to government or non-profit sources were still awaiting responses.

³²Federal agencies that have budgets in excess of \$100 million for research conducted by others (extramural research) are required to use 2.5 percent of these budgets to establish and operate a Small Business Innovation Development program. The program is intended to stimulate technological innovation, use small businesses to meet federal research and development needs, foster and encourage participation by minority and disadvantaged persons in technological innovation, and increase private sector commercialization of innovations derived from federal

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of others mentioned that military funding agencies were not as focused on developing low-cost technologies with broader market appeal, because aerospace or military applications do not need to achieve the same low costs and market appeal as consumer or commercial applications.

ARPA-E Officials Have Taken Steps to Coordinate with Other Department of Energy Offices in Advance of Awarding Funds

According to ARPA-E officials and documents, agency officials have taken steps to coordinate with other DOE offices in advance of awarding ARPA-E funds to help avoid duplication of efforts. These coordination efforts can be categorized into three areas:

Pre-funding coordination. ARPA-E officials told us that program directors engage with officials from related DOE offices in advance of announcing the availability of ARPA-E funds. Early in the development of a funding announcement, ARPA-E program directors told us they conduct outreach with industry, academic, and government officials both inside and outside of DOE in an attempt to identify funding gaps related to the technology they wish to develop. For example, by doing such outreach, one program director determined that there had been little funding at DOE or elsewhere for lithium air or lithium sulfur batteries, which have the potential to last significantly longer than existing lithium ion batteries. Program directors also hold workshops and invite relevant participants, including those from other DOE offices and from other federal agencies, to identify technologies that have little to no existing research funding but that have transformational potential. ARPA-E officials told us that directors use the workshops and other meetings to identify research areas that other DOE offices are not working on, and the other DOE officials provide insights on funding areas where they are not active. For example, one of these ARPA-E program directors told us that he met with officials from DOE's Office of Electricity Delivery and Energy Reliability and the Solar Energy Technologies Program within the Office of Energy Efficiency and Renewable Energy (EERE) before announcing available funds for the electrical power electronics funding announcement.³³ According to this program director, this coordination helped him identify that there had been little funding for the development of magnetic devices for use in electrical power electronics. He ultimately designed

research and development. Eleven federal agencies participate in the SBIR program, with \$16 billion awarded to date. Initial SBIR awards normally do not exceed \$150,000 and are usually for a period of 6 months.

³³Electrical power electronics modify electrical energy (i.e., change its voltage, current or frequency) and can be found in applications like lighting, motors, and electric vehicles.

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the ARPA-E electrical power electronics funding announcement to focus, in part, on the development of improved magnetic devices because of the lack of funding elsewhere.

In addition to inviting officials from other DOE offices to ARPA-E workshops, program directors told us they also engage with other DOE officials in other ways, both formally and informally. The program director responsible for ARPA-E's work on advanced batteries said that he was a member of DOE's Energy Storage Technology Development Team and regularly met with other officials who are engaged in applied battery research. This director said that it had become clear that DOE's Vehicle Technologies Program will continue to focus on incremental improvements to existing lithium ion battery technologies that are currently on the market, while ARPA-E will fund newer, alternative battery technologies. Other program directors told us that they have regular discussions with counterparts within DOE to avoid duplicating efforts, although through other means than a formal committee.

Coordination of application reviews. Some ARPA-E program directors told us that they have recruited officials from other DOE offices to review applications submitted to ARPA-E and that these officials made up as many as one-third of the reviewers for one director. These application reviewers rate and recommend proposals for potential ARPA-E funding. ARPA-E program directors told us that these DOE reviewers help them stay aware of the types of projects that other DOE offices are funding. For example, according to one program director, DOE reviewers indicated on a number of occasions that an ARPA-E advanced battery applicant would be better suited for funding under DOE's Vehicle Technologies Program because it was for a more developed technology. ARPA-E has also used application reviewers from other federal agencies, such as the Department of Defense. One program director told us that these reviewers have also helped avoid funding projects similar to those potentially funded elsewhere.

Official DOE coordination groups. ARPA-E is also a participant in DOE's SunShot Initiative within the Solar Energy Technologies Program. The SunShot Initiative is an effort to coordinate solar energy research across DOE's Office of Science, four national laboratories, the National Science Foundation, and ARPA-E, with the goal of achieving costs of \$1 per watt for solar-generated electricity. One ARPA-E program director is a member of the SunShot Initiative advisory board and therefore able to coordinate ARPA-E solar-related activities with other

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SunShot Initiative members. SunShot Initiative officials told us that DOE plans to make it a model for DOE's internal coordination efforts and that DOE hopes to expand the approach to other research areas.³⁴

Additionally, the ARPA-E Director created the Panel of Senior Technical Advisors (PASTA), which is a group of high-level DOE managers that meet periodically to discuss current and future DOE research efforts. ARPA-E officials told us that PASTA is an attempt to avoid duplicating efforts within DOE. PASTA meeting attendees have included officials from DOE's applied and basic science offices.

We were not able to directly evaluate the effectiveness of ARPA-E's efforts to coordinate with other DOE offices. Nevertheless, we found that based on our interviews with ARPA-E award winners and contingently selected applicants, four award winners and two contingently selected applicants had received prior funding from other DOE offices.³⁵ According to these award winners and contingently selected applicants the prior funding was either for more proven technologies or was focused on more basic or foundational research than was the ARPA-E funded project.

Conclusions

ARPA-E recognizes the need to ensure that the agency is not funding projects that would be otherwise funded by the private sector, and has taken steps to get information from applicants on their other sources of funding. The agency has also taken steps to coordinate with other DOE offices in advance of awarding ARPA-E funds. However, for the applications we reviewed, we found that ARPA-E's current funding announcements have generally yielded limited information from applicants that had prior sources of private funding. Where applicants provided little information, ARPA-E's program directors spent time and resources to determine the extent

³⁴In addition, SunShot Initiative program officials told us they are trying to share elements of ARPA-E's selection process with other offices within DOE—current DOE funding announcements generally take 15 months to carry out, compared with 6 to 8 months for ARPA-E. For example, ARPA-E officials also told us that DOE's Energy Efficiency and Renewable Energy office is adopting their online application system because of its advantages over paper-based systems.

³⁵These award winners included those in our nonprobability sample of 13, as well as the 18 we identified with VentureDeal data.

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of such funding for projects related to or similar to the applicants' proposed ARPA-E projects. The agency's requirements for information on private sector funding could be improved. For example, ARPA-E does not provide guidance to applicants, such as a sample response, on how to meet its information requirement on prior private funding. An approach used by another federal program that funds advanced research is for applicants to provide letters from private investors to document why their projects could not be privately funded. This approach was used by one ARPA-E award winner, who included a letter from the company's venture capital investors to explain why the investors were not willing to fund the project proposed to ARPA-E. Also, ARPA-E officials said that they have not used venture capital data to identify applicants with prior private investors and to check information applicants provide to them, but that they have considered doing so. Examining such data allowed us to quickly cross-check applicants' self-reported prior private funding. Without additional tools to better understand prior private funding, ARPA-E program directors will continue to spend time and agency resources taking additional steps to clarify prior private funding and may miss opportunities to avoid duplication with private investors.

Recommendation for Executive Action

To ensure that ARPA-E uses a more complete range of methods to ensure that limited federal funds are targeted appropriately, we recommend that the Secretary of Energy consider taking the following three actions:

- provide guidance with a sample response to assist applicants in providing information on sources of private funding for proposed ARPA-E projects.
- require that applicants provide letters or other forms of documentation from private investors that explain why investors are not willing to fund the projects proposed to ARPA-E.
- use venture capital funding databases to help identify applicants with prior private investors and to help check information applicants provide on their applications.

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Agency Comments and Our Evaluation

We provided a copy of our draft report to ARPA-E for review and comment...

As agreed with your offices, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the report date. At that time, we will send copies of this report to the appropriate congressional committees, the Secretary of Energy, and other interested parties. In addition, the report will be available at no charge on the GAO Web site at <http://www.gao.gov>.

If you or your staffs have any questions about this report, please contact me at (202) 512-3841 or ruscof@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made major contributions to this report are listed in appendix V.

Frank Rusco (signed)

Director, Natural Resources and Environment

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Appendix I: Comments from ARPA-E

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Appendix II: Scope and Methodology

To examine ARPA-E's use of criteria and other considerations for making awards and the extent to which applicants identify and explain other private funding information, we reviewed 20 applications drawn from a nonprobability sample of the 4,788 applicants ARPA-E received during its first three funding rounds. We selected applications from a range of ARPA-E technology program areas to which the applications were submitted and applicant institution types (e.g., small company, university). Because we selected a nonprobability sample of applications to review, information we collected cannot be generalized to all applicants; however, it provided us with an understanding of ARPA-E's criteria and other considerations for making an award. We also interviewed and reviewed the applications from our sample of 18 award winners, which were private companies that we identified as having received funding from private investors prior to receiving an ARPA-E award. We identified these 18 companies by searching for evidence of prior private funding for the 121 award winners in the VentureDeal venture capital database.³⁶ In our review of these applications we focused on the extent to which applicants disclosed prior private funding.³⁷ We also spoke with all eight ARPA-E program directors to discuss ARPA-E's process for making awards and managing projects of award winners.

To analyze the extent to which ARPA-E projects could have been funded through the private sector, we conducted three sets of interviews with ARPA-E applicants and award winners.

Specifically:

- We conducted structured interviews with 22 of the 33 contingently selected applicants that ARPA-E encouraged to submit full applications during its second and third funding rounds.³⁸ Each of the contingently selected applicants fulfilled ARPA-E's selection criteria, had the same characteristics as ARPA-E award winners, and, according to

³⁶VentureDeal is a company that maintains data on private venture capital funding. The VentureDeal database only includes businesses and does not include data on venture capital funding secured by universities or national laboratories. However, according to a VentureDeal official, universities and national laboratories are not likely to directly receive venture funding. In addition, we were not able to verify the completeness of VentureDeal data, and there may have been ARPA-E award winners that had prior private funding that did not appear in these data. We identified 1 of these award winners through an examination of ARPA-E data.

³⁷Eight of these 18 companies also appeared in the sample of 20 applicants that we selected to examine ARPA-E's criteria for making awards.

³⁸The remaining 11 contingently selected applicants did not respond to our requests for an interview.

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ARPA-E officials with whom we spoke, would have been selected for an award had additional funds been available.³⁹ This approach allowed us to consider the potential of ARPA-E-type projects to receive private funding.

- We conducted structured interviews with a nonprobability sample of 13 award winners selected from ARPA-E's first three funding rounds.⁴⁰ We selected subjects for this sample across a range of ARPA-E award winner characteristics including the technology program area for which an award winner received funding, the stage of development of an award winner's project, and an award winner's type of institution (e.g., small company, university). Because this was a nonprobability sample, the information from these structured interviews cannot be generalized to all award winners but can provide examples about award winners' experiences. We conducted content analyses⁴¹ of the award winners' and contingently selected applicants' interview responses to quantify issues such as the ability of each group to secure private sector funding for ARPA-E-type projects.⁴²
- Third, we spoke with the 18 ARPA-E award winners we identified through the VentureDeal database to discuss key differences between their prior research and their ARPA-E-funded projects.⁴³

We also conducted interviews with a variety of companies and individuals knowledgeable about research associated with ARPA-E-type projects, including: six venture capital firms⁴⁴ and the National Venture Capital Association (NVCA), a trade association, to determine the availability of private capital for ARPA-E-type projects and the criteria venture capital firms apply in making

³⁹We spoke with one applicant twice because the applicant applied for two different projects. For each of the 33 contingently selected applicants, we also searched for entries in the VentureDeal database to determine if any had received private venture capital funding prior to and following ARPA-E's selection process.

⁴⁰We selected 15 award winners as part of our nonprobability sample but 2 award winners did not respond to our interview requests.

⁴¹Content analysis is a systematic research method for analyzing textual information in a standardized way that allows evaluators to make inferences about that information.

⁴²We conducted pre-tests of our structured interview questions with three award winners and three contingently selected applicants to ensure that the questions were understandable and unbiased.

⁴³Four of these 18 award winners also appeared in our nonprobability sample of 13 award winners.

⁴⁴These firms were Khosla Ventures; Kleiner, Perkins, Caufield, and Byers; U.S. Venture Partners; Rockport Capital; Mohr-Davidow Ventures; and Polaris Ventures. We selected these venture capital firms because they were knowledgeable of ARPA-E-funded companies according to NVCA.

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their investment decisions; two additional public companies that were awarded ARPA-E funding to discuss the ability of a public company to internally fund research⁴⁵; and three economists to discuss the role and effectiveness of government-funded research and development of technology.⁴⁶

To examine the extent to which ARPA-E coordinates with other DOE programs to avoid duplicating efforts, we spoke with the ARPA-E program directors as well as officials from other DOE program offices including the Office for Energy Efficiency and Renewable Energy (EERE) and the Office of Science. In addition, we met with officials from the SunShot Initiative, which is a collaboration between EERE, the Office of Science, and ARPA-E to make solar energy technologies cost-competitive with other forms of energy. We also spoke with officials from DARPA and the DOE Office of Inspector General. During our interviews with the award winners and contingently selected applicants previously mentioned, we asked them to discuss their understanding of other potential sources of DOE funding for their projects.

To assess the reliability of data from ARPA-E and VentureDeal, we reviewed relevant documentation and interviewed key data system officials at ARPA-E and VentureDeal and determined that data were sufficiently reliable for the purposes of this report.

We conducted this performance audit from November 2010 to December 2011 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

⁴⁵These two companies did not appear in our earlier samples.

⁴⁶We selected these economists based on their publication of literature on the role and effectiveness of government funded research.

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Appendix III: ARPA-E Program Technology Areas

Funding Round 1

- **Biomass Energy**—Biomass energy projects focus on means to convert crops, along with plant waste from other industrial processes, into energy through chemical, biological, or thermal techniques.
- **Building Efficiency**—Building efficiency projects focus on technologies that heat, power and maintain buildings.
- **Carbon Capture**—Carbon capture and sequestration projects seek to create new methods to prevent the release of carbon dioxide into the atmosphere from traditional fossil fuel sources such as coal, natural gas, and petroleum.
- **Conventional Energy**—Conventional energy projects seek to significantly increase the efficiency of traditional fossil fuel power production and reduce waste generated from this use.
- **Direct Solar Fuels**—Direct solar fuel projects seek to utilize photosynthetic microorganisms to produce liquid fuels and fuel precursors directly from solar energy.
- **Energy Storage**—Energy storage projects seek to revolutionize battery, capacitor and other energy storage methods for significantly improved efficiency.
- **Energy Efficient Water Purification**—Water technology projects seek to reduce the water intensity of the electricity and fuel sectors and, reciprocally, to reduce the energy intensity of the water sector.
- **Renewable Power**—Renewable power projects focus on innovative technologies in several sustainable energy areas such as extremely efficient photovoltaic solar collectors, wind turbines and geo-thermal energy.
- **Vehicle Technologies**—Vehicle technology projects seek to advance efficiency in vehicles through technologies like new hybrid engines to those that convert on-board waste-heat to electricity.
- **Waste Heat Capture**—Waste heat capture projects seek to use thermal energy expelled by traditional industrial processes, such as coal smokestacks, and efficiently convert that heat into electricity.

Funding Round 2

- **Batteries for Transportation**—Batteries for Electrical Energy Storage in Transportation (BEEST) projects seek to develop batteries for plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs) that can make a 300-500 mile range electric car.
- **Materials for Carbon Capture**—Innovative Materials and Processes for Advanced Carbon Capture Technologies (IMPACCT) projects seek to reduce the cost of carbon capture significantly through a combination of new materials, improvements to existing processes, and demonstration of new capture processes.
- **Electrofuels**—Electrofuels projects intend to explore new paradigms for the production of renewable liquid fuels that are compatible with today's infrastructure. They seek to

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use microorganisms to harness chemical or electrical energy to convert carbon dioxide into liquid fuels without using petroleum or biomass.

Funding Round 3

- **Grid Scale Electricity Storage**—Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS) projects seek to develop new energy storage technologies that are comparable in reliability and cost to pumped hydropower and that are modular and can be deployed in any location in the country.
- **Building Efficiency**—Building Energy Efficiency Through Innovative Thermodevices (BEETIT) projects focus on developing new approaches and technologies for cooling equipment used in heating, ventilating, and air conditioning (HVAC) systems in buildings, as well as in refrigeration.
- **Electrical Power Electronics**—Agile Delivery of Electrical Power Technology (ADEPT) projects strive to reinvent the basic building blocks of circuits from transistors, inductors, and transformers to capacitors for a broad spectrum of power applications. ADEPT focuses on two areas: (1) creating the world's first kilovolt-scale integrated circuits, and (2) developing transistor switches operating at grid-level voltages that would exceed 13 kilovolts.

Funding Round 4

- **Advanced Thermal Storage**—High Energy Advanced Thermal Storage (HEATS) projects seek to develop revolutionary cost-effective thermal energy storage technologies. HEATS focuses on three areas: (1) high temperature storage systems to deliver solar electricity more efficiently around the clock to allow nuclear and fossil base load resources the flexibility to meet peak demand, (2) fuel produced from the sun's heat, and (3) HVAC systems that use thermal storage to dramatically improve the driving range of electric vehicles.
- **Electricity Network Integration**—Green Electricity Network Integration (GENI) projects focus on innovative control software and high-voltage hardware to reliably control the grid network. GENI focuses on two areas: (1) cost-optimizing controls to manage sporadically available sources, such as wind and solar, alongside coal and nuclear, and (2) resilient power flow control hardware to enable automated, real-time control of grid components.
- **Plants Engineered To Replace Oil (PETRO)**—PETRO projects seek to advance technologies that optimize the biochemical processes of energy capture and conversion in plants to develop farm-ready crops that deliver more energy per acre with less processing.
- **Rare Earth Alternatives for Energy Technologies**—Rare Earth Alternatives in Critical Technologies for Energy (REACT) projects work on early-stage technology alternatives that reduce or eliminate dependence on rare earth materials that may jeopardize the widespread adoption of many critical energy solutions by developing substitutes in two key areas: electric vehicle motors and wind generators.

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- **Solar Electrical Power Technology**—Solar Agile Delivery of Electrical Power Technology (Solar ADEPT) projects focus on integrating advanced power electronics into solar panels to extract and deliver energy more efficiently. Solar ADEPT projects are centered around advances in magnetics, semiconductor switches, and charge storage.

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Appendix IV: Description of ARPA-E Award Winners with Prior Private Investment

The 18 award winners we identified as having received prior private venture capital told us that, with the ARPA-E funding, they were generally able to pursue the development of energy technologies with greater scientific or technical uncertainty than what they were working on with their private funding. About two-thirds of these award winners told us that the ARPA-E funding is allowing them to develop prototypes or to prove basic technology concepts on more advanced ideas than their prior work—7 of these award winners said this was for completely new research and 6 said it was for major advancements to prior research. A few of these award winners also told us they were able to work on projects with outstanding scientific research questions which private investors would not have allowed. Five of these award winners reported that they would likely have been able to pursue some research similar to their ARPA-E projects, but it would have taken years longer without ARPA-E funding.

The following 3 examples reflect in more detail much of what we heard from these 18 award winners regarding the distinction between research funded by their prior investors and ARPA-E funded work:

- *Sun Catalytix*. Sun Catalytix was founded by a professor at the Massachusetts Institute of Technology to commercialize a set of catalysts to split water into hydrogen and oxygen gases. This reaction allows these gases to be cheaply produced for a variety of purposes, including renewable energy. Sun Catalytix was initially funded by a Boston area venture capital firm to develop a product based on these catalysts. According to a representative from this firm, the venture capital funding allows Sun Catalytix to attempt to develop a product that would potentially earn the venture firm a return on investment in a reasonable amount of time. At the time of the ARPA-E award, Sun Catalytix representatives told us they were still some years away from a commercial product using this new technology. According to these representatives, had the firm not won an ARPA-E award, further venture capital might not have been available to develop an initial version of their products. Sun Catalytix representatives told us that ARPA-E funds allowed the company to conduct additional applied scientific research that led to their discovery of a new platinum-free and therefore lower-cost catalyst with much wider market potential, including renewable energy applications. A representative from the

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venture firm told us that they would not have funded the additional advanced scientific research needed to develop the new, cheaper catalyst.

- *Agrivida*. This small biotechnology company based in the Boston area is developing genetically modified sorghum, corn, and switchgrass crops for use in biofuel production. Agrivida representatives explained that the goal of their ARPA-E project is to generate crops capable of producing enzymes within the plant itself to internally break down the plant's own cellulose after harvest. This technology would significantly lower the costs of cellulosic biofuel production, because enzyme treatments are currently a large part of the costs of current production methods. Before winning an award from ARPA-E, Agrivida had received venture capital funding to develop the technology. We spoke with a representative of the venture firm that funded Agrivida, who told us that this venture funding was only for research on the corn crop enzymes; the firm was not willing to fund additional research on other crops because the amount of funding they could provide to any one company in the early stages of research was limited. Agrivida officials told us that the ARPA-E award allowed them to expand the scope of their work and conduct additional research on switchgrass, which may have potential to become a major biofuel crop. They said that the ARPA-E funds have enabled rapid progress, allowing them to complete laboratory work in one year that would have otherwise taken five years. Officials from Agrivida said they hope to have made enough progress by the time they complete their ARPA-E research to be able to attract additional investors and secure commercialization partners.
- *24M*. This is a startup company that is developing flow batteries for use in transportation and electrical grid applications. Unlike normal batteries, flow batteries generate electrical current by internally circulating electrically active liquids, which translates into much lower costs than traditional batteries. However, flow batteries do not exist for use in tight spaces like cars where their cost advantages could allow for significant improvements to electric vehicles. In 2010, concurrent with their ARPA-E award, 24M received \$10 million from two venture capital firms to develop flow batteries for consumer and commercial applications. A representative from one of these venture firms told us that his firm would not have been confident in funding the 24M project without ARPA-E involvement. Representatives from 24M said that the ARPA-E award was critical to their ability to secure private investment and to launch the company and that they now expect to have a working prototype by the end of their ARPA-E project.

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In addition, the two public companies we spoke with that were awarded ARPA-E money told us that although their companies had internal resources devoted to research and development, they were not able to internally fund the projects they proposed to ARPA-E. They told us there were two reasons for this. First, the companies said that existing product lines placed heavy demands on their internal research and development budgets, and that there is continuous pressure from existing customers and competitors to improve existing products; since ARPA-E projects were still a number of years away from a return on investment, these investments could not be justified. Second, these companies told us that internal investments had to meet minimum investment return thresholds, and that ARPA-E-type projects were not able to meet these thresholds. Officials from one company told us that the rate of return on investment required by its management was at least 20 percent per year.

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Appendix V: GAO Contact and Staff Acknowledgments

GAO Contact: Frank Rusco, (202) 512-3841 or ruscof@gao.gov

Staff Acknowledgments: In addition to the individual named above, Paola Bobadilla, Cindy Gilbert, Robert Marek, Justin Mausel, Tim Minelli (Assistant Director), Alison O'Neill, Jeanette Soares, and Franklyn Yao made important contributions to this report.