NTNU – Trondheim
Norwegian University of
Science and Technology

The role of government agencies in stimulating innovation in energy technology

The case of ARPA E projects

Torstein Berteig
Nora Fredheim Johnsen
Iver Roen Velo

Industrial Economics and Technology Management
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Supervisor: Arild Aspelund, IØT

Norwegian University of Science and Technology
Department of Industrial Economics and Technology Management

NTNU
Det skapende universitet

MASTERKONTRAKT
- uttak av masteroppgave

1. Studentens personalia

Etternavn, fornavn	Fødselsdato
Berteig, Torstein	**13. feb 1989**
E-post	Telefon
torstber@stud.ntnu.no	**91869053**

2. Studieopplysninger

Fakultet	
Fakultet for samfunnsvitenskap og teknologiledelse	
Institutt	
Institutt for industriell økonomi og teknologiledelse	
Studieprogram	Hovedprofil
Industriell økonomi og teknologiledelse	**Strategi og internasjonal forretningsutvikling**

3. Masteroppgave

Oppstartsdato	Innleveringsfrist
15. jan 2014	**23. jul 2014**
Oppgavens (foreløpige) tittel	
The role of government agencies in stimulating innovation in energy technology **A case study of ARPA-E projects**	
Oppgavetekst/Problembeskrivelse The pressing need for increased renewable energy production and increased efficiency in energy consumption, combined with the current underinvestment by free market forces in developing new energy technology, shows a need for government initiatives to drive innovation in the energy sector. The aim of this study is hence to investigate how government agencies can be designed to actively stimulate innovation in energy technologies. Our focus is on the level of individual projects being supported by such programs, and the subsequent effects they experience in their innovation processes. Specifically, we study projects supported by the U.S. government through ARPA-E.	
Hovedveileder ved institutt	Medveileder(e) ved institutt
Førsteamanuensis Arild Aspelund	
Merknader	
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MASTERKONTRAKT
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1. Studentens personalia

Etternavn, fornavn	Fødselsdato
Johnsen, Nora Fredheim	**03. okt 1989**
E-post	Telefon
norafredheim@gmail.com	**92460552**

2. Studieopplysninger

Fakultet	
Fakultet for samfunnsvitenskap og teknologiledelse	
Institutt	
Institutt for industriell økonomi og teknologiledelse	
Studieprogram	Hovedprofil
Industriell økonomi og teknologiledelse	**Strategi og internasjonal forretningsutvikling**

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Merknader **6 uker ekstra p.g.a utenlandsopphold. + 1 uke ekstra p.g.a påske.**	

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Student

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MASTERKONTRAKT
- uttak av masteroppgave

1. Studentens personalia

Etternavn, fornavn	Fødselsdato
Velo, Iver Roen	**21. okt 1985**
E-post	Telefon
iverroen@stud.ntnu.no	**91622982**

2. Studieopplysninger

Fakultet	
Fakultet for samfunnsvitenskap og teknologiledelse	
Institutt	
Institutt for industriell økonomi og teknologiledelse	
Studieprogram	Hovedprofil
Industriell økonomi og teknologiledelse	**Strategi og internasjonal forretningsutvikling**

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Førsteamanuensis Arild Aspelund	

Merknader
6 uker ekstra p.g.a utenlandsopphold. + 1 uke ekstra p.g.a påske.

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Trondheim 21.05.14
Sted og dato

Iver Roen Velo
Student

Hovedveileder

Originalen lagres i NTNUs elektroniske arkiv. Kopi av avtalen sendes til instituttet og studenten.

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SAMARBEIDSKONTRAKT

1. Studenter i samarbeidsgruppen

Etternavn, fornavn **Berteig, Torstein**	Fødselsdato **13. feb 1989**
Etternavn, fornavn **Johnsen, Nora Fredheim**	Fødselsdato **03. okt 1989**
Etternavn, fornavn **Velo, Iver Roen**	Fødselsdato **21. okt 1985**

2. Hovedveileder

Etternavn, fornavn **Aspelund, Arild**	Institutt **Institutt for industriell økonomi og teknologiledelse**

3. Masteroppgave

Oppgavens (foreløpige) tittel
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Hovedveileder

Torstein Berteig

Nora Fredheim Johnsen

Iver Roen Velo

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Abstract

The pressing need for increased sustainability in the energy system combined with underinvestment in new energy technology demonstrates the need for government initiatives to drive innovation in the energy sector. In this thesis, we have investigated how design characteristics of a government agency intended to support market focused energy technology innovation affect the projects in its portfolio, and consequently suggested considerations that should be made in the design of such an agency on the basis of our findings.

Our focus is on the level of individual projects being supported by such programs. An embedded single-case research design was chosen, where the units of analysis were projects supported by the U.S. agency ARPA-E. The primary source of data was semi-structured, open-ended interviews with representatives from 13 projects in California.

Following our research, the following findings emerge: The innovation process of projects within *early-stage, transformative high-risk energy technology* is affected by design characteristics related to the program design, project selection process and the support provided by an active management model in the agency. The organizational structure of the agency and the quality of its managing officials are important moderators of these factors.

As guidance to policy makers, we establish the order of importance of design considerations to be made in the creation of such an agency. This thesis contributes to theory by presenting an integrative framework of interlinked factors describing these effects, as well as a cohesive portfolio of rationales for government intervention in energy sector innovation.

Sammendrag

Det presserende behovet for økt bærekraft i energisystemet, kombinert med underinvestering i ny energiteknologi, demonstrerer behovet for statlige initiativ for å drive innovasjon i energisektoren. I denne oppgaven har vi undersøkt hvordan utformingen av en offentlig etat ment å støtte markedsrettet innovasjon innen energiteknologi påvirker prosjektene i dens portefølje, og på bakgrunn av våre funn fremheve hensyn som bør tas i utformingen av et slikt organ.

Vårt fokus ligger på prosjekter som blir støttet av slike programmer. Forskningsdesignet er en enkeltsaksstudie, hvor analyseenhetene var prosjekter som er støttet av det amerikanske byrået ARPA-E. Hovedkilden til data var semistrukturerte, åpne intervjuer med representanter fra 13 prosjekter i California.

I løpet av våre undersøkelser har vi funnet følgende: Innovasjonsprosessen i *tidlig-stadie, høyrisiko, transformative innovasjonsprosjekter innen energi-teknologi* påvirkes av de byråets designegenskaper knyttet til design av støtteprogrammer, prosjektutvelgelsesprosessen og støtten som tilbys i en aktiv forvaltningsmodell. Den organisatoriske strukturen i byrået og kvaliteten på dets administrerende tjenestemenn er viktige moderatorer av disse faktorene.

Som veiledning til beslutningstakere, etablerer vi prioriteringsrekkefølgen av designhensyn som bør tas i etableringen av et slikt organ. Denne avhandlingen bidrar til teorien ved å presentere en integrert rammeverk av sammenkoblede faktorer som beskriver disse effektene, samt en oversikt over begrunnelser for offentlige inngrep innen innovasjon i energisektoren.

Preface

This thesis within the program Strategy and International Business Development accomplishes our Master of Science program in Industrial Economics and Technology Management at the Norwegian University of Science and Technology (NTNU).

The overarching aim of this study is firstly to investigate how the design of a government research program can affect the innovation process of the projects it supports. Secondly, to use these results to form a more comprehensive understanding of the considerations that should be made when creating programs intended to stimulate innovation in energy technologies.

We would like to thank The Norwegian Research Council for giving us the idea, opportunity and financial support to investigate such an interesting topic, and we hope this thesis would contribute in designing their future energy program, ENERGIX. Our thesis would not have been possible to write if not for the contributions of our interviewees, who kindly found the time to meet with us and answer our questions. For this we are extremely grateful!

We would also thank our supervisor professor Arild Aspelund, for guiding us and giving valuable ‘to-the-point’ advice during the course of this endeavor.

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1 Introduction

The growing concern about the consequences of increased pollution and global climate change has led to a common agreement that there is a need for innovations in energy technology (Christiansen, 2002). Immediate, cost effective 'quick fixes' to the environmental problem will not be enough to mitigate these problems in the long run, and it is necessary to develop cleaner energy technologies in order to reach the goals of a sustainable energy system (e.g. Buen, 2006; Christiansen, 2002; Jaffe, Newell, & Stavins, 2005; Loiter & Norberg-Bohm, 1999).

It is widely recognized that relying on free market processes alone will result in underinvestment in research and development compared to the socially optimal level (e.g. Martin & Scott, 2000; Salmenkaita & Salo, 2002), and most economists agree that it is desirable that governments support activities leading to technological innovations (Jänicke & Jacob, 2004; Klette, Møen, & Griliches, 2000). There is hence a need for government support and public policies to stimulate technological change through innovations in new energy technologies (Jaffe et al., 2005).

There are several types of innovation policies *"intended to influence the behavior of both public and private organizations in the development and commercialization of new technologies"* (Salmenkaita & Salo, 2002, p. 184) that a government can implement to target these challenges. These include direct regulation, economic instruments, university research, government labs, science parks, technology advisory services, R&D support, and demonstration programs (Christiansen, 2002; Guellec & van Pottelsberghe de La Potterie, 2003; Storey & Tether, 1998), and can be classified mainly as driving technological change through technology-push or demand-pull (e.g. Buen, 2006; Christiansen, 2002; Loiter & Norberg-Bohm, 1999; Roessner, 1984).

Government funding through public research programs can take many forms, from the way funds are granted to how projects are monitored and supported upon receiving funding. The results of these programs are important for many parties, and as such it is important to understand how such programs can be designed to create the proper incentives for all actors involved, especially due to the large variations in historical successfulness (Foxon & Pearson, 2008; Jaffe, Newell, & Stavins, 2001). It has also been recognized that there is a need for more practical guidelines for policy makers designing a sustainable innovation policy regime (Foxon & Pearson, 2008).

The overarching aim of this study is therefore *firstly to investigate how the design of a government research agency can affect the innovation process of the individual projects it supports*. Secondly, to *use these results to form a more*

comprehensive understanding of the considerations that should be made when creating agencies intended to stimulate energy technology innovation by supporting early-stage, transformative, high-risk projects.

In order to answer our research question we start by identifying the challenges to developing and commercializing new high-risk energy technology, and highlight the potential failures in the innovation system inhibiting innovation of new energy technologies. We subsequently apply this context to propose different roles research programs can take to promote innovation of new energy technology. The U.S. governmental research agency ARPA-E is then used as a practical example of a functioning research program. We seek to understand the complex effects on the innovation process through an embedded single case study of the interaction between ARPA-E and the projects it supports.

In order to delimit our thesis, we do not seek to investigate whether innovation programs like this are in fact able to increase the number of new energy technologies that are successfully commercialized. Nor do we question whether such programs can contribute to reach advances that would not have happened if the task was left to private investments, as these issues have been dealt with by other researchers (Brown, 2001; Guellec & van Pottelsberghe de La Potterie, 2003; Jaffe et al., 2005; Klette et al., 2000; Martin & Scott, 2000; Mazzucato, 2011)

Public research programs and government funding schemes typically have the mandate to support only parts of the innovation process from basic research to commercialization of a technology. In order to increase the applicability of our findings for public policy and to make the study practically feasible to undertake, we delineate our research to programs supporting the early innovation stages from applied research to pre-commercial technologies. Some of the findings of our study might however be relevant for programs supporting other stages of the innovation process.

We have contributed to research by identifying and developing an integrative system of interlinked factors that affect the projects' abilities to reach their end goals. As a foundation for this research we have also developed a cohesive framework of rationales for government intervention in the energy sector. We believe this framework can be useful for future researchers embarking on investigating other research agencies with the same intended purpose, as well as a guideline for practitioners aiming to stimulate energy technology innovation by supporting early-stage, transformative, high-risk projects.

2 Rationales for government intervention in the energy industry

Innovation is a prerequisite for economic growth, and can provide technologies that have the potential to realize environmental benefits (Foxon et al., 2005). As stated by Jaffe et al. (2001, p. 5) "*New technologies may create or facilitate increased pollution, or may mitigate or replace existing polluting activities"*. In order to understand what government agencies can do to stimulate the development of new energy technologies it is necessary to understand the conditions under which innovation occurs in a market economy and how those relate to the energy industry. More specifically we believe it is necessary to identify *how* and *why* the private actors in the energy system fail to deliver these technologies on their own. By understanding these failures or challenges we can further identify the necessary roles a research program should take in an effort to mitigate them.

The views on what position a government should take in fostering innovation through public policy intervention spans from the 'laissez-faire'-style argument that the free market forces will drive innovation with the government only laying the foundation for this to occur, to the belief of an 'Entrepreneurial State' which proactively invests in radical, growth-enhancing innovations (Mazzucato, 2011). Since the objective of this thesis is not to debate the overall role of the government in fostering innovation, nor provide an exhaustive list of potential rationales for government intervention, we draw on the argument by Edquist (2001) which neatly summarizes what these views have in common. According to Edquist (2001) two conditions are necessary to justify public policy intervention in a market economy. Firstly, the market mechanisms and firms must fail to achieve the socially defined objectives, which in our case is to create new sustainable energy innovations. Secondly, the government and its public agencies must be able to solve or mitigate these problems.

In the following sections we identify the conditions leading to a failure to meet the socially defined objectives of innovation in the energy industry. We then describe roles a government research agency should take in response to these issues.

2.1 The energy sector as a CELS

According to Weiss and Bonvillian (2011) the energy sector is one of the so called *Complex Established Legacy sectors* (CELS). Innovations within these sectors must overcome an array of well-established and well-defended paradigms that are favorable for existing technology. Although some technologies, like light emitting diodes (LEDs) have been successfully launched

into niche markets and later advanced into more established ones, new entrants must launch into “occupied territory”, where conflicts with incumbent firms with established technologies will be frequent and inevitable (Bonvillian & van Atta, 2011). According to Bonvillian and van Atta (2011) actors in the energy sector therefore need to find first adopters or initial markets in order to cope with the barriers of especially commercialization.

Narayanamurti, Anadon, and Sagar (2009) also argued that the innovation process of energy technologies is especially complex, because the new technology eventually has to take on strong incumbent technologies while overcoming network and infrastructure effects upon its integration into the existing energy system, as well as dealing with the challenge of limited and uncertain market signals for energy R&D.

For this reason most new energy technologies to date have been, and still are, more reliant on favorable government regulation and subsidies compared to new technologies that can create new markets. New energy technology effectively must be able to directly compete with the incumbents in the current market. This essentially means that disruptive technologies must meet strict cost requirements both in early development and immediately upon market entry.

2.2 Market failures

There are several different ’Market failures’ that can be associated with underinvestment in energy technology innovation, giving rise to the need for government funding of such activities. Market failures can be defined as “*the conditions under which the amount of funding allocated to R&D by market forces is less than what is socially optimal* (Salmenkaita & Salo, 2002, p. 187). Three such market failures can be identified to have an impact on the level of innovation in energy technologies; financial market failure (Jaffe et al., 2001, 2005; Martin & Scott, 2000), the positive externalities of knowledge (Foxon & Pearson, 2008; Jaffe et al., 2001, 2005; Martin & Scott, 2000; Salmenkaita & Salo, 2002) and the negative externalities of pollution (Foxon & Pearson, 2008; Jaffe et al., 2005).

2.2.1 Capital market failure

The first issue that arises in the view of R&D as an investment activity, is its particular risk characteristic, which distinguishes it from investments in tangible assets (Jaffe et al., 2001). The uncertainty associated with return to investment in innovation is often larger (Jaffe et al., 2005). While its success often has a high value associated with it, the probability of success is low (Jaffe et al., 2001). Furthermore, the asset produced by an R&D investment is specialized, sunk and

intangible. The high risk combined with resulting products commonly being confined to particular niches makes the R&D effort challenging to finance using capital market mechanisms (Foxon et al., 2005; Jaffe et al., 2001).

The process of raising funds for technology research investments is additionally challenged by the market failures related to asymmetric information, as the researcher often will be in a better position to understand the potential value of the technology than outside investors (Jaffe et al., 2005). These market failures, commonly denoted as financial market failures, are an indication that "*a strict reliance on a market system will result in an underinvestment in innovation, relative to the socially desirable level*" (Martin & Scott, 2000, p. 438).

For innovations in energy technology specifically, there is additional uncertainty related to the impact of climate change, and any associated policy responses (Jaffe et al., 2005). Many of the technologies currently being developed to increase the sustainability of the energy system are reliant upon favorable government regulations or subsidies to survive in the market, due of the reasons stated in section 2.1. Such technologies include for example electric vehicles, CO_2 capture and several technologies using renewable energy sources. These subsidies and regulations can be unpredictable due to political changes, e.g. from one government to the next or changes in the political climate. Policies and subsidies of new energy technologies can therefore greatly affect early adoption by stimulating initial markets (Moniz, 2012).

Including the challenges of developing and launching new energy technologies in the existing markets, as discussed in section 2.1, all of these hurdles easily make development and refinement of risky and potentially revolutionary innovations within energy technology a daunting task, far out of reach for most private sources of funding.

While it is a far too vast subject to include in this thesis, this need for subsidies is arguably not lessened by continued subsidies of fossil energy technologies, e.g. with Coal, Natural Gas and Petroleum Liquids receiving approximately 15.5% of the electricity production subsidies in the United States according to the Energy Information Administration (2011, p. xviii).

2.2.2 Appropriability problem: the positive externality of knowledge

Another aspect distinctive to investment in R&D is that the asset produced, knowledge, is hard to exclude others form using (Foxon & Pearson, 2008; Jaffe et al., 2001). It is also difficult to sell, because a purchaser cannot determine the value of the knowledge before receiving it, after which he has little need to pay for it (Arrow, 1962). The innovator will hence not be able to keep all the benefits

from the produced knowledge for herself, i.e. prevent others from reaping benefits from the same knowledge.

This knowledge spillover represents a positive externality to society, which infers that the innovator sees a lower appropriable return on her R&D investment than its return to society as a whole, implying that the attractiveness of the R&D investment is lower for the innovator than for the society as a whole. This suggests that private firms might underinvest in R&D relative to the social optimum, and provides a rationale for public support for R&D (Foxon & Pearson, 2008; Martin & Scott, 2000; Salmenkaita & Salo, 2002).

In the case of new energy technologies, these positive externalities can obviously be linked to innovations that e.g. increase the energy security and help alleviate problems of pollution and climate change, but one cannot expect private firms to make large investments in high-risk R&D just because of the societal benefits which may result from that work.

2.2.3 Negative externalities of pollution

In addition to the positive externality of knowledge, for the case of new sustainable energy technologies, there will be a negative externality of pollution (Foxon & Pearson, 2008; Jaffe et al., 2005). The unregulated polluter does not pay the full cost of undertaking activities that have negative impacts on the environment. This cost is therefore absorbed by the society as a whole, e.g. bad air quality in in densely populated cities due to emissions from traffic or climate change due to polluting activities. By not being liable for these costs, there is a lack of incentive for the polluter to decrease his emissions, for example by investing in cleaner technologies. This suggests that the free market will allow too much pollution if left to its own devices (Jaffe et al., 2005), and provides an argument for government intervention to internalize the externalities (Foxon & Pearson, 2008).

However, such an internalization mechanism would be external to the research agency itself, and is consequently beyond the scope of this thesis. We therefore leave this subject as informational background for the market failures contributing to underinvestment in energy technology innovation.

2.3 Structural rigidities, path-dependence and lock-in

Another problem for the development and commercialization of new energy technologies are the difficulties for complete systems, in this case the energy system, to adapt to new technological paradigms. This is known as ’Lock-in failures’ (Foxon & Pearson, 2008; Klein Woolthuis, Lankhuizen, & Gilsing, 2005) or ’Structural rigidities’ (Salmenkaita & Salo, 2002).

The premise behind this argument is that technological development exhibits path dependence, and that the dominance of incumbent technologies creates barriers to the adoption of new technologies. Incumbent technologies have benefits such as economies of scale, learning effects, adaptive expectations and network effects, which create barriers to the adoption of new technologies. Institutions supporting the existing technological systems have similar increasing returns to its adoption, adding on to the lock-in of the system. Because of this interdependence of technologies to their social and economic environment, new technologies must compete with both the incumbents and the system they are embedded in (Foxon & Pearson, 2008).

In addition, technologies often follow paradigms, as the actors in the innovation system build upon and develop expertise on a given path (Salmenkaita & Salo, 2002). This can be seen in the energy system, where the exploitation of fossil fuels is continuously refined (Foxon & Pearson, 2008).

A potential role for a government agency can therefore be to create variation and flexibility in the innovation system by promoting new alternative energy technologies and funding efforts to build new areas of expertise, and at the same time recognize that new technologies need a system of supporting technologies and institutions in order to be sustainable. However, it is important that the government agency has the ability to identify possible technological directions if this position is to be taken (Salmenkaita & Salo, 2002).

2.4 Systemic and weak network failure

Innovation occurs in a system of institutions including universities, research centers and firms, where the innovative performance is influenced by the interactions of the actors involved (Salmenkaita & Salo, 2002).

One reason interactions in the innovation system influences innovative performance is related to '*weak network failures'*, where a lack of linkages between actors in the innovation system results in insufficient use of complementarities, less interactive learning and fewer new ideas (Klein Woolthuis et al., 2005). Different priorities for each actor in the innovation system might inhibit collaboration. Salmenkaita and Salo (2002) referred to this as '*systemic failures'*, which occurs "*if the practices, incentives and priorities are optimal at the level of individual organizations while the overall innovative performance of the system is sub-optimal"* (Salmenkaita & Salo, 2002, p. 188). Government agencies can mitigate such failures by creating incentives that encourage collaboration between actors in the innovation system.

Systemic failures can also occur if the innovation process is viewed as a linear set of phases, and the feedback mechanisms between these phases are not accounted for. In this view innovation occurs only at the research phase, and input from the later stages of product development and commercialization is not included. A potential role for a government agency can here be to facilitate network connections and knowledge transfer between actors in the system who are at different stages in the innovation process (Salmenkaita & Salo, 2002).

2.5 The roles of a research agency in fostering innovation

As highlighted by the previous sections, there are failures and challenges in a market economy that lead to a need for government intervention in order to obtain a socially optimal level of innovation. Most industrialized countries therefore employ policies designed to stimulate innovation and technological development (Jaffe et al., 2001). Salmenkaita and Salo (2002, p. 184) define innovation policies as "*policies that are intended to influence the behavior of both public and private organizations in the development and commercialization of new technologies."*

In relation to innovation policies targeting the energy industry, government initiatives may play a particularly important role due to the negative externalities of pollution on one end and the positive externalities from more environmentally benign energy technologies such as renewables on the other (Jaffe et al., 2001), as discussed in section 2.2.3 and 2.2.2. The successfulness of such policies has however been debated (Mazzucato, 2011), as the effects of a policy design are complex to quantify. There are also no clear directions for what elements policies should include and how they should be implemented (Salmenkaita & Salo, 2002). There does however seem to be a consensus that for the case of radical innovation, there is a need for a combination of initiatives that promote the development of new technologies, i.e. '*technology push'*, and measures that stimulate the development of new markets, i.e. '*demand pull'* (Foxon & Pearson, 2008).

One government policy intended to stimulate technological innovation is the establishment of research agencies. The primary role of such agencies is to provide funding for R&D projects in private firms, universities or research institutes, in order to mitigate the challenges to innovation related to market failures (Salmenkaita & Salo, 2002), as presented in section 2.2. Such agencies can also take on a multitude of additional roles in an effort to mitigate the other previously discussed challenges. These roles can alternatively be considered preemptive efforts to help the supported projects realize their full potential.

In the following subsections we propose potential roles of a research agency based on their connection to the failures and challenges presented in sections 2.2 through 2.4 and how these roles can affect the outcomes of funded projects.

2.5.1 Funding role

For projects trying to develop new energy technologies, the capital market failure is a tremendous challenge, as discussed in section 2.2.1. R&D in transformative energy technologies is especially risky, because the technology must compete with a system of incumbent technologies, in addition to the long timeframe of bringing the innovation to market and realizing returns. This is amplified by the low cost profile less environmentally benign incumbent technologies can have if their negative effects (i.e. environmental impact) are not factored into their cost, as discussed in section 2.2.3. Correspondingly, the cost profile of the new energy technology may not factor in the positive externalities created by being more sustainable than the incumbent, as discussed in section 2.2.2.

In the face of competition from less risky and potentially less time/capital intensive R&D projects, these issues present an obvious barrier against private financing of high-risk innovation projects. Government research agencies should therefore provide funds for the R&D of potentially groundbreaking energy technology innovations that otherwise would not get funded.

The funding role of a research agency also provides an opportunity to mitigate structural rigidities. As discussed in sections 2.1 and 2.3, new energy technologies must either fit in the existing system of interconnected technologies, or be supplemented by new complementing technologies to be feasibly applicable for its potential users. By funding a set of complementary technologies, the research agency can support the development of a whole new system of technologies, which might increase both the long-term sustainability of the system as a whole, and ease the path to commercialization for each individual technology/project.

2.5.2 Legitimator role

An important reason for the capital market failure lies in the uncertainty connected to R&D projects. As research agencies decide which projects to fund, they should not only give them the financial means to go through with the projects, they should also be prominent enough to give them legitimacy towards potential investors. Having the project go through a competitive and diligent selection process where it is deemed promising enough to be awarded government funds may reduce the risk perceived by the potential investors or prospective strategic partners. In his study of the Canadian triple-helix intermediate Precarn, Johnson (2008) emphasized this legitimizing role as an asset the supported projects can use to attract further venture capital.

The role as a legitimator can also be related to weak network failures in the innovation system. For a relatively unknown start-up, having the 'quality stamp' and publicity provided by a research agency might open doors to potential collaboration partners. This legitimacy can bring together actors that otherwise would have been unlikely to collaborate (Johnson, 2008), mitigating failures related to a weak network. From the point of the particular project, the legitimacy that comes with being chosen for a research program can therefore translate into more opportunities to attract investment, form new partnerships, and draw on the complementary knowledge of others.

2.5.3 Network role

The role as a networker most obviously targets the failures related to a weak network.

In order to increase the use of complementarities and knowledge transfer, a research agency can exploit its position as a central link between all the projects connected to it. Because the agency has an overview of all the projects, it can see areas where there are potential synergies between the projects and act by connecting them (Johnson, 2008). We believe this would be especially useful if the research agency funds projects developing similar or related technologies with potentially similar challenges, as it then can contribute to the knowledge transfer by sharing relevant lessons learned and solutions that might be beneficial for more projects (Foxon et al., 2005; Johnson, 2008). For the individual projects, this means that they can learn from insights other projects have made, and possibly avoid making the same mistakes or doing redundant work by pursuing previously investigated technical paths.

A research agency can also provide its projects with access to outside expert knowledge to the project. The can be done either by connecting them to external experts (given the necessary scientific network) or by utilizing its overview of all funded projects within the agency to connect them to internal experts. Such activities can provide the individual projects with necessary knowledge they do not possess themselves, reducing the need to explore research outside of their core expertise.

Efforts to network R&D projects with industry actors and potential strategic partners or customers can also prove worthwhile (Foxon et al., 2005; Foxon & Pearson, 2008; Suvinen, Konttinen, & Nieminen, 2010). Connecting the various actors can help align the incentives and priorities between them, for example by adjusting the R&D efforts to the needs of a customer or strategic partner, reducing the impact from systemic failures. Additionally, on the level of the individual projects, having connections with industry actors and customers might enable the development of solutions that are better aligned with the demand in

the market, potentially increasing their chance of success. If relationships are formed with strategic partners or potential investors, the networking role of the research agency can also contribute to the project securing additional resources, mitigating market failures.

3 ARPA-E: Background and design description

The Advanced Research Projects Agency-Energy (ARPA-E) is a U.S. government research agency within the Department of Energy (DOE), mandated to advance transformational new energy technologies. It is acclaimed to offer a new innovation institutional model to meet energy technology challenges (Bonvillian & van Atta, 2011) and identified by Hernes, Brunvoll, and Løvdal (2014) as likely to be the most interesting agency of its kind. It was therefore chosen as the model research program for our study.

ARPA-E was established with explicit intention of creating commercial success in complement and cooperation with the capital markets, permeating the features of its design: *"(…) ARPA-E funded projects that are successful in reaching the marketplace stand to benefit the U.S. greatly through the* ***creation of new industries and jobs****, access to* ***more cost-effective energy technologies****, and an* ***accelerated timeframe for achieving the Nation's energy goals****."* (ARPA-E, 2011, p. 1)

In the following sections, we present background information on ARPA-E relevant for understanding the premises for how the agency interacts with and supports its projects.

3.1 Establishment

Congress requested in 2005 that the National Academics should "*identify the most urgent challenges the U.S. faces in maintaining leadership in key areas of science and technology*" (ARPA-E, 2011, p. 9). The report recognized the need to develop reliable and clean energy technologies that are cost effective compared to the dominating incumbents coal, oil and gas. A new government agency was created in order to pursue this goal, the ARPA-E. Modeled after the successful defense program, Defense Advanced Research Projects Agency (DARPA), ARPA-E was formally authorized by Congress as part of the America COMPETES Act, which was signed into law by President George W. Bush in August 2007. However, ARPA-E was not funded until 2009, when Congress appropriated and President Barack Obama allocated USD400m to fund it (ARPA-E, 2013b).

From April 2009 to February 2014, ARPA-E has invested over USD900m in 362 potentially transformational energy technology projects. Accounting for USD95m of ARPA-E's investments, technical and commercial achievements in 22 ARPA-E projects had attracted more than USD625m in follow-on private sector funding, with a further 24 projects continuing the technological development by forming new firms (ARPA-E, 2014a).

3.2 Purpose and targeted stage of technological development

ARPA-E's main goal is to accelerate the development of transformational energy technologies. The main obstacle to transformational energy innovation is insufficient private sector funding, as total spending on energy research and development (R&D) in the U.S. private sector was only 0.3% of revenues in 2010 (Wurzelmann, 2012).

In its first Annual Report, ARPA-E (2011, p. 1) delineated its commercial and political purpose eloquently: *"ARPA-E invests in and manages the development of only transformational energy technologies that hold the potential to radically shift our Nation's energy reality. Transformational technologies are by definition those that disrupt the status quo. They do not seek evolutionary improvements – they drive revolutionary ones. They do not merely outperform current technologies – they make those technologies obsolete.*

ARPA-E ensures its funding programs have commercial relevance – first, by considering potential market impact when developing new programs, and second, by incorporating market-relevant cost and performance criteria into each funding solicitation and the subsequent review and selection process"

ARPA-E uses a nine-point Technology Readiness Level (TRL) scale (replicated in the Appendix, section 12.1) to assess the maturity of new technology, which is an important metric for which projects it is intended to support. While most of the projects funded by ARPA-E have ranged in maturity from TRL levels 2 through 4 prior to receiving funding, it has also funded projects ranging in maturity from TRL 1 through 6, usually progressing projects to a maturity on TRL 5 to 7 by the end of the support period (ARPA-E, 2011).

In these early stages of development, the high risk associated with these projects tends to discourage investments from private investors and other public sector entities. This is further outlined in section 2.2.1. However, ARPA-E support is justified by the potentially high rewards from technological breakthroughs in the most promising projects (ARPA-E, 2011). ARPA-E uses a 'hybrid' model, which means that it can support projects undertaken by a wide range of entities from small companies and academic researchers in universities, to high-risk endeavors in the R&D departments of large corporations (Bonvillian & van Atta, 2011).

3.3 ARPA-E's structure

There are several agencies that operate under the U.S. Department of Energy (DOE), and ARPA-E is only one of them. In order to avoid conflict with the other parties in the DOE, the U.S. Secretary of Energy, Steven Chu, recommended ARPA-E to focus on four objectives[1] that should distinguish them from current activities in the Department (Stine, 2011). Bonvillian and van Atta (2011) highlighted that ARPA-E should also work on building internal connections within the DOE and turn them into allies and supporters. Since ARPA-E is targeting projects early in the technological development, it could work as an intermediate that accelerates projects from basic concepts through initial validation and prototyping, and later hand them over to more applied agencies in the DOE for later stage development and operational demonstration.

ARPA-E has an agile and adaptive structure that makes it possible for the agency to quickly develop and execute new programs when there is a need (ARPA-E, 2013e). It aims to actively recruit highly talented and experienced persons, and is even allowed to hire people on a different basis than other federal organizations to achieve that goal (Bonvillian & van Atta, 2011; "America COMPETES Act," 2007). The ARPA-E organization can be considered to be fairly flat and non-hierarchical, as the senior leadership consists of only three people including the ARPA-E Director, overseeing 14 Program Directors[2]. The Program Directors have the responsibility to design and manage their own program, including the authority to make the final judgment on funding awards (ARPA-E, 2014a, 2014c; Bonvillian & van Atta, 2011). All ARPA-E projects are

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[1] As referenced in (Stine, 2011, p. 2): "*1. Bring a freshness, excitement, and sense of mission to energy research that will attract many of our best and brightest minds—those of experienced scientists and engineers, and, especially, those of students and young researchers, including those in the entrepreneurial world. 2. Focus on creative, out-of-the-box, potentially transformational research that industry cannot or will not support.3. Utilize an ARPA-like organization that is flat, nimble, and sparse, yet capable of setting goals and making decisions that will allow it to sustain for long periods of time those projects whose promise is real, and to phase out programs that do not prove to be productive or as promising as anticipated. 4. Create a new tool to bridge the troubling gaps between basic energy research, development, and industrial innovation. It can serve as a model for how to improve science and technology transfer in other areas that are essential to our future prosperity.*"

[2] The wording 'Program Manager' was in Section 904 of the 'America COMPETES Reauthorization Act' changed to 'Program Director' ("America COMPETES Reauthorization Act," 2010). This updated wording is used throughout the thesis.

also provided financial, technical and commercialization assistance through specialized teams within the organization (ARPA-E, 2011).

Amadi-Echendu and Rasetlola (2011) highlighted that skilled employees and experienced managers are a necessary factor to successfully commercialize new technology. This is also recognized by ARPA-E, which recruits leading professionals with solid experience from universities, industry and national laboratories. However, in order for ARPA-E to provide an up-to-date perspective on the technology and market conditions, it uses a short employment model requiring employees to 'cycle out' of the agency after three to four years of service (ARPA-E, 2013e).

3.4 Program creation

ARPA-E has two different types of programs. Most of the projects it supports are part of a 'focused' program, targeted programs "*which are developed by Program Directors to address a specific energy challenge"* (ARPA-E, 2013e, p. 2). Projects not appropriate for any of the targeted efforts can be proposed in the 'open' project solicitations "*which seek applications for any idea that has the potential to produce game-changing breakthroughs in energy technology"* (ARPA-E, 2013e, p. 2).

ARPA-E's focused programs draw on the latest scientific discoveries and envision the commercialization path to market for the technology (ARPA-E, 2013e). They are designed to fill gaps where *"high-impact, high-potential investment by ARPA-E could lead to transformational technologies enabling entirely new ways to generate, store, and use energy*" (ARPA-E, 2013e, p. 2).

The focused programs are developed through a vigorous process that takes into account the needs in the energy sector, the readiness level of the technologies that fit in the program (Wurzelmann, 2012) and the commercialization process of the technologies (Bonvillian & van Atta, 2011). Firstly, the needs in energy is explored through technical workshops with experts on current and emerging energy technology solutions (Wurzelmann, 2012) from diverse science and technology communities (ARPA-E, 2013e). These workshops focus on technologies that can bridge basic science and early stage technology, and their path to market (ARPA-E, 2013e; Wurzelmann, 2012). The program proposal then have to go through rounds of brainstorming and vetting with the other Program Directors, to ensure its technical and economic viability (ARPA-E, 2013e; Bonvillian & van Atta, 2011). The program proposal must then be signed off by the ARPA-E Director (Bonvillian & van Atta, 2011).

The objective of the open project solicitations is to ensure that potentially transformative ideas that are outside the scope of the focused programs are also considered for funding. These projects should pursue novel approaches to energy innovation, and meet technical needs not addressed by other agencies or the private industry (ARPA-E, 2013e).

Upon the creation of a new program, ARPA-E will formally announce it to the public and solicit proposals by issuing a Funding Opportunity Announcement (FOA) (Wurzelmann, 2012). ARPA-E has so far funded 18 different focused programs, two open programs, and two upcoming programs were announced in late April 2014 (ARPA-E, 2014a)[3].

3.5 Project application, screening and selection process

The process of screening and selecting projects to an ARPA-E program is divided into several steps. The applicant responds to the FOA by submitting a short pre-proposal in the form of a 4-page concept paper on the idea through ARPA-E's online application portal, eXCHANGE. ARPA-E then performs an independent preliminary review of the conceptual idea, to determine whether the application fulfills the criteria for that particular FOA. The practice of having the applicants submit short pre-proposals first is consequently an effort to spare applicants from spending the time and expenses required for a full application unlikely to be selected for award negotiations (ARPA-E, 2014b).

If the criteria for the FOA are fulfilled, ARPA-E encourages the award applicant to submit an extensive and highly detailed full application (ARPA-E, 2013d). After ARPA-E has processed the full proposal, the applicant receives feedback on its proposal, and then has the opportunity to reply to the comments of the reviewers (ARPA-E, 2014b; Bonvillian & van Atta, 2011). According to Bonvillian and van Atta (2011), this two-stage screening process has resulted in several applications being reconsidered, possibly improving ARPA-E's project portfolio.

The decision to fund a project is ultimately taken by the Program Director, who is supported in her decision by the opinion of a peer review panel and discussions with fellow colleagues. The conservatism and caution that generally characterize projects being selected only through peer review is therefore avoided, which is

[3] Please refer to the Appendix for program descriptions, section 12.4

suitable given ARPA-E's mandate to fund high-risk, high-impact projects (Bonvillian & van Atta, 2011).

When ARPA-E's vetting process is completed and the agency has made their decision about who to fund, they publicly announce the projects (e.g. ARPA-E, 2014a). This announcement makes the projects visible through press releases, the ARPA-E website or other media channels that find it interesting (e.g.Lane, 2013; Morris, 2013; Olson, 2012).

ARPA-E's first FOA received approximately 3,700 applications, of which 312 were encouraged to submit a full proposal, resulting in the selection of 37 projects (Majumdar, 2009).

4 ARPA-E: Design characteristics

ARPA-E has special design characteristics intended to enhance its projects' ability to develop transformational energy technologies. These characteristics are highlighted in ARPA-E's Strategic Vision for 2013 (ARPA-E, 2013e):

"ARPA-E focuses on energy technologies that can be meaningfully advanced with a small investment over a defined period of time. ARPA-E's ***rigorous program design****,* ***competitive project selection process****, and* ***hands-on engagement****, ensure thoughtful expenditures while empowering America's energy researchers with funding, technical assistance, and market awareness."* (ARPA-E, 2013e, p. 1, our emphasis)

In other words, the design of the ARPA-E programs and how projects get selected for ARPA-E funds, as described in sections 3.4 and 3.5, and how the ARPA-E officers manage and support the projects are highlighted as characteristics that empower the agency and its projects in advancing transformational energy technologies.

In the following sections, we discuss how some of these characteristics, as presented in Figure 1, are manifested through the roles presented earlier in section 2.5, before discussing how specific operational characteristics of ARPA-E affect the individual projects.

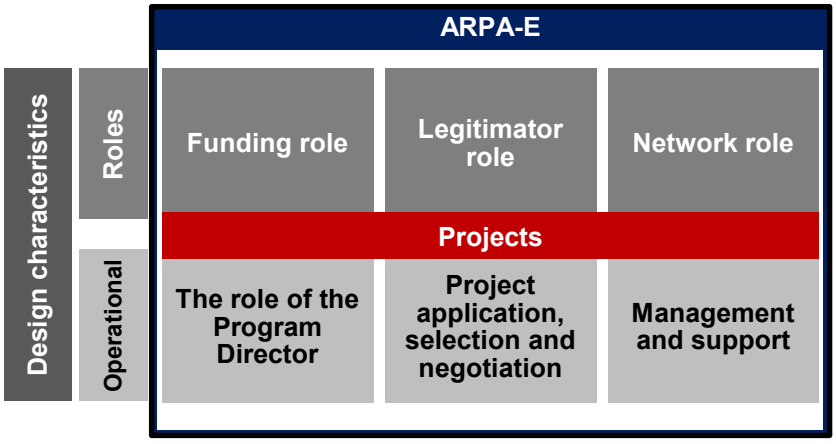


Figure 1 - Design Characteristics of ARPA-E

4.1 The roles of ARPA-E

As discussed in section 2.5, a research agency can mitigate the failures and challenges to innovating in the energy system by funding and legitimizing high-risk, high-reward R&D efforts, and by building up a network around these efforts. In this section, we present and discuss how ARPA-E takes on these roles, and subsequently propose how we believe these roles affect the innovation process of its projects.

4.1.1 Funding role

ARPA-E takes on the funding role by funding projects developing potentially transformative energy technologies that are proven to be too risky to be taken on by private industry (ARPA-E, 2013e; Bonvillian & van Atta, 2011; Wurzelmann, 2012). We therefore propose that ARPA-E is filling the 'funding gap' arising from capital market failures, as explained in section 2.2.1 and 2.5.1, and that the projects would have been unlikely to be realized without funding from ARPA-E.

The funds are provided through a cost share model, where the awardee is obliged to pay a cost share as a percentage of the total cost of the project (ARPA-E, 2014b). The exact percentage of cost share depends on the kind of entity that receives the award, where educational institutions, public laboratories and non-profit entities generally pay a lower portion than larger profit-seeking entities (ARPA-E, 2013d). Depending on the FOA and the classification of the entity receiving the award, the cost share generally varies from 0 to 20 percent, although large businesses are strongly encouraged to provide more than that (ARPA-E, 2014b). The project may provide the cost share as cash outlays in the project or as in-kind contributions. In-kind contributions include e.g. personnel costs, indirect costs, facilities and administrative costs, rental value of buildings or equipment, the value of a service or other resource, or even contributions from a third party. ARPA-E specifies that the cost share may not be covered by federal funds (funding duplication) or expected future revenues (ARPA-E, 2014b).

Since projects that receive ARPA-E support are too risky for private investment by design, attracting investors or strategic partners to provide resources for the cost share might be a challenge. In addition, providing the cost share internally might be especially challenging for start-ups and small companies that may simply not have enough assets or cash to provide the cost share themselves or for educational institutions and government laboratories if most of their internal funds are derived from federal sources.

The program design and project selection process, as described in 3.4 and 3.5, may mitigate systemic failures, as the focused programs are developed in a way that take account of the needs in the energy sector in consideration of the

commercialization path of the technologies. Before a project is selected to receive a grant, the implementation process for the technology is considered (Bonvillian & van Atta, 2011), reducing the risk of funding projects that are unlikely to make it to market regardless of funding. Additionally, structural rigidities may be avoided by funding related technologies that complement each other, in order to launch a self-supportive system of technologies. We believe ARPA-E is trying to meet this challenge by funding projects in relatively focused programs.

The project application process, as described in section 3.5 may be important for the Agency's ability to fulfill the funding role. Writing a full proposal is an extensive process, and the resources put into it are inherently sunk. This might be especially demanding for resource-constrained or inexperienced entities that have a hard time justifying allocating the time and resources required by a full proposal, especially without indication of whether ARPA-E considers their ideas to be worth pursuing. Allowing the applicants to first submit only a pre-proposal might therefore attract a higher number of suitable project applications due to the relatively low effort required for the initial part of the process. Additionally, by allowing the applicant to elaborate on points that perhaps were unclear or outright misunderstood by the reviewers, fewer projects should be discarded due to the reviewers failing to understand the technology.

4.1.2 Legitimator role

As presented in section 3.5, applicants to ARPA-E have to go through a diligent and competitive process before being granted an award, indicating that the risk perceived by potential investors or prospective strategic partners could be reduced.

Bonvillian and van Atta (2011) called this the 'Halo effect', and pointed out that ARPA-E consciously takes advantage of having private investors and firms consider its process of selecting projects as diligent and rigorous. They therefore claimed that having the ARPA-E 'stamp of approval' and related publicity from the announcement increases the visibility and credibility of the project towards venture capitalists (VCs) and potential commercial partners. While these parties would still conduct their due diligence processes, ARPA-E's vetting process and publicity help them identify and validate the projects as potential investment candidates. We argue that presence at the Energy Innovation Summit should further add to this visibility for ongoing projects, as presented in section 4.1.3 below.

We therefore believe ARPA-E have a legitimizing effect on the projects it funds, reducing investors perception of the projects' risk. We also argue that it generates visibility along with this credibility which can be leveraged in

networking. The increased visibility and credibility may for instance prove helpful when trying to build connections with external parties such as potential future customers, hence reducing consequences of weak network failures.

We also believe this increased credibility towards prospective private investors and strategic partners can have a positive effect on the projects' ability to raise funds or other resources for their developments efforts, reducing the challenges of capital market failure.

4.1.3 Networking role

We believe ARPA-E takes on the networking role on two different levels, within its project portfolio and by facilitating the connection with external parties.

By funding similarly focused projects within each program, these projects are likely to have overlapping and related areas of expertise, creating opportunities for exploiting synergies between them. Having one Program Director for each program should facilitate this role, as he will have oversight over all the projects in his portfolio, permitting easier identification of which projects could benefit from collaborating or exchanging experiences. In ARPA-E's case, we assume that this would be most relevant in its focused programs, as the projects funded through the Open FOAs are likely to be considered too disparate to find much common ground.

As a way of connecting projects together and networking them towards private investors or strategic partners, ARPA-E holds an annual Energy Innovation Summit with its awardees. According to Bonvillian and van Atta (2011), this has helped create a community around advanced energy technologies, and has increased the understanding and visibility of emerging energy technologies among private investors and firms. The network benefits of such conferences was also highlighted by Johnson (2008), who pointed out that they can be a good opportunity for various experts to interact and for building valuable linkages between different actors.

As discussed in section 2.5.3, such networking activities towards external parties such as industry actors or customers might help align the product development process with the needs of the market. This might further increase the chance of commercial success for the developed technologies, especially if prosperous relationships are made, and hence reduce weak network failures. Connecting with investors could also help reduce the challenge of raising additional later-stage funding. In line with Bonvillian and van Atta (2011), we believe that ARPA-E may facilitate the hand-off to later-stage funding by assisting awardees in connecting with other government entities, as highlighted in section 3.3.

4.2 Operational characteristics of ARPA-E

In addition to the roles taken on by ARPA-E as presented above, it possesses a set of operational characteristics that are proposed to affect the performance of the individual projects in terms of developing and commercializing new energy technologies. These factors are presented in the following sections.

4.2.1 The role of the Program Director

The Program Directors have a central role in the management and support of the projects. In this section we will discuss how this, combined with their experience and expertise affects the projects.

4.2.1.1 Experience and expertise of the Program Directors

The ARPA-E Program Directors are highly respected experienced individuals within the technical area of their programs (Bonvillian & van Atta, 2011). They typically possess both scientific expertise from academic research and commercial experience from larger firms or start-ups (Bonvillian & van Atta, 2011). Being responsible for all the projects within their program, their technical expertise and practical experience is useful when reviewing and assisting awardees with technical issues (ARPA-E, 2013e), as well as helping the awardees understand possible commercialization paths and how to move their technologies to market (Bonvillian & van Atta, 2011).

Having a solid technical and practical foundation enables the Program Director to better understand the technology being developed and potential challenges in the R&D process than a layman, which we assume can improve the quality of the dialogue between the Program Director and the project team.

The networking role of the agency can also be better executed by leveraging any real-world industrial experience the Program Director may have, especially with regards to professional network. Connections within academia could also help in this regard. Having a pre-existing network in industry or academic fields relevant for the program should intuitively help the Program Director make relevant introductions for the projects in her portfolio.

However, excessive amounts of specific, expert knowledge might work to the program's disadvantage. Whether intentionally or unintentionally, a Program Director with much in-depth knowledge within the technical area of the particular project might end up micro-managing the project team or driving them in a certain direction. This might feel suffocating for the project's team members and also harm the progress and end results of the project if the direction set by the Program Director proves to be flawed. Very result oriented Program Directors might force the project teams to leave potentially prosperous opportunities unexplored.

4.2.1.2 Responsibilities of the Program Director

The Program Directors are responsible for developing the area of inquiry for their programs, as well as selecting the projects for their program in cooperation with the ARPA-E Director. They can exercise a significant amount of flexibility and control over their project portfolios, and hence stand accountable for the results of the projects they decide to fund. There are no formal personnel evaluation of the Program Directors, so they are incentivized by the prestige of having their portfolios produce results and succeed (Bonvillian & van Atta, 2011). The Program Directors are thus heavily invested in their projects, and are likely to put a lot of effort into driving the projects forward.

Since the Program Directors have so much freedom when it comes to developing and selecting projects for their own programs, it is obvious that they need a high level of relevant experience and expertise. These aspects can also impact the funding and legitimator roles of the agency. The funding role is directly affected by the Program Directors' abilities to employ technical and commercial rigor when designing appropriate programs and selecting the most promising projects. We argued in section 4.1.2 that the screening and vetting process is connected to ARPA-E's abilities as a legitimator. We therefore assert that these abilities and diligent processes should contribute to the legitimacy associated with ARPA-E as well.

4.2.2 Management and support of projects in ARPA-E

ARPA-E has opted for a highly involved project management and support regime. In the following two sections we accentuate how aspects of this regime can impact the supported projects.

4.2.2.1 Support and monitoring: A part of the project team

Another design aspect particular to ARPA-E is the approach used in the interaction between its officials and the projects. As opposed to most research agencies, where the role of the agency primarily is to select the projects to be funded, the ARPA-E Program Directors have a hands-on relationship with their award recipients during the entire support period (ARPA-E, 2013e; Bonvillian & van Atta, 2011).

This hands-on relationship starts already when negotiating the award. After ARPA-E has selected its projects, the prospective awardees enter a negotiation process to set deliverables, technical milestones and budget. ARPA-E typically pushes for ambitious milestones and an aggressive deadline for the completion of the negotiation process, usually 60 to 90 days after selection (ARPA-E, 2013a). An obvious negotiation challenge for the prospective projects will be to balance the trade-off between agreeing to tough milestones to keep the interest of ARPA-E, while making sure that the plan is feasible to execute.

The milestones are clearly defined, and progress is tracked against the milestones in regular meetings and on-site visits (ARPA-E, 2013e). These visits are also an arena where the Program Directors can support the progress of their projects by e.g. discussing and working on technical challenges or establishing helpful contacts (Bonvillian & van Atta, 2011). The experience and expertise of the Program Directors, as previously discussed in section 4.2.1.1 above is therefore an important enabling factor for the Program Directors to be able to take on this kind of 'project portfolio manager role'.

The hands-on, high-involvement project management style ARPA-E has elected to use seems to include a set of benefits and drawbacks. We argue that the frequent on-site visits and meetings can prove beneficial for the projects by allowing the ARPA-E teams to more closely assess the needs of each project and contribute with appropriate support. Examples can for instance be providing productive technical feedback, suggestions on technical issues or suggesting network opportunities. However, as highlighted in 4.2.1.1, we believe that exercising too much influence over the projects could be counterproductive, as the awardees should be the experts on whatever the projects are trying to develop.

We view flexibility on the timing and content of the original milestones as a potential issue. As the project progresses, discoveries may for instance suggest a completely different direction in order to reach its overarching goal. Being bound to milestones with little relevance may in such a situation impede the performance of the project, or even lead to its failure. We therefore argue that exercising reasonable flexibility to change milestones when justified by the scientific or commercial nature of the project could be potentially decisive in the continued success or failure of a project, and that the Program Director has an important role in this regard.

With a project duration of only three years, ARPA-E must focus on projects that can advance from technology concept to a scalable prototype in a relatively short timeframe (Bonvillian & van Atta, 2011). This can amplify the drawbacks of a narrow result-oriented focus, as discussed in section 4.2.1. As a project develops over time, new interesting paths might be discovered or one might meet unexpected challenges. Without additional time to deal with these issues, the project might be less successful, possibly constraining the potential to create radically new technologies.

Intuitively, there are overhead issues to consider in the choice of a high-involvement project management model, issues that ultimately require spending time and resources which could otherwise be spent doing development work. In addition to spending the time on the reviews, we believe that the frequent monitoring and reporting schedule might be considered cumbersome and

intrusive for some groups, especially academic researchers accustomed to basic research environments without much focus on commercial aspects and deliverables. We also argue that the administrative overhead associated with reporting could prove to be a significant burden for smaller organizations, especially those without preexisting financial reporting infrastructure or financial strength to hire dedicated staff for reporting, such as start-ups or small firms.

4.2.2.2 Commercialization focus: Bringing the technology to market

The ability to commercialize new technology is indisputably critical for its success in the marketplace. This is especially true for the energy sector, since it serves a broad and diverse public and private market (Stine, 2011), with established incumbents and strict cost restrictions due to the usually fungible nature of its basic products (e.g. electrical energy).

ARPA-E incorporates a focus on commercialization throughout the entire life of its projects. Firstly, in order to ensure that there are a plausible pathway to adoption in the market, the commercial viability of all projects are considered before being awarded funding (Bonvillian & van Atta, 2011). Secondly, ARPA-E has implemented a Technology-to-Market function (ARPA-E, 2013e) with dedicated officers who work full time to promote the implementation and commercialization of the technologies within ARPA-E-supported projects (Bonvillian & van Atta, 2011). The Technology-to-Market function provides the funded projects with both practical training and business information to give them a better understanding of the market needs, subsequently enabling an alignment of the technology development to market demand (ARPA-E, 2013e).

All projects are required to create a Technology-to-Market plan before being granted an ARPA-E award (ARPA-E, 2013e). The objective of this plan is to increase the likelihood of a successful commercialization of the technology (Wurzelmann, 2012). The project team can also work together with the ARPA-E Technology-to-Market advisors throughout the project lifetime to develop customer strategies. In addition, ARPA-E facilitates networking activities with entities which may potentially help the awardees moving their technologies towards commercialization as part of the Technology-to-Market support (ARPA-E, 2013e).

We argue that this early commercialization focus, brought on by the Technology-to-Market requirements the projects have to fulfill, and the commercialization support they receive will have a positive impact on the projects' ability to adapt their products to the needs of the market, hence reducing systemic failures. We believe an especially important aspect of this are the incentives and support for talking to industry stakeholders and potential customers to get a comprehensive understanding of what they are interested in. The efficacy of such activities might however vary depending on what stage in the development process the projects

are in, as potential customers for example might have difficulties evaluating the value of a technology that is only at a concept stage.

The need for a Technology-to-Market support function might also vary depending on the type of organization that is hosting the project. For project teams without much commercial experience, such as university researchers or first-time entrepreneurs, this commercialization support might be critical to successfully transition projects from ARPA-E to private investors or commercial partners at the end of ARPA-E's funding period. Having projects succeed in that hand-off can be critical for bringing the developed technologies to market, and is hence very important for the success of ARPA-E itself. As outlined above, ARPA-E therefore has a strong focus on commercialization, and requires the project teams to assess and act on the potential paths to market from the very inception through to the end of their projects.

4.3 Summary of the proposed effects

Given the large amount of proposed direct, indirect and interrelated effects on the supported projects, we summarize these relations in Figure 2 in an effort to maintain overview for the following chapters. We note that Figure 2 is not exhaustive, as we have left out some moderating or secondary effects to the individual factors (e.g. potential difficulties of raising the cost share) to maintain some level of clarity for the reader. Additionally, we highlight the direct impact of the funding aspect on the existence of the project, and therefore its performance, with a solid line. The dashed, black lines indicate moderating factors on the project's ability to reach its end goals.

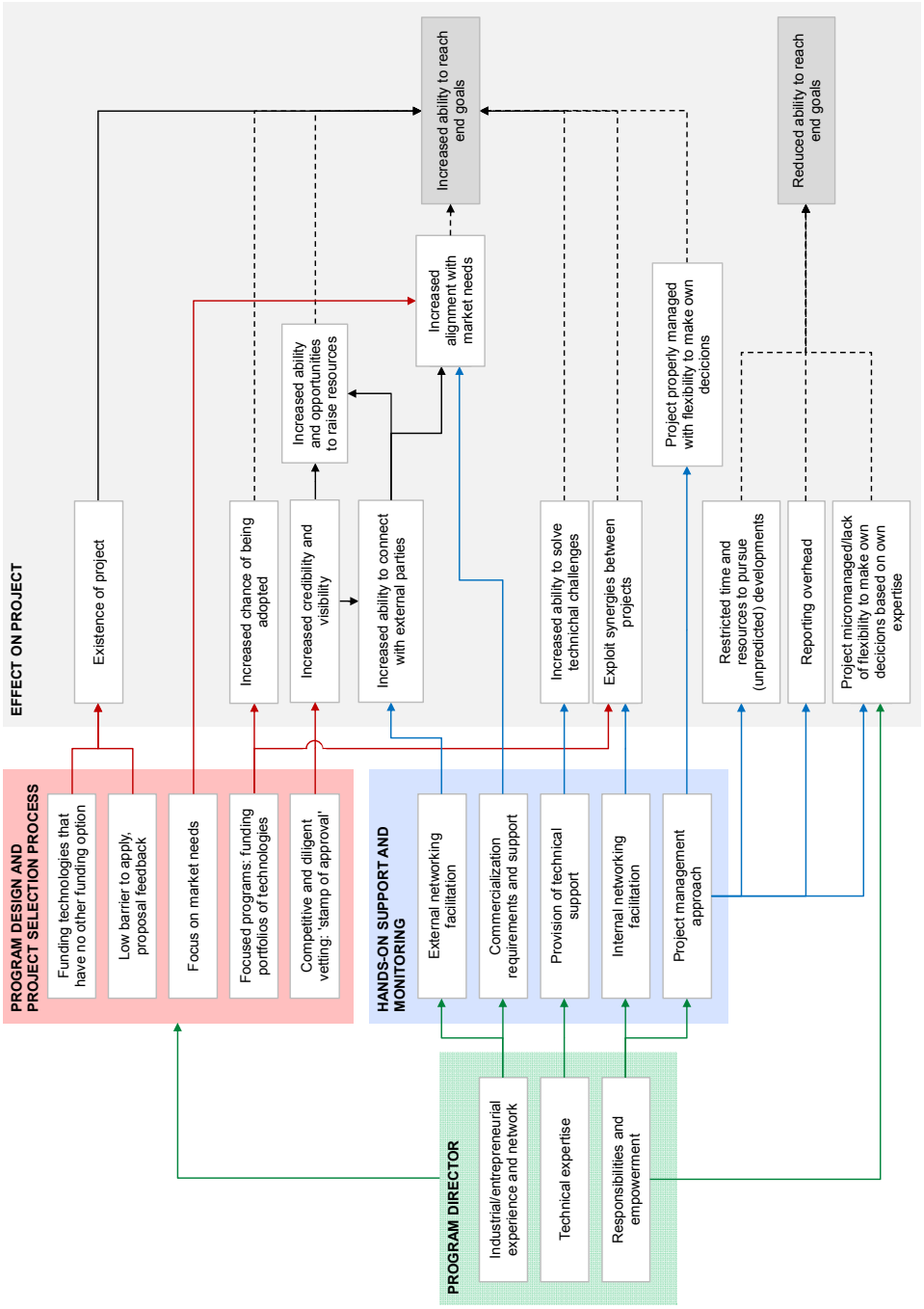


Figure 2 - Proposed effects and interrelations between the project and active design characteristics of ARPA-E

5 Method

5.1 Rationale for research method and research design

Our research question addresses the potential benefits and limitations of direct government support of entities working on commercialization of new, high-risk energy technology. This necessitates investigating entities which have been supported by such programs. The U.S. agency ARPA-E has through a preliminary review carried out by The Norwegian Research Council emerged as the most interesting institution to research in this relation (Hernes et al., 2014), and was therefore chosen as the focus of our research. A further delimitation of the scope of our research is that we are focused on the individual projects being supported by such programs, and the subsequent effects they experience in their innovation processes as a result of having support from such an agency.

We have therefore chosen an empirical study using the case study method. Since our research question is a 'How' question of an explanatory nature, the number of variables are too many to be covered by a more quantitative method, such as surveys, which would not sufficiently describe the phenomenon (Yin, 2014). Additionally, due to the relatively young age of ARPA-E, the sample of firms that have gone through a full or partial cycle of support would arguably be too limited to permit any meaningful quantitative analysis.

We therefore opted for an embedded single-case research design, where the units of analysis were projects which are or have been supported by ARPA-E. The primary source of data was semi-structured, open-ended interviews with 13 Project Managers/Principal Investigators, conducted in California during three weeks in mid-March through early April 2014. We also intended to interview strategically important representatives from ARPA-E, most notably Program Directors, but our interview requests were unfortunately denied by ARPA-E officials.

5.2 Preparation and collection of data

In preparation of the data collection phase we developed a case study protocol, including an overview of the case study, the data collection procedure and the data collection questions, as advised by Yin (2014), in addition to a project plan with all our planned deliverables and milestones. This was sent to our stakeholder, the Norwegian Research Council, to ensure we had a common understanding as to how we would conduct our research.

The data collection and preparation phase followed a stepwise process akin to the procedures outlined by Strauss and Corbin (1990).

We first identified potential interviewees and their contact information using ARPA-E's publicly available repository of supported projects (ARPA-E, 2014e). In order to make the study practically feasible within our travel and budget limitations, we limited the initial sample of potential interviewees to Project Managers for ARPA-E supported projects in California. As a backup, we would expand the sample to neighboring states if needed. The initial sample was then trimmed by eliminating duplicate project entries and additional projects with the same Project Manager. One project was also removed due to being mislabeled as Californian. This left us with a gross initial sample of 63 Project Managers to contact.

The identified Project Managers were then requested to contribute to our research via e-mail. The e-mail and the request letter from The Norwegian Research Council can be found in their complete forms in the appendix (section 0). The request e-mails were sent in two batches; the first consisting of ten randomly selected candidates from the sample. The first batch was sent out a few days in advance of the remaining e-mails. In order to maximize the efficacy of the request letter, we subsequently revised the language of the letter based on questions we received in the responses from the initial batch. The revised letter included clarifications with regards to the location of the interviews and that the interview would be held in English.

After getting responses from the contacted Project Managers on whether they would participate in our study, we prepared fact-sheets on all of the interviewees that had agreed to participate. This was used as a preparation for the interviews to get a general understanding of the project and the program it belonged to, in order to be able to adapt the interview accordingly.

Table 1 - Interviewee sample

Response	#	Relative share
Gross sample in Californian repository	68	100.0 %
Additional project/duplicates	4	5.9 %
Mislabeled entries	1	1.5 %
Gross sample contacted	63	92.6 %
Undelivered/unreachable	4	5.9 %
No response	42	61.8 %
Negative response	4	5.9 %
Net sample (Positive responses)	13	19.1 %

The interviews were scheduled in three batches according to the time and place of convenience for the interviewees. Our initial interview topics were based on

our theoretical and empirical foundation, as presented in Chapters 2–4. In order to allow the interviewees time for sufficient preparation, the interview topics (included in appendix, section 12.3) were prepared and sent to each interviewee approximately one week ahead of the scheduled interview. We initially sent the topics to and interviewed four Project Managers in the third week of March 2014. After each interview, we reassessed the relevance of each topic according to the learning experience and analytical cues obtained up to that point of the interview process, and incorporated that knowledge in following interviews, as recommended by Strauss and Corbin (1990). Following the first batch of interviews, the written topics were then refined based on this learning experience, and sent out to the remaining nine Project Managers, which were interviewed in the two weeks following the initial interviews.

According to Yin (2014), the case study researcher should follow a line of inquiry guided by his case study protocol, while framing the questions in an unbiased and conversational manner. In order to ease the conversation for the interviewee and to avoid talking over each other, one member of the group acted as the primary interviewer in all of the interviews, supported by attentive listening and follow-up questions from the two others. While remaining cognizant of framing each question in an unprejudiced manner, this allowed continuous refinement of the questions from each interview to the next as our understanding of each issue improved, while retaining the flexibility to adapt the line of inquiry to the live situation. The end result was a fairly coherent line of inquiry which was tailored to each specific conversation.

Before conducting each interview, we also asked the interviewee about his/her confidentiality preferences, as well as requesting permission to record the audio in order to ensure completeness and accuracy of the resulting transcripts.

Following the interview process, every audio file was transcribed following a two-step process. After initial transcription, each transcript was then reviewed and revised by at least one of the other authors in order to ensure accuracy and acceptable quality of the transcribed interview. The finished transcripts were then returned to the respective interviewees to allow potential revision of any factual errors made in the interview or other inconsistencies. Upon approval, two minor typing errors were corrected, both of non-critical nature to our thesis.

5.3 Analytical approach

Following Strauss and Corbin (1990), the coding process was guided by the conceptual categories we had formed on the basis of our theoretical and empirical analysis, as presented in Chapters 2–4. More specifically, our

analytical approach was based on a combination of the axial coding process with the iterative nature of the open coding process (Strauss & Corbin, 1990).

This work was primarily completed using a combination of the highlighting and commenting tools in Microsoft Word for initial labeling of comparable concepts, and subsequently manually structured, compared and grouped into relevant code groups in Microsoft Excel. Following this initial sorting, all three members of the group reviewed the code groups for accuracy and consistency, after which they were developed into larger categories corresponding to the anticipated categories in the presented theoretical and empirical background, again comparable to the procedures recommended by Strauss and Corbin (1990).

When processing this material into the final results, statements pertaining to specific 'facts' were validated against appropriate documentation whenever possible, cf. the importance of data triangulation according to Yin (2014). An example of this was the verification of specific cost share levels against FOAs issued by ARPA-E.

During this work, it became clear that many of the data points had links to several parts of the theoretical and empirical background, or suggested interrelations between the identified categories. As recommended by Strauss and Corbin (1990), we honed in on these issues as they emerged during the interview process in an effort to collect as much data on these relationships as possible. We then continued to investigate these relationships in a structured manner during our data analysis, by noting which and in what way elements were influencing or interrelating with other elements.

5.4 Description of the interviewee sample

In this section we present some background information on our interviewee sample in order to provide helpful context for our results, while retaining the anonymity of our interviewees and their projects. The net sample resulting from our inquiry consisted of Project Managers or Principal Investigators from 13 different projects, of which one alumnus, one suspended and 11 active. Overall, the projects were spread across several different programs and varied in age, organization type and size of their awards.

The projects were relatively dispersed, with only two of the ARPA-E support programs being represented with more than one project in our group, as shown in Figure 3. In addition to representing a wide array of technologies, the majority of our interviewees therefore had different Program Directors as well, which could be useful for understanding diverging results due to individual attitudes in the ARPA-E teams.

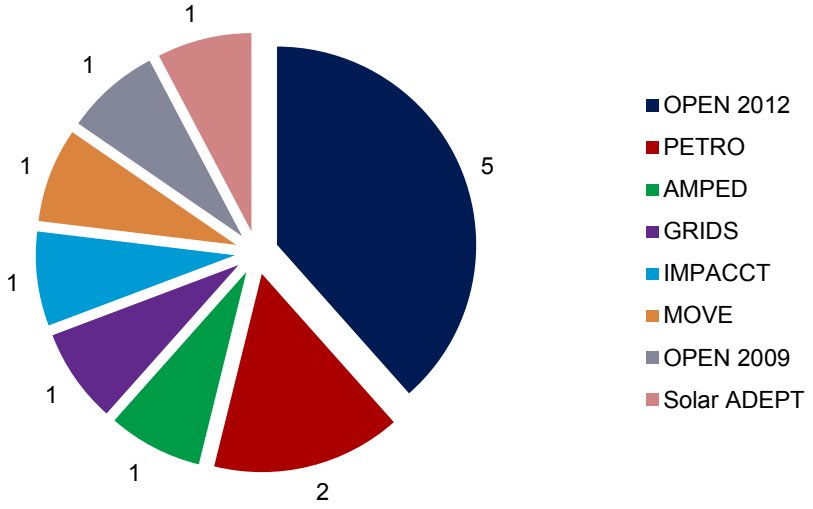


Figure 3 - Visual representation of the project dispersion across ARPA-E programs

With the exception of two projects, all of the projects represented in our sample were currently receiving support at the time of the interview. One project had finished ahead of our research, and one project had been suspended at the time of the interview. Ten of the remaining eleven projects had completed 30-80% of their project periods.

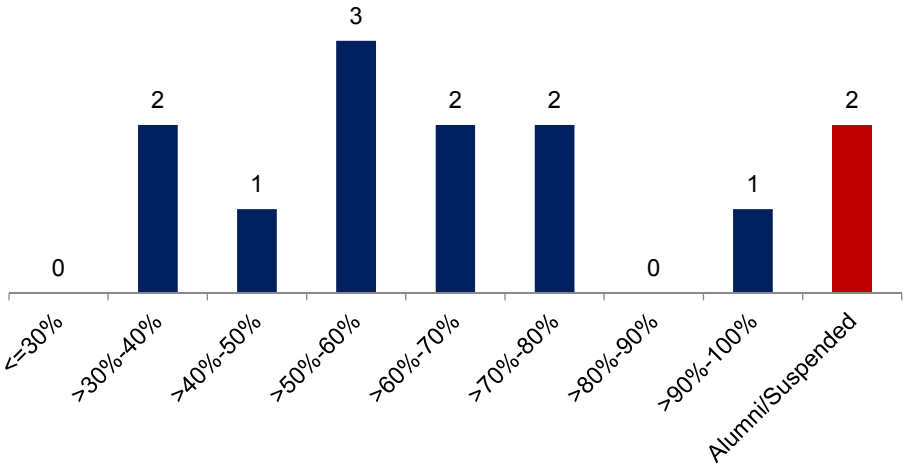


Figure 4 - Relative time passed in each project out of the total duration supported by ARPA-E at the time of the interview

Our interview sample consisted of a majority of private firms, of which five considered themselves to be start-ups more or less dedicated to the project; four were medium to large firms where the ARPA-E project accounts for a minor part of operations, two projects were connected to universities and two to national labs.

Table 2 - Interviewees by organization and project status

Interviewee	Small firm / Start-up	Medium / Large firm	University	National Lab	Project status
PM1			X		Active
PM2				X	Active
PM3	X				Active
PM4	X				Active
PM5		X			Alumni
PM6		X			Active
PM7	X				Active
PM8	X				Active
PM&PI9		X			Suspended
PM10		X			Active
PM11	X				Active
PM12			X		Active
PM13				X	Active

Our interviewees had been awarded varying amounts of funding. The average award size was USD3.1m, whereas the median was approximately USD3.5m. In order to protect confidentiality we can only show limited information, however we do note that there seemed to be a clustering of projects in the USD1.5-2.5m range on the low end and in the USD4-5m range on the high end, with few projects in between.

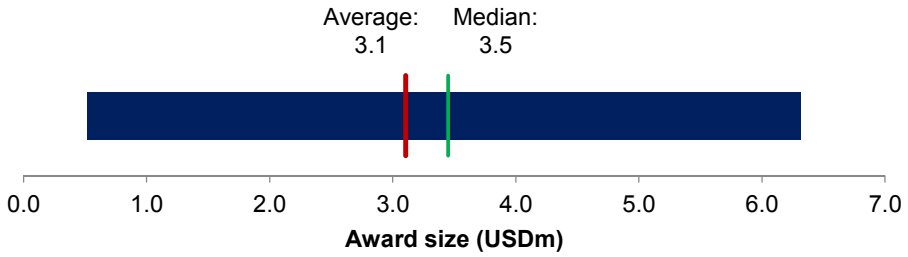


Figure 5 - Award sizes in our interviewee sample

6 Results

The resulting material from our interviews was structured and sorted into groups corresponding to the suggested roles and important design characteristics as predicted by our theoretic and empirical analysis. The results are therefore presented here following the same structure as Chapter 4, incorporating the theoretical background from Chapter 2.

6.1 Funding role

In this section we present results dealing with ARPA-E in the funding role. The recurring themes in this context were anchored in the market failure of securing funding and challenges associated with the cost share. Another important subject emerging from our interviews with Project Managers and Principal Investigators in various projects was *the importance of the size of the awarded funding.*

6.1.1 Market failure: ARPA-E's role in overcoming the funding gap

Several informants expressed that ARPA-E seemed like the only funding source willing to accept the necessary risk and commitment to make their projects happen, proving essential to their existence.

The projects funded using resources internal to the company or raised from VC owners also stressed that ARPA-E involvement allowed them to take on high-risk projects that they otherwise would not have been able to fund themselves, indicating that the ARPA-E support alleviated some of the concerns their senior management and/or investors would otherwise have had.

6.1.1.1 Overcoming the funding gap: ARPA-E considered an enabling force of high-risk innovation projects

Many of our interviewees explicitly focused on the importance of ARPA-E for the existence of their projects and consequentially in the development of their technologies.

PM4 found ARPA-E to be the enabler of their project: "*We had a lot of interest doing this project, but to VCs in the area and everyone else we showed it to, it seemed so outlandish that everyone said "that would be really interesting if it could work, but all you have to show is a concept of what you think could work,*

and it's so different from the norm". We made a bunch of prototypes here, but for the particular project we actually really needed funding in order to make a proper prototype that would actually prove out the concept. ARPA-E gave us a couple of years of funding to do this, and it has been interesting. They understood that if we could do what we said, then it would be really disruptive. But unlike someone like a VC or a project developer, they didn't have to know for sure that that was true. [ARPA-E] giving us that money has enabled us to make our prototypes, and now when we show that prototype to the same people, they get it in a way they didn't get it before." PM4 concluded that "*if you're working on energy, even if you're really convinced you have an incredible idea, not everyone wants to fund you before you have a really compelling prototype.(...) [ARPA-E] definitely bridged the gap from concept to realistic enough product/prototype that people would want to actually talk to you.*"

PM6 also experienced the lack of willingness to invest from private funding sources, and summarized that "*Without government support and ARPA-E in particular, it would be very difficult for us to do this [project]. (...) I don't think we would have been able to come as far along as we are [without ARPA-E]. There are certain things I would say we couldn't have done at all without ARPA-E support. So the money has been tremendously helpful*."

ARPA-E's essential role in the project's existence was also explicitly noted by PM3, who stated that "*Without [ARPA-E], I don't think this project would have necessarily got off the ground.*" Being part of a venture capital funded firm, PM7 expressed that "*The most beneficial thing [with ARPA-E support] was that we could try new ideas, which we wouldn't have been able to do with the VC funds [only]*", adding that ARPA-E funding attracted the venture capitalists to provide the cost share for riskier projects: "*They [the VCs] like us doing the more difficult projects, because it helps us to create new openings in the technology, so it is also good for the VC.* "

PM11 elaborated on this issue, noting the structural incompatibility with VC funding due to their limited time horizon. He explained that "*ARPA-E always wants to avoid funding things that can raise money anyway*" and that he therefore had to substantiate why his project would not be able to get funding elsewhere. Having talked to several venture capitalists that ended up not funding the project, PM11 explained: "*I actually got letters from other VC firms, saying this is interesting technology, and we refuse to invest for reason 1, reason 2, reason 3. And then ARPA-E could see, "these guys are not lazy about raising money, actually we need to invest or nobody will"* PM11 then concluded in line with PM6 and PM3: "*(...) It's actually extremely important to have an agency like ARPA-E, because it doesn't make financial sense for private investors to come in for early stage technologies. (...) If we hadn't gotten [the ARPA-E funding], we*

probably wouldn't be here today. But we did, so a year and a half later, here we are."

PM10 expressed the same concern as PM11, however from the perspective of companies rather than external investors: "*There are not a lot of options for this kind of high-risk, high-reward type of research funding today. (...) Most companies today don't look out ten years toward what crazy research idea might become successful. (...) There are very few entities that will do that.*"

PM&PI9 had also experienced the dearth of investment by larger companies in their sector, and noted the funding gap ARPA-E fills in that space: *"(…) [ARPA-E] is great, because it is providing funding for a specific area that's not going to receive a lot of private development. (...) There are not a lot of the big-eye companies investing in this sort of technology. I think, if anything, the big-eye companies are pulling their investments out of this sort of technology.*"

PM2 elaborated on the importance of ARPA-E in overcoming the market failure: "*ARPA-E fills an important void in the science and engineering space. It is possible to get state of the art money to do pure science. But in this space, it is hard to get significant money to do innovation. (…) When you walk through the display at the Energy Summit, there are just hundreds of really exciting things happening. And that is the magic of ARPA-E, that they have been able to fund these things. They're targeted, but still they're 'out there', they're long range. And in that energy technology space, the industrial engineering space that you're examining, that money doesn't really exist anywhere. Companies do not invest at that level, and government tends to put a lot of money in pure science. (…) If it wasn't for ARPA-E, [our project] would never have happened.*"

PM5, PM8 and PM13 elaborated on the difficulties of finding government funding outside ARPA-E suiting the risk profile of their projects. PM5 said he experienced that *"(...) a lot of the other government agencies (...) didn't seem to be willing to take the risks in terms of both successes and failures*", while PM13 thought that *"(…) it would be difficult to get funded otherwise [without ARPA-E], because they are in this kind of little borderline crazy ideas, (...) a little too high risk for other areas of DOE to fund, certainly [the U.S. Department of Agriculture] and [the National Science Foundation]*".

While applauding the funding ARPA-E provides for the early development stage of his project, PM11 remained cognizant of funding challenges awaiting between the ARPA-E support and actual commercialization: "*As far as raising ten times as much money as I have now to do initial manufacturing, that's going to be really hard, whether or not I've got the ARPA-E money, and that's going to be the biggest barrier [to commercialization]. For a lot of these companies, like mine, it costs a ton of money to be able to manufacture on scale bigger that just a lab*

with a dozen people in it. The challenge of raising that funding is independent of having support from ARPA-E or not."

6.1.1.2 Willingness to invest and take risks if ARPA-E invests

While remarking that it would be infeasible to fully fund their projects using venture capital or internal funds, PM11, PM&PI9, PM10 and PM7 provided interesting perspectives on an apparent willingness from private entities to commit funding knowing that they are investing alongside funding from ARPA-E.

PM11 probably contributed with the most explicit example of receiving investment contingent on ARPA-E support: "*I got a letter from the VC firm that ended up investing in us, and it said: "If these guys actually win the ARPA-E grant, and we can complete our technical due diligence and it looks good, then we'll put in more than enough money for the cost share." And they did."*

PM&PI9 discussed the notable impact resource constraints have on the ability and willingness to take on high-risk projects using only company funds: "*We're a small company, and we have limited funds. And so, we have to be very strategic about what we apply those funds to. We do make calculated risks on new technology, or more risky technology, but typically we don't fund that ourselves - or we fund it at a very, very low level. We definitely use public funding for projects such as this."* PM&PI9 continued this argument when asked about the primary benefit of receiving ARPA-E support: "*(...) the main benefit [with ARPA-E] is that it funded something that we would not have invested in ourselves. (...) We did [the project] here specifically because ARPA-E funded it.* "

PM10 indicated a similar situation for his firm: "*It is on higher side of the risk spectrum, for [the company] to entirely fund this magnitude of funding for a three-year project. (…) [The company] would perhaps have funded a small portion of this [project], but I don't think it would have been enough to address all the technical questions. Perhaps the risk tolerance, if we had missed some of the early goals, would have probably been lower.*"

6.1.2 Cost share difficulties

The discussions on the cost share revolved around three main themes; the funding challenge it presents in itself, how to meet the cost share even though resources are scarce and whether or not the cost share is necessary.

Introducing this topic, PM11 eloquently pinpointed the incongruity of requiring cost share, concluding that: "*[The cost share] is something I don't think ARPA-E handles particularly well. In the proposal you have to prove to ARPA-E why they need to invest, because no one else wants to invest. But then technically they require that you already have the cost share.*"

6.1.2.1 Market failure and duplication issues with federal funding

When discussing the cost share, we noted that the reasons our interviewees provided for why the cost share is challenging seemed to overlap with the reasons for why it is hard to raise capital for the high-risk projects ARPA-E funds, directly linking it to the results on the market failure and funding challenge itself as discussed in previous sections.

The rules on duplication of federal funding sources (section 4.1.1) were also challenging for some of the project teams, which had enough internal resources to provide the cost share, but weren't allowed to use them because of deriving that income from the federal government.

PM2 acknowledged that providing the 20% cost share can be fairly effortless for private companies if they already have the resources. However, for universities and laboratories which may not have those funds at all, providing the cost share can be challenging if they are federally funded: "(…) *even if I had the funds, my funds all come from government one way or another so I couldn't use them to [provide the cost share], it wouldn't count. (…) So we had to get a partner [that] provided the 20% cost share*."

Following PM2's concern, PM5 explained that duplication issues can be a relevant issue for private companies as well, especially when company policy restricts outside investment: "*We actually won other awards and had to turn them down [because of the cost share]. It's terrible. (...) We have internal money that we can spend at the company, but that money is generated from government contracts [and] cannot be used for another federal program*".

PM2 then connected the cost share to the challenge of raising funds for high-risk projects in general: "*It is a substantial commitment. On a project that is such a state of the art, big-leap, high-risk, that's the thing that becomes challenging in ARPA-E.* (…) *[the industrial partner] wouldn't think of that kind of investment on that long range, high risk… that is unusual for them. That's probably the biggest challenge in ARPA-E, that you have convince two people who have money that you have a good idea, the industrial partner who is going to use it down the road, or if you're a small company you'll have to convince your investors to do that. Then you have to convince ARPA-E.*" PM4 expressed the same sentiment: "*The same reason that you need ARPA-E funding is the same reason why it is really hard to pull off those cost shares."*

PM8 presented a similar argument as PM4: *"It is a lot of work [to come up with the cost share]. Having it be matched 4-to-1 by the government helps a lot, but it still a lot of work, because all of these projects are - by definition - pretty risky and long-term bets.* (…) *I think the constraint on us mostly has been the cost share requirement, which is challenging.*"

PM13 also added the disadvantage of not having any pre-existing industrial network, indicating a weak network failure: *"If it's a project that you are interested in, and you want to send in a proposal, you need 20% cost share. If you don't have any established contacts with industry, trying to get that from industry is difficult."*

6.1.2.2 Solving the cost share challenge

When discussing how to provide the cost share, issues faced by the respective interviewees revolved around duplication of federal funds, finding someone to provide the cost share in time and especially ways to provide the cost share in-kind, i.e. without having to come up with cash.

Following their issues with duplication and company policy preventing outside investment, PM5 explained that one of the ways they used to get around it is to "*work with a university and they can help cover some of that cost-share. They have multiple streams of money that they can leverage. They can just say: "Well, we just use the federal stuff here" and they can trade around. They can work their magic and they do a great job with that.*"

PM11 outlined a different workaround on the duplication issue using state grants: "*While the federal government doesn't want to give out two different grants for the same [project], that's not the case with state money. So had the timing been right, I could have gone to a State of California agency, the California Energy Commission does a lot of grants with new technologies (…) These are small grants. People use those grants as cost share. It's not enough money for them to use the grant for anything practical, [but] a few hundred thousand dollars is enough for the cost share for 2-3 million from the federal government. (…) State grant money does not count as duplication. It might as well be a private source, as far as the federal government is concerned.*"

PM11 also highlighted that while ARPA-E technically requires the cost share to be in place when announcing the award, the agency can exercise some flexibility on that timing: "*ARPA-E will bend the rules now and then and give you more time to raise the cost share. And if the program gets delayed before it starts, by six months, it's OK. The program doesn't start on day one anyway. (...) Before actually working out the contracting, they make the public announcements about who is getting the awards. Then you are basically publicly married, and you have to find a way to work it out. But theoretically we should have already had the cost share money in our bank account by the time they make that public announcement. In our case, we didn't. Not everybody does.*"

Several of the interviewees went into detail on in-kind cost sharing, in terms of providing the cost share through the depreciation of assets, paying below-market salaries for the project team or supplying services at a discount. PM11

summarized the incentive behind meeting the cost share requirements in-kind: "*So what some people will do is effectively [to] find non-cash assets that can [be] provided as cost share to get away with it.*" PM12 expanded this notion after highlighting the discounted services option: "*It was just a matter of finding the right thing that satisfies the requirement of cost share.*" However, PM12 added that, while there is no cash involved, "*(…) you have to show that you actually contributed 20% of the 'cash', even though cash doesn't move around. That is a big challenge*." Interestingly enough, PM11 highlighted that intellectual property costs that normally would reach a USD15,000 funding limit in the ARPA-E contract, such as patenting costs, count towards the cost share (ARPA-E, 2012), elegantly bypassing the funding restriction on intellectual property while meeting the cost-share as well.

After discussing whether it makes sense to allow in-kind cost sharing, PM13 explained the rationale: "*If you try get cash from a company, that's really difficult. If they can use their infrastructure, it is OK. Because otherwise you have to find that someplace else, maybe you rent it. That would be expensive, so it is real cost-share. It is just that it is not cash.*"

6.1.2.3 Is cost share good? The value of accountability

Leaving the challenges associated with the cost share aside, both PM3 and PM6 elaborated on whether it is something an agency like ARPA-E should retain. PM6 had no issues with the government wanting companies to share the risk, stating that "*(…) the company has to be OK with providing its own cost share. That doesn't give me any heartburn. If I'm the government, and the company is not willing to share the risk, it sounds like they're not in the game*."

PM3 made a more philosophical point on accountability to explain why he thinks the cost share is important: "*I think that accountability is good for people, for companies. There is a conversation we had today in our ARPA-E meeting, "is the cost-share good?" Even ARPA-E balances this question, because it is not about the money, it is about accountability. I mean, their prerogative is to do the best thing for the technologies. They are making a choice to force companies have 'skin in the game' because they believe it will be better for the projects. There is all that about accountability, and I think that having that is good.*"

6.1.3 Promoting a portfolio of technologies

Besides the primarily financial part of ARPA-E's funding role, PM3, PM7 and PM13 touched upon its potential role as a promoter of technology ecosystems (cf. sections 2.5.1, 4.1.1), whether complementary or interdependent in nature.

PM3 explained his perception of being part of a deliberate ecosystem conceived by his Program Director: "*When our Program Director developed the program, he looked at the big picture: "What do we need to do for natural gas to be adopted, and what are the major problems?", so he had already created that narrative for us. It forces upon us to see where we are in that landscape. We are part of [A], some are part of [B], some are part of [C] (...) they have done a really good job of developing a narrative that we are all going to then regurgitate and pitch and find out where we are. I think that is really important, and they've done a great job of that. Now I know "where am I in this ecosystem, what else needs to succeed? What is my competition, how far [from commercialization] are they?" Not on a specific level, but just on a technology level, like [technology X] compared to [technology Y].*"

PM7 was more specific, as his technology is directly dependent on another being developed: "*All new technologies are dependent on other technologies, that is the problem. (…) We've got to make [a device with specific capabilities], and then you don't have a [material with the needed properties] to do that"*, noting that *"[Handling this issue] is something that ARPA-E did very well. They looked at all of these [technological] areas, and in each of these areas they had groups that are working."*

PM13 connected this aspect of ARPA-E to the Program Director, who "*(…) could see that if we fund these [projects], we get a very good complementary set of projects. (…) It is not only selecting projects because they're good, also because they fit well together as a program. (…) [the projects] can complement each other, so we can see ideas from different groups that (…) maybe two years from now, we are at a stage where we [can] collaborate. So that is something that the Program Director could see.*"

6.1.4 Project application, screening and selection process

This section is focused on the process of applying for ARPA-E grants and the selection process as perceived by the applicants. The interviewees highlighted the two-step selection process and their thoughts on being able to reply to reviewers' application comments. Additionally thoughts on the effect of the applicants' proposal writing skills were discussed, along with the project application timeframe.

The application process was summarized by PM6: *"You submit a whitepaper, you are encouraged or discouraged, you submit the full proposal, you get reviewer comments on the full proposal, opportunity to respond, and then they decide."* PM6 further commented: *"On multiple levels that seems to me to be a good structure. The agency has lots of opportunity to evaluate the merits of the proposed work."*

6.1.4.1 Two-step selection process

The two-step structure of the application process was praised by the interviewees, as it reduces the risk of wasting a great deal of time if the proposal is outside what ARPA-E is looking for in the particular FOA. One interviewee, PM1, even claimed that she would not have applied if she had to go straight to writing the full proposal: "*I think [the application process] is very effective, to have a pre-proposal, which doesn't take so much work to do, and then you get notified whether you are encouraged to submit a full proposal or not. That is a model that I absolutely endorse, because I never would have written a full proposal."*

PM4 was of a similar experience, explaining why: *"The full proposals take so long, that you really want to have a short concept paper, because if they can just tell you this isn't (...) sometimes it is not even that your idea is bad, so much as it doesn't fit into that piece of funding as there are certain structures around that. I think not having to go through the 100+ hours that it takes to put together a full proposal makes the concept paper very appealing."*

PM8 supports PM4's statement regarding the workload that would be wasted if not being granted an award, but also debates whether the process of only submitting a pre-proposal first might negatively affect the thoroughness of the selection process: *"It saves you the trouble if they aren't interested in the pre-proposal. I think it is good in that sense, since the proposals take an enormous amount of effort to put together. On the other hand, you never know what the screening mechanisms is for the pre-proposals, and it is possible that the volume of pre-proposals they get is so large that the screening is not very in depth, and that you could be tripped up by not having the right keyword"*

When PM10 applied for ARPA-E funding this mechanism was not in place. He described how he experienced the application process when the full proposal had to be submitted directly: *"We had to write about 60 pages of material in about a month, with supporting financial statements. Mostly 'going in blind'. And so it's a fair amount of time and effort involved. I would say we spent the better part of 2-3 weeks more or less full-time doing this. Not just me, but a small team of us. Since then [ARPA-E has] have made it more efficient. Now they have a two-stage process."*

In order to elaborate on the workload required by a full proposal, we include PM11' explanation, which matches most of the comments of the other interviewees as well: *"I worked full time for probably three and a half weeks on it. And full time for me is not 40 hours a week, it's a lot more. So this is probably between two and three hundred hours of work by one person on an application".* PM11 explained that *"one of the reasons it took so long time was because I had never done it before, and I did it by myself. It also took longer for me because*

we have a new [product]" and further: *"So I had a harder story to tell. It took up more space, it was longer. That is fine. It was worth doing it obviously, we got the grant. The other thing is, that level of detail would be required for someone to honestly evaluate if we were making stuff up or not".* PM1's team had even used a professional proposal writer to help them with the formalities and format of the proposal to increase their chances, although they had taken on most of the writing themselves.

6.1.4.2 Response to comments

ARPA-E is systematically trying to avoid misunderstandings in the review-process, as evidenced by the thorough review process highlighted by PM12: *"So officially [ARPA-E has] a two-step screening process. Within this time period, [the] 6-7 months review period, I think we had at least 10 conference calls with them, just to try to make sure that they understand what we were talking about."*

PM13 pointed out that ARPA-E, and now even other DOE agencies, offer the opportunity to *"(…) argue, respond to the comments, and that's not only for show I realized. They really take that into account, the Program Director and his team, (…) and make the decision based not only on the reviewers' comments, but also on our response. I think in both our projects, our response to the reviewers' comments have been really important. (…) Sometimes the reviewers just didn't get it."* PM13 also highlighted that the response mechanism could be essential for getting the award if there is one dominant person that influences the rest of the review panel.

PM8 debated the actual influence his response had on ARPA-E's decision, but appreciated the opportunity to respond. The initial peer review responses to his proposal didn't seem to have considered it with proper rigor, and had been dismissive as a result: *"We had the opportunity to respond to it, which we did. (…) it is hard for me to know how useful it was, but I was glad to have the chance to respond."* PM7 added that ARPA-E would challenge the content of the proposal as well, not just clarify potential misunderstandings.

6.1.5 Critical award size

An unexpected detail of the funding role that emerged in some of the interviews was the importance of the size of the award itself. We did not predict this result in advance, and therefore find it important to report.

PM6's support of this notion seems like a proper introduction: "*(...) [ARPA-E] are more willing than most agencies to take big swings. They have more money, and that matters.*"

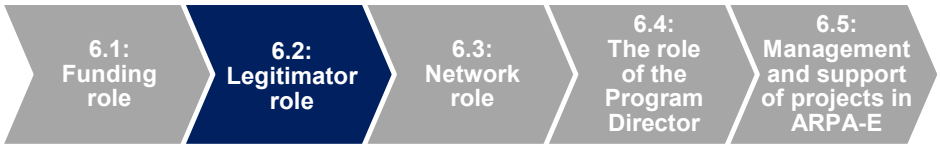
PM1 went into somewhat more detail, appreciating size of ARPA-E's commitment in both funding and timeframe: "*Maybe we could have found other*

resources to build this, but just the sheer size of the award made it possible to create a momentum and an infrastructure (...) Essentially having them express their confidence that we could try something that was risky, and give us a big chunk of money to really give us the opportunity to do it. It could have been easy to make the mistake of saying "This is risky, so we just give you a little bit of money, and if you get something done, then we'll give you a little more", but I think that it is a critical activation energy, or a critical threshold."

PM11 presented thoughts in line with PM1, linking the size of the award directly with the potential achievements resulting from the funding opportunity: "*The most important benefit is that ARPA-E is giving us enough money to succeed or fail. Whereas I said an SBIR is usually a small amount of money, we can't get much done. (…) Without ARPA-E it would have been impossible to raise that much money, all at once, to do it. That is a huge benefit*. (…) *I don't need to worry about going out and asking for money every six months. So I get to focus on making [technology] that work.*"

PM2 put this into perspective by comparing the award size to the costs of performing applied research with the ambitious goals of ARPA-E: "*It is relatively easy to get a couple of hundred thousand dollars, which in a laboratory like this, pays for half a year of somebody's time. That's good, but it doesn't make the kind of projects we are talking about happen. So ARPA-E is really the only money in the energy space that allows you to do those big jumps with enough money to really make progress.*"

6.2 Legitimator role



While ARPA-E is still a young agency, our interviewees claimed that it is able to act as a legitimator. In this section, we have reported the recurring elements highlighted by the interviewees with regards to the legitimizing effects they may have experienced from receiving the ARPA-E award. We have grouped these results into three themes: The apparent risk reduction provided by being vetted and approved by ARPA-E, incoming interest from being associated with the ARPA-E name, and its value when reaching out. In some cases, the interviewees reported to not have seen much difference.

PM3 provided a frank conclusion on the legitimizing effect of ARPA-E, summarizing the opinions provided by most of our interviewees: *"(…) [ARPA-E] legitimizes you, you can leverage that. They give you exposure for free."*

6.2.1 Risk reduction through ARPA-E vetting

How ARPA-E's detailed proposal process and its two-stage review process had affected the risk and uncertainty perceived by parties that may have interest in investing in the project was brought up by some of the interviewees.

PM7 pointed out that the vetting process ARPA-E employs is important, as it gives financial investors such as VCs a better understanding of the technical merits of the project: "*I do think what ARPA-E projects do is it helps VCs to in a way have ideas vetted indirectly. Now, VCs are good businessmen, but they may not know all the technologies, and they are not sure whether they are funding the right groups. When you get a project from ARPA-E, they know that it has been checked out by people who know the area and so on. So that has been good for us"*

The awardees also get the legitimacy of the DOE, since ARPA-E is a DOE agency. PM4 highlighted that this makes it easier to pitch new ideas: *"You get the funding for the unusual idea, but you also get the legitimacy of being supported by the Department of Energy. Especially because ARPA-E is so well thought of in the U.S. right now, it means that you can take this unusual idea and people will automatically assume that what you're saying is something that has some backing to it, especially because they are vetting us throughout the process."*

PM11 relates the legitimacy brought on by being awarded funds from ARPA-E to his project's ability to raise money from VCs. When his funding award was made public, PM11 suddenly saw renewed interest from a VC that had previously rejected the investment opportunity: *"We heard you got the money from [another VC], would you rather have us invest instead?"* PM11 elaborated: *"That is what the ARPA-E name gets you. ARPA-E is believed, regardless of any other faults it may have, that they have such good technical expertise, that if they make an investment in something, it's actually interesting. So investors will look at us just because we have ARPA-E next to our name."* Despite this added legitimacy, PM11 also implied that the actual technical diligence a VC would go through before investing would be similar regardless of having support from ARPA-E: *"The data I would show that VC would be data that I would have had to provide to them whether or not I got the ARPA-E program."*

PM10 had had a similar experience, albeit with strategic partners: "*This has been extremely valuable for us".* PM10 explained that "*Early on, when we were still (…) writing the proposal for ARPA-E funding, there were a lot of people who*

just dismissed our ideas as cranks. Almost calling us cranks. (…) It was even a challenge to get a [product] manufacturer to partner with us". PM10 further explained that "*as soon as we got ARPA-E funding, the floodgates for the [product] manufacturers opened. Which was very interesting to me. In fact literally hours after we got the funding announcement, the other [product] manufacturer sent me an e-mail".*

Another potentially legitimizing factor brought up by PM12 and PM5 was the low share of applicants that actually were granted funds by ARPA-E, and that people remained cognizant of this fact. PM5 explained: "*It was less than 1% that got funded, and people knew that. As a consequence people knew, if they selected you, then whatever you working on must have been really good*".

6.2.2 Visibility

The publicity and the visibility projects get from external parties by being granted an ARPA-E award was noted by all of our interviewees to some extent. For some, the visibility has resulted in new partnerships or other valuable connections.

The case of being granted an award was expressed by PM1 to have *"(…) been huge, and bigger than I expected*". The private company involved in her project saw a lot of new inquiries. PM1 pointed out that people seem to read the news of who get an award, even graduate students who apply for a job at the company. "*The private company that is in our project, (…) they have gotten a lot of new inquiries (…) I think it has been very big for their business. It has been very big for me personally, and for members of our team, because it turns out a lot of people seem to read these news items of who got an ARPA-E award. I had no idea. For example, there are graduate students who apply to our department saying: "I would like to work with you, I've heard about this very cool ARPA-E project that you doing!"."*

PM&PI9 experienced that being granted ARPA-E funds helped them with *"(…) publicity in terms of having other people interested."* They also received inquiries from firms and researchers that saw the press release or other statements at the ARPA-E website.

According to PM3, ARPA-E had actively made his project more visible for venture capitalists and industry professionals by advertising for the project: *"[ARPA-E has] done a good job of advertising, so all of the major manufacturers have come knocking on our door. (…) The exposure is great, I think they do a good job of exposing projects to the various follow-on opportunities that are out there. They put your name on the call list of venture funds and of large corporations, and that is helpful".*

While PM8 received attention from investors, peers in related companies and from press who were interested in knowing what they were working on, he also stressed that it was too early to determine if the interest could translate into real partner opportunities for his project.

PM12's project got more recognition after being granted ARPA-E funds, "*but not as much as we thought*". He received some calls and congratulations in the beginning, but also highlighted that people forget it after a while. PM12 said ARPA-E does more than other research agencies "*because they tend to publicize all the information about the projects they are funding. It is a little different, for example DARPA, they don't publicize all the projects, it is a secret. So you don't get much public recognition"*. However, PM12 felt that ARPA-E's website could be more organized: "*ARPA-E has their own website to pitch the technology, but there is just way too many things going on on the website."*

PM5 said that his firm was approached by several other companies with varying interests, such as selling sub-products to use in the final product, scaling the product, partnering, licensing or buying the technology if it was successful. PM5 also considered both the positive and negative effects of this added publicity: *"There are two sides on every coin, if you are an ARPA-E awardee it is really good, you go out and get publicity and they give you publicity too, they feature you at the shows, they have this little thing on the website. The other aspect of that is that, if you don't want publicity, it is hard to be stealthy, and in the commercial world there are a lot of projects (…), where companies like to [stay] 'under the radar' for several years before they actually make their appearance. So it's kind of the double-edge side of that, you are going to get publicity, but whatever you're doing is not going to be that secret anymore".* PM5 concluded: "*ARPA-E definitely has a lot of good, I would say PR, at least right now, it may be changing over time, but for now it is kind of this new poster-child of a new way of doing business."*

PM13 said that being a part of ARPA-E as a high-risk, high-reward project led to a lot of attention, as ARPA-E awards were in high regard. Overall he thought this had been positive for the project, as investors, industry and other researchers had contacted them, but he however pointed out that the publicity could be both positive and negative: "*In this day of age if you get media-attention, people see some interesting projects, some industry reads about it, and there could be YouTube-video about it, people can get information. It can really generate a lot of good interest, bad interest too of course. (…) that's another thing that can backfire on you."*

PM6 thought that the effect of added visibility generated from having an ARPA-E award would have a more decisive impact on smaller firms rather than projects

within a large company: "*If we were a standalone company I think it would have a more decisive impact, than it does as a small piece of a larger company".*

In addition to the above comments, many interviewees highlighted the added visibility and interesting opportunities generated at the annual Energy Innovation Summit, as detailed in section 6.3.3.

6.2.3 Credibility

According to our interviewees, ARPA-E not only helps their projects become more visible, but also gives them credibility when contacting external parties, e.g. other firms in their industry. Some interviewees from larger organizations also highlighted an increased internal credibility towards management. We highlight the statements dealing with these factors in the following sections.

6.2.3.1 External credibility: Value in networking

The benefits of being related to ARPA-E were commented on by 5 of the interviewee, highlighting the usefulness of leveraging the ARPA-E name in outgoing networking activities.

PM12 felt that ARPA-E recognition helped the project getting credibility and when reaching out to other parties "*(…) because people out there know how competitive this thing is (…) getting this project funded by ARPA-E really helps me get credibility in this area that is for sure. When you say I've got this ARPA-E funding, people go 'oh, wow'."*

PM8 pointed out the value of the ARPA-E 'stamp of approval' when reaching out to other entities, for a young and small organization such as his: *"It gives us a legitimacy that we wouldn't otherwise have in a lot of folks' eyes - it is a 'foot in the door', and that's been really valuable for us."*

PM10 also stated that ARPA-E *"gives you a lot of credibility once you get the funding"*, which is something he leverages directly in conversations: *"I've learned that I have to make that clear up front: "We have an ARPA-E award on this"."*

When contacting other companies within the same industry PM&PI9 had also used the award as a pitch: *"We have got ARPA-E funding, I want to talk to you about the project (...)"*. While appreciative of the publicity, PM&PI9 did draw its actual impact in question, since a lot of companies in their industry are start-ups that might be more willing to listen anyway. PM&PI9 thought the same was true with academic researchers who *"(…) are pretty willing to talk to you, and pretty willing to help with your issues. I have contacted a lot of researchers at universities, and for the most part, they are really open."* She further explained: *"I've never actually had an issue, nor do I know of anybody who have had an*

issue contacting another researcher with a problem, and then having them not be helpful."

PM11 commented on how the ARPA-E name was valuable in networking, despite being a fairly young agency: *"Basically, having the ARPA-E name is really valuable for networking. Rightly or wrongly, ARPA-E has gained a lot of credibility technically, in spite of not being a very old agency. It basically opens doors for us".*

PM2 related the credibility of ARPA-E to its political story of improving the energy security, improving the climate *and* creating jobs, concluding that: *"I think the outcomes [of ARPA-E] have been good, and perhaps more importantly, the political story on it has been well accepted by everyone".* However, PM2 did not share the view of PM11 on the value of the ARPA-E name in a quality context: *"ARPA-E is new enough that it doesn't have a reputation yet for producing products. So it doesn't create that kind of 'stamp of quality'. What it did do in its early years was it got a lot of venture capitalists connected to a lot of technology people, and there was a lot of interest there. They did a good job of that (…)."*

6.2.3.2 Internal credibility

According to PM13, PM10 and PM6, ARPA-E did not only influence external parties, but could also help legitimize the project within the context of larger organizations.

PM13 explained that it had helped him raise the cost share: *"[My institution] has said they would provide that [cost-share] for ARPA-E projects, so they have provided the 5% cost-share because it is an ARPA-E project."*

PM10 highlighted the appreciation of his award by the management of his firm: "*[My company] has had an energy program going on for about 2-3 years, so ARPA-E has been on [our] radar for a while. In fact, we were the first project to be awarded ARPA-E funding [here], so [our] management was pretty pleased by that."* PM6 expanded on the internal credibility in a larger company: *"(…) it is a great stamp of approval. (…) internally, it is also very helpful. I've seen this before in different contexts, (…) [if] you go off and win a government contract, particularly from a prestigious agency, it gives you more credibility within the company. So it's really both internally and externally, very helpful."*

6.3 Network role

In this section we present results connected to the networking role of ARPA-E. The recurring topics discussed by our interviewees were how and the extent to which ARPA-E facilitated networking with parties outside ARPA-E, and how ARPA-E connected projects within ARPA-E and facilitated collaboration between projects where synergies could be made. In addition, our interviewees highlighted the annual Energy Summit hosted by ARPA-E as an important topic.

6.3.1 External networking role: Connections to experts, industry and potential customers

All of our interviewees had some experience with ARPA-E's role of networking the projects with external parties, typically commenting on its efforts to connect them to industry, customers, researchers, potential strategic partners, regulators or other entities within the DOE. Around half of the teams we spoke to had positive experiences with ARPA-E's external networking efforts. PM10 provided a suitable conclusion corresponding to the general impression: *"Not all connections will work out. So I would say ARPA-E connections in general tend to have a higher hit rate than the average networking event."*

6.3.1.1 Connections with industry

PM5, PM1, PM11, PM4 and PM8 had experienced that ARPA-E helped them connect with industry, indicating that these connections related positively to commercialization efforts and provided resources external to the project.

PM5 felt that ARPA-E mainly connected the project with industrial entities, and associated that with ARPA-E's focus on getting the products commercialized. PM4 explained that ARPA-E introduced her to relevant big companies to talk about commercialization. PM8 was of a similar opinion: *"They are making connections for us where they have good ones to offer, and (...) helping to brainstorm on potential companies to approach even if they don't have personal connections there. They are definitely engaged in that, and it is very important to them that we have that plan in place."*

PM1 perceived it as helpful ARPA-E had industry contacts it encouraged them to connect with: *"They have contacts from people in private industry, and they'll say "You should call so and so at whether it is at Siemens, or ABB, or Alstom", or whoever, "Here is your contact person", so we can go straight to the right person. I think that have been really helpful."*

PM11 noted that not all of the connections gave concrete results, but highlighted that ARPA-E made a good effort to help the project get in touch with the people they needed: *"If we need introductions in industry, whether it is a strategic partner to help us make some little lab equipment, or get some material, or to do the market development, the business development. They make these introductions when I need them. Not all of them pan out, but they are definitely doing work to try to help us there."* PM11 also pointed out that ARPA-E's ability to connect the projects to relevant industrial entities depended on the Program Director's previous experience in that industry, arguing that Program Directors with academic backgrounds (such as university professors) would be unlikely to have similarly large networks to leverage.

PM2 had a somewhat different opinion on the usefulness of ARPA-E in finding industrial partners for the projects, and stated that ARPA-E hadn't helped his project at all in getting the industry connections they had. He explained what he thought was the reason for this, underpinning the importance of personal relationships: *"ARPA-E would like to be able to help with things like that, but it is so dependent on personal relationships that it is very hard to de-personalize technology. When you guys talk to me about this technology, you have a general idea about what I'm doing, right? But you don't know if I can pull it off, and if you had USD3m to invest in me, you'd be [thinking] "I don't know if I want to invest my three million dollars there, do I want to spend it somewhere else?" It is a lot of one-on-one, and you have to have experts, spend a lot of time, and ARPA-E has a hard time, they can't send out a brochure and convince somebody to spend millions of dollars doing something. So, it is still individuals working with that."*

6.3.1.2 Connections with customers

Two of the interviewees, PM7 and PM11, talked about ARPA-E in relation to getting connections with customers. Both of them saw limitations in the extent to which ARPA-E could reasonably facilitate such relationships. PM11 commented that even though many of the people in ARPA-E have useful connections they could introduce the project to, it would be outside their responsibilities to perform the business development work of establishing customer relationships: "*A lot of the people in ARPA-E are coming from industry, so they can make connections for us. They don't really have a lot of leverage, basically to get us real resources. They are not going to do the business development work. That is our job to do. But I would say they a provide support role just for meeting people. And that's helpful*."

PM7 pointed out that customer relationships had to be built by talking to the customer one-on-one, and explaining how the technology works. He didn't believe that was something a government agency or any third-party could do,

because the developer would have to be there to control and tailor the flow of proprietary information according to the needs of the particular customer.

6.3.1.3 Connections with experts

PM1, PM&PI9, PM4 and PM12 commented on ARPA-E's efforts to help them identify and connect with experts if they met challenges they were unable to solve with their internal competencies.

PM4 explained that they had met difficulties finding experts on a specific material they needed, something they didn't have in-house, but upon asking ARPA-E for help, they would connect them to someone.

PM&PI9 were of a similar perception: *"If I had any issue that was really blocking something that we wanted to do, they were very willing, and probably able to make the connections for us."*

PM12 pointed out that even though the ARPA-E team was knowledgeable in the basic science of what he was working on, they didn't possess the level of expertise necessary to help them with technical challenges. Similarly to PM&PI9, the ARPA-E team was nevertheless very helpful in suggesting experts the project could contact to get advice or technical suggestions. PM1 also expressed this opinion.

6.3.1.4 Other connections

Some of the interviewees also talked about other types of entities ARPA-E were bringing into a networking process. PM10 mentioned that the technology they were developing would need to be approved by regulatory bodies, which were following the development process and had representatives present in the program conferences. PM3 went into more detail: "*As the technology develops we will be working in parallel with the certification bodies. ARPA-E has done a pretty good job of, during their annual meeting especially for this project, trying to bring those people into the loop, the companies that write certifications and the government entities that approve them"*

PM10 commented on ARPA-E's efforts to facilitate the funding hand-off by connecting the project to other government funding sources: *"There are actually some related programs going on in DOE and DOD. And so we've got initial connections to those people. We had initial discussions. In fact in January when we had the [program name] annual meeting, they arranged a closed-door meeting for us with government Program Directors from various DOE and DOD agencies. (…) It is still too early to talk about a crystal project follow-on."*

6.3.2 Internal networking role: Knowledge sharing in the ARPA-E project portfolio

A large majority of the interviewed projects mentioned the efforts ARPA-E undertakes to connect the projects in its portfolio. Recurring topics included how leveraging complementarities among the projects could create synergy effects, the role of the Program Director in facilitating connections between the projects, and experiences regarding the program conferences.

6.3.2.1 Synergy effects between ARPA-E projects: sharing complementary knowledge

Eight of our interviewees the interviewees highlighted that the efforts made by ARPA-E to connect different projects together had created opportunities to share experiences or help each other where they had complementary competencies. PM&PI9 pointed this out during the interview: "*They did a good job on networking, bringing people together - maybe they have similar problems, similar solutions or helping each other out with solutions."*

PM7 experienced that when his project needed a special design for a component, ARPA-E had introduced him to another ARPA-E project that was developing that specific technology and advised him to contact them. The connection worked out very well, and he pointed out that he would never have gotten in touch with that project if it wasn't for ARPA-E.

PM4 and PM12 also talked about how many of the various ARPA-E projects are complementary and can be connected to a larger ecosystem of technologies:

"There are a lot of other ARPA-E projects, they connect us to any projects they think might complement our technology, because a lot of the technologies are just one piece of a larger system. That has been really great, to build up a whole community of scientists in this space. It is especially encouraging when you realize how enabling your technology might be for someone else." (PM4)

"When we have a technical challenge, if we don't have any experts within the team, we just call ARPA-E and ask for help, so they get us hooked up with the experts they have in-house or within their projects. They constantly talk about how all the different projects that are independently moving forward can actually be unified to make it larger." (PM12)

6.3.2.2 The role of the Program Director in facilitating connections

Three of the projects pointed out the central role of the Program Director in facilitating helpful connections and interactions between projects. As PM13 explained: *"So we have these different performers, and then after a while you meet them at different venues, the big summit and so forth. And after a while you start collaborating, and much of that is facilitated by the Program Director. (...)*

since [the Program Director] has an overview of the entire [program], they see what other groups are doing, and they see where you can have synergies, where you can work together."

PM3 had experienced helping another project upon request by the Program Director: *"[The Program Director] often comes to meetings and pitches problems that [other projects are] having, and we've actually helped solve one of the problems that one of the groups was having, because our expertise is in a place that they didn't necessarily have. We're happy to do that, I think that the 'rising tide will float us all' in that area."*

In a similar vein, PM2 explained how the Program Director would help other projects solve issues they were bound to encounter by knowing about issues other groups had encountered before. PM2 exemplified how his project had solved a challenge that others in his program were likely to meet as well, and the Program Director had then asked the other projects how they had planned to deal with that particular issue, essentially sharing knowledge without revealing any critical information.

6.3.2.3 Program conferences

One of the efforts that were brought up by many of our interviewees was the biannual program conferences that ARPA-E Program Directors arrange for projects within the same programs.

PM2 describes these events as a valuable arena to share knowledge and helpful insights: "*Something that has been incredibly valuable is that little cadre of people who got funding in the [program name] program would get together twice a year. We talk about each other's projects, we'd have dinner together, we'd just chat, "what is the problem, what are we doing, how are we solving that", that was incredibly useful because you created this little 'user group' of people who had a shared set of challenges, working with a similar set of rules and had sort of established themselves"*

PM&PI9 also highlighted the efforts made by ARPA-E to have the projects share experiences and potentially help each other at the program conferences: *"I think they were working very hard, trying very hard, especially in those meetings twice a year, to have those twelve groups in one room, and say "Do you have a problem, or does anybody have a solution? (…) Help each other out." They were doing very well there, I think."*

The close relationship built through these meetings was highlighted by PM3: "*I see the people who are running all the projects [the Program Director] funds every year, twice a year. So I know all of those guys, I know all of the projects [working on the same area of technology] that are funded through ARPA-E. I*

know the project leaders by name. We have had some friendly technical relationships with several of the groups, and I think that's facilitated pretty well by [the Program Director]."

Contrary to the other interviewees, PM5 expressed that there were limited potential for real outcomes of interacting with other the projects due to issues of propriety knowledge and intellectual property: "*I don't think there was any conversation with any of these performers that gave me enough insight to come back and actually solve a hard technical problem that I was working on. And to really go that deep of a dive can get very (...), I think very proprietary."* PM5 elaborated: *"You get the connections with other technologies, like it seems like they are doing, but it may be harder to protect your IP then, if you're doing that. Basically it's great to share stuff, at the same time people only share 'so much', because of potential IP [issues]. Because of that, I just feel like (...) if you don't really share that much it is really not that valuable.(...) as far as I know there is not a lot [of collaboration between projects], and a lot of that revolves around IP. (...) I am sort of new to the whole commercial world, and I didn't realize how complicated some of this things could be. The lessons that we learn, may actually help somebody else's project, but for some reason, you can't tell them."*

PM1 also brought up the potential issues of sharing delicate information, noting that ARPA-E doesn't force the projects to share information with others*: "[ARPA-E] are very explicit about how we should have a plan for managing our intellectual property, and we can file patents and [so on], so we have no requirement to share things. There is certainly encouragement to have collegial collaboration, but I've not felt any pressure to reveal anything that I would not want to reveal."*

Another aspect related to these conferences is that they are mainly relevant for projects in focused programs. For some projects in Open FOAs, there are not necessarily any related projects, and in those cases the potential benefits of having complementary projects within ARPA-E may be unavailable. PM8 detailed this matter: "*We were part of the Open FOA. When they have (...) awardees that are all part of a [focused] program, they have these regular get-togethers and they all share results. It is not really relevant for us, because we are in this open group, and the other people that were funded in the open group are all working on these very disparate technologies."* ARPA-E is however trying to work around this problem whenever possible, as he continued explaining: *"That said, (…) there is a new program that has been funded that does overlap more with our area. I don't think they've had any of their meetings yet, but last time that our Program Director was out here, he was saying maybe it would be good to invite us to attend those meetings, just so we can network with the other folks in that program. So they are looking for those opportunities, I think."*

6.3.3 ARPA-E Energy Innovation Summit

Several of the interviewees brought up the ARPA-E annual Energy Innovation Summit as a positive networking event organized by ARPA-E.

PM10 described the basics of the Summit: "*As part of our contract we are required to attend the summit every year. (…) At the Summit they have a lot of high-level overview talks, and then there is this industrial exhibition kind of thing, which they call the technology showcase. Every awardee is required to have a booth, and then they also open that up to other companies that don't have awards, but most of the people who are there are awardees. And they invite a lot of industry people, so it's a good two-day window to show off your technology to everyone"*

The Summit was regarded by many as an opportunity to give their projects exposure, highlighting the incoming interest from people approaching their booths, as PM11 explained: *"Over the course of three days a hundred people are going to come up to me and ask: "Hey, what are you about? I heard about you, what's going on?" And some of them will be interesting."* The same was true for PM&PI9: "*We had to man the booth, but it is fun to talk to people, have people come up that are interested in your program*".

PM13 was of a similar opinion, highlighting the industry-specific interest: "*I think it is fun, it's so many representatives for industry there, and they get interested."* PM11 also brought up this point, highlighting its potential importance for the future success of his project: *"All these other guests from industry are going to come and see you, and it's basically (…) [ARPA-E is] forcing you to get out of your daily routine and make connections that will help you be successful later. It's an investment for ourselves to go to these things."*

ARPA-E also tries to attract venture capitalists to the Summit, as explained by PM&PI9: *"[ARPA-E] really gear it towards having Venture Capital there, (…) a lot of the companies for the other programs are really trying to get funding for their technology, and I think that is a good forum for those introductions."*

PM11 mentioned that they had experienced getting interest from investors through the Summit, and PM12 commented that ARPA-E invited potential customers to the Summit to facilitate to talk about potential cooperation.

PM7 saw the Summit as an opportunity to connect with the other ARPA-E projects he could possibly work with: *"[At the Summit] you can see all the projects everyone are doing. That gives you a pretty good idea of with whom you want to interact with."*

PM8 experienced the Summit as an event where one could actively make useful connections: *"[The Summit] was a good networking opportunity for us. Our Program Director definitely went out of his way to find people that he thought would be useful to us and sent them over to us to make connections, which we also really appreciated."*

6.4 The role of the Program Director

In this section we present results related to the role and qualities of the Program Director. The two main topics discussed by the interviewees were the importance of the Program Director having a certain level of industrial experience and academic expertise in the general technology area of the projects and how the empowerment of the Program Directors affected the projects.

6.4.1 Experience and expertise of the Program Directors

The importance of the Program Directors having some level of experience and expertise relevant to the technologic field of the project was highlighted by a large majority of our interviewees.

PM3 succinctly summarized the opinion of our interviewees: "*Our Program Director, for example, he has a PhD, he ran a start-up [and] got a bunch of money, similar to us. He knows how it is to have a budget, have milestones, spend the money."*

6.4.1.1 Expertise and experience as a prerequisite for fulfilling the Program Director responsibilities

PM13 was one of the interviewees that commented on the importance of having an experienced Program Director: "*We've been lucky. Maybe we all have. Our Program Director (…) is extremely knowledgeable (…) That is important, because otherwise it is difficult for them to be authoritative.*" He followed on by saying their Program Director had a relevant background in their field of technology, noting: "*That is almost a given, because they pitch for the DOE and Congress. And if they don't have the credibility, nothing would come out of it. So it is very important that the Program Directors are knowledgeable."*

PM3 also connected the competency of the Program Directors to the decision of awarding funding: *"[Our Program Director] gave us the money because he felt that we had a rigorous physics argument (...) and he appreciated that because he is from that particular background. I think you have to have a Ph.D. in some technical field to be a Program Director at ARPA-E."*

PM11 said that having the right background was crucial for the personal credibility of the Program Directors: "*Without that [level of expertise] it would be really hard for us to have confidence in any feedback they give us."* He also added that the industrially experienced Program Directors usually have useful networks in addition to the scientific expertise: "*We've gotten some really technical people, but they also have pretty good industry connections. (…)There are definitely people at ARPA-E that are professors. (…) Technically they may be fantastic, but they are not going to have the same industry connections as the personnel that we happen to be working with."*

6.4.1.2 Program Director's support of projects

While most interviewees found it important that the Program Directors had a certain level of expertise in the technology area of the project, they weren't experts, but were still able to provide some level of support in the technology development process. PM11 noted: "*They have worked in the industry before. They get it. They don't know the details because we are the ones making new things here, but the feedback they give is generally on target."*

PM6 thought that the Program Directors having a certain level of technical expertise created a better foundation for having a useful dialogue: *"We certainly don't rely on their expertise to solve our problems. We are the experts, we will solve our problems. However, having them have some level of expertise I think puts them in a stronger position to dialogue with us. To understand the significance of what we are doing, and also understand that 'such and such' an obstacle is a small obstacle, versus a large obstacle, or vice versa. So I would say it's helpful having that technical competence."*

PM12 also perceived that a high level of technical knowledge was helpful, even though they weren't experts. He added on that the Program Director would suggest people to talk to if they needed technical expertise: *"All the folks over there [at ARPA-E] have a PhD in engineering or science, so they know all the basics. But they are not particularly experts in the area we are pursuing here. But I quite often call them and ask, "Do you know somebody who knows this stuff well?" so I can get a quick feedback or technical suggestion. They actually give us a couple of names quickly. That has been very helpful."*

PM10 explicitly found it useful that the Program Director had a more general insight in the technical area of the project: *"Both of [our Program Directors] had*

worked on [relevant] technologies before, and have PhDs. So they had expertise very relevant towards what the program was about. (…) At the same time they were sort of outsiders, because their expertise was in [specific technology], and not necessarily in management of [specific technology]. And that has also been useful. Because often for a breakthrough, you need someone who is not in the daily grind of things."

PM2 related the technical insights of the Program Manager to his ability to perform his responsibilities in managing the projects: *"I think [our Program Director] is a good example of somebody who knew enough about the process, and knew enough about chemical engineering to be a good manager and advocate and evaluator. He would listen to all of these things, and say "that makes sense, that doesn't make sense" and bring good things forward."*

PM2 then connected the level of experience to the risk of having the Program Director steer or micromanage the project too much: *"I have seen some other programs within ARPA-E where the Program Director knew too much, and walked in with a really specific idea of what he thought that area should look like. [ARPA-E] basically focused the entire program on one very high-risk aspect of the approach that they could take, and it was one that the Program Director was familiar with and liked a lot. (…) That isn't necessarily good, so what you want to have are people that are really competent, but not necessarily world experts in that area."* PM&PI9 had personally experienced that lack of technical contributed to the Director forcing the development process in a direction they didn't perceive as viable, because the ARPA-E team didn't really appreciate the difficulty of what they expected them to do. Results on the broader issue of ARPA-E representatives possibly exercising undue influence on the projects are presented in section 6.5.1.3.

6.4.2 Responsibilities of the Program Director

Several interviewees brought up the empowerment of the Program Directors, as discussed in 3.4 and 4.2.1.2, and how it is related to their motivation to help the projects succeed.

The level of investment the Program Directors put in supporting and driving the projects towards success was highlighted by some of the interviewees. PM13 related this to the fact that the Program Directors stand responsible for the projects they choose: "*ARPA-E is very involved in the projects; they support it not only financially, but also management-wise. Some people would call it micromanagement because they're really involved. [This is] because they [the Program Directors] pitched for their projects. So the Program Director for our program, pitched for the concept of this program at DOE. I think there are 10 performers in this program. If all of them were to fail, it would be a failure for the*

Program Director and the whole team. So they want all the projects, at least most of them, to work, so they are very involved."

PM8 found the empowerment of the Program Directors as a positive characteristic, as this enabled a deep level of involvement when combined with their expertise: "*The thing that I think is best about [ARPA-E] is the quality of the Program Directors, and the freedom and flexibility that they are given to use their own technical judgment in advancing the projects.*

PM5 had also taken notice of the passion and drive the Program Director had for his projects, and found it different from other government agencies: *"[Our Program Director and Scientific Advisor] love what they're doing, and they like working on the cool technology, but I've never seen anybody work so hard as those guys. It is very different for a government agency as well."*

6.5 Management and support of projects in ARPA-E

6.5.1 Support and monitoring: A part of the project team

In this section, we present the major topics emerging from our discussions about ARPA-E's monitoring and support regime. This was an important subject for our interviewees, who devoted a quite significant amount of time to describe their impressions and experience with ARPA-E in this context. Particular interest was given to ARPA-E's initial negotiation of the project, the use of milestones and their part of the project planning and negotiation, the quarterly reporting and reviews, the project management style and interaction with the ARPA-E teams, as well as overhead issues and time constraints associated with these characteristics.

6.5.1.1 Acceptance and negotiations before final commitment

The process of negotiating the project deliverables and milestones before final approval of the project was discussed fairly extensively by some of our interviewees, as we reveal in this section.

PM11 highlighted that the negotiation was split into two parts; the technical goals and the budget, both of which would be decisive for the funding award. For the negotiation of milestones PM11 had used the technical objectives from the proposal as a basis. He also experienced that ARPA-E didn't just approve the

milestones and the budget, but also contributed to make it more accurate: *“Then you go through all the parts of the budget you submitted. They’ll say "We have already funded 20 [similar] companies. You guys forgot this thing, put it in.” or “We don’t think you have enough personnel on that project, it’s a hard project, so put more people there" and you don’t get all that done in one day in person. They usually say “go figure this out”, and within a week or two, you got it worked out and send it back to them, and they say “Yes, this makes sense”.”*

The negotiation process of the milestones was given considerable attention by our interviewees. PM10, PM11, PM8, PM13 and PM5 felt that ARPA-E had pushed for more aggressive milestones, while both PM1 and PM12 saw the negotiations oriented towards practical feasibility.

PM10 summarized the process neatly: “*During the award negotiations they made us come up with a list of milestones for every quarter. (…) You go through a negotiation with them as towards how the milestones should look like and what they should be at different phases of the project. They push you to make them quantitative and aggressive*.” PM5 made a similar statement. PM11 elaborated on the last point, stating that “*ARPA-E will drive us to set impossibly hard milestones, because they know we are going to work really hard. (…) We're only going to get two thirds of it done. But if we had started with less ambitious goals, we would only have gotten two thirds of that done. Because you get complacent, it's human nature. So they’ll come in and they will try to negotiate you to basically an impossible amount of success.*”

In PM13’s case, the negotiations had ended in milestones that were too aggressive and which were renegotiated later. PM13 said it was “*(…) quite an ordeal to reach an agreement [on the milestones] and after a while we felt like we basically gave up and let them win.* (...) *You could renegotiate, which we have done. We think they were a little bit too high*.”

Knowing that ARPA-E could push for more aggressive goals, PM1 did not want to promise too much initially, and then experienced that ARPA-E adjusted the proposed milestones in a more feasible direction: “*[ARPA-E] might push us to do a little more in some areas.(…) In our case they actually encouraged us to promise less in one of the performance areas. That was interesting; they really wanted to help us make realistic promises*.” She also highlighted that the negotiations “*took a long time, there were many iterations back and forth*.”

Having proposed a very ambitious proposal, PM12 experienced the same push towards realistic goals as PM1: “*We requested 36 months, but they [ARPA-E] cut it down to 24 months by cutting 50% of what we proposed.(...) What they did is actually very, very helpful, because we were over-enthusiastic. (...) I think they want to make sure that things actually happen. Because of the research money*

situation in the U.S., professors at university tend to over-promise to attract money. (...) So they try to make it realistic, something that is practically possible."

6.5.1.2 Milestones and project evaluation

The overall impressions on the use of milestones were comparable across the group of interviewees, although some reported somewhat mixed experiences with regards to the flexibility exercised by their Program Directors on non-critical milestones. Missing' go-no-go' milestones however, are generally considered a reason for suspension or cancellation of the project, and some highlighted that ARPA-E actively aborts non-performing projects, with PM&PI9 currently being suspended. Others also highlighted that the milestones, deficiencies aside, can be useful for coming up with accurate budgets and even as a supporting tool for managing their projects later on.

Milestone flexibility

Another frequently discussed matter along with the milestones, was the flexibility exercised by the Program Director in altering them underway. Ten interviewees expressed that, given appropriate justifications, ARPA-E had been flexible with regards to changing the milestones, e.g. by pushing deadlines, switching milestones around or removing irrelevant milestones altogether. Some also mentioned that ARPA-E acts proactively on changing the milestones by periodically assessing their relevance against the end goal of the project. Due to an overwhelming amount of material on this subject, we include only a selection of material in its original form in this section in order to maintain brevity.

PM1 explained the flexibility exercised by ARPA-E in a clear fashion, largely equivalent to the statements of PM6, PM10, PM11 and PM7: "*There was one milestone that we realized about half a year into it that it did not make sense. When we had written it, none of us realized that to do A, we really needed to do C first. And in one of the on-site visits we just said: "You know what, we need to do C before we can do A, can we push A back to month seventeen?", and they said "sure". And we did not go through a formal re-approval process. My sense is that they are flexible when it comes to [changing milestones because] we had a good reason.*" PM2 added to this by explaining that ARPA-E had no qualms when he changed some milestones in order to better align with the overall goal of the project. PM3 highlighted the predominant focus on success: "*I have a set of milestones that I agreed on with my Program Director at the beginning, but if I think that they should change, I talk to him, they change. (...) They're very flexible. They just want to see success.*"

PM10, PM11, PM5 and PM8 added to this flexibility by highlighting that their ARPA-E teams were flexible in terms of assessing the continued relevance of the original milestones. PM10 was *"(…) a little concerned promising milestones for three years at the outset. But they [ARPA-E] have shown flexibility at the end*

of the year review as to whether the milestones that you promised at the start still make sense one year in, based on what you've learned. So they've shown some flexibility on renegotiating at the end of the year. That's useful. Because in a three-year high-risk, high-reward project, things are bound to change as you learn." The same was true for PM11. PM5 made a statement in a similar vein, explaining that his ARPA-E team would alter milestones if new discoveries prompted a different direction. PM8 expressed gratitude for having a Program Director that proactively reassessed milestones: "*We proceeded pretty much according to the original plan, but it has always been something that our Program Director has been careful about asking each time we meet, "do the milestones that we laid out still make sense? Do we need to make changes to these based on where things stand and what you've learned?" So I appreciate that flexibility*". PM8 also added that his project even includes reassessment of the milestones as one of the end-of-year milestones.

PM5 highlighted that ARPA-E would try to alter the level of support depending on how the project was meeting the milestones, giving a few examples pointing to its networking role (reported in section 6.3.1.3): "*The whole program is really milestone-driven, so you have some target at the end, but then they have tiny checkpoints and targets along the way. Depending on how we were hitting or not hitting those targets, would really change the level of support that they would need [to provide]. (…) They were like: "Okay, if you're not quite getting all the way there, what do we need to do differently? What kind of targets would make sense for this? If you're not hitting these targets, can they be achieved with getting another partner on board? (...) Is it something that has scientifically figured out first? When you understand that, then you can go into you engineering tweaks to actually make that work"*

As one of the two interviewees who expressed concern over the lack of flexibility in the milestones and review process, PM4 indicated that her milestones didn't always match the actual timeline in her project, and that she did not see much flexibility in that regard: "*I think the main constraint has been the scrambling for milestones occasionally, when the timeline isn't really matched up with what it would optimally be. That has been a little bit hard, it'll be a milestone that is kind of far out, and you can always stretch your time to that milestone, and then the next one will be really compressed. I mean that might just be the event flow of any company, but sometimes it would seem nice if you could move the milestones a little bit around. (…) Luckily, I think our initial milestones were framed in such a way that it hasn't been grossly off. It has just been some times we wished we could've pushed them one way or another.*" In line with PM5, PM4 also added that "*if you miss something, it is not so much as they take away your funding, they try to give you extra resources so that you can get back on track. They try to connect you to the right people.*"

The other project team having issues with flexibility was PM&PI9. Discussing this matter in retrospect of being suspended from ARPA-E support, they highlighted opportunity cost as well: "*I think some of the drawbacks are that, despite being a little bit flexible, it wasn't flexible enough for us to really get the full benefit of what the technology potential could be. We are private company. [Receiving ARPA-E support] is not necessarily just funding, it is opportunity cost for us. [The Principal Investigator] could be working on something else with his time, even though we are getting funding, him working on this project means that he is not working on another project. No more do we want to work on a project that is a dead-end, just to prove out some sort of hypothesis that we had. That is not our business model. (…) We were in that middle ground of "well, it is working, just not as well as we hoped". It would have been nice if we had some flexibility to try some other things that maybe could've gotten us to that goal.*"

'Go, no-go' milestones and funding cut-offs

While most of our interviewees had the same impression of flexibility on milestone changes, seven interviewees emphasized ARPA-E's firm attitude when it comes to the critical milestones, the 'go, no-go' decision points, and the end goals of the projects.

After emphasizing his appreciation of ARPA-E's flexible approach, PM7 moderated his comment somewhat by highlighting the result orientation: "*They are flexible about micro-tasks, but they are focused about the end-goals. So you just set up that you've got to do this, that they won't change. You can take different paths, but you've got to go there.*"

PM1 eloquently stated that "*There are 'go, no-go' milestones along the way, so if you can't meet certain performance criteria they might cut you off.*" PM10 corroborated PM1's statement: *"At the end of the year they have some defined 'go, no-go' milestones. If you don't meet those there is the possibility that your project might need major renegotiation, or that it might be cancelled."* PM3 articulated a similar view, and both PM10 and PM2 gave examples on ARPA-E cutting funding for non-performing projects.

The best example of funding being cut off was however provided by PM&PI9, which had been suspended from their program relatively recently: "*(…) we're on probation, we're suspended from ARPA-E, because we didn't meet milestones."* PM&PI9 explained that after having struggled to meet critical technical milestones due to unforeseen scientific issues and probably staying too long on the same course, both ARPA-E and themselves came to the conclusion that pursuing the project further would be a waste of time and effort, suspended the project and cut funding, referring to the opportunity cost argument highlighted earlier.

PM13 connected this accountability factor to ARPA-E's public reputation: "*If you don't make your 'go, no-go' decision points they cut the funding. (…) And that's part of why ARPA-E has such a good standing at Congress, because Congress doesn't like if the taxpayers' money [is being wasted] (...), but here you see that if it probably doesn't work, they cut the funding*."

Evaluation of milestones, project planning value

To conclude the discussions on milestones, PM4 and PM10 shared their opinion on the usefulness of the milestones as well as highlighting their potential value as a supporting tool in managing their projects.

PM4 succinctly opined that "*I feel like there might be too many milestones, it would be nice if you could have some big milestones along the way, but you could fill in all the pieces as you go. Especially in the early stages*. (…) *there are a lot of milestones along the way. (…) If you can't ever change those milestones, maybe means that you're working to meet specifications that aren't your optimal pathway to the end goal. So that has been a little bit frustrating some times.*"

PM4 then elaborated on the usefulness of planning with milestones: "*I think it is useful for a project to descope, I don't think we could have figured out what the budget was going to be without figuring out what the milestones were going to be ahead of time. Even if the timeline of when those milestones happen would change, I think the detail of which we set up our milestones was correct for the project, and the budget ended up being correct too. I think if you just say "oh, I think it will cost this much", I'm not sure you get there as efficiently.*"

PM1 even highlighted the milestones' value in project management: "*[The milestone negotiations] left us with a pretty detailed plan that was helpful for managing the project; I think it is a helpful reference for managing the project. The intent is to help us be organized and succeed.*" This notion was also stated by PM10: "*I definitely had doubts about (...) the usefulness of a full list of milestones for three years. But in retrospect, it is actually useful. I will probably appreciate them even more after I'm done with the whole project. But, yes in retrospect you tend to appreciate those as project manager.*"

6.5.1.3 Project management style

The project management style employed by the various ARPA-E teams was another subject that was given considerable attention in our interviews, usually discussed in close relation to the reporting and review format. Our interviewees had several opinions in common, especially with regards to the openness and flexibility of their relation to ARPA-E staff, as well as the 'non-bureaucratic' nature of the ARPA-E teams' involvement. Many connected their management style to their experience and professional and technical capabilities, and characterized them as a highly involved party, almost as part of the team, having a strong

desire to see projects succeed. There was some variance in perception, however, which is reflected in this section. Some interviewees also commented on the balance between active and passive direction from the ARPA-E team.

Summarizing the general perception of most of the interviewees, PM3 shared his thoughts on ARPA-E's motivation for the resource-intensity of the review process: "*I think that underlying it all, they want to see market success. ARPA-E needs its projects to win, in order for it to continue to look good and to succeed and to continue to get funding."*

Open, professional relationship

PM1 described the professional relation with her ARPA-E team as open, yet firm: *"They keep the tone of the relationship were much like they want to help us (…) I think they are open minded about if we have to change something in the milestones, but they are not inviting feedback [on the review frequency], it's more like: "How is May 26th for a visit day, and plan us being there from 9am to 3pm."*

PM7 commented on the approachability of the ARPA-E team: *"The reviews are fairly (...) it is not like we have a 'fight' with them, it is collaborative. (…) It is very open. At any time, if I am really in a crisis I can call them and get some response. That is very unique."*

PM8 highlighted the strong relationship and the empowered Program Director as one of the primary benefits of receiving ARPA-E support: *"(…) the relationship with the Program Director, which is a more close relationship than it is with other funders, has been really valuable in making connections, being able to talk openly about different potential technical paths and business paths, and get the support from the funder that, even if we want to change direction fairly radically, if we can make the case to him, then he can make the case to [the ARPA-E Director], and we can be funded to do 'that', instead of this. Knowing that we have that level of support has been really valuable.*" PM8 concluded: "*The monitoring has been much more hands-on than for any of the other government funded projects that we've had. It is good, I think.*"

PM4 explained how the positive experience exceeded her expectations: *"When we started, we were worried about (...) them just making sure we're spending the money correctly and that we're doing everything right. I was a little worried about them being more of an oppressor. Instead it has been more of a partnership where they've been helping us. I don't know if everyone in ARPA-E has that experience, but we definitely had that with our particular team. (…) As the project developed and we created a relationship with them, (…) it has become a lot easier to work with them, because we aren't worried so much about telling them [about issues], we just tell them everything, and they help us out with*

whatever they can." PM6 elaborated on the open atmosphere in the review meetings: "*When they've come here, they've typically spent five hours, reviewing progress with us. We're I would say very open with them, and I think they've appreciated that. You know, "here is what we have accomplished, here are some achievements, here are some setbacks, and here is what we're doing to catch up". It's been good.*"

PM10 said that "*Both [Program Directors] have been extremely good to work with. I actually enjoy the discussions on an intellectual level. (…) it's not like they just give you the money and they are harshly judging at the end of the quarter. They actually work with you to make sure that the award is used smoothly, [with] the right level of questioning at the end of each quarter and challenging us intellectually. It's been very good."* PM13 described a similar open relationship as PM4 and PM10, and elaborated: "*(...) the further the projects have evolved, the more we see the benefit of this management [style], because they have an oversight that we do not have. My feeling in the beginning was that it was stressful, but we got used to it, and it actually works to your advantage after a while.*"

PM3 stated that "*They [the ARPA-E team] are not entrenched in the bureaucracy of the government at all. They're very much on our side. (...) I think it is great that our Program Director feels like he is an advocate for our start-up, and that he benefits and is incentivized to have us win.*" This impression of little bureaucracy was appreciated by PM12 as well: "*I feel like they are a little different from other, traditional, government funding agencies. (…) I don't feel like I am dealing with government. It is very flexible and very helpful. One of the best government agencies I've ever dealt with.*"

Part of the team: Hands-on involvement in the development of the project

When asked about the quarterly review and reporting process, the interviewees gave coherent answers on the quarterly reporting format, indicating a very detailed and standardized process for the written reporting of technical and financial status. With regards to the quarterly technical review meetings, there were some differences in the specifics of how they were executed in terms of varying the frequency of on-site reviews opposed to web or phone-conference based reviews. In this subsection, we expand on this context by reporting on the managerial style applied by the ARPA-E team.

PM10 probably made the most sophisticated summary of the value of the intensive project management methods employed by ARPA-E, despite some annoyances in going through the various forms and details: "*[The review and reporting process] is actually extremely valuable, because it forces you to think bigger, pause, and look back on what you did in the quarter, and it's a good way to document things. It's kind of a mixed blessing. I would say I find it useful to*

have this quarterly [reporting] (...) In an ideal world we would get money from somebody, and they would just "forget" about us for three years then after three years they would ask what happened. But in the practical world, no. I don't think it is too bad. I've heard of other funding agencies that require monthly reporting, which I think can get a little overwhelming. At that point you might spend half you time just reporting. I think quarterly is kind of a sweet spot." PM10 also highlighted the project management value of the monitoring process: *"It also helps me, because I lead a large team. (...) these quarterly reviews help me steer the team as to what is expected. It is very easy to get lost in the daily details, and lose sight of [objectives]. [Having the due dates of the report and review come up] kind of energizes the team around the short-term goals.*"

While personally liking the involved, hands-on management style, PM1 reported that "*Some colleagues [on other ARPA-E projects] view it as being perhaps overly micromanaging or intrusive (…) I think it's more involved than some other agencies, it is a very 'hands-on style'. So far, I find it constructive. (…) I like to think that they are erring on the side of being very pushy in the beginning, but of course their intention is to help us succeed.*"

PM8 also commented on the high involvement in ARPA-E compared to other government programs: "*(…) most of the other [government] programs don't have this level of involvement. Often the Program Director is overseeing a huge suite of different programs as well as doing their own research or their own policy work, and so it is really just a 'side thing' where there is a decision made to fund [the project], and they will read the reports and stamp your payment requests, but not really dig in at the level that the ARPA-E teams are. Certainly, this quarterly, in-person monitoring is something that is much more resource-intensive than in the other program we've been in.*"

PM2 explicitly pointed out the impression of having ARPA-E as part of the team: "*With ARPA-E you felt very much like you're part of a team. They're not just monitoring you, they're knowledgeable. The people who manage it, (…) they know about how to do these things. They know what the other teams are doing. They would say "this has been an issue for the other projects, how are you dealing with this? How is your formulation of approaching this problem?" There was real feedback."* PM5 highlighted the management style as particularly insightful and supportive, as the ARPA-E team would leverage their own industrial experience in technical discussions and ask: "*what are the issues you're encountering, and do you have ideas of how to tackle those? If you don't, let's discuss it. Where you do have ideas, let's discuss them and see if there's anything that we can help or advise on."*

Continuing PM2 and PM5's impressions of useful discussions, PM12, PM7, PM11, PM8 and PM6 highlighted the benefits of having the ARPA-E team as 'full

partners' in this context. While the actual results of the technical discussions varied, they appreciated that the ARPA-E team would occasionally ask the 'right questions' and make suggestions that sometimes proved fruitful.

PM7 and PM12 made similar appreciative comments about having the ARPA-E team as part of the project and the value of being asked the right questions, as PM12 highlighted: "*They are very, very goal-oriented, and they really help us (…) to make sure we are on track, and we get closer to what we think is successful completion of the project. (…) they ask the right questions, and sometimes we get a technical suggestion from them. So it is a great experience. I am very happy to be working with them. (…) Other agencies (...) they don't say that they are part of this team, but the ARPA-E guys, they all say "we're all in the same boat". I think that is a very nice thing to hear."*

PM8 and PM11 explicitly connected the management style to the technical capabilities of the ARPA-E team, as PM11 summarized: "*[The in-person reviews are] actually probably the most helpful, because face-to-face they can understand things. I can explain and we can have this back and forth conversation about things they don't understand in the quarterly report. (…) They have enough experience in our field of work that they'll make suggestions that turn out to be useful. Some suggestions they make are good, some of they are not. (...) Occasionally we will get a pretty good idea from them. And that's where it really pays off to have real experts doing this sort of job*."

While not reliant on their technical support, PM6 made a similar statement: "*Their style of operating is different, and I find it to my liking. The program officers want to be full partners in what you are doing, rather than just receiving reports [performing] 'pro-forma' reviews. They're really engaged, and I think that's helpful. (…) I wouldn't say that they have helped to solve our problems by giving us pointers, we came up with that ourselves, but the discussions with them have been very positive and beneficial.*"

PM&PI9 on the other hand communicated a somewhat different perception of the nature of the review meetings than the other interviewees, experiencing a regime more towards monitoring than two-way interaction, indicating a mismatch of technical capabilities, as previously highlighted in section 6.4.1.2: "*When [the ARPA-E team] came out, it was more monitoring, we would just give them a report on what had happened since the last time we had talked to them, and if they had suggestions, they would make them at that time. (…) I think [the project] was a little bit outside of their expertise. I mean, they had some suggestions some times. When you get to this high level, it is pretty detailed. You can't be an expert at everything.*"

Undue influence: Making suggestions without instructing

One of the emerging topics related to ARPA-E's involvement in the projects was the balance of ARPA-E making suggestions while avoiding giving active instructions. PM5 gave an example of how the ARPA-E team would make suggestions if his project had run into issues: "*[ARPA-E would say] "Maybe you should talk to companies about the design [of a specific component]?" It has to be generic, they can't just say: "Go talk to this company". They would say: "Maybe you can find a company that could [help solve a specific technical problem]. You can take it from there and figure it out".*"

PM11 also discussed this issue: "*I don't know all the laws that go into why these things are the way they are, but for whatever reason they're not allowed to tell us what to do. It is deemed as sort of an undue influence of the activities of the projects, and that can cause problems somewhere in the government bureaucracy. I don't know the details. So they are limited in the amount of quasi technical or consulting support they can give us.*"

PM6 mentioned that he believed that "*(…) there are projects where as a consequence of the interaction between the ARPA-E Project Director and the team, the project has gone off in a significantly different direction. We have not done that. There have been tweaks to technical approach and so on, but our basic thrust has remained unchanged.*"

Interestingly enough, PM&PI9 speculated whether active direction could have been partly at fault for the under-performance and eventually the suspension of their project. After seeing that the planned approach was not viable, PM&PI9 had proposed a different way of reaching the end-goal of the project: "*From the beginning, what happened was that we tried something risky because they wanted something risky. And if [the first technologic path] had worked out, we would possibly use it for other things too. It didn't. I also feel like we wanted to abandon earlier with [the first technologic path], and [the ARPA-E team] really pushed us to stay the course with it and see if we could figure it out, because they really wanted that [result of succeeding in the first technologic path]. That sort of pushed us to stay on it for a little bit longer before really insisting that we needed to go to something that we could do."*

PM&PI9 even highlighted that they had taken a different approach already before being awarded support due to feedback from ARPA-E representatives during the application process: "*Our first application actually targeted [X], and then (...) during the application process (…) they [ARPA-E] actually had some comments that they thought [X] wouldn't be a good [way to reach the target], so we actually changed that to [Y]."*

6.5.1.4 Technology-specific time constraints

While appreciative of some milestone flexibility, PM5, PM&PI9 and PM13 highlighted some of the rather technology-specific time constraints they had faced in developing technology where each iteration of testing and development may take several months, which might not suit a process driven by milestones and quarterly reviews very well. PM5 highlighted that "*(…) some of the targets might be six months of testing, which you can't do it in a quarter. It means if you are going to hit the target for the next quarter, you actually have to start both of those the previous quarter, and it is going the entire quarter. If something fails during that process, then you already know you're not going to hit that target. It's pretty tough because [this device is] meant to [operate for] long periods of time, and if we going to [test that], it's going to take a very long time.*" PM&PI9 made a similar argument, highlighting that catching up with the original timeframe of the project within the duration of their three-year project was very challenging when things went wrong for their time-intensive technology.

PM&PI9 pinpointed the perceived inutility of a quarterly frequency for technologies where the iterations can take extended amounts of time, highlighting that quarterly reviews *"(...) may be good for other projects, but [for this particular technology] not always a lot happens in twelve weeks. Sometimes we were struggling with what we were going to report that was going to be different from the last time they visited us.*"

PM13 on the other hand referred to the issue with not having time to pursue observations that might work better than the original one: "*(…) here you can't do that because when we are branching into unchartered territories, we lose time. So here we have to ignore that, and then focus on our milestones. (…) We felt that we don't have time to follow up on interesting things that might benefit the project, because we are hunting for our milestones all the time. It works, but I think we would have benefitted from a little (...) I guess more time.*" In this context, PM13 suggested that no-cost extensions could be valuable for technologies having inherent time constraints with regards to the time each iteration takes: "*[It would be nice to have] the ability to have an extra year, even if it's not funded, if something takes longer because you have to wait for [each cycle of this time-intensive development].*"

6.5.1.5 Reporting overhead issues

The negative side effect of a high involvement model is that it can include significant overhead. Several interviewees said that reporting overhead was relatively high, especially with regards to the financial side. Some teams find this to be very stressful, especially academics and small companies without access to dedicated accounting infrastructure. The overall opinion seemed to be that

this is a slightly sub-optimal part of the deal, but still worth it given the size of the awarded grants and support enabled by ARPA-E.

PM8 summarized the tradeoff of the monitoring overhead on one side, and the support on the other: "*Initially, I was worried a bit, because (...) the amount of reporting overhead was really high (…). So I was apprehensive initially, but I think having worked with them now for a year, that hard push is offset on the other side by a deep engagement with what we are doing, and a real desire to advance it. It is a tradeoff that's worth it for us, for sure. I've been impressed by the agency.*"

With a fairly long experience with ARPA-E, PM2 commented on its change over time: "*ARPA-E has slowly gotten more bureaucratic during its existence. We were one of the first sets of projects in the door, and now the ones who are starting out [have to deal with more paperwork], and more rules (...) I don't think that is a big deal either way. You just have to recognize that it is government money, and their people have expectations of the amount of control that's going to be exercised over that.*" PM7 expanded this notion: *"In the beginning ARPA-E did not have a very tough audit group. Now it has a much tougher audit group. That is the main change I've seen. Technically they have been the same, their attitude has not changed.*"

PM5 commented on the financial issues associated with having additional administrative tasks introduced during the course of the project: "*They didn't have a lot of rules. So that's why they were able to move fast. As the project has gone on (…), they've started to impose more rules and more structure that is slowing things down. I could see that by the end of the project, there was more hoops you had to jump through, and things you had to fill out that had nothing to do with technically succeeding on the project, it was just satisfying some government audit or form* (…) *In general it became more difficult because (...) they are basically adding more work and more scope to the project, but there was no increased amount of funding. That made it pretty difficult because (...) when I inherited the project it was already sort of over budget, so I had a pretty tight budget to begin with*."

While they did not have issues with the high involvement reporting, PM&PI9 added that the overhead might be different for organizations without support functions such as dedicated staff for running the financial side of the reporting. Along with PM1, they highlighted that some of their academic counterparts in other projects felt that the process was intrusive: "*I felt a very strong involvement from their part, and I didn't see that as something negative. In some of the academic groups, it was like "oh, it was so much work!" I think they were probably a little bit harder on them. (…) The advantage we have is that we have our accounting system close by, and we can take decisions quicker on that. (...)*

We heard from other academic teams, who took a very long time. With them, there was a little bit more irritation, I'd say. That they were being 'harassed' by the ARPA-E team. We didn't have that."

PM12 elaborated on this point: "*One thing that is a little challenging for those are in academia is, it is so well planned, detailed, at a very detailed level. So all these students working on this project, they have been under constant stress, because the review comes up every quarter. (…) If that motivates them, that would be a benefit, but that is kind of the thing that I have a little mixed feelings about. But, because of the nature of ARPA-E, I think I can live with that. It is not a pure science project."* PM12 also highlighted the contents of the quarterly reporting: "*It is really extensive reporting, including all the financial reporting. They also track us in terms of the money that we spend. This extensive quarterly report also includes all the [technical issues]. We have to be really honest with them."*

When it comes to the level of detail required on the financial side, some of the interviewees gave conflicting answers. PM1 highlighted for example that "*One thing they [ARPA-E] have been pretty good about is not second guessing particular travels, we have a travel budget and I don't think we have to be super specific in "which trips are you going to take to charge to this account?" We have had other funding agencies, in particular in California, where they scrutinize every airline ticket and every hotel, and say "really, are we supposed to pay for this, where did you go, why did you have to go so far?", and we did not have that issue at all*."

In direct opposition with PM1, likely due to having a better overview over the financial side of the grant, PM&PI9 reported that "*I have to say that our Accounting department is* ***not*** *happy with this grant, and they are very happy that it's probably going away. It was a very high burden. (…) Typically with grants, and I think this is the [reason] why the academics were so upset, is that if you get a grant from NSF, they wire you $150,000. You spend it over six months to twelve months, you submit your technical report at the end, and that's it. This is like, you're reimbursed. So every month, we had to submit [a description detailing the employees], the hours that they worked, our travel receipts, with the alcohol subtracted. Here was the flight cost, and the hotel. Every detail. And they would come back commenting: "you exceeded the limit on your dinner". (…) For other grants, you'd put in your budget proposal, $2000 for travel, and they'd take you at your word that you're going to spend $2000 for travel. (…) [The accounting department] spent quite some time and energy, and money, in basically financially running whatever they wanted. The [level of] financial requests, or the justification of the budget, was very high. That was a little bit of*

a downside for them. We didn't have to deal with it." (emphasis added to reflect original emphasis in the interview)

In support of PM&PI9, PM11 explained: "*The Department of Energy is extremely cautious about making sure all the money goes to exactly what we say it does. So we close our books with our accountant the way a much bigger company does.(…) They are very careful about this stuff. I don't know if that would be necessary in another situation, but for DOE it is. So we are sending in really detailed financial statements quarterly. (...) Before we get paid there is a pretty detailed financial review, to make sure we are honest. Which is fine. If we weren't, then that would be a problem. I guess we find this to be a little bit burdensome, because we are a smaller company. A big company or big university has dedicated staff for all of that.(…) I can't afford one person to be doing the budget for us. So I've got a guy who is in here a few hours a week, covering the books, and it's good enough.*"

PM11 elaborated on this side of the process, concluding that while it is the primary hurdle to working with ARPA-E, it is worth it given the support: "*ARPA-E was set up as a new [entity], but within the framework of the federal government. So the process for accounting, for contracting, for getting paid, for doing even an application like this, are really burdensome for a small company. All of that is really hard. But my philosophy has been [that] it is still a great deal. Yes, there are ways to make it more efficient for relatively untrained, but well-meaning people running small businesses in order to get paid to invent things, to avoid doing bureaucratic work rather that technical work. There are ways to do that. But that is a small price to pay to actually have the resources to get to do something. Can things be better? I would say yes, logistically, but the amount of support we are getting. You can't complain.*"

6.5.2 Commercialization focus: Bringing the technology to market

Almost all of our interviewees discussed ARPA-E's Technology-to-Market efforts and commercialization focus, as discussed in section 4.2.2.2. The most prevalent topics were the Technology-to-Market plan and associated milestones, the early focus on commercialization and the next stage development after leaving ARPA-E, the support provided by the Technology-to-Market team and the varying usefulness of this support according to the type of organization responsible for the project.

6.5.2.1 Early commercialization focus

Some interviewees emphasized how ARPA-E pushed for thinking about commercialization already when developing the project plan at the onset of the project. PM1 explained: *"One of the things that they really pushed us to do, was to start thinking about [the commercialization] process now, and don't start*

thinking about it when you are ready to sell the products. (…) We have to report on our thinking and we have had to have meetings and conversations with people in industry who would be prospective buyers of this equipment. (…) So there is actually a lot of preparation work that they prompted us to do, which is good."

PM13 agreed: "*One thing that you are not used to in other [research programs] is the importance of having a tech to market outlook from day one, and the business model from day one."*

PM11 felt that pushing for much Technology-to-Market work at the beginning of the project would be inefficient use of resources, because his project was at such an early stage of development: *"We are doing the T2M activities already, but what we find is that because it's such an early stage technology, even our ability to labor in a time efficient way for our staff to do T2M, it would be so much better if we already had a little bit more traction on the technology side."* He had however found a solution to this issue: *"ARPA-E has the rule that 5% of the money for the program got to be spent on T2M. We anticipated that, so when we proposed our budget for the whole three years we said we were going to hold it back, and we are allocating a lot of money to do testing with customers in the third year."*

PM10 was of a similar opinion in the beginning, but realized the value of starting early as his project progressed: *"When I started on the project, I was questioning, "Shouldn't all of this [Technology-to-Market work] be loaded into the third year?" Then [ARPA-E] steered me into having some milestones in the first and second year, and in retrospect I'm grateful for that. Because it is really valuable to talk to stakeholders early on as well, to get an early sense of what they are interested in."*

6.5.2.2 Technology-to-Market plan and milestones

PM10 commented on the incorporation of Technology-to-Market plans as a milestone in the deliverables of the project: "*[Technology-to-Market] is actually a defined task within our task and milestone sheet. There is one task just called Technology-to-Market. That includes things ranging from cost performance modeling analysis, to filing Intellectual Property, to follow-on commercialization. (…) That also includes talking to OEMs, [analyzing] markets [etc.]."*

PM8 brought up how ARPA-E pushed the project to develop Technology-to-Market plans concerning the hand-off to other funding sources, and commented on why this was critical to ARPA-E: *"They don't want to be funding things that are a dead-end, so we are definitely developing our plans around that. What our [ARPA-E funding] will get us to (…) is an advanced, high-performance prototype, but still not a real product. How do we bridge that gap? (…) There is a lot of*

effort that goes into trying to plan that and prepare for it. (…) [ARPA-E] wants to see those plans, and that is one of the things that they milestone (...), the definition of that plan and identification of all of the sources of strategic support that are required to get there."

6.5.2.3 Technology-to-Market team and support

Several of the interviewees commented on the support they had received from ARPA-E's Technology-to-Market team. PM1 concisely described the role of the Technology-to-Market advisor assigned to the project: *"[He] is specifically the expert on commercialization, on this technology transfer. He has a lot of ideas and suggestions*."

PM6 elaborated on his positive impression of the Technology-to-Market team: *"This Tech-to-Market [effort] that ARPA-E is doing, I think is a good thing. They're taking it seriously, and the people that they brought on are people with (…) genuine industrial experience and I think understand what one is up against to be successful commercially. Our interaction so far has been very positive".* PM6 specified that he had received useful support from the Technology-to-Market advisor: *"We had a very good discussion with him shortly before the new project started, which was frankly very helpful."*

For some of the interviewees, the Technology-to-Market team from ARPA-E had proved useful in getting industry or customer relations, as PM11 explained: "*The person that does the business development, the Tech-to-Market for us, she was formerly a senior scientist in a [relevant] company. Before that, she was working as a chemist for 30 years at a big chemical company. [If we say] "we are doing this new chemical synthesis, and this is what we are seeing so far", she can chime in and say: "Talk to those guys if you need that polymer." It is really helpful to have that kind of support and in person setting."*

PM12 similarly had experienced that the Technology-to-Market advisor assigned to his project had been helpful in creating connections with customers: *"He basically introduces us to potential customers he believes will be a good match."*

PM1 was also of a similar opinion, saying that the Technology-to-Market team gave both feedback on planned outreach and suggested contact possibilities, something she viewed as useful.

Overall, PM8 found the support for commercialization very useful, as his project didn't have enough resources to take care of that all on its own: *"We are a small team that is very technically focused and (...) we don't have the luxury of having very much of a market focus yet. Having some of that support from ARPA-E's side has been really useful. They push hard on that side of things as well, which helps us keep focused on those important questions."*

Contrary to the others, PM13 and PM10 had found the Technology-to-Market function to be partly lacking. PM13 had worked with two different ARPA-E projects, and in the first project there weren't any support for commercialization, which was something he had missed. This was however rectified in his second project. PM10 noted that his project currently doesn't have a dedicated Technology-to-Market advisor from ARPA-E, although his previous Program Director had taken on this role as well: *"That being said, the first Program Director, before he became the [Name of program] Program Director, he was a technology to market senior advisor. So he was kind of the tech to market person himself."*

6.5.2.4 Needs for Technology-to-Market support

Judging by the opinions of our interviewees, there seems to be a variable need for a dedicated Technology-to-Market support according to the type of institution responsible for the project.

PM&PI9 assumed university researchers would have greater use for Technology-to-Market support: *"ARPA-E is so involved, they have all of these workshops where (…) they talk about commercialization, they talk about IP, they talk about freedom to operate. A lot of university researchers are just (...) that's not their realm, they have no idea [about it]. I think it is good in that they are ensuring that university researchers are really focused on [the commercial aspects which should be considered prior to acquiring a piece of research]."* PM&PI9 added that ARPA-E probably adjusted the Technology-to-Market support according to the needs of the projects: *"We probably had less pressure on Tech-to-Market [activities], just being a private company, than universities did."*

PM6, being from a larger organization with several different R&D projects, believed that made them less dependent on Technology-to-Market support than start-ups or universities: "*We are a smaller part of a larger organization, and we spent a lot of time thinking about commercializing our products before we joined the ARPA-E team. ARPA-E funds a lot of university efforts, and they fund companies that are just getting started."*

PM3, having founded a start-up company for his project, believed on the other hand that start-ups would be more incentivized to focus on commercialization, especially when located in an entrepreneurial local environment: *"[Our Technology-to-Market person] is really great, but that is not as important for us since we're right in the bubble here, we come from 'start-up'-land. A lot of the people that they fund are working in universities or national labs, and they are less incentivized or nested in an environment, a culture that supports spinning out ideas into companies."*

7 Discussion

In this chapter we use the theoretical and empirical foundation we presented in Chapters 2 and 4 to analyze and interpret the results of our interviews, as presented in Chapter 6. This chapter therefore presents how the results correspond to or diverge from the relations we anticipated using the theoretical and empirical background, as highlighted in Figure 2 in section 4.3.

Given the rather complex structure of these relations, this chapter follows the same overall sequence as Chapter 4 and 6 in order to maintain tractability. We therefore leave the overarching review of the effects with regards to the research question to the end of the chapter.

7.1 Funding role

In section 4.1.1, we argued that ARPA-E fills the funding gap arising from the market failures presented in section 2.2. This topic was given considerable time by most of our interviewees, who elaborated on the existence and probable causes of this funding gap. The results from these discussions gave a fairly coherent conclusion: Government support and ARPA-E in particular had been vital for the existence of their projects, whether or not they were organized in an established organization, small firms, start-ups, national labs or academia. We therefore find support for the assumption that **the funding gap for high-risk energy technology innovation projects is indeed an issue that needs government intervention, and that ARPA-E is acting as an enabler for the existence of its projects, and is therefore acting in the funding role.**

Complementing our assumptions regarding the cost share, some interviewees also highlighted an increased willingness from private entities to invest and take risks when the risk is shared by ARPA-E. We therefore suspect that **risk sharing with ARPA-E might be attractive for private entities,** but leave the investigation of this inference to future research.

In the following sections, we analyze the secondary aspects of this role, relating to the portfolio approach to funding, program design and screening process. We also present analysis on the award size, since it emerged as a highly important topic.

7.1.1 Cost share and duplication

We reasoned that the very same reasons government intervention is needed to overcome the funding gap, could for some organizations give rise to issues with raising the cost share in ARPA-E's model. This notion found support in several interviewees, who had encountered troubling issues when raising the cost share.

The primary issue was the funding challenge, which for smaller firms and start-ups seemed to be of particular importance. Our impression is therefore that **the cost share model can moderate the effect of the funding role in overcoming the funding challenge.**

In that context, we also highlighted that funding duplication restrictions could be an issue for entities deriving most of their income from federal sources. For interviewees in national labs or companies deriving a large amount of their income from government contracts, this was indeed indicated as a substantial hurdle, as they could have covered the cost share using in-house funds, but weren't allowed due to the duplication rules. This leads to the consideration that **the duplication challenge can moderate the effect of the funding role in overcoming the funding challenge.**

7.1.2 Market orientation, portfolio approach

We proposed that using targeted FOAs to fund related technologies could help promote self-supportive technology systems, increasing the chance of projects being adopted, consequently reducing challenges of structural rigidities. PM3, PM7 and PM13 discussed ARPA-E's role as a promoter of technology ecosystems, and all three seemed to appreciate this aspect of their respective programs. Whether this will translate into increased chance of adoption in the market is inconclusive based on the information in the interviews, and **we cannot say whether the portfolio approach in fact reduces challenges of structural rigidities.** However, this approach to funding did present useful opportunities for collaboration, as further analyzed in section 7.3.5.

We argued that the market oriented approach to program design and project screening could lead to a project selection with increased alignment towards the market, reducing systemic failures. While our interviewees confirmed ARPA-E's focus on commercialization even before finalizing the award (see section 7.5.2), we were not able to obtain any useful information on whether the market-oriented program design and screening process contribute to increased market alignment. **We therefore cannot say whether the market-oriented program design and project screening contributes to reducing systemic failures.**

The young age of the agency and having only one alumnus in our interviewee sample is a clear limitation here, as there simply isn't much of a track record to analyze in this context.

7.1.3 Application process

Achieving the purposes of the funding role was also argued to be facilitated by having an attractive application process with a low barrier to apply, as a short pre-proposal reduces the upfront risk of wasting resources on a dead-end full application. We predicted that this two-step application process could increase

the number of interesting applicants for ARPA-E programs by lowering the effort needed for the initial application. This is obviously hard to answer on the basis of qualitative data, and is left to future research.

Additionally, our interviewees explained that the effort needed to compose a full proposal was substantial; PM1 had even hired a professional proposal writer to help. However, they did not indicate that the resources required to compose the full proposal was a deterrent for continuing the application process after being encouraged to apply. An obvious limitation to this observation is that we have only interviewed people who did go through with the application, and as such lack insight into why some applicants, if any, didn't submit a full proposal despite being encouraged to do so. We can only speculate whether the attractiveness of the two-step process might have offset the deterring aspects of the full proposal.

7.1.3.1 Two-step application process

Limitations aside, our interviewees applauded the two-step process. PM1 explicitly said that she would never have applied if she had to write a full proposal directly. Other interviewees appreciated the process, but **did not state that they wouldn't have applied if they had to write a full application directly.** PM10 received his award prior to the two-step application process, and referred to it as more efficient than *"going in blind"*. We therefore summarize that while the results have a positive connotation, we only have circumstantial evidence which **indirectly suggests that the two-step process may increase the number of applications pre-proposal lowers the barrier to apply.** We do however maintain that there is sufficient agreement among the interviewees to conclude that **the two-step application process is well liked by applicants**, even though more in-depth research would be needed to conclude whether it has a meaningful effect on the number of applications.

7.1.3.2 Response opportunity

In connection to the previous section, we argued that giving the applicants the opportunity to respond and elaborate on comments from reviewers would reduce the risk of rejecting suitable applicants due to reviewers' lack of understanding. PM12, PM13, PM8 and PM7 gave appreciative answers on the opportunity to clarify misunderstandings and explain their concepts further if needed for the understanding of ARPA-E's review panel and the Program Director. While we are limited to one side of this story with regards to whether this saved any of the interviewees from having their projects rejected, it seems like a useful mechanism to reduce the risk of wrongful rejection, especially in PM8's case, who had initially received dismissive reviews characterized by little rigor. Consequently, we therefore maintain that **the opportunity to respond to reviewers' comments positively influences the existence of the projects**.

7.1.4 Award size

Lastly, in addition to the results covering the anticipated characteristics of the funding role was the unexpected attention our interviewees gave the size of the award itself. PM6, PM1, PM11 and PM2 explained the critical importance of the size and duration of the financial commitment from ARPA-E, in that the kind of high-risk, 'long-leap' goals ARPA-E wants its projects to have would be infeasible to actually realize with too small or too time-constrained grants. We therefore understand that **the committed award has to be large enough to explore the full potential of the technological idea,** and consequentially include in our framework that **a sufficiently large award size positively influences the outcomes of high-risk energy innovation projects.**

7.2 Legitimator role

This section is related to the legitimator role presented in section 6.2, with the proposed factors that could impact the projects from section 4.1.2. Most of the interviewees described ARPA-E's efforts in legitimize them in providing visibility and credibility. We therefore find support for that **ARPA-E takes a legitimator role.** We describe this finding in the following sections, where we analyze ARPA-E's role in providing credibility and increased visibility, and the proposed secondary effects of increased abilities to successfully connect with other parties and raise additional funding or other resources.

7.2.1 Credibility through 'stamp of approval'

We argued that ARPA-E's program design and its competitive and diligent selection process would reduce the risk perceived by external parties. We also argued that ARPA-E's 'stamp of approval' and associated publicity would increase credibility and visibility of the projects. Many of our interviewees highlighted being associated with the ARPA-E name and the competitiveness of the selection process as important for their credibility and legitimacy towards investors or strategic partners. While noting the external credibility, PM2 was the only interviewee to disagree on the 'stamp of approval', at least in a quality context. However, PM2's project is almost done, and his comment was made in retrospect to when ARPA-E was freshly established and had little reputation. Overall, we therefore still believe that **ARPA-E's program design and competitive screening process with diligent vetting contribute to reduced perceived risk in its projects for potential investors and strategic partners, and increases the credibility of the projects.**

PM3, PM4 and PM7 also connected the credibility to the ongoing vetting process through the monitoring process, i.e. holding the project teams accountable by terminating funding for underperforming projects. This leads us to believe that

ARPA-E's ongoing vetting through reviews contribute to the credibility of the project.

7.2.2 Increased visibility and credibility

We argued that the publicity garnered by the funding award and presence at the Energy Innovation Summit would increase the visibility and credibility of the projects. This was supported to various degrees by our interviewees, who claimed that being associated with the ARPA-E name through the announcement and being present at the Energy Innovation Summit was helpful for publicity and making new connections. The visibility and credibility from the award had in some cases also led to renewed interest from external parties who had previously rejected partnering with or investing in the projects. PM6 highlighted that the value of being associated with ARPA-E was likely to be higher for smaller firms than his own. We argue that this could be the reason why not all projects had the same opinion about the usefulness of the publicity. The majority of the interviewees nevertheless opined that ARPA-E recognition helped the visibility and credibility of their projects. Some interviewees also highlighted the internal credibility winning an ARPA-E award had given them. We therefore consider our assumptions supported, and believe that **being supported by ARPA-E increases the credibility and visibility of the project, both internally and externally.**

Having increased visibility was pointed out to be a potential issue for firms wanting to pursue 'stealthy' strategies. Nevertheless, none of our interviewees highlighted this as something they wanted instead of the visibility.

7.2.2.1 Increased ability to connect with external parties

We also argued that a secondary effect of this credibility and visibility would be an increased ability to successfully connect with external parties. Our interviewees highlighted increased incoming interest in connecting due to visibility and smoother connections when leveraging the ARPA-E award in the initial pitch. Combined with the support for the previous inference, we therefore conclude that **the legitimacy provided by being associated with ARPA-E increases the project's ability to connect with external parties.**

7.2.2.2 Increased ability to raise funding or other resources

Lastly, we argued that the increased credibility towards prospective investors and strategic partners could positively affect the projects' ability to raise funds or other resources. However, as few of our interviewees have finished the project or reached its final stages, few could go into detail about how credibility had affected negotiations or resulted in concrete results from efforts to secure follow-on funding. Nevertheless, some interviewees made this connection when talking about how they raised their cost share as either funds or in-kind support from

other entities, as reported in section 6.1.1, along with the previously highlighted increased interest from other investors and strategic partners wanting to commit funding or partnering following the award announcement. The internal credibility helped some projects securing internal funding for the cost share. The overall positive support for our assumption therefore lead us to conclude that **the increased credibility from being associated with ARPA-E increases the project's ability to raise funding and resources from external and internal sources.**

7.3 Network role

In this section we analyze and discuss the proposed effects of the networking role on the projects, as presented in section 4.1.3, compared to the results presented in section 6.3. Almost all of our interviewees reported that ARPA-E made efforts to facilitate networking both towards external parties and internally, we find support for the overarching assumption that ***ARPA-E takes on the networking role.*** We elaborate on this finding in the following sections.

7.3.1 External networking facilitation

We suggested that ARPA-E can connect the projects to external parties by facilitating networking activities. Our interviewees supported this notion, and had experienced that ARPA-E facilitated network building towards industry, customers, researchers, potential strategic partners, regulators or other entities within the DOE. Since around half of the interviewees had spoken positively of these efforts, we argue that **the external networking facilitated by ARPA-E has the potential to increase the projects interaction with external parties.** However, our interviewees also diverged somewhat on the actual level and benefit of the networking facilitated by ARPA-E. We believe this may be linked to the industrial network of the Program Director, and argue that **the network of the Program Director moderates ARPA-E's ability to facilitate the project's interaction with external parties,** which we will revisit in section 7.4.

We argued that the ARPA-E Energy Innovation Summit could spur interest for the technologies being developed within ARPA-E's programs and facilitate connections with external parties. Our interviewees seem to be of a similar opinion, as the event was seen as a way to gain visibility and interest from industry and investors, and was highlighted to be a good arena for actively making useful connections. PM10 also claimed ARPA-E-facilitated connections to have a higher hit rate than average networking efforts. Combined with the above support, we therefore infer that **networking facilitated by ARPA-E increases the projects ability to connect with external parties.**

We also proposed that the networking efforts towards investors could help mitigate challenges of securing later stage funding. While this notion was not disproved explicitly, it was not confirmed by any of the interviewees either. We therefore **cannot say that the ARPA-E efforts to increase networking with external parties led to an increased ability to raise additional funding.** However, we did see support from PM10 for the proposed networking facilitation to potential follow-on funding sources within the government. While it is unclear whether it will result in an actual follow-on funding agreement, we infer that **ARPA-E increases the opportunities of finding follow-on funding by facilitating networking with other potential sources for later-stage funding within the government.**

7.3.2 Market alignment: Introductions to industry and customers

We proposed as a secondary effect that ARPA-E would improve the projects' ability to align the technology development towards the needs of the market through connections with industry and customers. Overall, the results were indecisive on this matter. According to the interviewees, ARPA-E had put a good deal of effort into connecting the projects to industry actors, and some of these connections proved useful. Despite their usefulness, it is unclear whether these relationships had enabled the project team to better align its technology development process towards the needs of the market. A limitation to this study and a potential reason for the lack of clarity on this issue may be that most of the interviewees were far from ready to commercialize their products at the time of the interview, and it would hence be hard to evaluate the actual outcomes of these relations in a longer-term perspective. Even in retrospect it would be hard to prove that early industry interactions actually had a positive impact on the adaptation of each technology to the market. We therefore elaborate on earlier conclusions that introductions made by ARPA-E to industry actors and customers are helpful, but also that **we cannot say whether ARPA-E networking efforts translate into increased alignment of the technology development with the market.**

7.3.3 Limit to networking: ARPA-E cannot build relationships

An aspect we didn't consider in section 4.1.3 was that while ARPA-E could facilitate introductions to potential customers and industry partners, it would still be limited in creating prosperous relationships. Among our interviewees, there seemed to be a common perception that the extent to which a third party such as ARPA-E could facilitate the creation of such relationships would be limited. Despite useful introductions, they claimed that fruitful relationships had to be built up through personal interaction between the potential partner or customer and the actual developer of the technology. An important reason for this was thought to be that the customer or partner needs to be able to trust that the developer can actually deliver the technology on one end, and the need for the

developer to control and tailor the flow of proprietary information according to the needs of that particular customer on the other end. We therefore deduce that ARPA-E facilitates introductions to potential customers or partners, but **the actual customer relationships or strategic partnerships have to be built by the project team themselves.**

7.3.4 Networking as a means to provide technical assistance

ARPA-E's efforts to provide its projects with access to outside expert knowledge if they met technical challenges during the development process that were outside their expertise is an aspect to the networking role which we did not explicitly anticipate, despite touching upon it in section 4.2.2.1. This was brought up by our interviewees, who had experienced that ARPA-E had helped them identify and connect with both external experts and other ARPA-E projects possessing the technical competencies they needed. It hence seems that **ARPA-E supports the technical development process of the projects by connecting them to the experts they need.** This also connects to the abilities of the ARPA-E team to provide relevant support to solve technical challenges, as we discuss in section 7.5.1.

7.3.5 Internal networking: Realizing synergies in the program

We reasoned that funding similarly focused projects within each program creates opportunities for exploiting synergies between the projects. Many of the interviewees agreed to this notion, highlighting that the efforts made by ARPA-E to connect different projects together had created opportunities to share experiences or help each other where they had complementary competencies by being part of a portfolio of related technologies. Especially the program conferences were viewed as good opportunities to share experiences and help each other out with technical challenges, since projects within the same program sometimes faced similar technological challenges. Some of the projects in Open FOAs did however report limited opportunities to exploit synergies due to the lack of related projects. We therefore deduce that **the focused program design creates opportunities for exploiting synergies between projects, which ARPA-E actively encourages and facilitates.** It is however unclear to which extent such interactions could help the development process of the projects, since issues of proprietary knowledge and intellectual property naturally limits the project teams' willingness to share information.

We also argued that the potential to exploit these synergies would be facilitated by the overview the Program Director has by being responsible for all the projects within a program. PM13, PM3 and PM2 supported this expectation, and highlighted that the Program Director knows what challenges the different projects have, and has insight in who might potentially be able to solve them or how other projects have solved similar challenges. We argue that we see

support for our suggestion, and expand on the previous conclusion that **the Program Director has a central role in facilitating the exploitation of synergies between the projects in his portfolio.**

7.4 The role of the Program Director

In this section we analyze and discuss the proposed effects of the Program Director on the projects, as presented in section 4.2.1, compared to the results primarily presented in section 6.4. The three primary areas of interest for our interviewees was the importance of the Program Director's level of relevant experience and expertise for the technologic field of the project, and how these capabilities were related to the credibility he embodied and his ability to manage and support the projects in his portfolio. Additionally, the effect of having empowered and hence motivated Program Directors could be perceived as either supportive or constraining to the projects.

7.4.1 Experience, technical expertise and the effect on ARPA-E's funding and legitimizing capabilities

In section 4.2.1.2 we argued that the Program Director's freedom to designing programs and managing the project portfolio required a high level of experience and expertise, and that this would further add on to the legitimacy of the agency.

Our interviewees indicated that the Program Director's ability to perform his responsibilities was dependent on him having the necessary relevant experience and expertise. They claimed that these qualifications were needed in order for him to have credibility both in designing the program and in selecting and managing the project portfolio. We therefore consider this assumption supported, and that **the Program Director needs relevant experience and expertise to credibly perform his responsibilities**.

We had also claimed a direct influence from the Program Director on the funding role. Amidst circumstantial support from other interviewees, PM3 explicitly made the connection between the Program Director's technical competence and the decision to fund his project. We therefore retain our position that **the Program Director's experience and expertise influences the effectiveness of ARPA-E in the funding role.**

By connecting the Program Director's capabilities and credibility to his responsibilities in the screening process, we similarly asserted that the capabilities of the Program Director should influence the legitimating role of ARPA-E. None of our interviewees made this connection explicitly. We did however find support for the screening process' contribution to ARPA-E as a legitimator (section 7.2.1). Combined with the previous finding on the funding

side of this connection, we argue that this supposition to be circumstantially validated. We therefore infer that **the Program Director's experience and expertise affects ARPA-E's ability to act as a legitimator,** while noting that the properties of this relationship needs further investigation and validation by further research.

7.4.2 Program Director accountability and empowerment

We argued that the Program Directors are incentivized to see their projects succeed since the performance of their projects essentially determines the judgment of their own achievements, and that this would lead them to encourage their projects to target ambitious goals and put a lot of effort in driving the projects forwards. Our interviewees indicated that the Program Directors indeed worked very hard to make the projects succeed due to this responsibility, which is also highlighted by the analysis in section 7.5.1 below. This support leads us to conclude that **the Program Directors are motivated by being held accountable for their projects' performance, and therefore try to support them to the extent they can.**

We also supposed that this high level of involvement and empowerment of the Program Director could affect projects both positively and negatively. Some interviewees appreciated the freedom the Program Directors were given to use their own technical judgment in advancing the projects, and the high level of support this resulted in. Others however noted that if the Program Director had a very specific idea of what direction the project should take, he could potentially micromanage the project or force it to pursue an unsuccessful path. We therefore imply that **the approach to management chosen by the Program Director can affect the performance of his projects, both in terms of their potential for success or eventual demise.** We expand on the management style of ARPA-E in section 7.5.1.

7.4.3 Technical support enabled by technical expertise and industry experience

In connection to the above, we suggested that the technical expertise of the Program Directors would make them better able to assist the projects in the technology development process. This notion was supported to various degrees by the interviewees. While several interviewees found it important and appreciated that the Program Directors had a certain level of expertise in the technology area of their projects for management purposes, they didn't think the Program Directors were knowledgeable enough to provide solutions to technical challenges on a regular basis. However, they did emphasize the importance of having Program Directors who understand the significance of the different challenges their projects met, having enough technical insight to properly evaluate the developments made and generally have a good dialogue with the

project team. We therefore consider our suggestion to be supported, and that **the technical expertise of the Program Director is a prerequisite for him to be able to properly manage the technical aspects of the projects in his portfolio.** We return to the managerial style of the ARPA-E teams in section 7.5.1.

In section 4.2.1.1 we proposed that the Program Director's ability to connect his projects to relevant industry actors depends on his own existing network. The interviewees supported this notion, expressing that the way the Program Director helped the projects solve their technical challenges often was by leveraging his network to connect them to experts in the particular field, as previously discussed in section 7.3.4. PM11 highlighted that Program Directors from academia might not have the same industrial network to leverage as a Program Director that had worked in the industry. This can therefore be a reason for the somewhat diverging answers regarding the perceived level and benefit of external networking facilitated by ARPA-E, as most of the interviewees had different Program Directors. Nevertheless, we consider this idea to be supported, and conclude that **the pre-existing network of the Program Director is a decisive prerequisite for the level of technical support the projects can expect to receive, and subsequently their ability to solve technical challenges.**

7.5 Management and support of ARPA-E projects

7.5.1 Support and monitoring

In section 4.2.2.1, we highlighted various aspects related to the monitoring regime and interaction between ARPA-E officials and the awardees in the course of managing the projects, which we believed to affect the projects in various ways. Our interviewees devoted substantial attention to these aspects of being an ARPA-E awardee, as shown by the results in section 6.5.1.

7.5.1.1 Collaborative, high-involvement management approach

We first argued that the high-involvement approach taken by the ARPA-E team increases their ability to assess the needs of the projects. Our interviewees did not explicitly comment on that aspect directly, but almost all of our interviewees revealed this indirectly through elaborations about the open and collaborative nature of their relationship with the Program Director and the rest of the ARPA-E team. They found them to be good to collaborate with, using expressions such as 'full partners' or 'part of the team' to describe their relationship. Our interviewees also told us that they had received support from ARPA-E on various issues they had in response to the discussions in these meetings. We conclude

that our interviewees support the notion that **the high-involvement approach taken by the ARPA-E team increases their ability to assess the needs of the projects.**

We further elaborated this topic by anticipating that the ARPA-E team would, through the mentioned in-person review meetings and continued contact, be able to help the projects with technical issues and facilitating networking support according to their needs. Having different needs obviously yielded somewhat different answers from the interviewees in terms of what they emphasized, but the overarching theme was positive.

Technical support

In terms of the technical support provided by the ARPA-E team, almost all of the interviewees reported positive benefits, ranging relatively widely between some having seen little benefit besides appreciating meaningful technical discussions with their ARPA-E team, to a few having received suggestions or advice contributing to solve technical issues as a result of these interactions. PM&PI9 was the only group to report a real lack of technical understanding in the ARPA-E team as a hurdle for their project, and consequentially gave an impression of the review process more as being straight monitoring rather than collaboration. Overall, we still argue to have found support for the notion that **the insights the ARPA-E team have in the needs of the project increase their ability to provide proper technical support on the basis of their own expertise, on the condition of having the requisite technical expertise.**

Our interviewees did however emphasize that that even though the ARPA-E team assigned to the project had a general insight in the technologies of the different projects, they didn't possess the level of expertise necessary to really help them with technical challenges. This does however lead to an interesting facet that we had not anticipated explicitly, which is how the ARPA-E team would help provide relevant technical insight by facilitating network connections to relevant experts external to the agency when their own expertise was insufficient, as suggested by the analysis in section 7.3.4 and 7.4. We therefore elaborate on the previous finding, and conclude that **the insights the ARPA-E team have in the needs of the project increase their ability to provide proper technical support on the basis of their own expertise or by introducing the project to relevant experts.**

With regards to the networking role of the ARPA-E team in the review setting, these efforts are primarily covered by the analysis of the networking role, section 7.3.

7.5.1.2 Risk of undue influence

Tied into the above aspects of the high-involvement management style and the role of the Program Director (section 7.4), was the anticipated risk of the project underperforming because of too much intervention, micromanagement and/or lack of flexibility from the Program Director in particular. This topic was touched upon by five of our interviewees. PM5 and PM11 explicitly said that the ARPA-E team was limited in how they could give advice or suggestions in order to avoid issues of exercising undue influence on the projects. PM6 and PM2 spoke of this happening in a circumstantial fashion. Perhaps most interestingly, PM&PI9 gave the impression that undue influence had in fact been an issue in their project, and was the reason for its underperformance and subsequent suspension. We therefore conclude that **undue influence through specific instructions and micromanagement from the ARPA-E team may lead to underperformance or failure of the project.**

7.5.1.3 Monitoring regime: Milestone negotiations and flexibility

We suggested that various aspects of the milestones would be of high importance for the projects. We highlighted the importance of finding the right balance between aggressiveness and feasibility in the initial determination and negotiation of the milestones and having a sufficient amount of flexibility to change the milestones underway if e.g. technological discoveries leave existing milestones redundant or in conflict with the overarching goals of the project.

Negotiations: ARPA-E push for aggressive, yet feasible milestones

With regards to the negotiations, we proposed that the awardees would have to be careful to balance feasibility against setting tough milestones. Negotiating the milestones was indeed the primary process for agreeing to the technical goals, but the impression we were left with by our interviewees was somewhat different than the one-direction push for aggressiveness we expected from ARPA-E. The overall opinion among our interviewees was that **ARPA-E seeks to push for quantitative and aggressive milestones in order to aim for large leaps**, as expected in 4.2.1.1, but also that **ARPA-E seeks to make the milestones feasible to deliver**. Only one interviewee, PM13, had experienced that the milestones in his project was set too aggressively, and had to be formally renegotiated later. We believe that the reason for this variation may have been that PM13's Program Director had exercised his role somewhat more strictly than the Program Directors for the other projects.

Milestones: Flexibility to change the plan, not the goals

We also suggested that exercising flexibility to change milestones during the course of the projects would be an important managerial factor, and that the performance of the project with regards to the end-goal could be troubled by being bound to a development plan with milestones of little relevance. For our

interviewees, a large majority appreciatively expressed that ARPA-E had been flexible in changing milestones in terms of deadlines, altering their order or removing them, given better alternatives for reaching the overarching goals of the project. Some even reported that the milestones had been useful as a tool for managing their projects, and others reported that the ARPA-E team had proactively urged them to reevaluate milestones as part of the review process. PM4 and PM&PI9 were the only interviewees reporting concern over too rigid milestones, although PM4 didn't express any major adverse effects on her project from having less flexibility than she wanted. For PM&PI9, the exploration of the full benefit of the technology potential in their project had been constrained by the limited flexibility.

Also, potential funding cut-off for failing to meet agreed 'go, no-go'-milestones was generally accepted as a reasonable accountability factor, where ARPA-E remained firm. PM13 even connected this point to ARPA-E's good reputation in the Congress, as the 'go, no-go' milestones allow it to cut funding for underperforming projects. We therefore conclude that **ARPA-E exercises reasonable flexibility with regards to changing milestones in order to reach end-goals, but will terminate non-performing projects.** In broader terms, we argue that our assertion from section 4.2.2.1 has been supported, and that **reasonable flexibility should be exercised to allow deviations from the initial milestones in order to allow the project to prosper and reach its full potential.**

Technology-specific time constraints

We reasoned in section 4.2.2.1 that the inherent constraints on time and resources to overcome unexpected challenges or pursue interesting technological paths could impair the potential of reaching the end goals of ARPA-E's projects. PM5, PM&PI9 and PM13 highlighted this in a technology-specific context. These three projects had time-intensity in common, with each iteration of development and testing taking far longer than many of the other projects due to the technology-specific constraints. PM5 and PM&PI9 therefore suggested that the model driven by quarterly reviews perhaps wasn't the best fit for technologies requiring long testing cycles. We therefore imply that projects with ***time-intensive iteration cycles might require a monitoring frequency adapted to the inherent timing constraints of the technology.***

PM5, PM&PI9 also emphasized that if anything goes wrong in these cycles, it is challenging to catch up within the duration of the project. PM13 explained that the time restriction prevented him from pursuing discoveries that could have improved the project, and suggested that this concern could be alleviated by allowing non-cost extensions. We investigated some of the special terms and conditions attached to ARPA-E's cooperative agreement (ARPA-E, 2013c),

where Clause 13 states that a one-time, no-cost extension is allowed at the DOE Contracting Officer's discretion, but does not alter the schedule of the technical milestones and deliverables. We were unable to retrieve earlier versions of this document, and can therefore not conclude whether this clause also applies for projects predating this document. Regardless, we do not have the impression that this clause is commonly exercised. We therefore conclude that **the fixed duration of ARPA-E's projects can constrain the ability to maximize the innovation potential in time-intensive energy technology.** We also agree with PM13, that there should be an opportunity to push the funding forward into a non-cost extension year if cycles take longer than expected, and that the R&D spending in the project therefore moves slower as well.

Reporting overhead

Lastly, we intuitively suggested that the frequent monitoring might be considered cumbersome and intrusive for some groups, especially academic researchers, and that the administrative overhead associated with reporting could be a significant burden for smaller organizations lacking financial reporting infrastructure or dedicated staff, such as start-ups or small firms.

The first point was directly brought up by PM12, leading an academic team, and anecdotally mentioned by PM1 and PM&PI9 with reference to academic teams in their respective programs, suggesting that **ARPA-E's frequent monitoring and reporting schedule is considered cumbersome and intrusive by some project teams with academic backgrounds.**

In terms of the reporting overhead, it was mostly focused on the substantial administrative work required by reporting, which could otherwise be used for development work. PM11 even characterized this as the primary hurdle of working with ARPA-E. This concern was also raised by PM8, who like PM11 run a small start-up. Most of the larger organizations (universities, national labs and more established companies) having dedicated accounting departments and financial reporting systems did not share this concern, although some found the administrative overhead somewhat annoying. We therefore argue that our assumption from 4.2.2.1 has been supported, and conclude: **The administrative overhead associated with reporting is a challenge for smaller organizations without dedicated resources for reporting,** such as start-ups.

7.5.2 Commercialization focus

In section 4.2.2.2, we highlighted how ARPA-E incorporates commercialization focus in its project, and proposed how these aspects would influence the projects. Almost all of our interviewees shared their thoughts on this matter with us, as seen in section 6.5.2.

7.5.2.1 Effect of Technology-to-Market support for market alignment

We argued that the Technology-to-Market efforts would positively impact the projects' ability to adapt their innovations to the needs of the market, especially through connecting with and understanding industry stakeholders and potential customers. Overall, our interviewees appreciated the early commercialization focus and the Technology-to-Market support provided by ARPA-E, although PM13 and PM10 found it partly lacking in their projects in terms of dedicated staff. They did not indicate any need for that to be resolved, however. In terms of the networking aspect, we refer to the analysis in section 7.3, which indicated that the projects have benefitted in terms of increased connections with industry, experts and prospective customers. Some interviewees reiterated these aspects in the context of Technology-to-Market support as well, indicating that some market alignment is happening as a result of ARPA-E's support, providing circumstantial support for our proposal. Overall, we therefore believe that **the early focus on commercialization combined with ARPA-E's Technology-to-Market efforts forces the project team to consider commercialization throughout the project and align to stakeholders,** while noting that we do not have explicit support for the notion that the Technology-to-Market support enabled alignment of the technology development itself. We therefore conclude that **we cannot say whether the Technology-to-Market activities enable the project to adapt its technology development to the needs of the market.**

7.5.2.2 Variable need for Technology-to-Market support

Complementing this finding was our anticipation that the need for Technology-to-Market support could vary with the stage of technical maturity in the project. Our interviewees did not give this topic much attention, but PM11 thought it was slightly premature to schedule much Technology-to-Market work early in his project due to its technological state. While this notion may have some merit, we question it as an indication of variable need for Technology-to-Market support according to the technological maturity, since PM11 also voiced appreciation for the Technology-to-Market support he had received. We therefore **cannot say that the overall need for Technology-to-Market support is dependent on the technical maturity of the project.** However, we do still believe that it is highly likely that the *content* of this support is specific to the needs in each project.

We also expected that the need for a Technology-to-Market support function might vary depending on the project team in charge of the project. Judging by the opinions of our interviewees, there seems to be a variable need for a dedicated Technology-to-Market support among the projects in this context. The interviewees highlighted that private companies probably had less need for Technology-to-Market support due to inherently being market focused, also indicating that larger firms would need the support even less than smaller companies and start-ups. They also *anecdotally* pointed out that awardees

connected to research centers, universities or laboratories have a greater need for this support, and consequentially higher potential effects of this support on their projects. Despite being mostly supported by anecdotal evidence, we still believe that **the commercialization support is especially useful for project teams without much commercial experience, such as university researchers or first-time entrepreneurs.**

7.6 Contributions to theory: Analytical conclusions in connection to the research question

The preceding sections in this chapter led to a set of findings on the effects various design characteristics of ARPA-E have on the projects. Figure 6 below is an updated version of Figure 2, illustrating the factors in our framework after accounting for the empirical findings from our interviews. Drawing on these conclusions, we answer our research question by analytically implicating how different design characteristics of such a government research agency can affect the innovation process of the individual projects it supports.

*The most crucial aspect of a research program aiming at promoting innovation of new energy technologies is to provide funding for technologies that **do not have other funding options** due to the funding gap arising from market failures*. Without such provision of funds, the project will therefore not exist, and the technology will not be developed. The program design and project selection process is hence important to ensure that the right projects get funded. In this regard it is also important that the committed award is large enough to explore the full potential of the technological idea.

Another aspect of the program design and project selection process that might prove important for the selected projects is the impact it can have on their credibility and visibility. Given that the screening process of the program is commonly perceived as competitive and diligent, the projects that get selected will be associated with a positive connotation, a ‘stamp of approval’, contributing to reduced perceived risk for potential investors and strategic partners. This can positively impact the project’s ability to raise funding and resources.

By being granted an award that is regarded as prestigious, the project can leverage this credibility in its interactions with external parties. External networking can also be facilitated by the agency itself, for example by hosting networking events in order to increase the visibility of the funded projects, attracting incoming attention. It can also facilitate networking through direct introductions to e.g. potential strategic partners and customers in order to increase the projects ability to connect with external parties. The agency can

additionally support the technical development process of the projects by connecting them to experts in industry or academia.

A research agency can also facilitate networking between the projects in its portfolio. Given that there is a subset of projects with complementary competencies or similar technical challenges, such networking can provide the opportunity to exploit synergies between the projects and share relevant experiences.

Support for technical challenges and commercialization can increase the project's ability to solve its technical challenges and improve its chance of success in the market, respectively. These measures can be provided directly from the research agency. Such activities, including the networking efforts mentioned above, are facilitated by having a high-involvement approach to project management, as this increases the agency's ability to assess the needs of the individual projects, hence equipping it with an understanding of what support to provide. A hands-on management approach with clear goals can further help motivate and drive the project forward, given sufficient flexibility and freedom for the project team to make their own decisions based on superior technical insight. Allowing changes in the plan given reasonable technical and commercial considerations can enhance the prospects of accomplishing the end goals of the project. If such flexibility is not provided and the project is at risk for being micromanaged, this undue influence exercised by the agency may further lead to the underperformance and potential failure of the project. A hands-on management style also implies frequent monitoring of the projects, something that can be viewed as cumbersome and intrusive for the projects, and prove a substantial overhead problem for smaller organizations without dedicated resources for reporting.

The capabilities of the agency officials interacting with the projects can affect all of the above factors, given that an empowered and embedded model akin to that of ARPA-E is studied. The industrial and entrepreneurial experience and pre-existing network of the Program Director and his team directly affect the effectiveness of networking facilitation and commercialization support. Additionally, the technical expertise of the Program Director and his team is an enabling factor for the management of the technical aspects of the projects. These capabilities may also improve the credibility of the agency's vetting processes both before and during the support period, which in turn contributes to added credibility for the individual project. Given that the agency takes a high-involvement approach, we therefore deduce that the extent to which the projects can receive any worthwhile contributions as a result of this model is dependent on the experience and expertise of the agency officials, whether the agency is

designed akin to ARPA-E with a single empowered Program Director for each focus area or as a dedicated team of agency officials.

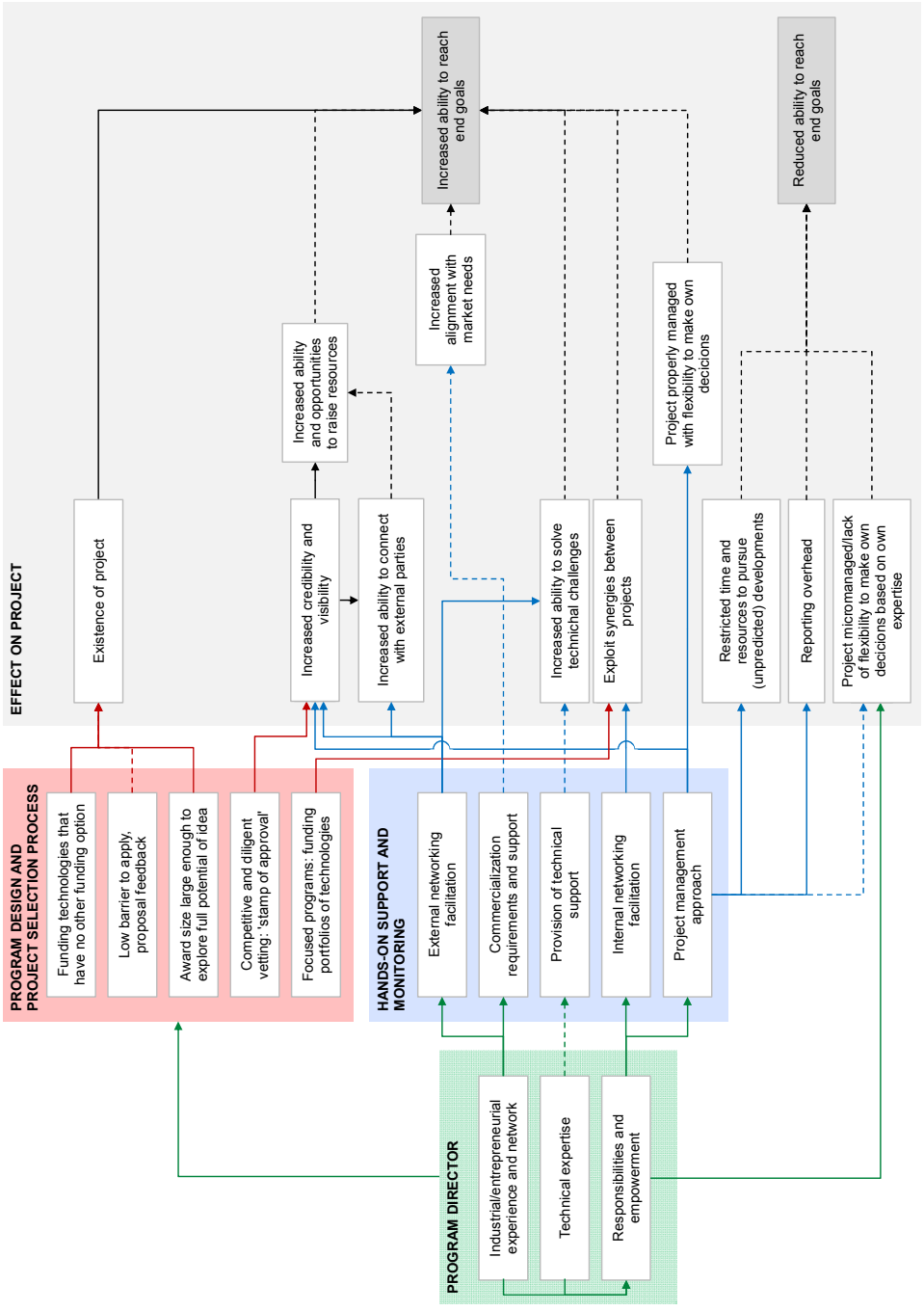


Figure 6 - Analytical relations of the discussion

8 Implications

8.1 Implications for policy

In this chapter, we present the areas policy makers should give particular emphasis when designing support agencies intended to support early-stage, transformative high-risk innovation projects within energy technology[4]. We discern their order of importance in a policy context by relating the overarching themes of the analytical conclusions in Chapter 7 to the mitigation of the failures we presented in Chapter 2.

An important restriction in this regard is that *we are not implying that a research support agency is better than other configurations of policy instruments*, as that discussion is beyond our scope and consequently impossible to answer on the basis of our research. These implications are therefore only considered valid in the context of policymakers *having already decided* to create an agency with this intended purpose. That said, we did not find any indication that an agency is a suitable policy instrument for mitigating challenges of structural rigidities, in which case the policymaker should investigate alternatives to the agency outlined in this section.

8.1.1 Market failure

The primary inhibitor of the discussed kind of innovation projects is arguably the various market failures culminating in a lack of funding for the targeted projects. This permeates our results, as is evident by the relations linked to the existence of the project. Albeit obvious, these aspects are by far the most important contributing factors in mitigating the discussed market failures. Policymakers should therefore devote significant attention to how the agency awards its funding and how it facilitates the hand-off to the private side for later-stage development and commercialization.

8.1.1.1 Awarding funding

Perhaps the most obvious way to mitigate the capital market failure is to *fund worthwhile innovation projects that no other entities will fund due to their risky nature.* Complementing this implication is the importance of the award size. The monetary commitment has to be large enough to allow a complete assessment of the potential inherent in the targeted technology, i.e. enough to succeed or fail on a sufficiently large scale to prove or disprove the concept properly. We argue

[4] Unless explicitly noted otherwise, we refer to this kind of project as “the targeted projects”, “the projects” or similar, whereas the supporting entity is referred to as “the agency” or similar in Chapter 8.

the lowered risk from a technologically proved concept should enable other entities to carry the technology forward to market, and issues on a manufacturing scale should therefore be left to other entities. Failures on a manufacturing-type, capital intensive scale could also harm the prospective support entity, as the losses associated with failed projects should be small enough to be made up for by the positive effects of successes in the eyes of the general public.

Maximizing the chances of identification and selection of the best projects is important in order to perform this role effectively. We therefore imply that an attractive application process is important in this regard and suggest a configuration incorporating the features of pre-proposals and response opportunities, as further detailed in previous chapters.

8.1.1.2 Ensuring follow-on funding for successful commercialization

In addition to funding the initial development of the targeted projects, we argue that securing the hand-off to follow-on funding is crucial for successful commercialization, given that *the agency's role is not to replace private industry*. To avoid confusion, we clarify that we also include continued internal funding in our discussions on follow-on funding for the project, for organizations who possess the requisite resources to carry the project forward themselves. We have found two primary precursors for enhancing the project's own abilities to identify and act on opportunities to raise resources; its credibility and visibility, and its ability to connect with external parties.

The design of the agency should actively contribute to building its credibility by incorporating a sufficiently stringent level of technical diligence and rigor in the screening process to build a solid reputation in relevant industry and investor environments. The agency should leverage this credibility to facilitate networking the projects with appropriate investors, strategic partners or initial customers. It should also act as an advocate of its projects, garnering publicity in order to facilitate the identification of the project for similarly appropriate entities. While further validation is required, we suggest that this should provide additional opportunities to hand the projects over to the private side. These aspects also directly contribute to the mitigation of systemic and weak network failures.

The competitiveness of the screening process can provide additional credibility for the selected projects if the agency is successful in attracting a large number of candidates, which we reason is dependent on its reputation. While not a design consideration, we therefore emphasize that policymakers should remain cognizant of maintaining the reputation of the agency itself.

8.1.2 Mitigating systemic and weak network failures

Mitigation of systemic and weak network failures is a secondary purpose the agency can have. The primary way the design of the agency can contribute to fulfilling this purpose is to incorporate efforts increasing the projects' alignment with market needs. While further research is needed to validate our inference, *the agency should provide extensive commercialization support* to achieve this goal, *especially for awardees lacking previous commercialization experience*.

8.1.3 Secondary support and internal alignment to intended goals

In addition to the above mentioned factors, we have identified a multitude of factors moderating the projects' abilities to reach end goals in the analytical conclusions in Chapter 7. These factors should be applicable as guidance for the specific considerations practitioners should have in mind when designing the specifics of the support agency, but are considered secondary to the discussion in this section.

In order to promote the alignment of the agency's intended purpose and the interests of its staff, we build on the fundamental aspects of a principal-agency theory problem (Braun & Guston, 2003), where the principal is the policy maker, and the agent is the person or team in charge of the agency. In order to maximize the effect of incentives to perform as intended, we suggest that the policy maker opts for a model where one person is in charge and responsible for each funding effort. This person is hereafter referred to as the Director. We therefore recommend *an accountability model where the Director is directly responsible for the supported projects and held accountable for their subsequent performance*, i.e. their ability to reach the overarching end goals: later stage hand-off to private market forces and ultimately commercialization. In order to ensure symmetry and fairness in this model, the Director should also be directly responsible for the final funding decision.

We argue that this alignment is likely to incentivize and embed the Director into promoting and ensuring the quality of any non-financial support provided by the agency, in order to ensure the success of 'his' projects. Combined with having the executive power in the funding decision, this implies a need for prerequisite capabilities within both relevant technology and commercial efforts, as highlighted in Chapter 7.

This combination of technical and commercial excellence suggests that the design of the agency should incorporate an employment model targeting leading professionals from relevant industry and academia in order to build teams with comprehensive understanding of both the commercial and technological aspects of developing new innovations.

In order to align incentives in the projects with the goals of the agency, and in turn the intentions of the policy maker, a cost share model should be considered to hold the project teams accountable. However, we emphasize that it important for the policy maker to carefully determine the required cost share in order to minimize additional issues of market failure in providing the required cost share. In-kind cost sharing seems like a reasonable way to ease this burden on the projects, while achieving the intended accountability.

8.1.4 Summary

In this section, we have presented the most important themes policy makers should consider when having chosen to establish an agency to mitigate market failures and systemic and weak network failures. We have also recommended incorporating accountability into the internal organization of the agency on the basis of our analytical results on positive effects such an agency can provide throughout the life of the project, from its initial identification through to its hand-off to private forces.

While we have presented design considerations particular for the energy sector, we remark that these implications might also apply to agencies aiming to support high-risk, long-leap innovation within other industries characterized by similar fundamental conditions, i.e. other complex, established, legacy sectors.

8.2 Implications for theory and future research

The contributions of this thesis are twofold. We have introduced and developed an integrative framework of interlinked factors consisting of the design characteristics of a research agency on one side, and their effects on the projects it supports on the other. The design characteristics affecting the innovation process of the projects were found to be related to the program design and project selection process, as well as the approach taken by the agency to manage and support the projects. Adding on to this system, we have included aspects of the design of the agency moderating its ability to deliver the mentioned effects. These aspects were found to stem from the organizational structure of the agency and the personal qualifications of the managing officials in the agency.

As a foundation for this research we have also developed a cohesive portfolio of rationales for government intervention in energy sector innovation, and related this to the roles a research agency can take on to mitigate the identified challenges to innovation in this space. We believe this framework can be a useful tool for future researchers embarking on investigating other research agencies.

Resulting from our implications are several avenues for future research. Since our contribution is a qualitative study of only one agency, the results proposed above should be further explored using quantitative methods in order to seek validity for our conclusions. To achieve that objective, this study could also be replicated using other agencies as a subject. Such studies will also have the potential to identify design characteristics not incorporated by ARPA-E, and subsequently determine their effects.

Furthermore, future research should investigate and quantify the impact of efforts made by ARPA-E to increase the technologies' chance of commercial success, such as Technology-to-Market support and network facilitation to potential customers and other stakeholders in industry, in order to uncover whether and to what extent these measures actually translate into increased alignment with the market. Similar investigative attention should be given to the relation between the projects' ability to raise follow-on funding and networking activities towards potential strategic partners and investors.

The potential benefit of having targeted programs with related projects is another area of exploration. We did not find conclusive results on whether targeted FOAs promoting self-supportive technology systems could translate into increased chance of adoption in the market, and suggest this as a potentially interesting area for further research. Furthermore, the effects of internal networking activities should be given additional attention in order to determine the actual value of this aspect, and to ascertain how considerations of proprietary knowledge affect the level of knowledge transfer between projects.

Another avenue for exploration is the impact the Program Director has on the funding and legitimating role of the agency. In particular it would be interesting to examine the requirements to technical expertise and commercial experience, as policymakers seeking to utilize a similar management model as ARPA-E will need to find suitable candidates for this position.

A more overarching question that could be interesting to investigate is the trade-off between the benefits of having a hands-on approach to project management and the resources this model requires in both in the agency and the supported projects. While ARPA-E's high involvement in the project have been claimed to benefit the projects more than constrain them, it is unclear whether this actually is a favorable balance. Other agencies with different organizational models should therefore be investigated in order to permit comparisons.

9 Limitations

In this chapter we present the key limitations to our study, divided into issues in the theoretical foundation and various underlying aspects of the sample and methodological validity.

9.1 Theoretical and empirical foundation

The framework developed in Chapter 2 might not be exhaustive. Additional rationales might exist for government intervention in the energy sector and the potential roles a research agency can take on to mitigate the challenges to innovation that we have not considered. In our empirical foundation, we may have made assumptions or accepted previously published material that might not be accurate and comprehensive. This could have impacted the area of inquiry brought on to our interviewees, potentially resulting in an incomplete picture of the effects of the processes between ARPA-E and its projects.

9.2 Sample

The primary source of data was semi-structured, open-ended interviews with Project Managers and Principal Investigators from 13 different projects in California. The majority of these projects are located in the vicinity of the San Francisco Bay Area, which is one of the most vibrant entrepreneurial environments in the United States, having the largest concentration of national labs, research laboratories and research universities, as well as the highest density of VC firms in the country (Institute). Being embedded in this environment might affect the reported effects of having ARPA-E support, as the environment itself might have contributed substantially to the positive effect of non-financial aspects of the ARPA-E support. In this context, we emphasize potentially enhanced outcomes of networking in particular, and stronger perceived effects of legitimizing aspects of the award. The interviewees may therefore have reported a more positive impression of ARPA-E efforts than what is experienced throughout the rest of the country. Conversely, the high ‘commercial awareness’ ingrained in the entrepreneurial culture in the Bay Area may also have reduced the perceived need and benefits of having commercialization support.

Due to the relatively young age of ARPA-E, there simply is little track record to analyze some of the situations mentioned in Chapter 7. Our interviewee sample contains only one awardee that has gone through a full cycle of support. This single instance is arguably a limiting factor in providing support for qualitative

longitudinal analysis of the support throughout the lifetime of the project. This weakness is further exaggerated as ARPA-E itself changes with time.

In Chapter 7, we highlighted that we had only interviewed projects that had received the award. This positive bias is a limitation in assessing the negative aspects of ARPA-E's application process, as none of our interviewees decided *not to* apply after being encouraged to do so. Additionally, we cannot be absolutely sure that most the projects we interviewed would be unable to eventually raise funding on their own without ARPA-E.

We intended to interview strategically important representatives from ARPA-E, but we were unfortunately not able to conduct interviews on record with neither any of ARPA-E's Program Directors nor any other ARPA-E representatives. This might be an issue for corroborating our interviewees' opinions, and is inherently limiting our results to only one side of the relationship between ARPA-E and its supported projects. This input could further strengthen our triangulation as mentioned by Yin (2014), since it appears that the Program Director is a central factor in ARPA-E.

Another limitation to this study is that we try to find the factors that influence the projects' ability to commercialize their technology and products a relatively long time before the intended execution of these events. It would also be challenging, if not impossible for the project teams to track, delineate and evaluate all their interactions, and in retrospect judge whether these relations had produced an advantage that would not exist otherwise.

9.3 Limitations for validity

An important limitation to our implications for policy is that we cannot be sure that ARPA-E's high-involvement, high-responsibility model is better than other choices to organize this support. Other government policy instruments could likely replicate or improve on some aspects of ARPA-E. Additional research will have to assess ARPA-E's performance compared to other support entities with similar purpose, as this is outside of the scope of this thesis.

Being an explanatory study, internal validity issues are of particular concern for our thesis (Yin, 2014). As a result of our research, we have suggested a casually interlinked, complex system of factors. Unintended gaps in our theoretical and empirical foundation and/or omitted subjects in our discussions with our interviewees may have led to the neglecting of important factors capable of impairing the internal validity of our results. For instance, if the risk sharing concept of having private investments matched 4:1 by the government accounts for most of ARPA-E's impact, one could envision a policy instrument doing only

this, while leaving the organization and configuration of other support mechanisms (e.g. commercialization support, networking facilitation) to the free market.

As this study only takes into account the characteristics held by ARPA-E we also recognize that our list of design characteristics of a research agency may not be exhaustive, and there might hence exist additional characteristics potentially impacting the innovation process of the projects supported by a research agency.

10 Conclusion

A research agency can impact the innovation process of the projects within *early-stage, transformative high-risk energy technology* through characteristics related to its program design, project selection process and the support provided by an active management model. The organizational structure of the agency and the qualities held by its managing officials are seen as important factors affecting the resulting effects from its characteristics.

These findings are especially relevant for policy makers intending to secure successful innovation and commercial implementation of new transformative energy technologies. We have identified the most important aspects that policy makers should give significant attention when creating an agency intended to mitigate challenges to innovation in the energy. The most important of these are *how the agency awards its funding* and *how it facilitates the hand-off to private market forces for later-stage development and commercialization*.

As a secondary purpose of the agency, policy makers should consider moderating challenges of systemic and weak network failure by incorporating efforts increasing the projects' alignment with market needs. We also recommend incorporating accountability into the internal organization of the agency to ensure alignment of the agency's staff to its intended goals.

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12 Appendix

12.1 Technology Readiness Levels (TRL)

As used by ARPA-E (2011, p. 10) in their Annual Report:

TRL 1	Basic principles observed and reported
TRL 2	Technology concept and/or application formulated
TRL 3	Analytical and experimental critical function and/or characteristic proof of concept
TRL 4	Component and/or breadboard validation in laboratory environment
TRL 5	Component and/or breadboard validation in relevant environment
TRL 6	System/ subsystem model or prototype demonstration in relevant environment
TRL 7	System prototype demonstration in an operational environment
TRL 8	Actual system completed and qualified through test and demonstration
TRL 9	Actual system proven through successful mission operations

12.2 E-mail and request letter

12.2.1 E-mail requesting interview

"Dear [interviewee name],

We are three Norwegian MSc students from the Norwegian University of Science and Technology who are currently undertaking our master's thesis, in which we are researching how the commercialization process of innovations within new energy technology can be successfully supported by government initiatives. ARPA-E has emerged as perhaps the most interesting candidate for further research in this space.

As a result of our research, we hope to be able to understand the importance and effects of the different supportive and collaborative efforts undertaken in the projects supported by ARPA-E. We further seek to present practical implications for innovators based on our findings. We are therefore planning a firm-level case study on the subject, in which the entities supported by ARPA-E are of particular interest.

We looked up your contact details on the ARPA-E website, and are wondering if you would be willing to be interviewed as part of this research. The interview should take no longer than 45-60 minutes, and we are hoping to schedule an interview between mid-March to mid-April at a time and place of your convenience. We are based in San Diego during this period, and are flexible with regards to the location of the interview.

Our work is supported by The Research Council of Norway, please see the attached research letter from Special Advisor Birgit Hernes for more details.

Before you agree to the interview we can confirm that:

- The interview will be held in English.
- With your permission will the interview be recorded.
- A transcript of the interview will be sent to you for review and revision.
- If preferred, your anonymity will be maintained at all times and no comments will be ascribed to you by name in any written document or verbal presentation. Nor will any data be used from the interview that might identify you or your company to a third party.
- You will be free to withdraw from the research at any time and/or request that your transcript not be used.
- A copy of the interview questions will be sent to you before the interview.
- We will write to you on completion of the research and a copy of our final research report will be made available to you upon request. The project scheduled for completion in mid-June 2014.

We sincerely hope that you will be able to help us with our research and thank you for taking the time to consider our request. If you have any queries concerning the nature of the research or are unclear about the extent of your involvement in it please contact us at torstber@stud.ntnu.no.

We look forward to your reply.

Kind regards,

Nora Fredheim Johnsen, Iver Roen Velo and Torstein Berteig

[Attachment: Request letter from the Research Council of Norway]”

12.2.2 Request letter from the Research Council of Norway

The Research Council of Norway

Contact person/tel.
Birgit Hernes, 0047 22037351

Our ref.

Your ref.

Oslo.
2014/02/04

To whom it may concern,

The Research Council of Norway is currently reviewing its support regime for disruptive innovation within renewable energy, energy efficiency and other new energy technologies. With the intent of implementing 'best practice' in its new 10-year research support program, ENERGIX, the Research Council considers efforts undertaken by institutions with similar purpose in other nations.

The US agency ARPA-E has, through a preliminary review, emerged as the most interesting foreign institution to research in depth, in order to understand how it works with supported entities in the early stages of innovation. As a follow-up to the preliminary study The Research Council has agreed to support three M.Sc. students from the Institute of Industrial Economics and Technology Management at the Norwegian University of Science and Technology (NTNU) to investigate the processes and collaborative methods used by ARPA-E and its supported entities to bring early concepts/ideas through development towards commercialization. The project is undertaken in association with their master's thesis, scheduled for completion in mid- June 2014.

On behalf of The Research Council of Norway, we would be grateful if you could assist our students with relevant interviews and available data material that may be required for their study. Do not hesitate to contact us if you have any questions.

Yours sincerely,

Birgit Hernes

Birgit Hernes
Special Advisor, the ENERGIX programme
Division for Energy, Resources and the Environment
The Research Council of Norway
Tlf. 0047 22037351/ 0047 99470907

Norges forskningsråd/
The Research Council of Norway
Stensberggt. 26
Postboks 2700 St. Hanshaugen
NO-0131 Oslo

Telefon +47 22 03 70 00
Telefaks +47 22 03 70 01
post@forskningsradet.no
www.forskningsradet.no
Org.nr. 970141669

12.3 Interview topics

TOPICS (MAIN TOPIC IN **BOLD**)
How is ARPA-E supporting your project? Has this support changed throughout the duration of the project?
How is your project monitored/managed by ARPA-E? How do you perceive this/these process(es)?
How did you perceive the process of setting milestones and deliverables in the proposal? How flexible has ARPA-E been following the initial planning?
How would you describe your relationship with the ARPA-E team assigned to you? Has this relationship changed throughout the project? How important do you feel it is that the ARPA-E team has a certain level of knowledge and experience in your area of technology and in how to bring that technology to market?
What is your assessment of the market potential for your technology? Have you made any plans or taken any action with regards to bringing your technology to market? Do you receive any support from ARPA-E in this regard?
How does ARPA-E assist you in terms of networking/connecting with other parties? What advantages/disadvantages have you experienced from participating in these activities?
How has being awarded ARPA-E support influenced your project's recognition in terms of interest from potential partners, prospective customers and/or private investors?
What attracted you to apply for ARPA-E support? How did you perceive the process of applying for ARPA-E support?
Do you have any influence over what kind of support ARPA-E provides as the project progresses? Are you asked to evaluate the support provided to you by ARPA-E on an ongoing basis?
Overall, what do you see as the most important advantages/disadvantages of being a recipient of ARPA-E support? Do you have any suggestions for improvement or for new support functions?

12.4 Description of ARPA-E programs

As described on the APRA-E website (ARPA-E, 2014d):

ADEPT

Agile Delivery of Electrical Power Technology

Program Description:
In today's increasingly electrified world, power conversion--the process of converting electricity between different currents, voltage levels, and frequencies--forms a vital link between the electronic devices we use every day and the sources of power required to run them. The projects that make up ARPA-E's ADEPT program, short for "Agile Delivery of Electrical Power Technology," are paving the way for more energy efficient power conversion and advancing the basic building blocks of power conversion: circuits, transistors, inductors, transformers, and capacitors.

AMPED

Advanced Management and Protection of Energy Storage Devices

Program Description:
The projects that comprise ARPA-E's AMPED Program, short for "Advanced Management and Protection of Energy Storage Devices," seek to develop advanced sensing, control, and power management technologies that redefine the way we think about battery management. Energy storage can significantly improve U.S. energy independence, efficiency, and security by enabling a new generation of electric vehicles. While rapid progress is being made in new battery materials and storage technologies, few innovations have emerged in the management of advanced battery systems. AMPED aims to unlock enormous untapped potential in the performance, safety, and lifetime of today's commercial battery systems exclusively through system-level innovations, and is thus distinct from existing efforts to enhance underlying battery materials and architectures.

BEEST

Batteries for Electrical Energy Storage in Transportation

Program Description:
The U.S. spends nearly a $1 billion per day to import petroleum, but we need dramatically better batteries for electric and plug-in hybrid vehicles (EV/PHEV) to truly compete with gasoline-powered cars. The projects in ARPA-E's BEEST program, short for "Batteries for Electrical Energy Storage in Transportation," could make that happen by developing a variety of rechargeable battery technologies that would enable EV/PHEVs to meet or beat the price and

performance of gasoline-powered cars, and enable mass production of electric vehicles that people will be excited to drive.

BEETIT
Building Energy Efficiency Through Innovative Thermodevices

Program Description:
The projects that comprise ARPA-E's BEETIT program, short for "Building Energy Efficiency Through Innovative Thermodevices," are developing new approaches and technologies for building cooling equipment and air conditioners. These projects aim to drastically improve building energy efficiency and reduce greenhouse gas emissions such as carbon dioxide (CO_2) at a cost comparable to current technologies.

ELECTROFUELS
Microorganisms for Liquid Transportation Fuel

Program Description:
ARPA-E's Electrofuels program is using microorganisms to create liquid transportation fuels in a new and different way that could be up to 10 times more energy efficient than current biofuel production methods. ARPA-E is the only U.S. government agency currently funding research on electrofuels.

FOCUS
Full-Spectrum Optimized Conversion and Utilization of Sunlight

Program Description:
High utilization of renewable energy is a vital component of our energy portfolio. Solar energy systems can provide secure energy with predictable future costs—largely unaffected by geopolitics and climate—because sunshine is widely available and free. The 12 projects that comprise ARPA-E’s FOCUS program, short for “Full-Spectrum Optimized Conversion and Utilization of Sunlight,” could pave the way for cost-competitive hybrid solar energy systems that combine the advantages of existing photovoltaic (PV) and concentrated solar power (CSP) technologies.

GENI
Green Electricity Network Integration

Program Description:
The 15 projects in ARPA-E's GENI program, short for "Green Electricity Network Integration," aim to modernize the way electricity is transmitted in the U.S. through advances in hardware and software for the electric grid. These advances will improve the efficiency and reliability of electricity transmission,

increase the amount of renewable energy the grid can utilize, and provide energy suppliers and consumers with greater control over their power flows in order to better manage peak power demand and cost.

GRIDS
Grid-Scale Rampable Intermittent Dispatchable Storage

Program Description:
The projects that comprise ARPA-E's GRIDS program, short for "Grid-Scale Rampable Intermittent Dispatchable Storage," are developing storage technologies that can store renewable energy for use at any location on the grid at an investment cost less than $100 per kilowatt hour. Flexible, large-scale storage would create a stronger and more robust electric grid by enabling renewables to contribute to reliable power generation.

HEATS
High Energy Advanced Thermal Storage

Program Description:
The projects that make up ARPA-E's HEATS program, short for "High Energy Advanced Thermal Storage," seek to develop revolutionary, cost-effective ways to store thermal energy. HEATS focuses on 3 specific areas: 1) developing high-temperature solar thermal energy storage capable of cost-effectively delivering electricity around the clock and thermal energy storage for nuclear power plants capable of cost-effectively meeting peak demand, 2) creating synthetic fuel efficiently from sunlight by converting sunlight into heat, and 3) using thermal energy storage to improve the driving range of electric vehicles (EVs) and also enable thermal management of internal combustion engine vehicles.

IMPACCT
Innovative Materials and Processes for Advanced Carbon Capture Technologies

Program Description:
IMPACCT's projects seek to develop technologies for existing coal-fired power plants that will lower the cost of carbon capture. Short for "Innovative Materials and Processes for Advanced Carbon Capture Technologies," the IMPACCT program is geared toward minimizing the cost of removing carbon dioxide (CO_2) from coal-fired power plant exhaust by developing materials and processes that have never before been considered for this application. Retrofitting coal-fired power plants to capture the CO_2 they produce would enable greenhouse gas reductions without forcing these plants to close, shifting away from the inexpensive and abundant U.S. coal supply.

METALS

Modern Electro/Thermochemical Advances in Light Metals Systems

Program Description:
The projects that comprise ARPA-E's METALS program, short for "Modern Electro/Thermochemical Advances in Light Metal Systems," aim to find cost-effective and energy-efficient manufacturing techniques to process and recycle metals for lightweight vehicles and aircraft. Processing light metals such as aluminum, titanium, and magnesium more efficiently would enable competition with incumbent structural metals like steel to manufacture vehicles and aircraft that meet demanding fuel efficiency standards without compromising performance or safety.

MOVE
Methane Opportunities for Vehicular Energy

Program Description:
The projects that comprise ARPA-E's MOVE Program, short for "Methane Opportunities for Vehicular Energy," are finding cost-effective ways to power passenger cars and other light-duty vehicles with America's abundant natural gas resources. Natural gas is currently less expensive than gasoline, and produces fewer harmful emissions than any other fossil fuel. Despite these advantages, significant technological and infrastructure barriers currently limit the use of natural gas as a major fuel source in the U.S. ARPA-E's MOVE projects are finding innovative ways to break through these barriers, creating practical and affordable natural gas storage tanks for passenger cars and quick-filling at-home refueling stations.

OPEN 2009
Open Funding Solicitation

Program Description:
In 2009, ARPA-E issued an open call for the most revolutionary energy technologies to form the agency's inaugural program. The first open solicitation was open to ideas from all energy areas and focused on funding projects already equipped with strong research and development plans for their potentially high-impact technologies. The projects chosen received a level of financial support that could accelerate technical progress and catalyze additional investment from the private sector. After only 2 months, ARPA-E's investment in these projects catalyzed an additional $33 million in investments. In response to ARPA-E's first open solicitation, more than 3,700 concept papers flooded into the new agency, which were thoroughly reviewed by a team of 500 scientists and engineers in just 6 months. In the end, 36 projects were selected as ARPA-E's first award recipients, receiving $176 million in federal funding.

OPEN 2012
Open Funding Solicitation

Program Description:
In 2012, ARPA-E issued its second open funding opportunity designed to catalyze transformational breakthroughs across the entire spectrum of energy technologies. ARPA-E received more than 4,000 concept papers for OPEN 2012, which hundreds of scientists and engineers thoroughly reviewed over the course of several months. In the end, ARPA-E selected 66 projects for its OPEN 2012 program, awarding them a total of $130 million in federal funding. OPEN 2012 projects cut across 11 technology areas: advanced fuels, advanced vehicle design and materials, building efficiency, carbon capture, grid modernization, renewable power, stationary power generation, water, as well as stationary, thermal, and transportation energy storage.

PETRO
Plants Engineered to Replace Oil

Program Description:
The 10 projects that comprise ARPA-E's PETRO program, short for "Plants Engineered to Replace Oil," aim to develop non-food crops that directly produce transportation fuel. These crops can help supply the transportation sector with plant-derived fuels that are cost-competitive with petroleum and do not affect U.S. food supply. PETRO aims to redirect the processes for energy and carbon dioxide (CO_2) capture in plants toward fuel production. This would create dedicated energy crops that serve as a domestic alternative to petroleum-based fuels and deliver more energy per acre with less processing prior to the pump.

RANGE
Robust Affordable Next Generation Energy Storage Systems

Program Description:
The projects that comprise ARPA-E's RANGE Program, short for "Robust Affordable Next Generation Energy Storage Systems," seek to develop transformational electrochemical energy storage technologies that will accelerate the widespread adoption of electric vehicles by dramatically improving their driving range, cost, and safety. RANGE focuses on four specific areas 1) aqueous batteries constructed using water to improve safety and reduce costs, 2) non-aqueous batteries that incorporate inherent protection mechanisms that ensure no harm to vehicle occupants in the event of a collision or fire, 3) solid-state batteries that use no liquids or pastes in their construction, and 4) multifunctional batteries that contribute to both vehicle structure and energy storage functions.

REACT
Rare Earth Alternatives in Critical Technologies

Program Description:
The projects that comprise ARPA-E's REACT program, short for "Rare Earth Alternatives in Critical Technologies", are developing cost-effective alternatives to rare earths, the naturally occurring minerals with unique magnetic properties that are used in electric vehicle (EV) motors and wind generators. The REACT projects will identify low-cost and abundant replacement materials for rare earths while encouraging existing technologies to use them more efficiently. These alternatives would facilitate the widespread use of EVs and wind power, drastically reducing the amount of greenhouse gases released into the atmosphere.

REMOTE
Reducing Emissions using Methanotrophic Organisms for Transportation Energy

Program Description:
The projects that comprise ARPA-E's REMOTE program, short for "Reducing Emissions using Methanotrophic Organisms for Transportation Energy," seek to enable highly efficient biological conversion of methane to liquid fuels for small-scale deployment. Specifically REMOTE focuses on improving the energy efficiency and carbon yield of biological routes from methane to a useable form for fuel synthesis while also examining high-productivity methane conversion processes and bioreactor technologies.

SBIR/STTR 2012
Small Business Innovation Research/Small Business Technology Transfer

Program Description:
Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs seek to stimulate technological innovation and commercialization among America's small businesses. SBIR/STTR programs are coordinated by the Small Business Administration (SBA) and administered by a number of federal agencies, including the Department of Energy and ARPA-E. Since its enactment in 1982, SBIR has helped thousands of small businesses compete for federal research and development funding and support. SBIR-funded small businesses have enhanced the nation's defense, protected our environment, advanced health care, and improved our ability to manage information and manipulate data. The small-business-led projects comprising ARPA-E's first SBIR/STTR program (SBIR/STTR 2012) are focused on advancing transformational technologies that reduce barriers to mass adoption of electrical energy storage for stationary and transportation applications.

SOLAR ADEPT
Solar Agile Delivery of Electrical Power Technology

Program Description:
The projects that make up ARPA-E's Solar ADEPT program, short for "Solar Agile Delivery of Electrical Power Technology," aim to improve the performance of photovoltaic (PV) solar energy systems, which convert the sun's rays into electricity. Solar ADEPT projects are integrating advanced electrical components into PV systems to make the process of converting solar energy to electricity more efficient.

SWITCHES
Strategies for Wide Bandgap, Inexpensive Transistors for Controlling High-Efficiency Systems

Program Description:
The projects in ARPA-E's SWITCHES program, which is short for "Strategies for Wide-Bandgap, Inexpensive Transistors for Controlling High-Efficiency Systems," are focused on developing next-generation power switching devices that could dramatically improve energy efficiency in a wide range of applications, including new lighting technologies, computer power supplies, industrial motor drives, and automobiles. SWITCHES projects aim to find innovative new wide-bandgap semiconductor materials, device architectures, and device fabrication processes that will enable increased switching frequency, enhanced temperature control, and reduced power losses, at substantially lower cost relative to today's solutions. More specifically, SWITCHES projects are advancing bulk gallium nitride (GaN) power semiconductor devices, the manufacture of silicon carbide (SiC) devices using a foundry model, and the design of synthetic diamond-based transistors. A number of SWITCHES projects are small businesses being funded through ARPA-E's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) program.