8-2015

Developing a Methodology to Characterize the Use of Emerging and Converging Technologies in Federal Agencies

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I am submitting herewith a dissertation written by Dorian Akerman Stiefel entitled "Developing a Methodology to Characterize the Use of Emerging and Converging Technologies in Federal Agencies." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Political Science.

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A Dissertation Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Dorian Akerman Stiefel
August 2015

Dedication

To my husband,

to our daughter, and

toward peace.

Acknowledgements

Dr. Bruce Tonn is the exemplar for dissertation chairs in particular and for human beings in general. In particular, he unerringly finds the balance between his professional guidance and my personal development. In general, I am profoundly grateful for the opportunity to work with someone who is unfailingly engaged, reflective, and brilliant. Bruce is phenomenal, or, as he would write it, "quite excellent."

Dr. John Scheb's kind attention has assured uncountable opportunities, including the opportunity to collaborate with Bruce. He always asks the right questions, which means he always asks the difficult questions. Finding the answers has been incredibly fulfilling.

Dr. David Houston sparked my imagination in our course together, and I remain thankful for every conversation since. Consistent with his commitment to seeing every student thrive, he encourages me to think about the nature of political science, public administration, and analysis techniques while remembering to question everything.

Dr. Stephanie Bohon reminds me in example and in word that anything is possible and that "circumstances" is just another word for "life." Her contributions to our society and her students are inspirational.

Dr. David Schumann taught me to reflect on my notions of exceptional teaching and learning as I implemented them in research and practice. His own notions of exceptional teaching, learning, and grace set the standard for all of us.

I acknowledge everyone who answered questions, coded documents, completed assessments, participated in interviews, crowd-sourced answers, or edited this manuscript. In particular, I am grateful to the government employees at the Department of Commerce and the Department of Energy who participated in interviews and to the government employees in the National Science Foundation and the Executive Office of the President's Office of Science and Technology Policy for their gracious assistance.

Finally, I acknowledge my family, friends, and colleagues. I am especially grateful to Adan Akerman, Jennifer Akerman, Dr. Alfred Akerman, Margo Akerman, Dr. Kirsten Benson, Laura Cosey, Dr. Bob Cunningham, Dr. Ian Down, Dr. Pat Freeland, Dr. Michael Gant, Sue Howerton, Glenda Hurst, Dr. Nate Kelly, Dr. Laura Madden, Dr. Tim Madden, Jill McMaster, Dr. Matt Murray, Dr. Tony Nownes, Dr. Brandon Prins, Dr. Anne Smith, Lore Stiefel, Tom Stiefel, Sonja Stiefel, Diana Tonn, Kelly Walker, Seth Walker, and Emily Wallace for their infinite kindnesses. Ian and Mairen Stiefel already know this is their dissertation, too.

Abstract

Although some methodologies exist for the systematic and strategic consideration of emerging and converging technologies, they typically do not incorporate agency current use, strategies, or foresight. This research develops a methodology to characterize current and potential United States federal agency use of emerging and converging technologies to fulfill agency strategic plans and serve society.

Phase 1 of this research develops a methodology to fulfill criteria derived from a literature review and an assessment of best practices. Designed to be implemented in four phases—develop, apply, evaluate, disseminate—the steps of this methodology include definition, collection, organization, analysis, synthesis, evaluation, and dissemination. Within the analyze step, a mix of qualitative and quantitative analysis approaches are applied to answer the defined questions. Current agency use of emerging and converging technologies is characterized with content analysis of strategic documents; technology assessment analysis by experts; and individual interviews with government employees. Potential agency use of emerging and converging technologies is characterized with individual interviews with government employees; plausibility matrix analysis by experts; and crowd-sourced intelligence. The methodology is applied in Phase 2 to two cases, the Department of Commerce and the Department of Energy, then evaluated in Phase 3 *versus* the design criteria and visual analytics, and disseminated in Phase 4 to researchers, policymakers, and the general public.

Key findings, results, and meta-inferences of this research are that many more potential uses exist for using emerging and converging technologies to fulfill agency strategies and the research identifies some of the potential uses by technology and strategy. These potential uses also are presented in terms of comparable technical feasibility and societal benefit. Implications for policymakers are that governing with foresight is critical; encouraging systematic agency consideration of emerging and converging technologies is necessary; and it is important to implement a government-wide methodology that will characterize current and potential use of emerging and converging technologies for fulfilling agency strategies. This research contributes the criterion for such a methodology as well as the methodology and the results of its application to two agency cases.

Keywords: emerging technology; converging technology; federal agency; agency strategic planning; foresight; public administration; governance

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List of Acronyms

A

ANP	Analytic Network Processes

B

BER	Biological and Environmental Research (DOE)

C

CEDCaP	Census Enterprise Data Collection and Processing
CHiMaD	Center for Hierarchical Materials Design (DOC/NIST)
CIO	Chief Information Officer
CKTS	Convergence of Knowledge, Technology, and Society
CO2	Carbon Dioxide
CRS	Congressional Research Service
CTO	Chief Technology Officer

D

DARPA	Defense Advanced Research Projects Agency (DoD)
DEA	Data Envelopment Analysis
DOC	Department of Commerce
DoD	Department of Defense
DOE	Department of Energy

E

ECT	Emerging and Converging Technologies
EDA	Economic Development Administration (DOC)
EOP	Executive Office of the President
EPO	European Patent Office
ESPAS	European Strategy and Policy Analysis System
ETIPC	Emerging Technologies Interagency Policy Coordination Committee
ETRAC	Emerging Technology and Research Advisory Committee (DOC)

F

FET	Future and Emerging Technologies
FY	Fiscal Year

G

GAO	Government Accountability Office (formerly General Accounting Office)
GBD	Global Burst Detector
GDP	Gross Domestic Product
GPRA	Government Performance and Results Act
GPRMA	Government Performance and Results Modernization Act
GPS	Global Positioning System
GWP	Global Warming Potential
GWU	George Washington University

I

IA	International Affairs
IARPA	Intelligence Advanced Research Projects Activity
IPC	Interagency Policy Coordination
IPC	International Patent Classification
IQSS	Institute for Quantitative Social Science at Harvard
IRB	Institutional Research Board
IT	Information Technology
ITA	International Trade Administration (DOC)

J

JGI	Joint Genome Institute (DOE)

M

MIT	Massachusetts Institute of Technology
MML	Material Measurement Laboratory (NIST)
MySQL™	My Structured Query Language

N

NAS	National Academy of Sciences
NBIC	Nanotechnology, Biotechnology, Information Technology, Cognitive Science
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology (DOC)
NNI	National Nanotechnology Initiative
NOAA	National Oceanic and Atmospheric Administration (DOC)
NOS	National Ocean Service (DOC/NOAA)
NRC	National Research Council
NRI	National Robotics Initiative
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration (DOC)

O

OMB	Office of Management and Budget (EOP)
OSTP	Office of Science and Technology Policy (EOP)

P

PDF	Portable Document Format (file extension for Adobe™ Acrobat files)
PHP	Hypertext Preprocessor (recursive acronym)

Q

QDA	Qualitative Data Analysis

R

R & D	Research and Development
RaDiUS	Research and Develop in the United States
RAND	Research and Development (contraction, name of a nonprofit corporation)
RDD&D	Research, Development, Demonstration, and Deployment

S

S & T	Science and Technology
STAR METRICS℠	Science and Technology for America's Reinvestment – Measuring the Effects of Research on Innovation, Competitiveness and Science
STEM	Science, Technology, Engineering, and Mathematics

T

TBW	File extension for Tableau™ files

U

UK	United Kingdom
US	United States
USPTO	United States Patent and Trademark Office

V

V2V	Vehicle-to-vehicle

X

XLS	File extension for Microsoft™ Excel files

#

3D	Three-dimensional

Chapter 1
Introduction

"*Gouverner, c'est prévoir*," "*to govern is to foresee*," French politician Pierre Mendès (Gouverner c'est prévoir, discourse d'investiture et réponses aux interpellateurs 1953).

"*…invest in the emerging technologies that will create high-quality manufacturing jobs and enhance our global competitiveness*" (Executive Office of the President 2014b).

Gaps exist in the information about United States (US)[1] federal agency use of technology—especially emerging and converging technologies (ECT)—to benefit individual agency strategies[2] and our society. Agencies collect some of this information, of course, and staffers in the White House Office of Science and Technology Policy (OSTP) sometimes collect this information from the agencies when needed for particular studies. As each requirement arises, staffers ask agencies to submit a report detailing science and technology use to accomplish specific objectives such as reducing disasters or enhancing Earth observations.

When I asked the Principal Assistant Director for Science at OSTP (Rubin 2013) if anyone in his office consistently collects data about federal agency use of technology in general and ECT in particular, he informed me that no one does. The other likely organization, the National Science Foundation (NSF), collaborates with other agencies on specific projects such as the National Robotics Initiative (NRI; National Science Foundation 2014b) and the National Nanotechnology Initiative (National Nanotechnology Initiative 2015; Paradise et al. 2008), and NSF does publish survey data about federal funds for research and development and federal science and engineering support to universities, colleges, and nonprofit institutions (National Science Foundation 2014a). However, extensive research and a cognizant NSF program manager (Yamaner 2015) confirm that these data do not include technology-level information and that, to his knowledge, technology-level information is not being collected elsewhere in the organization.

Gathering technology-level information about agency use of technology, especially ECT, is important because ECT can support federal agency strategies by facilitating the work itself or by facilitating the success of the agency's strategies. Longer lives, enhanced physical and intellectual abilities, improved control of our emotions, tailored manufacturing, guided decision making, economic growth, job creation, and public health and welfare are among the many societal benefits offered by ECT. Information about which ECT agencies could be using now or in the future is necessary so that researchers and policymakers can understand which available technologies might serve each agency strategy and thus benefit society. This gap in knowledge can be filled with a methodology that systematically answers two questions: 1) Are ECT being

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[1] Unless otherwise noted, all mentions of "government" and "agencies" reference the US federal government and agencies.

[2] Note that US federal agencies refer to "strategic" documents that detail the agency's strategy in decreasing increments from missions, goals, and objectives to "strategies." I use the terms "strategic" and "strategies" in the same manner for this research.

used to fulfill agency strategic plans?, and 2) Could ECT be used more extensively to fulfill agency strategic plans?

1.1 Overview of the Study

Researchers, policymakers, and members of the public need a multi-agency, publicly-accessible methodology for finding links among ECT and agency strategies. Researchers benefit from such a methodology, which can be developed to support a variety of research agendas; policymakers benefit from the findings and results; and members of the public benefit by knowing more about how ECT are being used and could be used to fulfill agency strategic plans. Using ECT for day-to-day accomplishment of the agencies' work and to facilitate the success of the agencies' strategies has the potential to benefit society in a variety of ways.

In this study, I develop and apply a methodology with multiple phases and analysis approaches to answer the two research questions. The application of the methodology answers the first research question—Are ECT being used to fulfill agency strategic plans (current use)?—using content analysis, technology assessment analysis, and individual interviews and answers the second research question—Could ECT be used more extensively to fulfill agency strategic plans (potential use)?—using individual interviews, plausibility matrix analysis, and crowd-sourced intelligence. These analyses produced tables of information characterizing current and potential agency use of ECT to fulfill agency strategies at the pilot agencies, the Department of Commerce (DOC) and the Department of Energy (DOE).

1.2 Problem Statement

Although federal agencies use ECT, they often are used with insufficient strategy or foresight. These two elements are necessary because strategic and foresight-oriented use of technology could help solve society's problems either to do the work of the agency or to fulfill agency strategies. For example, given the DOE's strategy to support battery-manufacturing capacity, high-speed materials discovery can speed the process of identifying and rejecting effective approaches and outcomes. Additive manufacturing can solve short-term problems with printed objects-on-demand and long-term problems with new, iterative approaches to development and demonstration.

Beyond facilitating the work itself or fulfilling agency strategies, why should agencies know which ECT are being used or could be used? Two trends demand systematic understanding of current and potential ECT: Agency uncertainty about budget amounts and timing and general increases in social problems that could be addressed or mitigated with ECT (Roco et al. 2013; Roco 2011b). Both could be offset with improved strategies for investments in ECT that depend upon improved characterization of current and potential use.

Any approach to strategic planning with foresight must maximize the benefits of agency investments in ECT and could support a coordinated federal investment strategy that would allow agencies to leverage coordination and financial commitments. A coordinated strategy would require an understanding of the current and potential uses of those ECT and any system that could make those characterizations must be easily updatable because the technology and strategy information change constantly. Moreover, for potential uses of ECT, some information about the probability of usefulness (i.e., technical feasibility) and priority for federal investment (i.e., overall benefits to society) is necessary.

Given the benefits of a systematic approach to solving these problems, many calls and mandates have been made for using technologies, including ECT. Despite these, the US does not have a federal methodology for characterizing how agencies are using the latest technologies (i.e., emerging) or combinations of technologies (i.e., converging) to fulfill strategies. At best, agencies conduct annual performance plans, annual program performance reports, and quadrennial strategic plans (Executive Office of the President 2014a) and submit aggregated data through the NSF's "Survey of Federal Funds for Research and Development" (National Science Foundation 2013a).

Private sector methodologies to characterize use of ECT fail to characterize current and potential ECT use for agency strategies. Theoretical proposals of methodologies for identifying potential uses of ECT are insufficient because they incorporate a single analysis approach, involve incomplete data, and, of course, remain theoretical. Applied work on methodologies is lacking because the methodologies only exist for potential use of ECT and rarely incorporate agency strategies. The most often referenced methodologies in this area provide only general foresight on specific outcomes (Twardy et al. 2014; George Mason University 2015; Halal 2013; George Washington University 2015).

My research addresses these gaps by answering two questions:

1) Are ECT being used to fulfill agency strategic plans (current use)?
2) Could ECT be used more extensively to fulfill agency strategic plans (potential use)?

1.3 Research Objective

The objective of this research is to develop and apply a systematic methodology for characterizing ECT based on the technologies' current and potential ability to fulfill agency strategies. I am studying this because enhanced information about agency use of technology allows agency employees to fulfill current agency strategies and inform future agency strategies. Secondarily, this work allows me to generate a framework for ECT assessment. If systematically applied, this could lead to increased scientific, technological, and business process innovation, which may account for up to half of economic growth in the US (US Department of Commerce 2014). Innovation and ECT also may support the types of outcomes encouraged by the President, such as promoting economic growth overall, job creation, public health and welfare (Executive Office of the President 2011) and ongoing international competitiveness (Executive Office of the President 2014b).

Building on the public administration, public policy, and interdisciplinary literatures on government use of ECT; strategic planning and forecasting; and the methodologies that characterize current and potential use, this research acknowledges the planning and forecasting that goes into government strategies and that can inform day-to-day choices; and the methodologies that have been developed to characterize current and potential government use of ECT.

1.4 Contributions of this Study

My research addresses two intellectual challenges. The first intellectual challenge is characterizing technology use from the standpoint of federal agency strategies: Technology can enhance human cognition and embed processors in fabric, but how does that help agencies? How could technical knowledge and innovation affect policy decisions? The second intellectual challenge is making systematic information available to researchers, policymakers, and the general public.

Solving these intellectual challenges yields three broader impacts. First, my research benefits society by systematically linking agency strategies with the technologies that could help to fulfill those strategies. Second, to enhance research and policymaker understanding, I tailored information about my methodology, findings, and results to the appropriate research, policymaker, and general public audiences and disseminated it. These two impacts lead to a third impact: An understanding of ECT that might solve current and future policy issues. Characterizing current and potential use based on technical feasibility and societal benefit is one way of prioritizing federal investments in science and technology (Grupp and Linstone 1999; Lee et al. 2008; Mulgan 2002).

Relative to the first broader impact, this work is theoretically relevant to the political science discipline because developing the methodology is based on political science notions of governance as engagement and theories of methodologies as well as other theoretical methodological development work. Using this methodology, political scientists can make theoretical extensions and connect agency strategies with emerging technologies to identify opportunities for changes in governance. Political science researchers and policymakers must understand ECT current and potential use to understand legislation and regulation of ECT and to leverage ECT for governance and public administration. The theoretical link between ECT and agency strategies is also a theoretical link between public policy, in the form of ECT investments, and public administration, in the form of the strategies and foresight necessary to make those investments. ECT drive changes in information and service delivery for public administrators and policymakers and understanding these requires coordinated research.

Relative to the second broader impact, my work contributes to the research literature and to society. To the public administration and public policy research literatures, I contribute a methodology that can be improved upon by other scholars and used by any agency or organization. To society, I contribute the public access to the methodology and the results via a public web site. I enhance researcher and policymaker understanding with tailored information about my methodology disseminated to the appropriate people.

The third impact is especially important: With an understanding of ECT current and potential use at agencies and with tailored information available to all of the relevant stakeholders, it may be possible to use information about technical feasibility and priority generated by the methodology to prioritize federal investments.

In the second chapter, I consider the research questions in the context of a review of the literatures related to political science and public administration research into ECT use in federal agencies; actual agency use of ECT; agency use of strategic planning and foresight; methodologies for characterizing agency use of ECT; and develop propositions. In the third chapter, I detail the methods that support each phase of the overall methodology and, in particular, detail the collection, organization, analysis, and synthesis that support each of the six analysis approaches in the methodology. In the fourth chapter, I present findings, results, and meta-inferences (Tashakkori and Teddlie 2010) for each phase and overall. In the fifth chapter, I discuss the themes revealed in this study; the key findings; the theoretical relevance; and the applied relevance. I conclude in the sixth and seventh chapters with policymaker recommendations, limitations, and opportunities for future research.

Chapter 2
Literature Review

Based in the political science literatures on governance for societal benefit; public administration and public policy literatures on agency strategic planning and foresight, agency use of ECT, and agency use of strategic planning and foresight for ECT; and the interdisciplinary literatures on methodologies that characterize aspects of the above, my research on federal agency strategic planning and foresight and current and potential use of ECT in the public literatures reveals four broad themes. First, federal agencies have strategies that are not strategic or foresight-oriented. Second, current and potential use of ECT is *ad hoc* and incremental. Third, strategic planning for current and potential use of ECT is also *ad hoc* and incremental. Fourth, theoretical and practical work on methodologies for capturing federal use in terms of research and development on ECT only capture some information, mostly at the project level and only for current use. Theoretical and applied methodologies do not focus on current and potential federal use of specific ECT in relationship to agency strategies.

2.1 Political Science and Public Administration Research on Agency Use of ECT

One view of governance is for societal benefit in which strategic planning, foresight, and use of ECT ensure these societal benefits. This view runs through each of the sections below and is explicit in the Convergence of Knowledge, Technology, and Society (CKTS) (Roco et al. 2013) work sponsored by the NSF. ECT current and potential use must be understood to legislate and regulate ECT, but they also must be understood to leverage ECT for governance and societal benefit.

The theoretical link between ECT and agency strategies is a theoretical link between public policy in the form of ECT investments and public administration in the form of the strategies and foresight necessary to make those investments. Unfortunately, the little research in this area only considers specific topics such as the potential link between technology innovation and inequality (Cozzens and Thakur 2014; Reiss and Millar 2014) or participation-based governance (Johnston 2010; Tonn and Stiefel 2012). For example, preliminary research on participation-based governance finds that access and input to government via information technology does improve the publics' future confidence in the agency (Morgeson et al. 2011), but public concerns about technology require careful attention to how and when information is conveyed (Roelofsen et al. 2010; Satterfield et al. 2013).

Coordinated research is required as ECT drive changes in service and information delivery for public administrators and policymakers. ECT also relate to how services [in the UK] (Schuppan 2009) and information [in Spain] (Rodriguez Bolivar et al. 2007) are delivered. Although initial research into government use of Internet and e-commerce finds that public quality is lower than private counterparts (Morgeson and Mithas 2009), it can be effective at increasing public participation (Desouza and Bhagwatwar 2012), especially for solving public challenges (Mergel and Desouza 2013).

2.2 Agency Use of Strategic Planning and Foresight

The best available science and technology should inform policy according to mandates from the President and staffers in the Executive Office of the President (Executive Office of the President 2009; Zients and Holdren 2012). Researchers remind us that scientific knowledge and policy-making processes are interwoven and inextricably interconnected (Jasanoff et al. 1998; Stine 2009). Both views inform my research, in which I argue that policies should be based on the best available science and technology (Executive Office of the President 2011) and that scientific knowledge is interwoven into agency policy documents such as strategic plans, Congressional Budget Justifications, and quadrennial technical reviews.

Agency strategic planning involves stating the agency's mission, goals, and objectives (US Congress 2010). Agencies complete strategic plans because they are required by law (US Congress 1993, 2010; Executive Office of the President 2014a) and because they are a way for government employees to consider what the agency is doing or could be doing relative to societal, presidential, or congressional mandates (Bryson 2011; Moore 1995). Agency strategic plans also are important tools for communicating with Members of Congress, the President, and the general public (US Congress 2010; Senge 2014).

The Government Performance and Results Modernization Act (GPRMA) (US Congress 2010, §306(a)) requires strategic plans in order to shift from an agency focus on activities and staffing to a focus on results (US General Accounting Office 1996, 2). To focus on results, the Government Accountability Office (formerly the General Accounting Office) finds that effective strategic planning involves stakeholders, assesses internal and external environments, and aligns agency activities to support mission-related outcomes (US General Accounting Office 1997).

An expectation exists in the congressional and presidential mandates regarding agency strategies (US Congress 2010; Executive Office of the President 2014a) that strategic planning is rational and that agency strategic planning generates strategy (Bryson 2011; Bryson and Roering 1988; Boyne and Chen 2007). The expectation is that strategic plans indicate priorities and areas of interest because that is the mandate (Executive Office of the President 2014a; US Congress 2010). Moreover, government employees take the time to write documents that they know will be read by stakeholders (as indicated in the cover letter and transmittal notices), including congressional appropriators (as indicated by the language in the documents), so they use words and justifications for funding priorities (especially in the strategic plans and Congressional Budget Justifications).

Whether foresight is an additional component of strategic planning is less clear. To involve foresight requires understanding the future with qualitative and quantitative analysis in order to plan and make decisions (Coates 1985). In strategic planning, this requires exploring various potential futures (Cornish 2004; Schwartz 1996) and various potential impacts on society (Sardar 2010; European Commission 2014; Fuerth 2012). Former Prime Minister Blair described this link between strategic planning and foresight as a combination of thinking systematically about the future and then figuring out how to get there: "Strategic policy making is a professional discipline in itself involving serious analysis of the current state of affairs, scanning future trends and seeking out developments elsewhere to generate options; and then thinking through rigorously the steps it would take to get from here to there" (Blair 2004).

Foresight is distinguished from simply thinking about likely futures by incorporating considerations about likely futures into current strategies, decisions, or preparations. The advantage of applying foresight to strategic planning is that humans then have a chance to make plans and improvements before the future arrives (Cornish 2004; Fowles and Fowles 1978; Schwartz 1996). Although corporations—and some nonprofit organizations—engage consultants from futures think tanks like the Global Business Network (Global Business Network 2013) or the Institute for Alternative Futures (Institute for Alternative Futures 2013) to include foresight in strategic planning, this is less common for federal agencies individually or for the US government collectively.

Federal agencies usually have a strategic planning function, but each agency handles strategic planning with little central coordination (Dreyer and Stang 2013; Fuerth 2012):

> "Well-established, but decentralised foresight programmes are scattered throughout the US government. Many agencies (State, FEMA, Defence, Treasury, Energy, OMB and especially GAO) have strategic planning capacities that use foresight to varying degrees. The National Intelligence Council produces major Global Trends reports every 4 years. As the world's foremost producer and user of foresight work in the last half century, the US military has an array of strategic planning and intelligence organisations, in which foresight work is well entrenched to inform planning" (Dreyer and Stang 2013, 31).

Moreover, a disconnect exists between public and private foresight experts (Dreyer and Stang 2013) as evidenced by the differences in the inclusion of foresight in the private versus the public sectors (United Nations Industrial Development Organization 2002; Dirk and Leonid Gokhbelexander 2013; Ughetto 2007) and ongoing calls for between-sector coordination (Calof and Smith 2010; United Nations Industrial Development Organization 2002; Cagnin 2008; US Congress 1982).

In contrast, the Horizon Scanning Programme Team in the UK (United Kingdom Government 2015) regularly reports to the Cabinet Secretary's Advisory Group on government-wide future trends and the attendant opportunities and threats. The Horizon Scanning Programme Team provides advice and guidance in support of government decisions by combining the latest evidence and futures analysis to provide foresight for platforms like humans, cities, disasters, or manufacturing (United Kingdom Government Office for Science 2013).

Agencies function in an era of limited time and money so each must maximize all benefits across agencies through strategic planning and foresight. Especially given these competing demands for federal funding in the US, foresight work is an important step in identifying technically-feasible policies and priority investments in ECT (Fuerth 2012; Martin and Irvine 1989): "If we are to remain a well-functioning Republic and a prosperous nation, the US Government cannot rely indefinitely on crisis management, no matter how adroit. We must get ahead of events or we risk being overtaken by them" (Fuerth 2012, 1). We must prepare with strategic planning, foresight, and effective use of ECT.

2.3 Agency Use of Emerging and Converging Technologies (ECT)

ECT are the foundation for important breakthroughs (Roco 2011a, 2007; Roco et al. 2011; Alford et al. 2012; Bainbridge and Roco 2005). For example, additive manufacturing via three-dimensional (3D) printers can provide on-demand objects that solve immediate problems for government researchers or employees. Advances in cognitive science can improve comprehension and speed learning, making it easier to conduct research or handle office work. Nano-strengthened materials could become core, reusable building materials in smart homes.

Each of these solutions requires emerging technologies, technologies that are so new that they are still being researched, developed, and applied to problems (Christensen 1997; Cozzens et al. 2010; Daim et al. 2006). Emerging technologies can be from any category of technology (i.e., any applications of knowledge, often in the form of machinery and equipment (Oxford Dictionaries 2015)) and are distinguished by their inevitability. Emerging technologies also can converge with other technologies or on platforms such as a computer, phone, or car to form converging technologies (Daim et al. 2009; Seelman 2008; Kelly 2010; Nordmann 2004; Bainbridge and Roco 2005; Roco 2011a; Roco et al. 2013). "[N]ovel technologies arise by combination of existing technologies ….” (Arthur 2009, 21). The technologies for electronic communication (e.g., email) converge on a variety of platforms so that we can read email on our watches or car's windshield. Biotechnology and cognitive sciences converge with each other to enhance human cognition.

ECT can benefit society in many ways. They may help to support the types of outcomes encouraged by the President such as promoting economic growth, job creation, and public health and welfare (Executive Office of the President 2011), among other outcomes. Additionally, they can facilitate ongoing international competitiveness, which depends upon policies and innovations (Feinson 2003) supported by agencies (Clinton & Gore 1993; Galbraith 2000; Gann 2000; Lall 2004; Samai et al. 2004). Regardless, agencies can use ECT to do the work (e.g., using cognitive science to enhance reasoning for hard problems) in addition to nurturing technologies to fulfill agency strategies (e.g., supporting development of advanced materials for photovoltaic cells).

For promoting economic growth and job creation, as much as half of income per capita growth in the US is attributable to technological developments (US Department of Commerce 2014). This assertion is supported by research studies in which income per capita growth is explained by technical progress in all countries and variation is explained by differences in technology levels, capital intensity, and human capital (Organisation for Economic Co-operation and Development 2012, 195; Fagerberg 1987; Lall 1992; Fagerberg 1994; Pavitt 1991). Expanding the research, development, demonstration, and deployment of ECT grows the US private sector economy and increases the opportunities to use those ECT to solve specific societal problems.

For promoting public health, ECT such as nanotechnology and biotechnology can be applied to regenerative medicine in which precision assembly of matter (nanotechnology) is combined with the building blocks of living systems using information technology and cognitive sciences (Roco 2011a). Public health also could be promoted through nanotechnology sensors in public places that identify disease emergence; biotechnology implants that sense and resolve disease; information technology processing of big data to pre-identify issues in an individual's or group's genome; or cognitive science enhancements that resolve mental illnesses and facilitate adherence to the cure.

For protecting public welfare, ECT can help recreate ecosystems and build new, more sustainable systems, options that we need. By 2050 the US and world populations are expected to be 422.6 million (US Census Bureau 2013) and 9.4 billion (US Census Bureau 2013), respectively. If those projected populations continue to use current technologies in the usual way, natural resources such as water, food, energy, and climate will be depleted more quickly than they can be replenished (Roco 2011a).

To develop ECT that can support these societal benefits, federal agencies rely on market incentives for innovation in science and technology but must fund research where the public good cannot be fulfilled through market incentives alone (e.g., public health research) (Conceição et al. 2004; Organisation for Economic Co-operation and Development 1996). Data about these public investments in and use of ECT are scarce, a part of the general data problem mentioned above that the Executive Office of the President acknowledges: “Inputs, outputs, and outcomes are not currently generated or combined in a systematic fashion. The development of consistent and reliable answers to stakeholder requests requires the use of common data sources and standardized methodologies for data cleaning and analysis" (Executive Office of the President 2014c, 64).

Even the theoretical literature on public sector use of ECT is scarce and focuses on information technology aspects such as sharing information (Liu and Chetal 2005). The exception to this is research by Hackler and Saxton (2007) in which the authors find that the utility of information technology for nonprofit missions is contingent on factors such as strategic communications, relationship-building, and partnerships—which could be seen as another form of sharing information—as a way of using information technology to support the not-for-profit's mission.

Still, there are signs of increased agency use of ECT. One sign is that President Obama launched the Advanced Manufacturing Partnership, an initiative to connect the agencies, industry, and universities for investments in emerging technologies (Sargent 2015). The NRI (led jointly by the National Institutes of Health, the United States Department of Agriculture, the National Aeronautics and Space Administration (NASA), and the Defense Advanced Research Projects Agency) (Kalil and Thorpe 2011; National Aeronautics and Space Administration 2011; National Robotics Initiative (NRI) 2015) and the National Network for Manufacturing Innovation (jointly led by the DOC, DoD, DOE, National Aeronautics and Space Administration, and NSF) (National Network for Manufacturing Innovation 2013) are already components of the Advanced Manufacturing Partnership for which the DOC recently proposed "Innovation Institutes" for research into biomanufacturing and nanocellulosics to begin to fulfill the mission of the National Network for Manufacturing Innovation. President Obama also launched the all-of-the-above strategy for researching and investing in energy technologies that support energy independence (Executive Office of the President 2015).

Another positive sign is the Emerging Technology and Research Advisory Committee (US Department of Commerce 2010), which is comprised of members from industry, academia, and research laboratories. Federal government participants include the DOC, DOE, and the White House Office of Science and Technology Policy, among others. However, the Committee's mission is not to expand use of ECT by federal agencies but instead to identify opportunities for joint civil and classified uses and to increase regulation for export control and national security. This group's focus on regulation and control seems to exclude a focus on leveraging ECT to handle day-to-day agency work or to fulfill agency strategies, although it is a positive sign that these projects and agency strategic planning documents even mention ECT.

2.4 Agency Strategic Planning and Foresight for ECT

Agencies know to produce strategic plans because they are required by the Executive Office of the President and the Government Performance Modernization and Results Act (US Congress 2010) and those requirements are based in the notion that some amount of strategic management is necessary to create public value and benefit (Moore 1995). The agencies know to use technology because agencies receive a copy of the annual Office of Science and Technology Policy science priorities memo (Executive Office of the President and Executive Office of the President 2012) and agencies are aware of relevant Executive Orders (e.g., Executive Order 13563 (Executive Office of the President 2011)).

Agency strategic planning and foresight connect with ECT indirectly. For example, in Executive Order 13563 (Executive Office of the President 2011, 1), President Obama called for the following characteristics in our regulatory system: "Our regulatory system must protect public health, welfare, safety, and our environment while promoting economic growth, innovation, competitiveness, and job creation. It must be based on the best available science." This mandate for considering ECT, among many other science and technology topics, is also acknowledged in agency strategic plans.

The DOC's previous strategic plan mentions emerging technologies, although only in the context of controlling exports (US Department of Commerce 2011); the new strategic plan mentions actual ECT (US Department of Commerce 2014). The DOE's previous strategic plan mentions the term "emerging" once, but in the context of reducing emerging nuclear threats (US Department of Energy 2011b). The current plan mentions emerging in the context of emerging commercial solutions, "emerging challenges in energy, environment, and national security," (US Department of Energy 2014, 10) and, of course, also mentions specific ECT.

Using ECT to fulfill agency strategies is difficult because ECT emerge and converge as policymakers attempt to make choices. This requires constant environmental scanning to know what is available, what the advantages and disadvantages are, and how to implement ECT to manage costs, opportunities, and risks, all while fielding other options (Eriksson and Weber 2008). These considerations may explain why domestic research on agency strategies and foresight for ECT is sparse. Technologies such as nanotechnology, biotechnology, and cognitive science are rarely discussed in this context, except by Roco and Bainbridge (Roco and Bainbridge 2002; Roco 2011a) and others engaged in the NSF CKTS activity (Roco et al. 2013). Moreover, even the CKTS activity tends to discuss nanotechnology, biotechnology, and cognitive science mostly as specific ways of improving human functions (Roco and Bainbridge 2003; Roco 2011b) rather than as general tools for supporting agency strategies.

International research on agency strategies and foresight for ECT is only slightly less sparse. The strongest work, discussed further in the next section, supports policymaking in Thailand (Gerdsri and Kocaoglu 2009) and focuses on prioritizing nanotechnology investments to support agency strategies for agricultural development and developing national policies that facilitate industry science and technology (S & T) innovations.

Agencies admit to the gaps in strategic planning for technologies, including ECT. For example, the following appears in the previous DOC strategic plan, "Encourage more resources to be directed at the needs of the future as compared to incremental developments based on today's technology" (US Department of Commerce 2011, 12). In the previous DOE strategic plan (US Department of Energy 2011b, 20), the agency made a similar acknowledgement, "We will support objective, thorough technology assessments, including analyses of technology diffusion and adoption paths that avoid technology advocacy." These gaps can be filled with a methodology for characterizing federal agency use of ECT.

2.5 Methodologies for Characterizing Use of ECT

To characterize current and potential use of technology, former Director of the White House Office of Science and Technology Policy Marburger once called for "the creation of a community of practice that would create the data sets, tools, and methodologies needed to assist science policy decision makers as they invest in federal research and development and make science policy decisions" (Marburger 2005). His request was acknowledged, to some extent, by the development of RaDiUS and STAR METRICS℠, discussed below. Despite these efforts in the decade since his editorial, work to meet his challenge remains fragmented and incomplete.

The National Science Board (2007) followed Marburger's call with a detailed list of NSF opportunities for enhancing support of transformative research. The National Academies (Committee on Prospering in the Global Economy of the 21st Century 2007, 7) recommended that federal technology investments "be evaluated regularly to realign the research portfolio to satisfy emerging needs and promises—unsuccessful projects and venues of research should be replaced with research projects and venues that have greater potential."

Consistent with the principles in Executive Order 13563 (Executive Office of the President 2011), other practical actions include the work accomplished through the Executive Office of the President to coordinate the Emerging Technologies Interagency Policy Coordination Committee (ETIPC) (Executive Office of the President 2010). The group has no public outputs to date, but the NSF has hosted a series of workshops and published reports. Following a charge from the President's National Science and Technology Council, an Interagency Task Group found that agencies use substantially different data and tools to understand their investments in science and technology. In short, the data infrastructure remains inadequate for decision-making (National Science and Technology Council 2008).

The methodologies that emerged to solve these problems for agencies can be organized based on three capabilities: 1) reporting current agency ECT use; 2) identifying potential agency ECT use; and 3) identifying any organization's potential use of ECT.

In the first category, tracking agency current use of ECT, no methodologies incorporate agency strategies. Individuals at the White House Office of Science and Technology Policy (Rubin 2013) and the NSF (Yamaner 2015) confirm that they know of no systematic collection of information about agency current use of ECT or technology-level investments in ECT.

Two methodologies track agency current use of ECT but do not incorporate agency strategies. The first, Science and Technology for America's Reinvestment: Measuring the Effect of Research on Innovation, Competitiveness and Science (STAR METRICS℠) (National Institutes of Health 2013; Executive Office of the President 2014c) was designed to provide information about the societal benefits achieved with federal research funds, especially outcomes such as job creation and economic growth. The National Institutes of Health (NIH), the NSF, and the Office of Science and Technology Policy (Executive Office of the President) are leading the project, which bodes well. However, the project depends upon voluntary quarterly reporting from research institutions, which means the data represent about half of the NSF and NIH portfolios (Lane 2012) and little of other government agency portfolios. The project is transitioning from estimating jobs created by federal science awards to building a searchable database of science awards from federal agencies; currently, the data set has one year of voluntarily-provided data (National Institutes of Health 2014). Consistent with national intentions to produce beneficial economic, scientific, and social outcomes, STAR METRICS℠ administrators ultimately hope to match existing administrative information with existing research databases on economic, scientific and social outcomes.

The second, RaDiUS, was proposed and developed by the RAND Corporation [contraction of Research and Development] to track federal grants for R & D and in support of the White House Office of Science and Technology Policy's efforts to catalog information about which contractors and grantees received how much federal money (Identifying Federally Funded Research and Development on Information Technology 2004). The advantage of the system was that it tracked some aspects of federal R & D spending; the disadvantages, of course, are that it did not track the information for every agency and the data were not connected with the agency strategies. Moreover, working with the data was challenging (Hall and Merrill 2005) and, now that the RAND contract has ended, the system is unavailable (RAND 2015) and is no longer being updated (Della-Piana 2015).

In the second category, tracking agency potential use of ECT, three key methodologies exist, of which only the first incorporates agency strategies. Gerdsri and Kocaoglu (2009) developed a methodology for supporting Thai policymakers in strategically defining policies for nurturing, guiding, and adopting emerging technologies. They applied the methodology by soliciting expert opinions about Thailand's mission (e.g., leading the world in sustainable agricultural-based economy), objectives (e.g., the set of achievements necessary to satisfy the mission), and technological goals (e.g., novel tools, smart treatment delivery systems, nanosensors) with respect to agricultural use of nanotechnology. Experts then identified and evaluated research strategies based on the top ranked technologies and the contributions to the overall mission.

Scientists working with the National Research Council (Committee on Forecasting Future Disruptive Technologies 2009, 2010) proposed a second method for predicting a class of ECT, disruptive technologies (i.e., technologies that will change the way we live and work). The proposed system had seven major steps, which form the basis for the methodology proposed in this study: 1) Decision makers define priorities and the problem set; 2) Analysts collect information from workshops, predictive markets, feeds, etc.; 3) Analysts clean and normalize the data; 4) The system processes the data with automatic monitoring and tools to identify signals in the data; 5) The public and experts analyze the data via crowdsourcing, predictive markets, and online games; 6) Policymakers allocate resources based on the forecast; and 7) Everyone reviews and revises. The advantage of this system is that many potential problems have been anticipated and solved. The disadvantages are that it probably has not been built yet and it is unlikely to be built. Moreover, because the work was initiated by the DoD, if it were built, individual members of the public and civil agency policymakers would be unlikely to know about the existence of the system or its findings. Foresight Engine (Institute for the Future 2012; Gordon 2012) solicits foresight on a variety of futures issues via online games. I include it in the section about agency potential use of ECT because it is an outgrowth of the Signtific (Institute for the Future 2009a, 2009b) project, which sought to use foresight to identify concerns about ECT for policymakers.

Finally, the third category, any organization's potential use of ECT, includes five methodologies, two of which have been applied and three of which remain theoretical. The federally-funded SciCast (George Mason University 2015) website allows crowd-based users to post predictions for a wide variety of science and technology questions ranging from, "When will the first car equipped with vehicle-to-vehicle (V2V) safety technology be offered for sale to the general public in the US?" to "Will the Mars Curiosity Rover discover organic matter on Mars by July 1, 2015?" (George Mason University 2015). Based on a prediction market algorithm, the forecasts are updated as new users make predictions or when current users update their predictions in response to new information or thinking. The system is designed to consider foresight for any outcomes that might incorporate technologies (Twardy et al. 2014).

The TechCast (George Washington University 2015) website encourages expert users to provide a continuous assessment of major technological advances. Emerging technologies are identified with environmental scanning and trend analysis, and panels of authorities are asked to forecast the year of advance and its associated probability. Over the years, experts have participated in at least four Delphi-like survey rounds to identify and forecast outcomes for more than 85 emerging technologies (Halal et al. 1997; Halal 2013).

The three theoretical systems in this last category are based on patent citation groupings. TrendPerceptor (Yoon and Kim 2012) was proposed to engross information about patents to predict technology trends. The advantage of a system like this is that the source information, patent data, is relatively easy to find. The disadvantage of a system like this is that it is entirely automated, so nuances in the data that a human analyst might catch go undetected.

In Shin and Kim's (2013) methodology, the focus is on predicting future technologies in support of policymakers. They build a list of current emerging technologies based on patent citations and fit a growth curve to the patent citation data to forecast the growth path by technology. Their intent is to forecast both the return and risk of future technologies in support of policymakers' decisions.

The latest global patent mapping system maps technology categories and technological areas based on cross-citations (Kay et al. 2014). Researchers built the map based on citing-to-cited relationships between categories of the International Patent Classification (IPC) of European Patent Office (EPO) patents and piloted the system by comparing nanotechnology-related patenting activities of two companies and two different nanotechnology subfields on the global patent map to visualize technological areas. Their most interesting finding was the new relationships between technologies that were revealed by separating them from their patent categories.

Regardless of the advantages and disadvantages of these various systems, even the theoretical systems, none provide the information about current and potential use of ECT for fulfilling agency strategies that I require. Given that existing methodologies do not accomplish all of the things that we need—and that most offer significant problems—I develop a new methodology.

2.6 Research Questions and Propositions

I am motivated by the general gaps in information about federal agency use of ECT and the specific opportunity to develop and apply a methodology that generates the necessary theoretical and applied information necessary to fill those gaps. The research objective is to develop and apply a systematic methodology for characterizing ECT based on their current and potential ability to fulfill agency strategies. Given the research problem and objective, I formed the following research questions and propositions:

- Research Question 1: Are ECT being used to fulfill agency strategic plans (current use)?
- Research Question 2: Could ECT be used more extensively to fulfill agency strategic plans (potential use)?
- Proposition 1: Develop a Methodology. Developing a methodology depends upon identifying design criteria and noting efficiencies and deficiencies in related methodologies. Thus, a methodology can be developed by identifying design criteria and using effective elements of related methodologies to meet the criteria.
- Proposition 2a: Apply to Characterize Current Use. The viewpoints of federal agencies are summarized in strategic documents and Congressional Budget Justifications, as required by the Executive Office of the President and the Government Performance and Results Act, and are known by people familiar with the

agencies and government employees. Thus, agency actual present use of technology can be characterized based on strategic documents, expert knowledge, and government employee knowledge.

- Proposition 2b: Apply to Characterize Potential Use. Potential use can be defined as a function of ECT, agency strategies, global trends, potential futures, and agency strategies. Thus, agency potential present use of technology can be characterized based on government employee knowledge, expert knowledge, and crowd-sourced knowledge.
- Proposition 3: Evaluate a Methodology. Evaluating a methodology requires a standard to evaluate against or use of a different analysis approach to see if it produces the same results. Thus, the methodology can be evaluated against a standard set of criteria and using a different analysis approach.
- Proposition 4: Disseminate a Methodology. Disseminating a methodology requires sharing it with a variety of audiences using a variety of media. Thus, the methodology and results can be disseminated by distributing them to members of academia, government employees, and the general public via websites.

Please see also Table 1, "Research Questions and Propositions Mapped to the Methodology,"[3] for a summary of propositions by research question and research approach. The table is best read from top to bottom and from left to right in order to follow the individual research questions, phases, and steps. The columns display research questions and are further divided by the analysis approaches necessary to address these research questions. The rows display the phases of the methodology and are further divided by the steps necessary to fulfill the developed methodology. Within each cell, the table also reveals the actions necessary to apply, evaluate, and disseminate this developed methodology. The next chapter details the methods for accomplishing this.

[3] All tables are in Appendix A, "Tables."

Chapter 3
Methods

Developing a methodology to characterize current (Research Question 1) and potential (Research Question 2) agency use of ECT for fulfilling agency strategies requires multiple phases and methods. The phases organize the workflow while the mixed qualitative and quantitative methods (Creswell 2003; Maxwell 2004; Tashakkori and Teddlie 2010; Onwuegbuzie and Collins 2007) are necessary to provide a variety of perspectives on agency uses of ECT and to yield findings and results that can be synthesized into a set of meta-inferences (Tashakkori and Teddlie 2010) about current and potential agency use.

The methodological approaches must fulfill the methodology's design criteria and vary by phase. In Phase 1, developing the methodology requires the creation of design criteria and steps based on an extensive literature review and assessment of best practice. In Phase 2, applying the methodology to characterize current agency use of ECT requires content analysis (Krippendorff 1980; Weber 1990; Neuendorf 2002; Grimmer and Stewart 2013; Krippendorff 2013; Potter and Levine-Donnerstein 1999; Stemler 2001); technology assessments (Braun 1998; European Parliamentary Technology Assessment 2014; Fleischer et al. 2005; Kameoka et al. 2004; Mali 2009; US Department of Energy 2012); and individual interviews (Weiss 1994; Denzin and Lincoln 2008; Rapley 2007; Maxwell 2004; Tashakkori and Teddlie 2010; Horizon Scanning Center 2008; Guba and Lincoln 1994). The characterization of potential agency use of ECT requires individual interviews; plausibility matrices (United Kingdom Government ; Green et al. 2007; Horizon Scanning Center 2008); and crowd-sourced intelligence (Howe 2006; Sunstein 2006; Ranard et al. 2014; Briscoe et al. 2015). To produce the crowd-sourced intelligence, the crowd must in turn draw on trend analysis (Sasuly 1934), forecasting (Cornish 2004; Fowles and Fowles 1978; Schwartz 1996), and foresight (European Commission 2014; Sanz-Menendez et al. 2001).

In Phase 3, evaluating the methodology requires visual analytics (Börner 2010; Lima 2011; Thomas and Cook 2006; Chen 2008; Keim et al. 2008). In Phase 4, disseminating the methodology requires only the distribution of the information to researchers, policymakers, and the general public. These phases and analysis approaches are summarized along with the research questions, propositions, data collected, and diagnostics in Table 1, "Research Questions and Propositions Mapped to the Methodology." This is, of course, a pilot application of the methodology that can be augmented by applying it to other organizations, different data, or over time.

In the next four sections, I detail the phases and analysis approaches and then explain how each section integrates with the others. For each analysis approach, I detail the collection, organization, analysis, and synthesis processes and conclude with the advantages and disadvantages of the approach.

3.1 Developing the Methodology

I developed this methodology by balancing the desired outcomes of the methodology—systematically identifying current and potential agency use of ECT to fulfill agency strategies—with theoretical work related to methodology development in general and methodologies related to foresight and ECT in particular.

3.1.1 Building from Existing Work

To establish the criteria and develop the methodology steps, I built on the theoretical work related to methodology development that underlies the related existing methodologies with foresight and ECT as summarized in Table 2, "Overview of Key Methodologies," especially the STAR METRICS℠ (National Institutes of Health 2015; National Institutes of Health 2014; National Institutes of Health 2013), RaDiUS (now defunct) (RAND 2015), SciCast (George Mason University 2015; Twardy et al. 2014), and TechCast Global (George Washington University 2015; Halal 2013) methodologies. I also studied many proposed systems, especially Forecasting Future Disruptive Technologies (Committee on Forecasting Future Disruptive Technologies 2009, 2010) and the system for identifying priority nanotechnology investments for Thai agriculture (Gerdsri and Kocaoglu 2009).

Table 2, "Overview of Key Methodologies," displays the relevant methodologies by agency current and potential use of ECT and by whether the methodology incorporates federal agency strategies. This table is best read from top to bottom and from left to right to follow the individual methodologies and to see the gaps in methodologies for characterizing agency use of ECT. The columns display methodologies by agency current and potential use of ECT and the organization's potential use of ECT. The rows display methodologies by whether they incorporate agency strategies. Within each cell, the table also reveals whether the methodology is applied (i.e., deployed in some way) or theoretical (i.e., contemplated in a document or on a website but not deployed). Each cell lists the methodologies that fit in that combination of row and column. The takeaway from this table is that the methodology developed, applied, evaluated, and disseminated in this research is necessary to fill major gaps in the applied and theoretical methodologies currently available.

3.1.2 Establishing the Criteria

To identify the criteria and design a methodology that meets those criteria, I began with the general criteria for qualitative and quantitative research: trustworthiness for qualitative research (Denzin and Lincoln 2008; Guba and Lincoln 1994) and external and internal validity, reliability, and objectivity for quantitative research (Shively 2009; Lewis-Beck et al. 2003; Hammersley 2003; Ondercin 2003; Brewer 2003; Chen and Krauss 2003). Ontological, educative, catalytic, and tactical authenticity were not relevant for this approach because this research does not consider behavior in natural settings (Denzin and Lincoln 2008; James 2008).

Building from existing work, I considered features such as the practicality of implementing and updating the approach; the ability to model actual and potential agency use of ECT; and the ability to incorporate potential technologies, platforms, trends, and futures, among others (cf. Tonn and Stiefel 2013). A methodology for estimating existential risks (Tonn and Stiefel 2013) and a methodology for forecasting disruptive technologies (Committee on Forecasting Future Disruptive Technologies 2009, 2010) share many aspects of the outcome required of this methodology and yield criteria such as the practicality of implementing and updating the approach and ability to solve the defined problem, respectively.

My preliminary methodology design criteria are detailed in Table 3, "Methodology Design Criteria and Minimum Standard." The purpose of this table is to summarize the methodology design criteria and the minimum standard that must be met for each. This table is best read from top to bottom and from left to right in order to follow the individual design criteria. The columns display the design criteria and the minimum standard that must be met for each. Each cell displays the minimum standard that must be met for each design criterion.

3.1.3 Identifying the Steps

Based on the design criteria and the existing theoretical work, especially the methodology for forecasting disruptive technologies (Committee on Forecasting Future Disruptive Technologies 2010, 2009), the methodology is seven steps: define, collect, organize, analyze, synthesize, evaluate, and disseminate. In a general application of this methodology, any foresight problem can be defined for any foresight topic (e.g., all technologies, overpopulation, income inequality) and the design criteria can be identified so that the remaining steps are consistent with the defined problem and design criteria. For the specific foresight problem in this research, details of the seven steps follow and are depicted in Figure 1, "Developed Methodology with Phases" (inspired by "Conceptual Process Flow for the Persistent Forecasting System" (Committee on Forecasting Future Disruptive Technologies 2009, 59)).[4] The purpose of this figure is to display the individual phases and the connections in the phases. It is also a useful way to view the mix of collection inputs; the variety of analysis approaches; and the attention to synthesis. This figure is best read from top to bottom in order to follow the individual steps within each phase:

Define. Given the research questions, the defined problem is to identify current and potential agency use of ECT to fulfill agency strategies.

Collect. Data collection is guided by the defined problem, the design criteria, and the analysis approaches. For example, the defined problem requires consideration of the ways government accomplishes things such as contracts, grants, regulations, tax expenditures, and loan programs (Kettl 2015) and so the collected information was from government employees, research scientists, online crowds, government reports, online articles, online datasets, and academic literatures.

Organize. Once data are gathered, and depending on the analysis approach to be used, the collected data must be organized into a variety of software packages and forms. Data from the government documents or interviews with government employees that will be analyzed for content can be organized into content analysis software such as QDA Miner (Peladeau 2013) or NVivo (NVivo 2014). Data from research scientists and other experts that will be used in technology assessments and plausibility matrices can be organized into Excel spreadsheets or an online form. Data for crowd-sourced intelligence can be organized into a MySQL (Oracle Corporation 2015) database serving a website built in Hypertext Preprocessor (PHP), and the results can be analyzed in any statistical package. Visual analytics data could be organized in visual analytics software packages such as Circos (Circos 2013), Gelphi (Gephi 2015), or Tableau (Chabot et al. 2003).

Analyze. I sought analysis approaches that would answer the research questions and fulfill the design criteria. This meant identifying multiple analysis approaches to triangulate findings and results (Jick 1979; Tashakkori and Teddlie 2010; Onwuegbuzie and Collins 2007). The analysis approaches are summarized at the beginning of the chapter and explained in greater detail in each of the subsections of Section 3.2, "Applying the Methodology."

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[4] All figures are in Appendix B, "Figures."

Synthesize. Findings for qualitative approaches and results for quantitative approaches are summarized into tables so that meta-inferences (Tashakkori and Teddlie 2010) can be drawn from the findings and results as a whole. Support for the research questions and propositions is considered.

Evaluate. The entire methodology is studied in comparison to the defined problem and the research questions that sourced it. Gaps in collection, organization, analysis, and synthesis (including outcomes) are identified.

Disseminate. Findings, results, and meta-inferences are disseminated to researchers, policymakers, and the general public so that the current research is known; choices can be made; and future research can be conducted.

After these steps are handled, researchers can apply it iteratively to keep up with changes in strategies and ECT. Please see also Figure 1, "Developed Methodology with Phases."

3.1.4 Integrating with the Other Phases

The methodology is comprised of the seven steps, which are accomplished in the four phases used to organize this research: 1) Developing; 2) Applying; 3) Evaluating; and 4) Disseminating. Consistent with outcomes of the methodology generated in the developing phase, I applied the methodology to two cases, the DOC and the DOE.

3.2 Applying the Methodology

I chose to apply the methodology to two agencies to gauge the differences across organizations and to avoid tailoring the model to a particular organization. I chose the DOC and the DOE because both focus on a range of societal benefits from economic growth to public health and welfare. Both agencies use ECT in their internal operations and to fulfill their strategic missions. Both engage in strategic planning in the form of agency strategic plans (US Department of Commerce 2014; US Department of Energy 2014); yet, agency strategic planning and foresight for use of ECT is mixed. For example, the DOE conducted a Quadrennial Technology Review to assess a variety of technologies, including some ECT (US Department of Energy 2011a, 2012). The DOC also seems to recognize an opportunity for increased innovation and foresight in their planning. In the Fiscal Year (FY) 2016 Congressional Budget Justification, the agency requests funds for an Idea Lab (representing Innovation, Design, Entrepreneurship, and Action) and the agency is one of the leads for the President's National Network for Manufacturing Innovation initiative (US Department of Commerce 2015b).

The high-level goals for both agencies are summarized in Table 4, "Agency Strategies." The purpose of this table is to summarize the language for each agency's high-level goals because I use abbreviated versions in the actual document. For example, I refer to Department of Commerce Goal 1 as DOC Goal 1 throughout the document to conserve space and as DOC 1.0 in the figures to further conserve space.

Consistent with the defined problem and applying the Phase 2 steps of the methodology—collect, organize, analyze, and synthesize—I used non-random qualitative sampling and non-random quantitative sampling (Onwuegbuzie and Collins 2007) across five analysis approaches to characterize agency use of ECT. Clearly, the application of a methodology across 6331 agency strategy pages, 61,000 agency employees (US Department of Commerce 2015a; US Department of Energy 2013), and 1.4×10^{13} potential use cases is still a pilot. Still, applying the methodology provided preliminary findings and results about the theoretical and practical utility of the methodology and yielded useful information for the two pilot cases.

3.2.1 Content Analysis (Analysis Approach 1)

Content analysis is an appropriate tool for characterizing current agency use of ECT because strategic documents contain information about priorities and planned investments. Finding information about those priorities and planned investments means identifying and collecting strategic documents; organizing them into appropriate software; analyzing them; and synthesizing the findings into tables by agency strategy and ECT.

3.2.1.1 Collect

I collected data from government documents such as agency strategic plans (US Department of Commerce 2014; US Department of Energy 2014), Congressional Budget Justifications (US Department of Commerce 2015b; US Department of Energy 2015), and Quadrennial Technical Reviews (US Department of Energy 2011a, 2012) (only available for the DOE). I considered any documents that contained information about government spending on direct tools of government (e.g., provision of services) or indirect tools of government (e.g., contracts and grants) (Kettl 2015) with a special interest in documents that addressed spending on ECT.

Two alternatives for data collection included using direct reports from agencies or indirect online database reports from agencies or contractors and grantees. For direct reports from agencies, I contacted the NSF's National Center for Science and Engineering Statistics; the Congressional Budget Office; and each of the Chief Information Officers or Chief Technology Officers at the agencies. Those who responded confirmed that no data exist that match agency use of ECT to agency strategies. I also performed extensive searches of agency sites, NSF, OSTP, performance.gov, science.gov, all of the open data, the Executive Office of the President's Office of Management and Budget (OMB), Congressional Research Service (CRS), Government Accountability Office (GAO), university databases, literature, National Academies of Science reports, and National Research Council reports to confirm that those organizations are not compiling or presenting information about current agency use of ECT by project, program, or strategy.

Other online database reports were not appropriate because agencies do not consistently or systematically report that information. The NSF only captures aggregate data by category (National Science Foundation 2013a, 2013b; Yamaner 2015), and the program-level data collection in STAR METRICS^{SM} (National Institutes of Health 2015; National Institutes of Health 2014; National Institutes of Health 2013) is not required, complete, or fully-operational. The STAR METRICS^{SM} data have the most potential for being useful when the system is more developed and participation has increased but it still will not offer information by technology—much less ECT—or by agency strategy.

3.2.1.2 Organize

I imported the strategic plans, Congressional Budget Justifications, and quadrennial technology reviews into QDA Miner (Peladeau 2013) with figures removed. Then, I organized the documents so that each document formed one case. This yielded 32 documents totaling 6331 pages.

3.2.1.3 Analyze

I used content analysis, a process for categorizing qualitative texts, to analyze these documents for current agency use because content analysis is an approach to "making replicable and valid inferences from data to their context" (Krippendorff 1980, 21). The advantage of content analysis is that it supports systematic examination of text documents and can even support quantitative analyses such as inter-coder reliability or frequency calculations (cf. Loia et al. 2007).

To use the automated text coding and retrieval functions in QDA Miner's related application, WordStat (Peladeau 2013), I updated the technology area definitions to match the definitions used elsewhere in this research and updated the word choices to match. I then trained and tested the model by successively applying the text-retrieval function in WordStat. For each of the three cycles, I coded all mentions of technology at the paragraph level so that the coded material would appear in the context of the surrounding language.

In the first cycle, I conducted a preliminary test of the model in which I hand- and machine-coded the agencies' strategies from previous years (US Department of Commerce 2011; US Department of Energy 2011b). I then performed a visual inspection of the coding agreement and disagreement lists to look for systematic errors and found none. To calculate inter-coder reliability, "the extent to which different judges tend to assign exactly the same rating to each object" (Tinsley and Weiss 2000, 98), between me and the software, I ran Krippendorff's alpha, which is appropriate for any number of coders and accounts for chance agreement (Lombard et al. 2002; Neuendorf 2011) with 10% overlap and code absence as agreement. The Krippendorff's alpha for the preliminary test was 0.803, which is considered acceptable for exploratory analysis of this type (Lombard et al. 2002; Neuendorf 2011).

In the second cycle, I hand- and machine-coded ten percent of the documents in the actual document set. For each, I performed a visual inspection of the coding agreement and disagreement lists to look for systematic errors and found none. I also ran Krippendorff's alpha, again with 10% overlap and code absence as agreement. The Krippendorff's alpha was 0.827, which was again acceptable for this type of research, so I proceeded to the actual analysis.

In the third cycle, I ran the actual analysis, in which I machine-coded all of the strategy documents. For diagnostics, I performed a visual inspection of the documents to see if anything important remained uncoded. I also manually updated the codes to eliminate incorrect use of emerging (e.g., as "emerging leader" or "emerging market"), materials (advanced) (e.g., as "nuclear materials" and "training materials"), and space (outer) (e.g., as "satellite offices") codes.

I used automated text coding and retrieval techniques because it is impractical to code thousands of pages by hand. The reviews of hand- and machine-coding inter-coder reliability and the disagreements were necessary to validate the model and the results of the actual analysis on the data. Additional validation was not necessary because the inter-coder reliability was at least 80% in the first and second cycles; the disagreement lists offered nothing of concern; and I visually validated the results each time. Given this, it was appropriate to synthesize and present these results.

3.2.1.4 Synthesize

After applying content analysis, I had a results list that included the agency technologies and strategies and information about how they are connected based on position in the actual documents. These findings are summarized in Chapter 4.

For future applications of this methodology, I would consider using natural language processing with more advanced machine learning algorithms to increase accuracy and speed (cf. Briscoe et al. 2015; Lehnert and Ringle 1982; Grimmer and Stewart 2013) as well as ontological matching (Doan et al. 2004; Ehrig and Sure 2004), which involves finding the correspondences between different concepts, in this case the technology areas and the agency strategies.

Still, as implemented, this approach met the key requirements for the overall methodology (please see also Table 5, "Evaluation of Design Criteria, Minimum Threshold, and Threshold Achieved," for a summary by criterion and analysis approach). The purpose of this table is to summarize the evaluation design criteria, minimum threshold required, and actual threshold achieved for each design criterion. This table is best read from top to bottom and from left to right in order to follow the individual design criteria. The columns display the minimum threshold for that design criterion (first column) and then the actual threshold achieved by analysis approach (remaining columns). Each cell displays a value of low, medium, or high to denote the actual threshold achieved. This summary display of the criteria confirms that each of the analysis approaches meets the minimum threshold for the design criteria.

In particular, the trustworthiness criterion—in the form of credibility, transferability, dependability, and confirmability (Denzin and Lincoln 2008; Guba and Lincoln 1994; Given and Saumure 2008)—was met by accurately representing the collected data; applicability of this approach to the same content again would produce the same results as would applying this approach to similar data from other organizations would produce similar results; and the findings are consistent with the data. To gather the next set of results about current agency use of ECT, I conducted technology assessment analysis with expert respondents.

3.2.2 Technology Assessment Analysis (Analysis Approach 2)

Technology assessment is "a systematic attempt to foresee the consequences of introducing a particular technology in all spheres it is likely to interact with" (Braun 1998, 28). In other words, technology assessment is the difference between thinking about the effects and systematically noting implications and connections. Technology assessment analysis is an appropriate tool for characterizing current agency use of ECT because experts have knowledge about agency use of technologies that can be meaningfully characterized by technology and strategy, especially if they can provide a probability to represent their certainty about the technical feasibility (Clemen and Winkler 1999; French 1983; Jacobs 1995). This is an important approach to characterizing the ECT that agencies are using now because it combines actual research on the agency with extensive experience. Results are achieved by identifying and collecting information about the agencies by line office and strategy; organizing the information into a matrix; gaining responses; analyzing the responses; and synthesizing the results into tables by agency strategy and ECT.

3.2.2.1 Collect

Collecting emerging technology definitions, agency strategies, and agency line office summaries was necessary in order to provide a summary of the day-to-day work of the agency components and how ECT and agency strategies might relate. I collected data about every office in each of the pilot agencies, beginning at the level of the Office of the Secretary and encompassing constituent offices within the component offices and administrations. For the DOC, I collected information about 241 offices or entities. For the DOE, I collected information about 266 offices or entities. That information, combined with the experts' extensive personal knowledge, provided the background for assessing the likelihoods of particular ECT supporting particular strategies now. The data matrix contained the following tabs: instructions; agency and office information that included the level within the organization, a description, and a link to the appropriate website for more information; and the actual matrix with the agency strategies on the x-axis and the ECT categories along the y-axis to produce 850 combinations of ECT and strategies for the expert respondents to code.

Technology assessment depends upon experts with knowledge about the agency, the technology, and current application of the technology within the agency. I restricted expert respondents to people who had extensive experience with the agencies through at least two of the following roles: employee, contractor, or interagency involvement. My intention was to ensure that the knowledge underlying the collection was sound. However, requiring extensive and current knowledge of both agencies severely limited my potential pool of respondents, which is a restriction that could be eased for future applications of this methodology by requiring less breadth of expertise or by asking expert respondents to provide answers only for parts of the strategies or the agencies.

Expert respondents were selected based on their background knowledge per their education and work experience (Camerer and Johnson 1997; Meyer and Booker 2001; Hora 2007) and the diversity of backgrounds (Meyer and Booker 2001). Only individuals who were confident about their knowledge of the technologies and the agencies agreed to complete the matrix, which confirmed their expertise and thus the value of their information. For this analysis approach, four expert respondents met the criteria.

These four expert respondents coded the current agency use of ECT as follows:

- 1 = there is a 0% probability that this technology is supporting this strategy now;
- 2 = there is a 25% probability that this technology is supporting this strategy now;
- 3 = there is a 50% probability that this technology is supporting this strategy now;
- 4 = there is a 75% probability that this technology is supporting this strategy now; and
- 5 = there is a 100% probability that this technology is supporting this strategy now.

I based this scale on the literature on Likert-type scale development (Likert 1974; Hinkin 1995; Clark and Watson 1995), choosing to include an odd number of choices because that is what people are used to and because it has a clear midpoint even though it may produce a slightly higher mean score than an even number of choices (Dawes 2008). The importance of wording that denotes a mostly equal step between each code to produce interval data (Carifio and Perla 2007) was satisfied with the even probability intervals.

Three potential concerns about this analysis approach require attention: the low number of expert respondents (n = 4); the heavy reliance on expert respondents' personal knowledge and experience; and the potential flaws in the scale. The low number of expert respondents is not a concern because these are the expert respondents with expertise about current agency use based on their academic training and work experience. Heavy reliance on personal knowledge is not a concern in this case as I know the expert respondents and am familiar with their knowledge and experience. Finally, the potential flaws in my scale are offset by the consistent use.

Alternatives for data collection included deploying the matrix at each organization; data collection mandated by staffers in the Executive Office of the President's Office of Science and Technology Policy; or data collection requested by staffers at the NSF. None of those approaches was appropriate because the mandates and requests are unlikely absent an executive branch project or legislative branch requirement. Moreover, this type of massive data collection from agencies is difficult. Even with a mandate from the heads of agency or the Executive Office of the President, responses are slow, incomplete, and overall response rates can be low.

3.2.2.2 Organize

I organized the respondent data into an Excel spreadsheet and captured expert respondent comments and concerns. I also removed personally-identifying information.

3.2.2.3 Analyze

I aggregated the probabilities using the linear opinion pool technique (Jacobs 1995; Genest and McConway 1990; Stone 1961), which involves combining the experts' distributions into a new distribution but with weighted responses. Even weighting of the responses (i.e., a simple mean) is appropriate in this case because the four expert respondents had equal personal experience with ECT in general, and the agencies' current use of them in particular. They also received the same instructions and background information prior to completing the matrix.

I conducted a sensitivity analysis (Gerdsri and Kocaoglu 2009; Caswell and Shyu 2012) of the results to understand the variability of the assessments above and below the "Current Use" threshold set in the analysis. A mix of agreement and disagreement is expected for this type of research (Mumpower and Stewart 1996; Meyer and Booker 2001) because of variations in personal experience. Disagreement highlights different ways of looking at a problem area (Mumpower and Stewart 1996; Meyer and Booker 2001), especially if it is multi-disciplinary (Mumpower and Stewart 1996) as this problem area was.

I considered other analysis approaches, especially supra-Bayesian, which involves combining the experts' probability distribution with any decision maker's prior distribution using Bayes' theorem (Jacobs 1995; French 1983; Gelfand et al. 1995). However, I discarded it because, although it does not increase additional analytical advantage, it does decrease transparency, one of the required criteria for the overall methodology.

3.2.2.4 Synthesize

After applying technology assessment analysis, I had a data set with the agency technologies, the agency strategies, and probabilities about how each could be used now to fulfill the agency strategies. These findings are summarized in Chapter 4, "Findings, Results, and Meta-inferences."

As implemented, this approach met the requirements for the overall methodology (please see also Table 5, "Evaluation of Design Criteria, Minimum Threshold, and Threshold Achieved," for a summary by criterion and analysis approach). In particular, the external validity (generalizability) criterion (Shively 2009; Ondercin 2003), was met by controlling the three main threats with a pool of experts; a realistic environment; and no opportunity for testing effects because it was too simple to require a pre-test or other requests that might bewilder or confuse respondents. Internal validity in the form of confidence that the independent variable has a causal relationship with the dependent variable (Crano et al. 2014; Creswell 2003; Brewer 2003) is not relevant because this analysis approach is an aggregation of simple probabilities. Reliability in the form of consistent responses over multiple measurements (Creswell 2003; Chen and Krauss 2003) is present because the expert respondents were familiar with the agencies, questions, and technologies. I supported that familiarity with hundreds of summaries of office-level work and with definitions for each of the technologies. Objectivity in the form of unbiased inquiry (Crano et al. 2014; Hammersley 2003) was met by the fact that none of the expert respondents has a particular interest or connection with any of the responses or the outcomes of this research.

This was the right approach for this part of the methodology because it provided the information I sought in a way that met the criteria for the overall methodology. To gather the final set of findings about current agency use of ECT, I conducted individual interviews with government employees at the two agencies.

3.2.3 Individual Interviews (Analysis Approach 3)

Qualitative individual interviews (Maxwell 1996) are an appropriate tool for characterizing current and potential agency use of ECT because they provide insight into the use and the considerations surrounding that use, or lack thereof. I also collected information about each employee's perceived future and other concerns they have related to agency uses of ECT.

3.2.3.1 Collect

I interviewed five government employees at the DOC and five government employees at the DOE, each of whom represented varying levels of public administration from mid-level manager through assistant secretary. One employee from each agency held a position with an explicit focus on policy and planning. An eleventh interview subject was a former DOE employee who also had served as a staffer for the US Congress and in the Executive Office of the President. These qualitative research interviews were open-ended conversations in which I sought to obtain knowledge about the employee's use of ECT for their own job and in fulfillment of the agency's strategies. I also sought answers about the employee's considerations when contemplating ECT search and adoption, each employee's view of the future, and any other considerations they thought were important to my inquiry.

Individual interviews have the benefit of adding insight and depth while allowing connections and insights into the big picture. The disadvantage is that all of the potential subjects (in this case 61,000 government employees at the two agencies (US Department of Commerce 2015a; US Department of Energy) cannot be interviewed so I selected a consistent number of typical government employees from each agency (Meyer and Booker 2001). To be consistent, I worked from the Miles and Huberman (2002) checklist to develop my interviewing strategy:

1. Relevant to the conceptual framework and research questions: Each government employee was familiar with current and potential agency use of ECT for themselves and the agency (and their lack of familiarity in some cases also was instructive);
2. Generate rich information about the phenomena: Each government employee had a lot to share about the topic;
3. Enhances the generalizability of the findings: This was not a goal of these interviews;

4. Produces believable descriptions and explanations: Given the convergence in answers between and within agencies and my personal and research experience with these agencies, the resulting descriptions and explanations are believable;
5. Is ethical: I had permission from the respondents to ask questions; ensured their comfort with pre-conversation materials; and offered a comfortable environment in their office or over the phone. I also had approval from the University of Tennessee's Institutional Review Board (please see also Appendix D, "Status of Certificate of Exemption for Human Subjects," for details); and
6. Is feasible: It was feasible to have these conversations as a mix of in-person conversations and phone conversations.

Interviews were conducted from December 2013 through February 2014 in Washington, District of Columbia; New York, New York; and by teleconference. The domain of inquiry was current and potential use of ECT by government in two main areas: 1) their work to handle the agency's day-to-day activities; and 2) the agency's work to fulfill the strategies and thus serve the nation (e.g., support economic growth or public health and welfare).

I was guided in the interviews by the questions listed in Table 6, "Types of Interview Questions," but, consistent with qualitative interview strategies, I followed the flow of the conversation and the subject's knowledge to ask additional questions or variations of these questions. I limited the interviews to these ten government employees because the overall methodology has to be reasonably implementable for other agencies and organizations and the mid-to-high-level employees had knowledge about science and technology strategy and policy.

Interviewing federal agency employees allowed me to identify areas of agreement and disagreement between the secondary sources (e.g., Congressional Budget Justifications or website information about the various offices) and actual agency employee experiences. The interviews were especially useful because they allowed me to ask detailed questions about ECT and to follow up with clarifying questions. They also yielded a great deal of information about the various approaches agency employees take when searching for ECT and the considerations agency employees must address to consider or adopt a technology for their own use or in support of the agency's strategy.

Conducting qualitative research interviews aided data collection by giving me insight into individual experiences within the agency and by revealing their knowledge about agency use of ECT on their own and in support of agency strategies. I considered two alternative collection methods: observation (Maxwell 2004) and open-ended questionnaires (Roberts et al. 2014; Krosnick 1999). Observation was infeasible because I sought a balanced set of subjects ranging from agency employees who use technology sporadically to agency employees who deal with technology portfolios daily. Observation may have yielded answers about current technology use but not the answers about current potential or future potential use. Questionnaires were infeasible because so many answers required follow up questions. Moreover, many of the people I interviewed were both busy and senior, characteristics that disinclined them to accept the interview request, much less use their time to complete a questionnaire. Qualitative interviews allowed me to explicitly address the research questions with the people who had the answers.

Table 6, "Types of Interview Questions," summarizes the interview questions I asked by the areas of inquiry. This table is best read from top to bottom and from left to right in order to follow the individual design criteria. The columns display the area of inquiry and the sample questions asked for each. Each cell displays sample interview questions.

3.2.3.2 Organize

I organized the material by typing all of the answers into Microsoft Word. I then created a QDA Miner project with one record per interview so that I could code the conversations based on the methodology.

3.2.3.3 Analyze

To analyze the interviews, I coded each record with codes for each of the two research questions, search for emerging technologies, considerations in the adoption of emerging technologies, and the imagined future. Using QDA Miner to code the information (Rapley 2007; Neuendorf 2002) allowed me to use multiple codes for the same statements, where appropriate, and allowed me to create a summary table of comments by research question, search for emerging technologies, considerations in the adoption of emerging technologies, and the imagined future, which I then synthesized.

3.2.3.4 Synthesize

I synthesized these findings by research question, area of interest, and agency (please see Chapter 4, “Findings, Results, and Meta-inferences”). This was the right approach for this part of the methodology because it allowed me to ask direct questions and visit the offices, which provided context for the answers.

This approach met the two key qualitative requirements for the overall methodology (please see also Table 5, “Evaluation of Design Criteria, Minimum Threshold, and Threshold Achieved,” for a summary by criterion and analysis approach). In particular, the trustworthiness criterion—in the form of credibility, transferability, dependability, and confirmability (Denzin and Lincoln 2008; Guba and Lincoln 1994; Given and Saumure 2008)—was met by accurately representing the conversations and the underlying context; applicability of this approach and the findings to other data in other public or private organizations; the fact that applying this approach to similar data from other organizations would produce a similar structure and the information could vary as necessary; and the findings are consistent with the data.

The first three approaches provided insight into the first research question, Are ECT being used to fulfill agency strategic plans (current use)? This last approach, individual interviews, also began to answer the second research question, Could ECT be used more extensively to fulfill agency strategic plans (potential use)? The next two approaches provide more answers to the second research question.

3.2.4 Plausibility Matrix Analysis (Analysis Approach 4)

Plausibility matrices help groups understand which connections are most probable in the future (Horizon Scanning Center 2008; United Kingdom Government 2004; Green et al. 2007), which can support prioritization for future search or investment. Plausibility matrix analysis is an appropriate tool for characterizing potential agency use of ECT because the expert respondents have knowledge about the technologies and the agency strategies and can provide informed responses about the technical feasibility of the technologies supporting the strategies now or by 2050. Finding information about those probabilities means identifying and collecting information about the technologies and agency line offices; organizing them into a matrix; collecting expert responses; and synthesizing the results into a table by agency strategy and ECT.

3.2.4.1 Collect

This analysis approach required emerging technologies, agency line office information, and agency strategies, which were collected as described for the Technology Assessment Analysis (Analysis Approach 2), above. The data matrix contained the following tabs: instructions; agency and office information that included the level within the organization, a description, and a link to the appropriate website for more information; and the actual matrix with the agency strategies on the x-axis and the ECT categories along the y-axis to produce 850 combinations of ECT and strategies.

I asked expert respondents to exercise judgment and make conclusions about an unknown quality (Amer and Daim 2013; Rohrbaugh 1979), in this case the technical feasibility of applying a particular ECT to a particular agency strategy based on the provided information about the current agency line offices; the ECT themselves; and the current agency strategies. Expert respondents were characterized by background knowledge based on education and work experience (Camerer and Johnson 1997; Meyer and Booker 2001) and the diversity of backgrounds (Meyer and Booker 2001). When considering the future, between eight and ten expert respondents are considered appropriate because they are the people with enough information about the agencies and the technologies to provide this type of input (Meyer and Booker 2001). Ten expert respondents provided information for this analysis approach.

These ten expert respondents—social and natural scientists with extensive expertise (and often doctorates) in fields ranging from management to physics—each completed the spreadsheet by coding the probability of a particular area of technology (e.g., cognitive science or quantum computing) supporting a particular strategy (e.g., DOC FY 2014 - FY 2018 Goal 1, Trade and Investment: “Expand the US economy through increased exports and inward foreign investment that lead to more and better American jobs” (US Department of Commerce 2014, 6)). Although these future events have not happened, they can have degrees of probability (Becker and Brownson 1964). The ten expert respondents coded the connection now or in the future between a funded technology and an agency strategy as follows:

- 1 = there is a 0% probability of this technology supporting this strategy by 2050;
- 2 = there is a 25% probability of this technology supporting this strategy by 2050;
- 3 = there is a 50% probability of this technology supporting this strategy by 2050;
- 4 = there is a 75% probability of this technology supporting this strategy by 2050; and
- 5 = there is a 100% probability of this technology supporting this strategy by 2050.

Three potential concerns in this analysis approach require attention: the low number of expert respondents (n = 10); the heavy reliance on expert respondents’ personal knowledge and experience; and the potential flaws in the scale. The low number of expert respondents is not a concern because I am characterizing knowledge of potential agency use and these are the expert respondents with that expertise based on their academic training and work experience. Heavy reliance on personal knowledge is not a concern in this case because I know the expert respondents and am familiar with their knowledge and experience. The potential flaws in my scale are offset by the consistent use.

Alternatives for data collection included open-ended surveys and Delphi sessions (European Commission 2014; Green et al. 2007) in which experts could independently or collectively discuss their expectations and analysis in several rounds of conversation until they aligned on their foresight expectations. None were appropriate because of the reasons mentioned for all of the previous approaches. In particular, Delphi sessions were inappropriate because I was not seeking open-ended qualitative feedback.

3.2.4.2 Organize

I organized the respondent data into an Excel spreadsheet. I also removed personally-identifying information.

3.2.4.3 Analyze

I aggregated the probabilities using the linear opinion pool technique (Jacobs 1995; Genest and McConway 1990; Stone 1961), which involves combining the experts' distributions into a new distribution with weighted responses. The even weighting of the responses (i.e., a simple mean) is appropriate because the ten expert respondents had equal personal experience with ECT in general and the agencies' potential use of them in particular. They also received the same instructions and background information prior to completing the matrix.

I conducted a sensitivity analysis (Gerdsri and Kocaoglu 2009; Caswell and Shyu 2012) of the results to understand the variability of the assessments above and below the "Current Use" threshold set in the analysis. This approach evidenced strong agreement, which is consistent with the underlying knowledge of the expert respondents and a general statistical tendency for the mean correlation between the median and true answer to increase with increasing sample size (Dalkey et al. 1969).

3.2.4.4 Synthesize

After the plausibility matrix analysis, I had a data set with the agency technologies and strategies as well as some information about the probabilities of them being connected now or in the future. These results are summarized in Chapter 4, "Findings, Results, and Meta-inferences."

As before, I considered the supra-Bayesian aggregation approach (Jacobs 1995; French 1983; Gelfand et al. 1995). However, I again discarded it because it does not increase additional analytical advantage but it does decrease transparency, one of the required criteria for the overall methodology.

This analysis approach has the advantage of meeting the methodological design criteria. It offers high transparency and coherence of inputs and outputs and high acceptability in the sense that linear opinion pooling has been used in other research (Genest and McConway 1990; Jacobs 1995; Stone 1961). This approach also met the two key quantitative requirements for the overall methodology (please see also Table 5, "Evaluation of Design Criteria, Minimum Threshold, and Threshold Achieved," for a summary by criterion and analysis approach). In particular, the external validity (generalizability) criterion (Shively 2009; Ondercin), was met by controlling the three main threats with a representative sample; a realistic environment; and no opportunity for testing effects because there was no need for pre-tests or other bewilderment of the expert respondents.

Internal validity in the form of confidence that the independent variable has a causal relationship with the dependent variable (Crano et al. 2014; Creswell 2003; Brewer 2003) is not relevant because this analysis approach is an aggregation of simple probabilities. Reliability in the form of consistent responses over multiple measurements (Creswell 2003; Chen and Krauss 2003) is present because the expert respondents were familiar with the agencies, questions, and individual technologies. I supported that familiarity with hundreds of summaries of line office work and with definitions for each of the technologies. Objectivity in the form of unbiased inquiry (Crano et al. 2014; Hammersley 2003) was met by the fact that neither the participants nor I had any interest or connection with a particular response or a general outcome to this research.

This was the right approach for this part of the methodology because it yielded informed probabilities that a particular ECT would be useful in fulfilling a particular agency strategy. It also complements the next analysis approach, crowd-sourced intelligence.

3.2.5 Crowd-sourced Intelligence (Analysis Approach 5)

To gather additional information about technologies that could be used now and in the future, I applied crowd-sourced intelligence (Howe 2006; Sunstein 2006) in which members of the general public apply trend analysis, consideration of data that is changing in a consistent direction over time (Sasuly 1934; Schwartz 1996), and forecasting, considering potential futures (1973; European Commission 2014), to offer foresight on an issue. I designed a public website, www.foresightchallenge.org, where users are presented with data and must identify an approach for using that data to address the related strategy (see Figure 2, "'Connect Technologies' Example from The Foresight Challenge"). This is an appropriate tool for characterizing potential agency use of ECT because crowd-sourced intelligence is a "…process by which the power of the many can be leveraged to accomplish feats that were once the province of a specialized few" (Howe 2006, 1; Sunstein 2006). Crowd-sourcing speeds medical advances (Swan 2012; Ranard et al. 2014), earthquake damage assessments (Barrington et al. 2012), and disaster relief (Gao et al. 2011), among other activities. In addition, it allows for general public answers to a problem; the value of those answers or prioritizations can be used as they are or can be further vetted by experts.

3.2.5.1 Collect

Data were collected in two parts: collecting the data for the website databases and collecting data from answers on the site. To build the website databases, I collected emerging technologies, agency strategies, platforms, global trends, potential futures, and societal risks/benefits, as described above. The data collected from the answers on the website include potential uses of ECT for fulfilling agency strategies; the technical feasibility of that technology fulfilling that strategy by 2050; and the societal benefit of that technology fulfilling that strategy. I also collected information about the particular societal benefit areas supported.

In part one, building the website databases, I collected the following data to populate the website databases:

- Agency missions and strategies as listed in the agency strategic plans (count = 50);
- Emerging technologies per extensive searches of agency grants awarded and the literature searches detailed below (count = 1110);
- Platforms based on literature searches (count = 73). The platforms are all nouns and that list on an extensive search of the various platforms that are supporting or could support converging technologies. The criteria for adding a new platform to the list are that it had to appear: 1) in the list of emerging technologies; or 2) individual searches of nouns related to technology;
- Global trends and forecasts based on the Tonn (2010) global trends and forecasts list and expanded via an extensive search (count = 363). The Tonn global trends and

forecasts list reflects more than half a decade of research and collection and is divided into topic areas ranging from socio-demographic to technological. For trends, defined as the tendency of a set of variables to increase or decrease over time (Clarke 2003; Bianchi et al. 1999; Schwartz 1996), sample data are based on the same month/period/quarter wherever possible to minimize seasonal variability effects. For forecasts, in this case potential future events in a particular topic area, sample data also are based on consistent timing and ranges wherever possible;

- Potential futures based on sets of medium- and long-range scenarios by the United Nations Economic Program (2007) and the Intergovernmental Panel on Climate Change (2000), respectively (count = 8);
- Societal risks/benefits based on President Obama's Executive Order: "[o]ur regulatory system must protect public health, welfare, safety, and our environment while promoting economic growth, innovation, competitiveness, and job creation" (Executive Office of the President 2011) (count = 7); and
- Data collection for converging technologies was not necessary because they are defined as the combination of an emerging technology with another emerging technology or on a platform.

The emerging technologies list is based on a variety of sources, among them:

- Massachusetts Institute of Technology's *Technology Review* (Massachusetts Institute of Technology 2013). This list, curated by the senior editors at the publication, is an appropriate foundational measure of emerging technologies because the editors are immersed in technology news, especially regarding emerging technologies. Also, the *Technology Review* has published the lists consistently since 2003, which provides an eleven-year history with ten emerging technologies per year;
- Annotated bibliographies published on Kurzweil's Accelerating Intelligence website (Kurzweil 2013);
- Articles from *The Futurist: A Magazine of Forecasts, Trends, and Ideas about the Future* (World Future Society 2013a);
- Articles from *World Future Review: A Journal of Strategic Foresight* (World Future Society 2013b);
- Projects funded (and not canceled) by the Department of Defense's Defense Advanced Research Projects Agency (Defense Advanced Research Projects Agency 2013); Office of the Director of National Intelligence's Intelligence Advanced Research Projects Agency (Intelligence Advanced Research Projects Activity 2013); and the Department of Energy's Advanced Research Projects Agency – Energy (Advanced Research Projects Agency - Energy 2013). These are especially helpful because they are examples of indirect tools for government action (Kettl 2015);
- Breakthroughs in the European Union (cf. Future Emerging Technologies Flagship Initiatives (European Commission 2013) or Imec (Imec 2013), Korea (cf. (Seoul National University 2013)), and Israel (Samid 2009);
- Papers from International Conferences such as the International Conference & Expo on Emerging Technologies for a Smarter World (Center of Excellence in Wireless & Information Technology 2013), MIT Technology Review EmTech (MIT

[Massachusetts Institute of Technology] Technology Review 2013), and O'Reilly Emerging Technology Conference (O'Reilly Media 2013); and

- The annual list from the World Economic Forum Global Agenda Council on Emerging Technologies (World Economic Forum 2013).

Work performed by National Nanotechnology Initiative Centers and Networks, work performed by biotechnology research centers, and projects funded by venture capitalists (e.g., Intel Capital, Felicis Ventures, Sequoia Capital, First Round Capital, or Kickstarter.com) was captured in part through the MIT and Kurzweil lists.

Relative to potential uses of ECT, global trends and forecasts underpin thinking about the future as extensions of the past or in its own right. Global trends could include the increase in US cities with more than one million inhabitants (by count) (Gibson 1998; Fey 2012); the decrease in the growth rate of people working from home (Global Workplace Analytics 2013); or the increase in the daily average volume of foreign exchange transactions (in US dollars) (Bank for International Settlements 2013). The list is based on trends published in bestselling books like *Megatrends* (Naisbitt and Cracknell 1984), popular press publications such as the *New York Times* or the *Wall Street Journal*, and journals such as *Futures*.

Relative to potential uses of ECT, potential futures also support futures thinking. However, few scholars or organizations publish general lists of scenarios so lists of potential futures are rare or incomplete. Most scenarios are written for a particular line of business or area of study. In fact, the two sets of futures scenarios I chose were published for environmental studies, but they are appropriate for this research because they do not have an environmental focus and are collectively exhaustive and mutually exclusive (Rasiel 1999; Minto 1996). The four medium-term regional and global scenarios (United Nations Environment Programme 2007) are organized by the underlying societal focus: Markets First, Policy First, Security First, and Sustainability First whereas the four long-term regional and global scenarios (Intergovernmental Panel on Climate Change 2000) range from a world with rapid economic growth to a world with local solutions for economic, social, and environmental sustainability. Together, these medium- and long-term scenarios offer eight different views of the future, each of which could lead to different ways of characterizing potential agency use of technology.

To avoid classified material—and to minimize conversations about harming others—all data for and from the website excludes content or answers that are intelligence- or defense-related.

In part two of the data collection, I designed a website interface and instructions that were intuitive and engaging. I based the connections between agency strategies, ECT, platforms, global trends/forecasts, and potential futures on the literature review and the underlying theories of this research. I based the technical feasibility (probability) and societal benefit (priority) scales on the literature on Likert-type scale development (Likert 1974; Hinkin 1995; Clark and Watson 1995), choosing to include an odd number of choices because the scale with my preferred language came in either five or seven choices (Vagias 2006) even though it may produce a slightly higher mean score than an even number of choices (Dawes 2008). The importance of wording that denotes a mostly equal step between each code to produce interval data (Carifio and Perla 2007) was satisfied by an existing list of Likert-type scale response anchors (Vagias 2006).

To connect technologies to agency strategies, users visit www.foresightchallenge.org (Stiefel 2015). After reading the case details, the user answers with an approach to connecting the ECT, platform, global trend or forecast, and potential future with the agency strategy. They can hover over any term for a description and reference. If the user does not want to consider the content in a particular box, he or she clicks the corner of the box to delete it. If the user does not want to answer or does not want the answer to be counted (e.g., if practicing), he or she clicks "Skip Case." The user concludes by clicking to account for the societal benefits and risks of the answer; to note the priority for federal investment (considering only the societal benefits and risks); and to note the probability that this technology or these technologies could support the provided strategy by 2050 (considering only the technical feasibility). Users must consider at least one ECT and the given agency strategy to submit a case or users can choose to "Skip Case." Please see the example in Figure 2, "'Connect Technologies' Example from The Foresight Challenge."

Figure 2 shows a sample entry screen for connecting ECT with agency strategies. Consistent with the concepts of producing converging technologies by combining two emerging technologies or by combining one emerging technology on a platform, this figure depicts the website's approach to serving up at least one emerging technology and then randomly adding another emerging technology, a platform, or both. This allows the agency strategy to be connected with a potential use of an emerging and/or converging technology. The figure also displays a randomly added global trend and a potential future so that the user also can consider the direction of a change or the potential future in which the change is already a fact. As the figure shows, the site allows the user to ignore all of the factors except the agency strategy and at least one of the emerging technologies in case the factors are nonsensical or, more likely, in case the user is unable to consider all of the factors simultaneously. Gaining insight into variations in mixes of converging technologies, global trends, and potential futures using those data prompts also is helpful. This figure is best read from left to right to follow the individual factors and then from top to bottom to consider the answer and the various societal benefits, risks, and ratings.

To rate other users' answers for technical feasibility (probability) and societal benefit (priority), users visit www.foresightchallenge.org (Stiefel 2015). After reading the case details, the user may click to note the priority for federal investment (considering only the societal benefits and risks); and the probability that this technology or these technologies could support the provided strategy by 2050 (considering only the technical feasibility). Please see the example in Figure 3, "'Rate Other Answers' Example from The Foresight Challenge."

Figure 3 shows a sample entry screen for rating other users' answers. Consistent with the concept of learning what the mix of respondents on the website think about the various answers, this allows the answer provided by another user to be rated based on the priority for federal investment (from not a priority to essential) and based on the probability of this technology supporting this strategy by 2050 (from 0% to 100%). This figure is best read from left to right to follow the individual factors and then from top to bottom to consider the answer and the various societal benefits, risks, and ratings.

Users learned about the website through a variety of avenues. I shared the information with researchers via colleagues and friends. I shared the information with government employees via the Chief Information Officers and Chief Technology Officers at the DOC and DOE and the individual interview subjects. I shared the information with the general public via the creators of related foresight websites (George Washington University 2015; George Mason University 2015; Code for America 2014) and colleagues. In each communication, I invited people to participate and to share the link with their friends and colleagues. Given that there are 1.4×10^{13} (14,947,985,052,000) possible cases, and given the potential variety of ideas for each case, there are plenty of opportunities to engage for any number of people to provide any type of information, the definition of crowd-sourced. Analysis in this research is based on the initial 23 registered users who entered 62 answers.

Alternatives for data collection included addressing each of the cases myself; assigning cases to respondents, including those who informed the technology assessment analysis and plausibility matrix analysis; or using a genetic algorithm, which involves solving the optimization problem using the algorithms of inheritance, mutation, selection, and crossover (Goldberg 2002; Whitley 1994) to find the most likely viable cases. None were appropriate because of the level of effort required to address so many cases and because the increased complexity of each alternative approach reduces the transparency and understandability.

3.2.5.2 Organize

Data were organized on the website so that users could interact in two different ways: to connect technologies or to rate other users' answers. Answers from the website were exported from the administrator's panel and organized in an Excel spreadsheet.

3.2.5.3 Analyze

Users analyze the data to enter two different types of answers

1. Connect technologies: For some or all of the areas of interest—emerging technology, converging technology, platform, global trend, potential future, and agency strategy—user can enter an answer or "Skip Case." They then click one or more of the societal benefits/risks. Finally, they rate their own answer based on technical feasibility (probability) and societal benefit (priority).
2. Rate other users' answers: For each answer presented by the website, users rate others users' answers based on technical feasibility (probability) and societal benefit (priority).

I analyzed user data to produce a summary table of findings in Chapter 4, "Findings, Results, and Meta-inferences," by technical feasibility (probabilities aggregated) and societal benefit (priorities aggregated). Findings and Results." I did not run diagnostics because these are descriptive data and only partially descriptive at that.

3.2.5.4 Synthesize

This was the right approach for this part of the methodology because it generated interesting answers from a mixed group of users. It also informed users and raised awareness about the opportunities to use ECT to fulfill agency strategies. The best advantage of this approach is that it acknowledges wild card technologies and applications (Taleb 2010; Committee on Forecasting Future Disruptive Technologies 2010, 2009). We can look for signposts (Schwartz 1996) that indicate unintended consequences and this approach is a great start at finding those signposts. For future applications of the methodology, however, I would consider genetic algorithms and ontological matching, with the descriptions, advantages, and disadvantages mentioned above.

Still, as implemented, this approach met the two key qualitative requirements for the overall methodology (please see also Table 5, "Evaluation of Design Criteria, Minimum Threshold, and Threshold Achieved," for a summary by criterion and analysis approach). In particular, the trustworthiness criterion—in the form of credibility, transferability, dependability, and confirmability (Denzin and Lincoln 2008; Guba and Lincoln 1994; Given and Saumure 2008)—was met by accurately representing the matrix and the collected data; applicability of this approach and the findings to other data in other public or private organizations; the fact that applying this approach to similar data from other organizations would produce similar results; and the findings are consistent with the data.

3.2.6 Integrating the Approaches

These approaches are connected by the agency use questions they answer (e.g., Approaches 1, 2, and 3 each answer questions about current agency use of ECT while Approaches 3, 4, and 5 answer questions about potential use) and the sources they use (e.g., Approaches 2 and 4 both rely on experts whereas Approaches 3 and 5 rely on information from the agencies themselves). Also important, Approaches 2, 4, 5, and 6 include a measure for the technical feasibility (probability) of the ECT supporting the agency strategies and Approaches 5 and 6 also include a measure for societal benefit (priority). Please see Figure 4, "Integrating the Approaches," for a visual summary of the relationships between the agency current and potential uses; the data sources; and the analysis approaches. This figure is best read from bottom to top to follow the individual analysis approaches and the related sources.

Approach 6, visual analytics, addressed in the next section, is designed to evaluate both the current and potential uses research questions using these findings and results. I also discuss the integration of this sixth approach with the other five approaches.

3.3 Evaluating the Methodology

I evaluated the methodology by reconsidering the defined problem and identifying gaps in the development, application, evaluation, or dissemination, and I employ Analysis Approach 6, visual analytics, to consider the connections between the various findings and results.

3.3.1 Reconsider the Defined Problem

Reconsidering the defined problem requires asking a series of questions: Is this defined problem still relevant? In what ways should it be restated or changed completely? Given the literature review, are there other questions I should be asking? Given the findings, results, and meta-inferences (Tashakkori and Teddlie 2010), should the current problem be redefined? Are there new problems that must be defined and addressed? Answers to these questions provided no reasons to reconsider the defined problem.

3.3.2 Identify Gaps

I identified gaps in the application of the methodology by considering the overall methodology, each approach, and the gaps in the application of each approach. Then, I created visual analytics (Thomas and Cook 2006) to support the evaluation of the gaps.

3.3.2.1 Gaps in Developing

The biggest challenge in developing the methodology was distinguishing the construct for ECT and distinguishing potential current use versus potential use in the future. Distinguishing the construct for ECT was handled by including all ECT in the model without distinction. Similarly, distinguishing potential current use versus potential use in the future also was not important to this research because any potential use can help fulfill an agency strategy and the technical feasibility provides probability information about that likelihood.

3.3.2.2 Gaps in Applying

Gaps in applying are identified by identifying gaps in collection, organization, analysis, or synthesis. For clarity, I detailed each of those potential gaps in the next subsection, 3.3.3, "Analyze Gaps." As a whole, however, four items are worth nothing relative to collection, organization, analysis, and synthesis. First, the gaps in current use and potential use collection are inevitable aspects of this study. As anticipated, the lack of centralized or coordinated federal data collection approach and individual agency unwillingness to participate drove those gaps, as did expert respondent disagreement about current uses. Also anticipated, the infinite nature of the potential futures and cases drives the gaps in the potential use collection. Neither of these gaps detracts from the quality or utility of the conclusions because the design and application of this methodology still provides important information about the categories of ECT that are or could be used, including technical feasibility (probabilities) and societal benefit (priorities) ratings.

Second, gaps in organization are unlikely given my careful attention to detail. However, data, findings, and results are available in the attachments as "File 1. Data" and "File 2. Findings and Results" to allow verification of the data organization and the replication of the attendant findings and results.

Third, for each approach, the analysis was carefully conducted to avoid incorrect results or conclusions. As noted in each approach section, there were trade-offs in the analysis and the diagnostics that must be considered in future applications of the methodology, but none was sufficient to generate concerns with the overall methodology or the findings and results. Critics could argue for more complex analysis approaches. However, given the criterion for utility to policymakers, and given the possibility of illiteracy and innumeracy in the executive and legislative branches of government, I chose to keep the methodology useful and the findings and results accessible to as many people as possible.

Fourth, when synthesizing the work as a whole, including the research questions, propositions, analysis, and results, the work is logically connected. The methodology addresses the defined problem as summarized in Figure 1, "Developed Methodology with Phases," and the approaches are integrated as summarized in Figure 4, "Integrating the Approaches." There are no gaps in the synthesis because the synthesized research meets the evaluation criteria (please see the summary in Table 5, "Evaluation of Design Criteria, Minimum Threshold, and Threshold Achieved") and answers the two research questions. However, the findings and results produced a gap as a function of the gaps in collection noted above, which is why this is a pilot application of the methodology. The visual analytics in the next subsection highlight those gaps for transparency and as a starting point for future researchers.

3.3.3 Analyze Gaps

Visual analytics is an emerging field in computer graphics characterized by the creation of images that display large amounts of data simply and intuitively to highlight patterns and connections in large, complicated data sets (Thomas and Cook 2006; Keim et al. 2008; Chen 2008; Börner 2010; Lima 2011). I used visual analytics to support visual reasoning (Thomas and Cook 2006) about the connections between technologies and agency strategies, whether current or potential, and to highlight the gaps in synthesis that arise as a function of the gap in collection, as discussed above. Visual analytics are an appropriate approach because they are designed to find interdisciplinary solutions based on complex, inter-related data (Keim et al. 2008; Thomas and Cook 2006; Thomas et al. 2009; Chen 2008) of the type found in this research.

3.3.3.1 Collect

Data for this approach were the findings and results tables from the first five analysis approaches.

3.3.3.2 Organize

The data were organized into a series of tables as required by the software, Tableau (Chabot et al. 2003), which is one of the software platforms that facilitates analytic data visualizations. The advantage of Tableau is that it produces interactive visual displays of the data that allow more or less access to detail as the user wishes. It also is intuitive so the resulting visual analytics are useful and accessible for other researchers, policymakers, and the general public.

3.3.3.3 Analyze

I created interactive visual analytics of the results using Tableau (Chabot et al. 2003) and embedded static images below and included the source files as attachments. Consistent with the terms of the Institutional Review Board's Human Subjects approval (see Appendix D, "Status of Certificate of Exemption for Human Subjects Research"), I did not include the data from the individual interviews.

Visual analytics are distinguished by the interactive nature of the visual: Users can change dimensions and drill for detail, and the data can be updated in near-real-time. Visual analytics are appropriate for evaluation of the research results because they present a new way of seeing the big picture and highlight gaps and anomalies. Here, I provide the figures that best present the big picture while also highlighting gaps and anomalies for each analysis type and between analysis types.

3.3.3.4 Synthesize

The findings from this analysis are a series of images that depict the gaps in technologies applied to strategies as identified via content analysis, technology assessment analysis, plausibility matrix analysis, and crowd-sourced intelligence. I considered alternative software platforms including Circos, a platform for visualizing data in a circular layout (Circos 2013), and Gephi, a platform for visualizing networks and complex systems (Gephi 2015), but neither supported the intuitive interactive experience offered by Tableau (Chabot et al. 2003).

As implemented, this approach met the two key qualitative requirements for the overall methodology (please see also Table 5, "Evaluation of Design Criteria, Minimum Threshold, and Threshold Achieved," for a summary by criterion and analysis approach). In particular, the trustworthiness criterion—in the form of credibility, transferability, dependability, and confirmability (Denzin and Lincoln 2008; Guba and Lincoln 1994; Given and Saumure 2008)—was met by accurately representing the results in visual form; applicability of this approach and the findings to other data in other public or private organizations; the fact that applying this approach to similar data from other organizations would produce similar results; and the findings are consistent with the data.

3.3.4 Assess the Methodology

The methodology is assessed by comparing the developed and applied methodology to the design criteria (see Table 5, "Evaluation of Design Criteria, Minimum Threshold, and Threshold Achieved"). I found no places where the methodology fails to meet the minimum evaluation threshold, but if I had, I could resolve the problem by cycling back through the phases of the methodology.

3.3.5 Integrating with the Other Phases

The evaluating phase integrates with the other phases by requiring the evaluation and attendant gap analysis to highlight the work accomplished in the other phases and the work still to be done. Someday, researchers will be able to evaluate this work by studying policy changes over time in this area. For now, the visual analytics figures are an important part of characterizing and evaluating current and potential agency uses of ECT.

3.4 Disseminating the Methodology

Including dissemination as a research phase supports and increases the utility and transferability of the methodology and results. The methodology's success—as measured by theoretical updates to the methodology or practical use of the results—depends upon others knowing about it.

To disseminate the methodology and results, and consistent with the Data Management Plan in Appendix C, I used a mix of approaches:

- Members of academia: Data and results in the Dataverse Network data repository and any manuscripts published from this work
- Policymakers: Data and results on www.foresightchallenge.org (Stiefel 2015) and the policymaker summary document (for the interviewees, Chief Information Officers (CIO), Chief Technology Officers (CTO), and specific Members of Congress)
- General public: Data, results, and policymaker summary document on www.foresightchallenge.org (Stiefel 2015)

3.4.1 Outreach to Members of Academia

This research primarily was disseminated to members of academia through the data, findings, and results posted to the Institute for Quantitative Social Science's (IQSS) Dataverse Network data repository and through any manuscripts I will publish from this work. I posted all of the files attached to this dissertation to IQSS, which included the data, results and findings, policymaker documents, and all of the visual analytics files.

3.4.2 Outreach to Policymakers

Policymakers have access to the files I posted to the Dataverse Network because I also posted them to www.foresightchallenge.org (Stiefel 2015). I also produced an executive summary document and distributed it to the agency employees I interviewed, Chief Information Officers, Chief Technology Officers, and some Members of Congress.

3.4.3 Outreach to the General Public

The general public has access to the data, findings, and results via www.foresightchallenge.org (Stiefel 2015) and to the executive summary document I distributed to policymakers.

3.4.4 Integrating with the Other Phases

The disseminating phase integrates with the other phases by requiring me to make the information about the previous three phases available to members of academic, policymakers, and the general public.

Chapter 4
Findings, Results, and Meta-inferences

The findings and results characterize current and potential agency use of ECT in the context of the agency strategies. They also allow interesting comparisons of the "meta-inferences," the synthesis of the findings and results from the mixed methods study (Tashakkori and Teddlie 2010).[5]

4.1 Findings from Developing the Methodology

The theoretical work to develop the methodology resulted in the methodology summarized in Figure 1, "Developed Methodology with Phases." The findings from developing the methodology are detailed in Section 3.1, "Developing the Methodology," because the subsequent application, evaluation, and dissemination phases depended on the development.

4.2 Findings and Results from Applying the Methodology

Applying the methodology resulted in a set of findings and results about current and potential use of ECT by agency strategy. The results presented here detail ECT use for the main goals from each agency (five for DOC and three for the Department of Energy).

4.2.1 Findings from Content Analysis (Analysis Approach 1)

Content analysis produced two sets of results: 1) current use of ECT by agency strategy (based on the two agencies' strategic plans (US Department of Energy 2014; US Department of Commerce 2014)); and 2) an overview of current use of ECT by agency (based on agencies' strategic plans (US Department of Commerce 2014; US Department of Energy 2014); Congressional Budget Justifications (US Department of Commerce 2015b; US Department of Energy 2015); and, in the case of the DOE, Quadrennial Technology Reviews (US Department of Energy 2011a, 2012)).

The analysis of the use of ECT by agency strategy—studying just the agencies' strategic plans—identified 44 mentions of ECT (20 for the DOC; 24 for the DOE) across the two documents totaling 88 pages. The analysis by all of the strategy documents identified 1996 mentions of ECT (862 for the DOC; 1134 for the DOE) across the 32 documents totaling 6331 pages. The counts of ECT mentions by each strategy in the strategic plans and sample statements from the strategic plans are summarized in Table 7, "Current Use of Emerging and Converging Technologies per Content Analysis of Strategic Plans (by Agency Strategy): Department of Commerce," and Table 8, "Current Use of Emerging and Converging Technologies per Content Analysis of Strategic Plans (by Agency Strategy): Department of Energy."

Table 7 summarizes the number of times a particular ECT is mentioned in relation to a particular DOC agency strategy. This table is best read from top to bottom to follow the ECT and then from left to right to follow the agency strategies. The columns list each of the agency goals; the rows list the ECT. Each cell contains the actual count of the times the technology is mentioned relative to that goal. If a particular ECT is mentioned relative to a goal, I also include

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[5] Data, findings, results, the policymaker summary, and the visual analytics files are in the nine attachments.

an example of the relevant mention. For example, energy technology is mentioned once in the context of the DOC Goal 3, Environment: "Boost exports of environmental and clean energy technologies (ITA [International Trade Administration])" (US Department of Commerce 2014, 27).

By ECT, this table reveals that specific ECT are mentioned rarely in the actual agency strategic plans. For the DOC, most of the mentions are in the context of the Internet. For example, in the context of supporting DOC Goal 3, Environment, the DOC strategic plan references, "Digital Coast is a web platform providing coastal geospatial information. The number of communities using Digital Coast is based on Census-designated places within coastal states, including all Census-defined cities, towns, townships, boroughs, and incorporated municipalities" (US Department of Commerce 2014, 42). By goal, this table reveals that DOC Goal 2, Innovation (13 mentions), and DOC Goal 3, Environment (5 mentions), are most likely to mention ECT for fulfilling those goals. The takeaway from this table is that the DOC strategic plan has few mentions of ECT and those mentions mostly are related to current use of ECT to fulfill DOC Goal 2, Innovation, and DOC Goal 3, Environment.

Table 8 summarizes the number of times a particular ECT is mentioned in relation to a particular DOE agency strategy. This table is best read from top to bottom to follow the ECT and then from left to right to follow the agency strategies. The columns list each of the agency goals; the rows list the ECT. Each cell contains the actual count of the times the technology is mentioned relative to that goal. If a particular ECT is mentioned relative to a goal, I also include an example of the relevant mention. For example, energy technology is mentioned once in the context of the DOE Goal 1, Science and Energy: "Conduct discovery-focused research to increase our understanding of matter, materials and their properties through partnerships with universities, national laboratories, and industry" (US Department of Energy 2014, 10).

By ECT, this table reveals that specific ECT are mentioned rarely in the actual agency strategic plans. For the DOE, most of the mentions are in the context of energy technology. For example, in the context of supporting DOE Goal 1, Science and Energy, the DOE strategic plan references, "Goal 1: Science and Energy. Advance foundational science, innovate energy technologies, and inform data driven policies that enhance US economic growth and job creation, energy security, and environmental quality, with emphasis on implementation of the President's Climate Action Plan to mitigate the risks of and enhance resilience against climate change." (US Department of Energy 2014, 3). By goal, this table reveals that DOE Goal 1, Science and Energy (14 mentions) is most likely to also have mentions of ECT for fulfilling the goal. The takeaway from this table is that the DOE strategic plan has few mentions of ECT and those mentions mostly related to current use of ECT to fulfill DOE Goal 1, Science and Energy.

I also analyzed the current use of ECT based on the 6331 pages in the strategic documents: strategic plans, Congressional Budget Justifications, and the Quadrennial Technology Reviews. Those findings are summarized in Table 9, "Current Use of Emerging and Converging Technologies per Content Analysis (by Agency)." The purpose of Table 9 is to summarize the number of times a particular ECT is mentioned in the full set of agency strategic documents, which includes the agency strategic plans, the congressional budget justification documents, and the quadrennial technology review (DOE only). This table is best read from top to bottom to follow the ECT and then from left to right to follow the agency strategies. The columns list each of the agency goals; the rows list the ECT. Each cell contains the actual count of the times the technology is mentioned relative to all of the strategic documents. If a particular

ECT is mentioned relative to an agency's documents, I also include an example of the relevant mention. For example, cognitive science is mentioned twice in the DOE strategic documents and the relevant mention is, "This philosophy extends further to the role of operator simulation environments as a platform for validation of the impact of the tools and techniques on decision-making processes. Decision support, cognitive task analysis, and visualization (i.e., human factors side of planning and operations) will be important to the effective implementation of new tools and models" (US Department of Energy 2012, 160).

By ECT, this table reveals that specific ECT are mentioned more often in the agency strategic documents than in the strategic plans alone. For the DOC, most of the mentions are in the context of the materials (advanced) (235 mentions). For example, in the context of supporting DOC strategies, the documents reference, "Complementary expertise at NIST and partner consortium CHiMaD [Center for Hierarchical Materials Design] to address critical materials challenges in both 'hard' (inorganic) and 'soft' (organic) advanced materials in fields as diverse as self-assembled biomaterials, smart materials for self-assembled circuit designs, organic photovoltaic materials, advanced ceramics and metal alloys" (US Department of Commerce 2015b, NIST-110). By agency, this table reveals that the DOE documents mentions ECT quite a few more times than the DOC documents (862 mentions versus 1134 mentions).

This analysis approach identified current use of all areas of ECT, except geoengineering. However, the following ECT were mentioned fewer than ten times, which indicates little current use:

- For the DOC, artificial intelligence, biotechnology, cognitive science, energy technology, geoengineering, robotics, and ubiquitous computing.
- For the DOE, artificial intelligence, biotechnology, cognitive science, geoengineering, nanotechnology, robotics, space (outer), and ubiquitous computing.

The disproportionately heavy reliance on space (outer) (122 mentions) ECT at the DOC makes sense given extensive satellite programs, as does the heavy departmental reliance on energy technologies (216 mentions) at the DOE given the department's mission. Consistent with the literature review, and as measured by the portion of the strategic plans that mention ECT, there is some current use of ECT but little strategic planning for ECT. In the DOC strategic plan (US Department of Commerce 2014), ECT are mentioned 20 times whereas in the DOE strategic plan (US Department of Energy 2014), ECT are mentioned 24 times.

This approach provides some answers to Research Question 1, Are ECT being used to fulfill agency strategic plans (current use)? Still, additional analysis in the form of the technology assessment, Analysis Approach 2, and the individual interviews, Analysis Approach 3, is required to learn more about current agency use of ECT.

4.2.2 Results from Technology Assessment Analysis (Analysis Approach 2)

For this analysis approach, I aggregated the technology assessments using a linear opinion pool with an unweighted average (i.e., simple mean) (Genest and McConway 1990; Jacobs 1995) and displayed the results in Tables 10 through 13. I listed the linear opinion pool results with dark green color-coding if the aggregated expert opinion probability is greater than or equal to fifty percent that the ECT is being used now and light green if the probability is less than fifty percent (see Table 10, "Current Use of Emerging and Converging Technologies per Technology Assessment Analysis (by Agency Strategy): Department of Commerce," and Table

12, “Current Use of Emerging and Converging Technologies per Technology Assessment Analysis (by Agency Strategy): Department of Energy”).

The sensitivity analyses were especially strict because I wanted to know how many of the findings would change if the expert respondents moved up or down by a single response (e.g., from 50% to 75% technical feasibility). I wanted to see the details of the variation around the fifty percent probability mark. For Table 11, “Current Use of Emerging and Converging Technologies per Technology Assessment Analysis (Sensitivity Analysis): Department of Commerce,” and Table 13, “Current Use of Emerging and Converging Technologies per Technology Assessment Analysis (Sensitivity Analysis): Department of Energy,” I prepared the data by creating two new tables, one with 25% subtracted from the aggregated responses and one with 25% added. If the resulting probability moved below or above the fifty percent threshold for a particular technology, I coded it orange and red on the chart, respectively. Because of the subtraction and addition, the scale for these responses ran from -25% to 125%.

Table 10 summarizes the linear opinion pool aggregation (simple mean) of the individual experts’ assessment (n = 4) of the current probability that a particular ECT is being used to fulfill a particular DOC strategy. This table contains data that underlie Figure 6, “Visual Analytics of Technology Assessment Analysis (Approach 2),” which is the visual display of these data combined with the data from Table 12, “Current Use of Emerging and Converging Technologies per Technology Assessment Analysis (by Agency Strategy): Department of Energy.” The table is best read from top to bottom and from left to right to follow the individual ECT. The columns display the various agency goals; the rows display the various ECT. Each cell displays the linear opinion pool aggregation (simple mean) of the individual experts’ assessment of the current probability that a particular ECT is being used to fulfill a particular agency strategy. Cells highlighted in dark green have a fifty percent or greater probability of currently being used. Cells highlighted in light green have a less than fifty percent probability.

In particular, the table highlights low (lower than fifty percent for the majority of the goals) probabilities for current use of biotechnology (averages 41%), cognitive science (averages 39%), geoengineering (averages 33%), quantum (usually computing) (averages 41%), space (outer) (averages 37%), ubiquitous computing (averages 46%), and virtual reality (averages 18%). Relative to DOC, the figure reveals that the most probable current uses of ECT are for DOC Goal 1, Trade and Investment (13 ECT ≥ 50%), DOC Goal 2, Innovation (15 ECT ≥ 50%), and DOC Goal 3, Environment (9 ECT ≥ 50%) (based on the majority of the ECT for those goals having probabilities of fifty percent or greater). Little ECT use is probable for DOC Goal 4, Data (5 ECT ≥ 50%), and DOC Goal 5, Operational Excellence (3 ECT ≥ 50%). The takeaway from this table is that some ECT probably are being used to fulfill specific agency goals, but many more are not at all likely to be used currently.

Table 12 summarizes the linear opinion pool aggregation (simple mean) of the individual experts’ assessment of the current probability that a particular ECT is being used to fulfill a particular DOE strategy. This table contains data that underlie Figure 6, “Visual Analytics of Technology Assessment Analysis (Approach 2),” which is the visual display of these data combined with the data from Table 10, “Current Use of Emerging and Converging Technologies per Technology Assessment Analysis (by Agency Strategy): Department of Commerce.” The table is best read from top to bottom and from left to right to follow the individual ECT. The columns display the various agency goals; the rows display the various ECT. Each cell displays the linear opinion pool aggregation (simple mean) of the individual experts’ assessment of the current probability that a particular ECT is being used to fulfill a particular agency strategy. Cells highlighted in dark green have a fifty percent or greater probability. Cells highlighted in light green have a less than fifty percent probability.

In particular, the table reveals the low (lower than fifty percent for the majority of the goals) probabilities for current use of biotechnology (averages 33%), cognitive science (averages 19%), energy technology (averages 38%), geoengineering (averages 25%), space (outer) (averages 21%), ubiquitous computing (averages 40%), and virtual reality (averages 22%). The low probable current uses of ECT are for DOE Goal 1, Science and Energy (12 ECT ≥ 50%), and DOE Goal 2, Nuclear Energy (10 ECT ≥ 50%) (based on the majority of the ECT for those goals having probabilities of fifty percent or greater). Little ECT use is probable for DOE Goal 3, Management and Performance (3 ECT ≥ 50%). The takeaway from this table is that some ECT probably are being used to fulfill specific agency goals, but many more are not at all likely to be used currently.

Table 11 displays the findings of the sensitivity analysis relative to expert assessments' probabilities about current ECT use at DOC. The sensitivity analysis identifies shifts above or below fifty percent probability given a hypothetical average change in the expert respondents' answers. This table is best read from top to bottom and from left to right to follow the individual ECT and the agency goals. The columns display the various agency goals; the rows display the various ECT. Each cell displays the new values for the probability the agency currently is using a particular ECT to fulfill a particular agency goal. These values are based on shifting the average expert response both up and down absolutely by 25%.

In particular, items highlighted in red indicate items for which the probability of current use to fulfill the agency strategy increases to equal or exceed fifty percent if the averaged response is increased by 25% in absolute terms. This is a large increase in proportion to the five-point scale, which produces a conservative sensitivity analysis. Items highlighted in red are, for the most part, highlighting expert respondent sensitivity to these increases in probabilities for DOC Goal 4, Data (10 ECT increase to ≥ 50%), and DOC Goal 5, Operational Excellence (12 ECT increase to ≥ 50%). Across the rows, there is consistent sensitivity to an increase in the averaged expert respondents' assessment across all five goals regarding DOC use of geoengineering. Items highlighted in orange indicate items for which the probability of current use to fulfill the agency strategy decreases to less than fifty percent if the averaged response is decreased by 25% in absolute terms. This is a large decrease in proportion to the five-point scale, which produces a conservative sensitivity analysis. Items highlighted in orange are, for the most part, highlighting expert respondent sensitivity to these decreases in probabilities for DOC Goal 1, Trade and Investment (10 ECT < 50%), and DOC Goal 2, Innovation (7 ECT < 50%). Across the rows, there is no consistent sensitivity to the decrease that crosses all five goals.

Table 13 analyzes how the findings about current ECT use at DOE shift given a hypothetical change in the expert respondents' answers. This table is best read from top to bottom and from left to right to follow the individual ECT and the agency goals. The columns display the various agency goals; the rows display the various ECT. Each cell displays the new values for the probability the agency currently is using a particular ECT to fulfill a particular agency goal. These values are based on shifting the average expert response both up and down absolutely by 25%.

In particular, items highlighted in red indicate items for which the probability of current use to fulfill the agency strategy increases to equal or exceed fifty percent if the averaged response is increased by 25% in absolute terms. This is a large increase in proportion to the five-point scale, which produces a conservative sensitivity analysis. Items highlighted in red are, for the most part, highlighting expert respondent sensitivity to these increases in probabilities for DOE Goal 3, Management and Performance (9 ECT ≥ 50%). The rows show consistent sensitivity across all five goals regarding DOE use of interfaces, quantum (usually computing), and ubiquitous computing. Items highlighted in orange indicate items for which the probability of current use to fulfill the agency strategy decreases to less than fifty percent if the averaged response is decreased by 25% in absolute terms. This is a large decrease in proportion to the five-point scale, which produces a conservative sensitivity analysis. Items highlighted in orange are, for the most part, highlighting expert respondent sensitivity to these decreases in probabilities for DOE Goal 1, Science and Energy (8 ECT < 50%). Note that the first two ECT are sensitive to decreases in probabilities for the first two goals and to increases in probabilities for the last goal. The last ECT, ubiquitous computing, is sensitive to increases in probabilities for the first goal and decreases in probabilities for the last two goals.

As the sensitivity tables reveal, the findings are sensitive to shifts in respondent answers. This is expected given the overall scale of the responses and my interest in movement of the probabilities in the middle of the scale. Geoengineering, for example, moves over the fifty percent probability of use threshold at the DOC for all five goals and only moves under the fifty percent probability of use threshold at the DOE for DOE Goal 1, Science and Engineering. DOC Goal 3, Environment, Goal 4, Data, and Goal 5, Operational Excellence, and DOE Goal 1, Science and Energy, have most of the technologies shifting into the fifty percent and above probability range with the addition of 25% probability.

This analysis approach indicates some current use of all of the ECT except geoengineering and virtual reality at the DOC and current use of all of the ECT except cognitive science, space (outer), and virtual reality at the DOE. These findings indicate the advantages of applying a multi-methods approach, especially in overlaying content analysis with intimate human subject matter knowledge. It also indicates the advantages of distinguishing ECT use by strategy to understand particular uses at a more detailed level. Consistent with the literature review, and as measured by the averaged responses that indicated a fifty percent or more probability of current use for a particular strategy, agencies currently use some ECT to fulfill strategies in agencies. Also consistent with the literature review, there are quite a few ECT for which averaged responses indicate a less than fifty percent probability of current use for a particular strategy, which means that it is unlikely that they currently are being used.

This approach provided some new answers to Research Question 1, Are ECT being used to fulfill agency strategic plans (current use)? Still, additional analysis in the form of individual interviews, Analysis Approach 3, is required to learn more about current agency use of ECT and, possibly, to explain the differences in the results from the first two approaches

4.2.3 Findings from Individual Interviews (Analysis Approach 3)

Qualitative individual interviews addressed both current use and potential use. As summarized in the next table, interview subjects at both agencies had similar views on current and potential agency use of ECT: most were focused on information technologies and incremental changes to their current work as technologies—especially information technologies—change. Many wished for more time to search for and more resources to adopt technologies.

In general, interview subjects at the DOC and DOE only mentioned two ECT: information technology and the Internet. Individual interview subjects at the DOC also mentioned energy technologies, information technology, materials (advanced), and nanotechnologies. The only ECT mentioned consistently was information technology despite interviewees' intimate use of ECT in their work or to fulfill the agencies' strategies.

Table 14, "Current and Potential Use of Emerging and Converging Technologies per Individual Interviews (by Agency)," synthesizes the answers. The purpose of this table is to reveal the findings from the qualitative interviews (n = 10) by agency and consistent with the research questions and specific ECT. This table is best read from top to bottom and from left to right to follow the various interview questions by agency. The columns display the interview questions (first column) and agencies (remaining columns); the rows display the various high-level areas of questions (which map to Table 6, "Types of Interview Questions"). Each cell contains the synthesized response from that agency for that high-level area of questions.

At DOC, information technology and sensors were mentioned in the context of current use although information technology also was mentioned as a way of potentially fulfilling agency goals. At DOE, energy technology and information technology were mentioned in the context of current use whereas energy technology, materials (advanced), and nanotechnology were mentioned in the context of potential use.

This table reveals employees' dual focus on technology from the perspectives of accomplishing their day-to-day work and the agencies' mission, which is consistent with the design of this research. The findings in this table confirm that few types of ECT are consistently considered for use in either agency.

This approach provides some answers to Research Question 1, Are ECT being used to fulfill agency strategic plans (current use)? and Research Question 2, Could ECT be used more extensively to fulfill agency strategic plans (potential use)? Still, additional analysis in the form of the plausibility matrix analysis and crowd-sourced intelligence is required to learn more about potential agency use of ECT.

4.2.4 Results from Plausibility Matrix Analysis (Analysis Approach 4)

For the fourth analysis approach, plausibility matrix analysis, I aggregated the plausibility matrix responses using a linear opinion pool unweighted average (i.e., simple mean) (Genest and McConway 1990; Jacobs 1995) and displayed the results in Tables 15 through 18. Below, I list the linear opinion pool results with dark green color-coding if the aggregated expert opinion probability is greater than or equal to fifty percent that the ECT could be used in the future and light green if the probability is less than fifty percent. See Table 15, "Potential Use of Emerging and Converging Technologies per Plausibility Matrix Analysis (by Agency Strategy): Department of Commerce," and Table 17, "Potential Use of Emerging and Converging Technologies per Plausibility Matrix Analysis (by Agency Strategy): Department of Energy" for high-level results.

These sensitivity analyses were especially strict because I again wanted to know how many of the findings would change if the expert respondents moved up or down by a single response (e.g., from 50% to 75% technical feasibility). For Table 16, "Potential Use of Emerging and Converging Technologies per Plausibility Matrix Analysis (Sensitivity Analysis): Department of Commerce" and Table 18, "Potential Use of Emerging and Converging Technologies per Plausibility Matrix Analysis (Sensitivity Analysis): Department of Energy" I prepared the data by creating two new tables, one with 25% subtracted from the aggregated responses and one with 25% added. If the resulting probability moved below or above the fifty percent threshold for a particular technology, I coded it orange and red on the chart, respectively. Because of the subtraction and addition, the scale for these responses ran from -25% to 125%.

Table 15 summarizes the linear opinion pool aggregation (simple mean) of the individual experts' (n = 10) assessment of the potential probability that a particular ECT is being used to fulfill a particular DOC strategy. This table contains data that underlie, Figure 7, "Visual Analytics of Probability Matrix Analysis (Approach 4)," which is the visual display of these data combined with the data from Table 17. The table is best read from top to bottom and from left to right to follow the individual ECT. The columns display the various agency goals; the rows display the various ECT. Each cell displays the linear opinion pool aggregation (simple mean) of the individual experts' assessment of the potential probability that a particular ECT is being used to fulfill a particular agency strategy. Cells highlighted in dark green have a fifty percent or greater probability. Cells highlighted in light green have a less than fifty percent probability.

In particular, there are low (lower than fifty percent for the majority of the goals) probabilities for potential use of biotechnology (averages 44%), geoengineering (averages 37%), materials (advanced) (averages 50%), nanotechnology (averages 49%), robotics (averages 56%), and space (outer) (averages 33%). Relative to DOC, the table reveals the low mentions of ECT (as detailed above) and that the most probable potential uses of ECT are for DOC Goal 1, Trade and Investment (14 ECT ≥ 50%), DOC Goal 2, Innovation (16 ECT ≥ 50%), and DOC Goal 4, Data (11 ECT ≥ 50%) (based on the majority of the ECT for those goals having probabilities of fifty percent or greater). These are all consistent with expectations. Little potential ECT use is probable for DOC Goal 3, Environment (9 ECT ≥ 50%) and DOC Goal 5, Operational Excellence (7 ECT ≥ 50%). The takeaway from this table is that some ECT potentially could be used to fulfill specific agency goals.

Table 17 summarizes the linear opinion pool aggregation (simple mean) of the individual experts' (n = 10) assessment of the potential probability that a particular ECT is being used to fulfill a particular agency strategy at DOE. This table contains data that underlie Figure 7, "Visual Analytics of Probability Matrix Analysis (Approach 4)," which is the visual display of these data combined with the data from Table 13, "Potential Use of Emerging and Converging Technologies per Technology Assessment Analysis (by Agency Strategy): Department of Energy." The table is best read from top to bottom and from left to right to follow the individual ECT. The columns display the various agency goals; the rows display the various ECT. Each cell displays the linear opinion pool aggregation (simple mean) of the individual experts' assessment of the potential probability that a particular ECT is being used to fulfill a particular agency strategy. Cells highlighted in dark green have a fifty percent or greater probability. Cells highlighted in light green have a less than fifty percent probability.

Relevant to DOE, the table reveals low (lower than fifty percent for the majority of the goals) probabilities for potential use of biotechnology (averages 46%), cognitive science (averages 28%), geoengineering (averages 39%), robotics (averages 52%), space (outer) (averages 35%), ubiquitous computing (averages 44%), and virtual reality (averages 46%). In addition to the potential uses of ECT (as detailed above), the most probable potential uses of ECT are for DOE Goal 1, Science and Energy (11 ECT ≥ 50%), DOE Goal 2, Nuclear Security (13 ECT ≥ 50%), and DOE Goal 3 (10 ECT ≥ 50%) (based on the majority of the ECT for those goals having probabilities of fifty percent or greater). These are consistent with expectations. The takeaway from this table is that many of the ECT potentially could be used to fulfill specific agency goals.

Table 16 analyzes how the findings about potential ECT use at DOC shift given a hypothetical change in the expert respondents' answers. This table is best read from top to bottom and from left to right to follow the individual ECT and the agency goals. The columns display the various agency goals; the rows display the various ECT. Each cell displays the new values for the probability the agency currently is using a particular ECT to fulfill a particular agency goal. These values are based on shifting the average expert response both up and down absolutely by 25%.

In particular, items highlighted in red indicate items for which the probability of current use to fulfill the agency strategy increases to equal or exceed fifty percent if the averaged response is increased by 25% in absolute terms. This is a large increase in proportion to the five-point scale, which produces a conservative sensitivity analysis. Items highlighted in red are, for the most part, highlighting expert respondent sensitivity to these increases in probabilities for DOC Goal 3, Environment (8 ECT ≥ 50%), and DOC Goal 5, Operational Excellence (9 ECT ≥ 50%). Items highlighted in orange indicate items for which the probability of current use to fulfill the agency strategy decreases to less than fifty percent if the averaged response is decreased by 25% in absolute terms. This is a large decrease in proportion to the five-point scale, which produces a conservative sensitivity analysis. Items highlighted in orange are, for the most part, highlighting expert respondent sensitivity to these decreases in probabilities for DOC Goal 1, Trade and Investment (9 ECT < 50%), and DOC Goal 2, Innovation (12 ECT < 50%). Note that across the rows, there is consistent sensitivity across all five goals regarding DOC potential use of cognitive science, energy technology, materials (advanced), nanotechnology, quantum (usually computing), ubiquitous computing, and virtual reality.

The takeaway from this table is that these findings have been subjected to a rigorous and conservative sensitivity analysis and the effects on the findings of major increase or decrease in expert responses. This is helpful to see, especially because such a large shift would difficult to produce across the four averaged expert responses.

Table 18 analyzes how these findings about current ECT use at DOE shift given a hypothetical change in the expert respondents' answers. This table is best read from top to bottom and from left to right to follow the individual ECT and the agency goals. The columns display the various agency goals; the rows display the various ECT. Each cell displays the new values for the probability the agency currently is using a particular ECT to fulfill a particular agency goal. These values are based on shifting the average expert response both up and down absolutely by 25%.

In particular, items highlighted in red indicate items for which the probability of current use to fulfill the agency strategy increases to equal or exceed fifty percent if the averaged response is increased by 25% in absolute terms. This is a large increase in proportion to the five-point scale, which produces a conservative sensitivity analysis. Items highlighted in red are, for the most part, highlighting expert respondent sensitivity to these increases in none of the goals. Across the rows, there is consistent sensitivity across all three goals regarding DOE use of everything except artificial intelligence, electronics, energy technology, information technology, and space (outer). Items highlighted in orange indicate items for which the probability of current use to fulfill the agency strategy decreases to less than fifty percent if the averaged response is decreased by 25% in absolute terms. This is a large decrease in proportion to the five-point scale, which produces a conservative sensitivity analysis. Items highlighted in orange are, for the most part, highlighting expert respondent sensitivity to these decreases in probabilities for all three DOE goals: DOE Goal 1, Science and Energy (10 ECT < 50%), DOE Goal 2, Nuclear Security (10 ECT < 50%), and DOE Goal 3, Management and Performance (10 ECT < 50%).

The takeaway from this table is that these findings have been subjected to a rigorous and conservative sensitivity analysis and the effects on the findings of major increase or decrease in expert responses. This is helpful to see, especially because such a large shift would difficult to produce across the four averaged expert responses.

As the sensitivity tables reveal, the findings are especially sensitive to shifts in respondent answers. This is again expected given the overall scale of the responses and my interest in the movement around the midpoint. Cognitive science, for example, moves below the fifty percent probability of use at the DOC, for the most part, but increases at the DOE for DOE Goal 1, Science and Energy and DOE Goal 2, Nuclear Security. The columns by goal reveal that most of these answers are sensitive to decreases in probabilities, which indicates that most of the probabilities are over fifty percent but less than 75%.

This analysis approach indicates potential use of all of the ECT at both agencies, with some variation by goal and ECT. This approach provides some answers to Research Question 2, How could agencies be using ECT to fulfill agency strategies (potential use)? Still, additional analysis in the form of the crowd-sourced intelligence is required to learn more about potential agency use of ECT.

4.2.5 Findings from Crowd-sourced Intelligence (Analysis Approach 5)

The crowd-sourced intelligence information was based on user inputs via www.foresightchallenge.org. The registered users (n = 23) entered 62 answers to average 2.7 cases completed per user. Many users reported that this was a challenging exercise and that it took between ten and twenty minutes to complete each case.

The probability of supporting a particular agency strategy by 2050 (based on technical feasibility) and priority for supporting a particular agency strategy by 2050 (based on societal benefit) are summarized in Table 19, "Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Commerce" and Table 20, "Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Energy."

If an answer was available for a particular combination of strategy and ECT, I included the provided technology or technologies and the answer. If the user was working from a converging technology formed from two emerging technologies, I organized the answers based on the ECT category for the first technology provided to the user. If the particular combination of strategy and ECT had multiple answers, I chose one at random to keep the summary tables to a reasonable size.

Table 19, "Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Commerce," summarizes the averaged responses to the cases on the crowd-sourced website in relation to a particular DOC agency strategy. This table is best read from top to bottom to follow the ECT and then from left to right to follow the agency strategies. The columns list each of the agency goals; the rows list the ECT's. Each cell contains a sample answer to a case and the averaged potential probability of using that technology to fulfill that goal and the federal investment priority. For example, artificial intelligence is addressed once in the context of the DOC Goal 1, Trade and Investment and this is the respondent's answer for combining converging building artificial intelligence into smartphones with converting light energy into mechanical work: "Converting light energy into mechanical work (the second emerging technology) could make it easier and cheaper to build artificial intelligence into smartphones (the first emerging technology), making a product that would be a popular export (the agency strategy)." The averaged potential probability that artificial intelligence is being used to fulfill Goal 1, Trade and Investment, is 100% and the federal investment priority is 4.

By ECT, this table reveals only anecdotal information about the comparative ECT because the cases are still being addressed (62 cases addressed for this project so far). The takeaway from this table is that this analysis approach has quite a bit of potential to yield great answers to using ECT to fulfill agency strategies and that those answers are especially useful with attendant potential probabilities of usefulness and priorities for federal investment.

Table 20, "Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Energy," summarizes the averaged responses to the cases on the crowd-sourced website in relation to a particular DOE agency strategy. This table is best read from top to bottom to follow the ECT and then from left to right to follow the agency strategies. The columns list each of the agency goals; the rows list the ECT's. Each cell contains a sample answer to a case and the averaged potential probability of using that technology to fulfill that goal and the federal investment priority. For example, biotechnology is addressed once in the context of the DOE Goal 2, Nuclear Security, and this is the respondent's answer for converging creating spontaneous 'cell' division in artificial cell models with speculating about former life on Mars: "Far-fetched: If Mars is habitable for humans (extension of the second emerging technology), then global nuclear security threats (the agency strategy) would be reduced for the humans who move to Mars. This fits with a potential future in which local identities are preserved because the Mars colony would be likely to develop a local identity." The averaged potential probability biotechnology is being used to fulfill DOE Goal 2, Nuclear Security, is 25% and the federal investment priority is 2.

By ECT, this table reveals only anecdotal information about the comparative ECT because the remaining cases have not been addressed; by goal, this table reveals only anecdotal information about the comparative ECT because the remaining cases have not been addressed (62 cases addressed for this project so far). The takeaway from this table is this analysis approach has quite a bit of potential to yield additional answers to using ECT to fulfill agency strategies and that those answers are especially useful when combined with potential probabilities of usefulness and priorities for federal investment.

Combined, these approaches represent the pilot application of the methodology and provided answers to Research Question 1, Are ECT being used to fulfill agency strategic plans (current use)? and Research Question 2, Could ECT be used more extensively to fulfill agency strategic plans (potential use)? In the next section, I present the findings from evaluating the methodology.

4.3 Findings from Evaluating the Methodology

For each analysis approach, except the individual interviews in Analysis Approach 3, I generated an interactive visual analytic file with which users can look at different aspects of each measure and drill down to see the underlying data. The opening images for each of those visual analytic files are embedded and discussed below.

The image in Figure 5, "Visual Analytics of Content Analysis (Approach 1)," displays the count of ECT mentions in the strategic documents by agency. It highlights the expected uses of energy technology and materials (advanced) at the DOC and DOE, respectively, and also demonstrates how few technologies receive more than a few mentions. Figure 5 displays a static image of the interactive visual analytics for the first analysis approach. The actual visual analytics file is available on IQSS and at www.foresightchallenge.org and is useful for viewing different combinations and aggregations of the content analysis data. Still, this static image is a useful view of the aggregate number of mentions of each ECT by ECT type and by agency. This figure is best read from left to right to follow the variations by ECT type. The x-axis lists each of the ECT types in alphabetical order; the y-axis lists the number of mentions in the agencies' strategic documents.

Relevant to both agencies, the figure reveals low (fewer than one hundred) mentions of biotechnology (9 for DOC, 5 for DOE), electronics (35 for DOC, 68 for DOE), geoengineeering (0 for DOC, 0 for DOE), information technology (70 for DOC, 75 for DOE), interfaces (18 for DOC, 36 for DOE), nanotechnology (12 for DOC, 4 for DOE), quantum (usually computing) (40 for DOC, 21 for DOE), robotics (7 for DOC, 2 for DOE), sensors (58 for DOC, 63 for DOE), ubiquitous (computing) (4 for DOC, 9 for DOE), virtual reality (12 for DOC, 23 for DOE). Relevant by agency, the figure displays disparate mentions of artificial intelligence (2 for DOC, 0 for DOE), cognitive science (2 for DOC, 0 for DOE), energy technology (6 for DOC, 216 for DOE), Internet (142 for DOC, 36 for DOE), materials (advanced) (235 for DOC, 475 for DOE), space (outer) (112 for DOC, 3 for DOE).

In particular, relative to DOC, the figure reveals the low mentions of the majority of the ECT (as detailed above) and that the majority of the mentions are related to the Internet, materials (advanced), and space (outer). These are all consistent with use in day-to-day management of the Internet, advanced materials use at NIST, and outer space use in the satellite programs at NOAA, respectively. Relative to DOE, the figure reveals the low mentions of the majority of the ECT (as detailed above) and that the majority of the mentions are related to energy technology and the Internet. These are consistent with the overarching energy mention of our nation's energy agency and use in day-to-day management of the Internet, respectively.

The takeaway from this figure is that most of the ECT are not being mentioned very much at all and those that are being mentioned the majority of the time are being mentioned in the context of current uses, which is both consistent with this type of federal document and with the intent for this analysis approach.

The image in Figure 6 is a heat map of the expert respondents' linear opinion pool (no weights) aggregated probabilities that the agency currently is using the technology. Agency strategies and the ECT form the x- and y-axes. This is a useful way of evaluating patterns of technologies that could support multiple strategies or strategies that are more easily supported by technologies across the board.

Figure 6 displays a static image of the interactive visual analytics for the second analysis approach. The actual visual analytics file is available on IQSS and at www.foresightchallenge.org and is useful for viewing different combinations and aggregations of the technology assessment analysis data. Still, this static image is a useful view of the average percent probability that a particular ECT is currently being used to fulfill a particular agency goal. This figure is best read from top to bottom to follow the variations by ECT type. The x-axis lists each of the agencies' main goals in numerical order; the y-axis lists the average percent probability that the particular ECT is currently fulfilling that particular agency goal per expert respondents (n = 4).

Relevant to both agencies, the figure reveals low (lower than fifty percent for the majority of the goals) probabilities for current use of geoengineering, space (outer), ubiquitous computing, and virtual reality. Relevant by agency, the figure reveals no disparate mentions of a particular technology. In particular, relative to DOC, the figure reveals the low mentions of ECT (as detailed above) and that the most probable current uses of ECT based on the darkest areas of green (highest values) are for DOC Goal 1, Trade and Investment, DOC Goal 2, Innovation, and DOC Goal 3, Environment (based on the majority of the ECT for those goals having probabilities of fifty percent or greater). Little ECT use is probable for DOC Goal 4, Data and Goal 5, Operational Excellence. Relative to DOE, the figure reveals the low mentions of ECT (as detailed above) and that the most probable current uses of ECT based on the darkest areas of green (highest values) are for DOE Goal 1, Science and Energy, and DOE Goal 2, Nuclear Security (based on the majority of the ECT for those goals having probabilities of fifty percent or greater). Little ECT use is probable for DOE Goal 3, Management and Performance.

The takeaway from this figure is that many of the ECT probably not being used to fulfill specific agency goals and those that are probably used are being mentioned in the context of current uses, which is both consistent with this type of analysis and with the intent for this analysis approach.

The image in Figure 7, "Visual Analytics of Plausibility Matrix Analysis (Approach 4)," is a heat map of the expert respondents' linear opinion pool (no weights) aggregated probabilities that the agency could be using the technology by 2050. Agency strategies and the ECT form the x- and y-axes. This is a useful way of evaluating patterns of technologies that could support multiple strategies or strategies that are more easily supported by technologies across the board.

Figure 7 displays a static image of the interactive visual analytics for the fourth analysis approach. The actual visual analytics file is available on IQSS and at www.foresightchallenge.org and is useful for viewing different combinations and aggregations of the probability matrix analysis data. Still, this static image is a useful view of the average percent probability that a particular ECT could potentially be used to fulfill a particular agency goal. This figure is best read from top to bottom to follow the variations by ECT type. The x-axis lists each of the agencies' main goals in numerical order; the y-axis lists the average percent probability that the particular ECT could potentially fulfill that particular agency goal per expert respondents (n = 10).

Relevant to both agencies, this figure reveals a low (lower than fifty percent for the majority of the goals) probabilities for potential use of biotechnology, geoengineering, robotics, and space (outer). The figure shows disparate mentions of cognitive science (much more probable at DOC), materials (advanced) (much more probable at DOE), nanotechnology (much more probable at DOE), ubiquitous computing (much more probable at DOC), virtual reality (much more probable at DOC). In particular, relative to DOC, the figure reveals the low mentions of ECT (as detailed above) and that the most probable potential uses of ECT based on the darkest areas of green (highest values) are for DOC Goal 1, Trade and Investment, DOC Goal 2, Innovation, and DOC Goal 3, Environment (based on the majority of the ECT for those goals having probabilities of fifty percent or greater). Little potential ECT use is probable for

DOC Goal 4, Data, and DOC Goal 5, Operational Excellence. Relative to DOE, the figure reveals the potential uses of ECT (as detailed above) and that the most probable current uses of ECT are for DOE Goal 1, Science and Energy, DOE Goal 2, Nuclear Security, and DOE Goal 3, Management and Performance (based on the majority of the ECT for those goals having probabilities of fifty percent or greater).

The takeaway from this figure is that many of the ECT probably do have potential use to fulfill specific agency goals and those with the most probability for being used are being mentioned in the context of potential uses, which is both consistent with this type of analysis and with the intent for this analysis approach.

The image in Figure 8, "Visual Analytics of Crowd-sourced Intelligence Probabilities and Priorities (Approach 5)," is a scatter plot of crowd-sourced users' assessments of a technology's probability (technical feasibility that it could support an agency strategy) and priority for investment (societal benefit). As before, agency strategies and ECT define the x- and y-axes while the y-axis is further defined by the priorities for each technology. The underlying data are the averaged responses by ECT categories for both potential probability and priority for each goal and its subsidiary objectives. The scales are zero to one for the potential probability and zero to five for the priority.

Bubbles in the top right of boxes reflect crowd-sourced intelligence that a technology has high technical feasibility and societal benefit for supporting that strategy. Conversely, bubbles to the bottom left of boxes reflect crowd-sourced intelligence that a technology has a low technical feasibility and societal benefit for supporting that strategy.

As more data are collected in the crowd-sourced intelligence website, I expect to continue to see this variety of dots throughout the squares by technology and goal. However, over time, I also expect more and more of the dots to cluster the top right and bottom left corners, which will further differentiate ECT with the technical feasibility for future use to potentially fulfill agency strategies.

Figure 8 displays a static image of the interactive visual analytics for the fifth analysis approach. The actual visual analytics file is available on IQSS and at www.foresightchallenge.org and is useful for viewing different combinations and aggregations of the crowd-sourced intelligence data. Still, this static image is a useful view of the average percent probability that a particular ECT could potentially be used to fulfill a particular agency goal and the priority that ECT should be given for federal investment. This figure is best read from top to bottom to follow the variations by ECT type. The x-axis lists each of the agencies' main goals in numerical order; the y-axis lists the average percent probability that the particular ECT could potentially fulfill that particular agency goal per crowd-sourced responses (62 cases). Note that empty squares indicate a combination of ECT and agency goal that website users have not yet chosen to address (including all of DOC Goal 5, Operational Excellence).

Relevant to both agencies, the figure reveals low (lower than fifty percent for the majority of the goals) probabilities for potential technical feasibility of none of the ECT. Low (lower than five for the majority of the goals) priorities for potential priority federal investment in artificial intelligence, biotechnology, electronics, energy technology, interfaces, and sensors. Relevant by agency, the figure shows no disparate mentions of ECT.

For example, the row for energy technology reveals consistently high probabilities and high priorities for energy technology uses at both DOC and DOE. Moreover, the one exception, with a 25% for probability and two for priority can be studied in the actual visual analytics file.

In this case, the user saw a benefit to the technology but the concerns about technical feasibility led to a low probability and its inability to improve competitiveness drove the low probability: "More efficient Solar cells using the Liquid Filter with Plasmonic Nanoparticles combined with well placed renewable energy storage facilities might make electricity more readily available in a weather disaster area. Restoring power is a key factor in restoring a communities [*sic*] functionality."

As another example, in the column for the DOC Goal 2, Innovation, information technology, interfaces, materials (advanced), and nanotechnology all have high probability and priority scores. Biotechnology has a mix of scores, which represents the variety of technologies presented to the users. These specific biotechnologies can again be studied in the actual visual analytics file: One user was presented with a biotechnology for 3D printing food in space and connected that to the innovation goal as follows, "3-D printing food will only add value in a novelty environment (candy, frosting, special events). I see global trends toward natural (recognizable) foods." The attendant probability and priority, 0% and one, respectively, are the user's assessment of the technology in the context of the provided case. Other uses gave low probabilities and priorities to using health-and-fitness monitoring headphones or sensing touch, humidity, and temperature with "Artificial Skin" in support of the DOC's Goal 2, Innovation.

In particular, relative to DOC, the figure reveals the low mentions of ECT (as detailed above) and that the most likely current uses of ECT are for DOC Goal 1, Trade and Investment, DOC Goal 2, Innovation, DOC Goal 3, Environment, and DOC Goal 4, Data (based on the majority of the ECT for those goals having probabilities of fifty percent or greater). Little potential ECT use is probable for DOC Goal 5, Operational Excellence. In particular, relative to DOE, the figure reveals potential uses of ECT (as detailed above) and that the most probable current uses of ECT are for all three DOE goals (based on the majority of the ECT for those goals having probabilities of fifty percent or greater).

The takeaway from this figure is that many of the ECT probably do have potential use to fulfill specific agency goals but that the priority for investment in them should be low (users are perhaps factoring in other concerns about the particular underlying technology or their own ideology about how governments should invest in ECT), which is both consistent with this type of analysis and with the intent for this analysis approach.

The image in Figure 9, "Visual Analytics of Technology Assessment and Plausibility Matrix (Approaches 2 and 4)," is a scatter plot of the expert respondents' probabilities (technical feasibility that it could support an agency strategy) of current *versus* potential use. Figure 9 displays a static image of the interactive visual analytics for the second and fourth analysis approaches. The actual visual analytics file is available on IQSS and at www.foresightchallenge.org and is useful for viewing different combinations and aggregations of the technology assessment and probability matrix analyses data. Still, this static image is a useful view of the average percent probability that a particular ECT is currently being used or potentially could be used to fulfill a particular agency goal. This figure is best read from top to bottom to follow the variations by ECT type. The x-axis lists each of the agencies' main goals in numerical order and is subdivided into sections for the potential probability of that ECT being used for that agency goal; the y-axis lists each ECT and is subdivided into the average percent probability that the particular ECT could potentially fulfill that particular agency goal per expert respondents (n = 10).

For example, the row for virtual reality reveals consistently low probabilities of current use and only slightly higher probabilities for potential use across the agency goals. This indicates that virtual reality technologies can be considered after other technologies and that, when considered, consideration could begin with the ways in which virtual reality technologies could support the two goals with slightly higher probabilities for potential use: DOC Goal 1, Trade and Investment, and DOE Goal 2, Nuclear Security. In another example, the column for the DOC Goal 2, Innovation, has current and potential probabilities that are mostly over fifty percent. This makes sense given the intention of the goal, but it also reveals another opportunity for focused search and investment: Technologies like robotics or ubiquitous computing have particularly high probabilities and could be studied first.

Relative to DOC, the intersection of current probability and potential probability shows high current and potential probable use for electronics, information technology, and Internet. It generally shows low current and potential probable use for biotechnology, geoengineering, quantum (usually computing), sensors, and space (outer). Expert respondents coded none of the ECT for high current use and low potential use but artificial intelligence, interfaces, and virtual reality all had higher codes for current use than for potential use. Expert respondents generally agreed about the high current and potential uses of ECT for DOC Goal 1, Trade and Investment, and DOC Goal 2, Innovation, and low current and potential uses of ECT for DOC Goal 3, Environment, DOC Goal 4, Data, and DOC Goal 5, Operational Excellence.

Relative to DOE, the intersection of current probability and potential probability shows high current and potential probable use for electronics, information technology, interfaces, nanotechnology, and sensors. It generally shows low current and potential probable use for biotechnology, cognitive science, space (outer), ubiquitous computing, and virtual reality. Expert respondents coded none of the ECT for high current use and low potential use or the inverse. Expert respondents generally agreed about the high current and potential uses of ECT for DOE Goal 2, Nuclear Security, and DOE Goal 3, Management and Performance.

The image in Figure 10, "Visual Analytics of Plausibility Matrix and Crowd-sourced Intelligence Probabilities (Approaches 4 and 5)," is a scatter plot of the expert respondents' probabilities of potential use *versus* the crowd-sourced probabilities of potential use. Figure 10 displays a static image of the interactive visual analytics for the fourth and fifth analysis approaches. The actual visual analytics file is available on IQSS and at www.foresightchallenge.org and is useful for viewing different combinations and aggregations of the probability matrix analyses and crowd-sourced intelligence data. Still, this static image is a useful view of the comparative percent probabilities that an ECT potentially could be used to fulfill a particular agency goal. This figure is best read from top to bottom to follow the variations by ECT type. The x-axis lists each of the agencies' main goals in numerical order and is subdivided into sections for the average potential probability of that ECT being used for that agency goal based on expert respondents (n = 10); the y-axis lists each ECT and is subdivided into the average percent probability that the particular ECT could potentially fulfill that particular agency goal per averaged crowd-sourced intelligence (62 cases).

For example, the row for artificial intelligence reveals both high and low crowd probabilities and consistently low expert assessments. More helpful is the row for information technology in which the experts and crowds mostly agreed that the probabilities for potential use were high. One of the areas of disagreement, under DOE Goal 1, Science and Energy, was interesting. The probability that made up that bubble from the crowd-sourced users' data was based on a specific information technology, designing a replacement to flash memory. Clearly the crowd thinks that has a lower probability of serving the goal than the experts thought about the technology in general.

In another example, the column for the DOC Goal 4, Data, the largest probabilities are for information technology, which makes sense. Artificial intelligence, energy technology, and quantum (usually computing) also require study given these probabilities. As more data are collected in the crowd-sourced intelligence website, I expect to see this same variety of dots throughout the squares by technology and goal. However, over time, more and more of the dots will cluster to the top right and bottom left corners.

Relative to DOC, the intersection of potential probability per expert respondents and potential probability per the crowd-sourced intelligence shows high potential probable use for electronics, information technology, interfaces, nanotechnology, and quantum (usually computing). It generally shows low potential probable use for robotics. Split opinions in which expert respondents coded a high potential probability and the crowd-sourced probabilities were lower occurred for biotechnology, cognitive science, energy technology, and Internet. There were mixed responses relative to the DOC goals.

Relative to DOE, the intersection of potential probability per expert respondents and potential probability per the crowd-sourced intelligence shows high potential probable use for nanotechnology and sensors. It generally shows low potential probable use for biotechnology, materials (advanced), quantum (usually computing), and robotics. Split opinions in which expert respondents coded a high potential probability and the crowd-sourced probabilities were lower occurred for artificial intelligence, energy technology, and information technology. There were mixed responses relative to the DOE goals.

4.4 Findings from Disseminating the Methodology

Disseminating the data, results, and policymaker overview from the research produced *ad hoc* feedback from the various recipients. From the members of academia, several have made suggestions about improving the website tool for theoretical and practical benefit. For example one member of academia suggested including the University of Tennessee logo on the www.foresightchallenge.org website to ascribe the imprimatur of the University to the website. Neither policymakers nor the general public have offered any feedback.

I had no expectations for the findings from this phase. Disseminating the methodology was about sharing the methodology, data, findings, results, and meta-inferences with interested groups. I had no requests or intentions for generating additional feedback or actions.

4.5 Integrating the Findings and Results

The findings and results from the first five approaches are summarized in Table 21, "Summary of Current and Potential Use of Emerging and Converging Technologies (by Agency and Analysis Approach)" and discussed in Chapter 5, "Discussion." Table 21 summarizes the findings across all ECT and both agencies. This table is best read from top to bottom to follow the variations by ECT type. The x-axis lists each of the agencies' main goals in numerical order; the y-axis lists each ECT and is subdivided into the five analysis approaches from applying the methodology: content analysis, technology assessment analysis, individual qualitative interviews, plausibility matrix analysis, crowd-sourced intelligence. Each cell contains the value from the analysis approach.

Within an ECT, this reveals the consistency of findings across the various approaches, bearing in mind that approaches one through three address current use and approaches three through five address potential use. For example, cognitive science is mentioned only three times in the strategic documents; the expert respondents (n = 4) for the technology assessment assessed a probability of current use of fifty percent or less for each goal; and it was not mentioned at all in the qualitative interviews. Relative to potential future use, it was not mentioned at all in the qualitative interviews; the expert respondents (n = 10) for the probability matrix analysis assessed between 45% and 65% of potential future use; and the crowd-sourced intelligence (62 cases addressed for this project so far) has identified a feasibility of 50% and a federal investment priority of 2.5.

Viewing the summary data as a whole by ECT reveals little support at either agency for current use of artificial intelligence, cognitive science, electronics, geoengineering, interfaces, quantum (usually computing), and virtual reality. In contrast, current use of energy technology, information technology, Internet, and materials (advanced) garnered quite a bit of support. Viewing the summary data as a whole by ECT reveals little support for potential future use of geoengineering, quantum (usually computing), and space (outer). In contrast, the potential future use of artificial intelligence, biotechnology, energy technology, information technology, Internet, nanotechnology, and robotics received quite a bit of support.

Viewing the summary data as a whole by goal reveals support for current use of ECT for DOC Goal 1, Trade and Investment, DOC Goal 2, Innovation, and DOC Goal 3, Environment, and DOE Goal 1, Science and Energy. Viewing the summary data as a whole by goal reveals support for potential use of ECT for DOC Goal 1, Trade and Investment, DOC Goal 2, Innovation, and DOC Goal 3, Environment, DOC Goal 4, Data, and DOE Goal 1, Science and Energy.

Chapter 5
Discussion

Given the premise that knowing what ECT agencies are using and could be using to fulfill agencies' strategies, the summaries of findings and results in the previous chapter are helpful; however, the findings and results pertinent to the research questions extend beyond tables of technologies and strategies. Also interesting are the disposition of the propositions, themes, meta-inferences (Tashakkori and Teddlie 2010), theoretical relevance, and practical relevance of this research.

5.1 Research Questions and Propositions

The findings from this research are consistent with literature review: a gap can be seen between the ECT agencies are currently and potentially using. Although it is true that some of the ECT are not yet sufficiently mature, others are ready for use now and could be used to support agency goals.

Relative to the first research question, Are ECT being used to fulfill agency strategic plans?, findings and results from the first three analysis approaches indicate that agencies are making current use of ECT but they could be used more to fulfill agency strategies. However, the individual interviews reveal that considerations like time and funds, including limited time to search for information about ECT, constrain the current use of ECT. Relative to the second research question, Could ECT be used more extensively to fulfill agency strategic plans (potential use)?, findings and results from the next three analysis approaches indicate that agencies could extend their potential use of technologies to use ECT across more strategies.

The disposition of each of the propositions is summarized in Table 22, "Disposition of the Propositions." Table 22 summarizes the propositions and whether or not each was supported by the analysis. In particular, the table shows which analysis approaches were designed to address the proposition. The takeaway from this table is that the propositions were all supported by the findings and results.

5.2 Themes and Meta-inferences

Seven themes and meta-inferences run through the findings and results: 1) Characterizing ECT that are being used currently and could be used potentially to fulfill agency strategies reveals interesting lists that can be used in a variety of ways; 2) It is possible to identify and prioritize R & D investment opportunities based on technical feasibility and societal benefit; 3) There are opportunities for DOC and DOE to collaborate; 4) There are some unexpected ECT to consider for current and potential use and others that were surprising for their absence; 5) This research reveals interesting glimpses into why agencies are not using more ECT; 6) These findings and results have unintended consequences that must be considered; and 7) This methodological approach is useful and could be applied in an extension of this circumstance or in other circumstances.

First, it is possible to characterize current and potential agency use of ECT for fulfilling agency strategies, especially with multiple approaches. Across the methods, I found that agencies are using ECT, but some are being used more than others. By technology, I found that biotechnology, electronics, information technology, and the Internet are getting the most traction toward fulfilling agency strategies. By strategy, the DOC's Goal 1, Trade and Investment, and

Goal 2, Innovation, and the DOE's Goal 2, Nuclear Security, have the most current uses for ECT.

It is also possible to characterize potential agency use of ECT for fulfilling agency strategies, also with multiple methods. Across the methods, I found that artificial intelligence, information technology, interfaces, and Internet have the most potential for fulfilling agency strategies. By strategy, the DOC's Goal 1, Trade and Investment, and DOC Goal 2, Innovation, and the DOE's Goal 2, Nuclear Security, have the most potential uses for ECT.

Second, assessing potential technical feasibility, as measured by the probability of technical feasibility by 2050, and potential societal benefit, as measured by the priority for federal investment, add additional information. When considering federal investments in ECT, policymakers can begin with the functionality of the ECT or the use it might make for fulfilling an agency strategy, and then add the information about the potential technical feasibility and potential societal benefit to make the decision for investment.

Third, despite disparate goals, a number of additional opportunities exist for DOC and DOE to collaborate. In particular, across the various approaches electronics, energy technologies, information technology, interfaces, and Internet each had high probabilities, high priorities, and most also were mentioned in the individual interviews. Although the applications may be different between the agencies, the opportunities to collaborate at the level of the technology are the same. I was especially surprised to see so many opportunities for emerging energy technologies at the DOC, a potential that is corroborated by language in the DOC's strategic plan, "Boost exports of environmental and clean energy technologies (ITA). Governments around the world are creating regulations and policies to address the changing environment. ITA, with the Department of Energy and the Environmental Protection Agency, will lead interagency efforts to support and anticipate the needs of US exporters and foreign investors" (US Department of Commerce 2014, 27).

Fourth, given the potential utility of artificial intelligence and cognitive science, I was surprised by how few times each was mentioned in the strategic documents; how low the probabilities were for current use and—in the case of cognitive science—for potential use; and how few times they were mentioned in the individual interviews, despite prompts. Both artificial intelligence and cognitive science offer tremendous potential to augment and extend human abilities and thinking, which seem like they would help all of the goals. I was not surprised that biotechnology and nanotechnology consistently appeared on the current and potential use lists. Both can support many aspects of the agencies' strategies; they are known to policymakers so they can be mentioned more often in strategic documents; and the expert respondents were familiar with them.

Fifth, this research reveals interesting glimpses into why agencies are not using more ECT. Beyond the expected answers of insufficient time and funds, the prose in the strategic documents and answers in the qualitative interviews reveal a lack of a search mindset among agency employees and difficult acquisition process that inhibits ECT investments and implementations. Language in the strategic documents is mostly about the continuation of current efforts, which explains the numbers of mentions for ECT such as energy and information technologies. Answers in the qualitative interviews related the difficulties of coordinating investments in any technologies, much less ECT that are defined by little information and many options. The acquisition process within each agency requires significant coordination and, depending on the size and type of investment, that process also can include the Executive Office of the President and, of course, appropriations from Congress.

Sixth, these findings and results raise interesting implications relative to unintended consequences. Low probabilities of current use but high probabilities of potential use (e.g., interfaces or sensors) may indicate a lack of familiarity about the technology or a consideration about unintended consequences from using it. Theoretically, identifying unintended consequences begins with identifying the signposts such as the events, trends, and statistics (Tonn and Stiefel 2014). Identifying the paths to these unintended consequences could begin by studying and finding ways to explain the differences between current use and potential use probabilities.

Seventh, this methodological approach is useful and could be applied in an extension of this circumstance or in other circumstances. The methodology could be applied as it is to any agency and any set of technologies. The underlying data sources (e.g., strategic documents, expert assessments, government employee information, crowd-sourced intelligence) are always changing as new information and new needs emerge. Applying this methodology continuously is both easy and appropriate. The methodology also could be applied as it is to any organization and any set of technologies or other decision areas. Following the methodology in Figure 1, "Developed Methodology by Phases," after clearly defining the problem the researcher must identify all of the relevant data sources and the appropriate analysis approaches for analyzing those data sources. Multiple approaches reveal multiple sets of findings and results that can be compared and contrasted, as demonstrated in this research, to identify the consistencies and inconsistencies in the findings and results. Simplifying the methodology also is appropriate, although it requires at least one analysis approach for current use and at least one analysis approach for potential use.

Together, these seven themes represent findings, results, and meta-inferences that can be useful in their own right. They also ensure theoretical and applied relevance, as discussed in the next sections, and form the basis for future research, as summarized in Chapter 7, "Conclusion."

5.3 Theoretical Relevance

In addition to the theoretical contributions detailed above, this work is theoretically relevant to the political science discipline because developing the methodology is based on theories of methodologies and other theoretical methodological development work. Using this methodology, political scientists can make a theoretical link between ECT and agency strategies as a theoretical link between public policy in the form of ECT investments and public administration in the form of the strategies and foresight necessary to make those investments.

Moreover, the role of governance in the application of the methodology and the findings and results is significant. Use of ECT to benefit society is a governance choice because both societal benefits and risks accrue as a function of the adopted ECT as well as those that are ignored or missed. Governance is at the heart of political science because with governance, senior agency leaders can drive the next innovations and find the biggest opportunities to serve the Nation and the world. Thus, this research is relevant to the discipline because it offers political scientists tools for analyzing the world as it is and as it will become, and then applies those tools to organization strategies until useful opportunities for governance in general. Also, investments in ECT in particular are characterized based on the technical feasibility and social benefits.

This research integrates the technological and political contexts based on the assumption that systematic and coordinated federal investments in ECT benefit society. Inherent in this assumption are the increased possibilities of federal regulation for ECT or decreased possibilities of federal regulation overall if ECT is handling reporting and transparency; decreased privacy for individuals; or decreased inequality. Various mentions in the content analysis, individual interviews, and crowd-sourced intelligence findings support these concerns. Additional research is necessary to make additional connections. Similarly, the content analysis, individual interviews, and crowd-sourced intelligence identified quite a few considerations regarding the search and adoption processes for ECT and most of these considerations seem to be caused by the political and public administration processes. As revealed in the content analysis, individual interviews, and crowd-sourced intelligence, considerations include concerns about knowing which technologies to consider are driven in part by who is elected and appointed to the various positions. Concerns about adoption are driven by the realities of the political process, especially the budgeting and appropriations processes, and the timeline for all of these versus the timelines for ECT and creative destruction.

The qualitative theoretical relevance of this work is high, as is expected for mixed methods research. In particular, the trustworthiness criterion, in the form of credibility, transferability, dependability, and confirmability (Denzin and Lincoln 2008; Guba and Lincoln 1994), was met by accurately representing all of the information; applicability of methodology and the findings to other data in other public or private organizations; the fact that applying this approach to similar data from other organizations would produce a similar structure and the information could vary as necessary; and the findings are consistent with the data.

The quantitative theoretical relevance of this work is mixed, as noted above. Regarding the reliability of this work in particular: To what extent will this methodology yield the same result when applied over and over to the same data? Different expert respondents might vary in how they code the technology assessment analysis matrix for current use. On the other hand, applying the methodology via crowd-sourced intelligence to determine potential current and future use could create a variety of results each time, especially given that people on the Internet are making those assertions.

The work is generalizable to other agencies because the methodology is generalizable to other defined problems even if the findings and results from this pilot application cannot be generalized beyond the DOC and DOE. Every agency is different and one ideal outcome of this work would be for future researchers to continue applying the methodology across more data and more expert respondents. Clearly, the developing and disseminating phases can be generalized to other agencies and organizations. The applying phase produces results that are peculiar to the two agencies in my study, but the societal benefits and risks affect other agencies and organizations. Finally, the evaluating phase will have specific results applicable to the two agencies individually and as a dyad, but other findings may be generalizable to other agencies.

5.4 Applied Relevance

This research offers a great deal of applied relevance. The methodology is applicable to any organization considering any set of options regarding any question as well as being specifically applicable to federal agencies because it accommodates data collection limitations and incorporates agency strategies and intentions. The pilot application of the methodology that is detailed in this research also yields specific answers that are useful to any stakeholders interested in the DOC and DOE.

The political science discipline needs more theoretical work in the methodologies that support applied political decisions, including decisions about investment prioritization (Grupp and Linstone 1999; Lee et al. 2008; Mulgan 2002). Federal agencies need a methodology for characterizing current and potential use of ECT, one of the recommendations to policymakers in the next chapter.

Chapter 6
Recommendations to Policymakers

Developing and applying this methodology revealed three overarching opportunities for policymaker engagement. First, it revealed a significant opportunity to govern with foresight at every level of government, from the Executive Office of the President, throughout all interagency coordination, and down to the agency line office work. Second, we can rethink the way we consider ECT in our daily work and to fulfill our organizations' strategies. Third, and finally, we have an opportunity to build and apply methodologies for systematically identifying ECT that support our national strategies and for characterizing them based on technical feasibility and societal benefit.

6.1 Govern with Foresight

The literature review, content analysis of strategic documents, and individual interviews with government employees reveal that thinking ahead is unusual for humans in general, and it is particularly challenging given the nature of ECT. Both the Fuerth recommendations (Fuerth 2012) and a European Union report (European Commission 2002) make the case for governance with foresight that must be managed by a government-wide office run through the Executive Office of the President (Coates 1985); coordination, consistency, and accountability are themes that cross most of the work on this subject.

The UK's Foresight Projects are coordinated through the Government Office for Science (United Kingdom Government Office for Science 2013) and are a successful example in another developed country. This office handles projects such as the future of aging (United Kingdom Government Office of Science 2014) or the future of cities (United Kingdom Government Office of Science 2015) and claims successes such as foresight reports on climate change, land use, and reducing obesity (United Kingdom Government Office for Science 2013). In fact, European foresight programs in Finland, France, Germany, Italy, the Netherlands, Norway, Russia, Sweden, Switzerland, and the UK have been so successful that European Union institutions are now building a joint foresight capacity—European Strategy and Policy Analysis System (ESPAS) to assess long-term global trends in order to improve policy planning (Dreyer and Stang 2013). Such a government-wide approach is needed in the US as well.

Calof and Smith (2010, 31) have even identified eight criteria for successful government foresight programs, which could be applied to such a government-wide approach and were applied to this research as indicated in each set of parentheses:

1. Clearly-identified clients (DOC and DOE);
2. Link between foresight and the policy agenda (connections between ECT and the agency strategies and the funding priorities established via crowd-sourced intelligence);
3. Link to senior policymakers (one-on-one interviews; questions throughout the research; access to www.foresightchallenge.org, the crowd-sourced website; and dissemination of the methodology and results);
4. Strong public-private partnerships (inherent in the conversations that support this work);

5. Development of methodologies and skills that are not already in use at agencies (the methodology and the underlying analysis approaches and skills are not consistently in use);
6. Clear communication (in the creation and dissemination of this methodology);
7. Integrated stakeholders (through one-on-one interviews; questions throughout the research; access www.foresightchallenge.org, the crowd-sourced intelligence website; and dissemination of the methodology and results; and
8. National-level academic engagement (begun through conversations and inherent to my current academic role but requires additional work).

US agencies with strategic planning offices (Dreyer and Stang 2013), including the DOC's Office of Policy and Strategic Planning and the DOE's Office of Energy Policy and Systems Analysis, have an opportunity to consider this research and these recommendations.

6.2 Encourage Systematic Consideration of ECT

One of the most interesting findings from the gap between current and potential use, and as detailed in the individual interviews, was that technology is considered incrementally, if at all. "The belief is that there is no middle ground for some advances because they depend on regulatory changes, complementary breakthroughs, specific circumstances, competing technologies, the effects of standardization, or other binary 'go, no-go' situations" (Halal et al. 1997, 7).

Content analysis of strategic documents and individual interviews reveal that strategy and funding are considerations when thinking about ECT. Timelines are too long and the results are too hard to change. ECT are moving faster and faster. Systematic consideration of ECT will allow big-picture looks at what is already available and in use, and what is needed given the potential futures. Combined with the first recommendation, foresight could mean taking action to consider ECT solutions to societal problems.

6.3 Support Methodologies that Connect ECT with Agency Strategies

As the findings and results from research project revealed, opportunities exist to improve agency data and access with a systematic methodology for characterizing current and potential use of ECT for fulfilling agency strategies. Despite data.gov (US Government 2015) and Google's Public Data Explorer (Google 2015), gaps exist in our nation's data, access to data, and ability to communicate about the quality of the various datasets. These issues with our national data was acknowledged recently by the Executive Office of the President:

> Any attempt to create a data infrastructure around the effects of research and development (R & D) must confront the fact that relevant data (e.g., funding agency R & D awards, educational institution outcome data, research publications) are currently drawn from disparate sources, using widely differing methodologies and approaches. Thus, building a coherent data infrastructure is particularly challenging. Inputs, outputs, and outcomes are not currently generated or combined in a systematic fashion. The development of consistent and reliable answers to stakeholder requests requires the use of common data sources and standardized methodologies for data cleaning and analysis (Executive Office of the President 2014c, 64).

Resolving the gap in our current information and adding new information about potential use will depend upon a systematic methodology for collecting, organizing, analyzing, and synthesizing the data and the findings and results.

Each of these can be accomplished with the methodology developed and applied herein. However, such accomplishment will require sustained political attention and action in the form of consistent funding and effort.

Chapter 7
Conclusion

This research advanced knowledge and understanding within political science, public administration, and public policy by providing a methodology for federal agencies to systematically use ECT to fulfill agency strategies. It also advanced knowledge and understanding in multiple disciplines by:

- Identifying ECT that are being used currently to fulfill agency strategies;
- Identifying ECT that could be used to fulfill agency strategies;
- Identifying and prioritizing R & D investment opportunities based on technical feasibility; and
- Identifying and prioritizing R & D investment opportunities based on societal benefit.

Applying this information has the potential to systematically support agencies' technology investments, which can enhance national innovation, which increases Gross Domestic Product (GDP) and thus increases quality of life (Diener, Diener, & Diener 1995). This information also could be applied to fulfill the President's request that agencies use "technology to make a real difference in people's lives" (Obama 2010).

7.1 Research Limitations

Research limitations include two data collection limitations and two research design conceptualization limitations. The primary data collection limitation is in the data about current agency use of ECT. I would have preferred to begin with agency-reported lists of technology matched to each strategy, but—based on correspondence with a variety of sources (as detailed in Chapter 3), and especially based on correspondence with individuals in the White House Office of Science and Technology Policy (Rubin 2013) and the NSF (Yamaner 2015)—the closest available sources are the DOE's Quadrennial Technical Review, the various agency strategies, and the Congressional Budget Justifications, all of which were used as the basis for current agency use in content analysis, Analysis Approach 1.

A secondary data limitation is that agency strategic plan content and Congressional Budget Justifications are conscribed by page limitations, the need for agency consensus, and the need to be acceptable to the Executive Office of the President and Congress so it is possible that many ECT are under consideration but are not mentioned. Moreover, mentioning ECT is not the primary purpose of these documents.

Of the two research design conceptualization limitations, the most interesting is that this research design cannot separate ECT that agencies potentially could be using now from the technologies the agencies potentially could be using in the future. This is easily remedied in future research by developing and applying a more rigorous definition of each term. Second, technology itself is often conflated with ECT, either due to the nature of the object (e.g., a smartphone) or because it has emerged in the course of the study (e.g., ubiquitous wristwatch computers).

7.2 Future Research

I recommend three types of future research based on this project: 1) Theoretical extensions and improvements to the methodology itself; 2) Applied research; and 3) Applied and theoretical work to extend the www.foresightchallenge.org website to improve support for R & D investment decisions.

7.2.1 Theoretical Future Research

Additional work is needed to extend the theoretical distinctions between technologies that agencies could be using now and could be using in the future and for technologies that are converging with each other and on platforms. Future analysis approaches could include genetic algorithms (Goldberg 2002; Whitley 1994) to distinguish and project the combinations of technologies over time or ontological matching (Doan et al. 2004; Ehrig and Sure 2004; Euzenat 2013; Otero-Cerdeira et al. 2015) to distinguish and link the strategies and ECT.

Future research must include more studies of the behavioral aspects of how government employees use ECT on a day-to-day basis and the specific decision-making processes related to agency use of ECT to fulfill agency strategies.

Studying behavioral and process aspects of how agencies search for and adopt ECT is an important next step in this research. Understanding how individual employees choose ECT for their day-to-day use and for agency investments is as important as understanding the processes that inhibit and support those choices. The interviews in this study hinted at more inhibitions to ECT choices than support. In addition to inhibitions as a result of funds and time, employees also revealed that they rarely, if ever, search out information about ECT and, even if their job is technology-related, do not think of themselves as proponents for ECT. Researchers could base this research on significant behavioral research and also could consider significant decision-making process research.

Researchers also could study the decision-making processes that underlie the use (or lack of use) of ECT. Excellent foundational work exists on this in the study of strategic use of information technology by non-profit organizations that could be the basis for this future research. In particular, researchers could apply the organizational competencies (e.g., planning, budgeting resources, using Internet, measuring effectiveness, leadership support) of strategic use of information technology for nonprofit organizations (Hackler and Saxton 2007) to the data gathered for this project.

Moreover, inspired by Fishkin's (2009, 198) notion of deliberative democracy, which is "defined by the combination of deliberation and political equality," a faculty member suggested studying the individual effects of contributing to national governance and policy via the crowd-sourced website. Scholars could collect individual-, group-, or organizational-level information about the participants to learn why they chose to participate; what they gain by participating; and how the experience of participating has shaped their views or changed other aspects of their civic participation. Results could be analyzed via social network analysis or a Delphi panel could study the visual analytics.

7.2.2 Applied Future Research

Future research must apply the methodology in two important ways. First, it must incorporate additional agencies. Second, it must consider interagency coordination, especially coordinating mechanisms for federal science and technology regulation and investment such as the federal Demonstration Partnership or the National Academies of Science. Technologies cited more often may be more important or more likely to be important and so could be prioritized earlier.

This methodology can be applied to any public or private organization. For any organization, the methodology can be applied annually to capture changes in technologies, strategies, and the other results. Any findings and results from these future applications can be compared to successive applications for that organization or among organizations.

7.2.3 Website Tool

Another logical extension of this work is to expand the website (www.foresightchallenge.org) into a place where federal decisions about investments in science and technology can be made. This would require adding in the data from every federal agency (either through the method I employ in this methodology or by direct requests for data) and building other functionality based on best practices in decision support systems. Extending the website tool will require work in more sophisticated natural language processing for the data collection and analysis.

7.3 Conclusions

The methodology I developed allows us to improve our understanding of how agencies are using ECT to fulfill their strategies now and how they could be using technologies to fulfill their strategies. It also offers information about technical feasibility and societal benefits of each ECT relative to the strategy. By developing, applying, evaluating, and disseminating this methodology, I contributed a theoretical understanding of the developed model, the relationship to governance, and a theoretical link between public policy and public administration. I also contributed an applied understanding of which ECT the DOC and the DOE are using and could be using. With the systematic strategic planning, foresight, and use of ECT made possible by this methodology, our society benefits.

List of References

Advanced Research Projects Agency - Energy. 2013. *[Advanced Research Projects Agency - Energy] arpa-e: Changing What's Possible* 2013 [cited March 2 2013]. Available from arpa-e.energy.gov.

Alford, Kristin, Sarah Keenihan, and Stephen McGrail. 2012. "The Complex Futures of Emerging Technologies: Challenges and Opportunities for Science Foresight and Governance in Australia." *Journal of Futures Studies* 16 (4):67-86.

Amer, Muhammad, and Tugrul Daim. 2013. "Expert Judgment Quantification." In *Research and Technology Management in the Electricity Industry*. Dordrecht, The Netherlands: Springer.

Arthur, W. Brian. 2009. *The Nature of Technology: What It Is and How It Evolves*. New York: Simon and Schuster.

Bainbridge, William Sims, and Mihail C. Roco. 2005. *Managing Nano-Bio-Info-Cogno Innovations: Converging Technologies in Society*. Edited by National Science Foundation. Dordrecht, The Netherlands: Springer.

Bank for International Settlements, Monetary and Economic Department. 2013. "Triennial Central Bank Survey: Foreign Exchange Turnover in April 2013."

Barrington, Luke, Shubharoop Ghosh, Marjorie Greene, Shay Har-Noy, Jay Berger, Stuart Gill, Albert Yu-Min Lin, and Charles Huyck. 2012. "Crowdsourcing Earthquake Damage Assessment Using Remote Sensing Imagery." *Annals of Geophysics* 54 (6).

Becker, Selwyn W., and Fred O. Brownson. 1964. "What Price Ambiguity? Or the Role of Ambiguity in Decision-Making." *The Journal of Political Economy*:62-73.

Bianchi, Marco, Martin Boyle, and Deirdre Hollingsworth. 1999. "A Comparison of Methods for Trend Estimation." *Applied Economics Letters* 6 (2):103-9.

Blair, Tony. 2004. "Full Text: Blair's Civil Service Speech." *The Guardian*.

Börner, K. 2010. *Atlas of Science: Visualizing What We Know*. Cambridge, MA: The MIT Press.

Boyne, George A., and Alex A. Chen. 2007. "Performance Targets and Public Service Improvement." *Journal of Public Administration Research and Theory* 17 (3):455-77.

Braun, Ernest. 1998. *Technology in Context: Technology Assessment for Management*. London, England: Routledge.

Brewer, Marilynn B. 2003. "Internal Validity." In *Encyclopedia of Social Science Research Methods*. Thousand Oaks, CA: Sage Publications.

Bright, James Rieser, and Milton E. Schoeman. 1973. *A Guide to Practical Technological Forecasting*. Englewood Cliffs, NJ: Englewood Cliffs, NJ, Prentice-Hall.

Briscoe, Erica J., Scott Appling, and Joel Schlosser. 2015. "Passive Crowd Sourcing for Technology Prediction." In *Social Computing, Behavioral-Cultural Modeling, and Prediction*. Dordrecht, The Netherlands: Springer.

Bryson, J. M. 2011. *Strategic Planning for Public and Nonprofit Organizations: A Guide to Strengthening and Sustaining Organizational Achievement*. Hoboken, NJ: Jossey-Bass.

Bryson, John M., and William D. Roering. 1988. "Initiation of Strategic Planning by Governments." *Public Administration Review*:995-1004.

Cagnin, Cristiano. 2008. *Future-Oriented Technology Analysis: Strategic Intelligence for an Innovative Economy*. Edited by M. Keenan, R. Johnston, F. Scapolo and R. Barre. Dordrecht, The Netherlands: Springer.

Calof, Jonathan, and Jack E. Smith. 2010. "Critical Success Factors for Government-led Foresight." *Science and Public Policy* 37 (1):31-40.

Camerer, Colin F., and Eric J. Johnson. 1997. "The Process-Performance Paradox in Expert Judgment: How Can Experts Know So Much and Predict So Badly?" *Research on judgment and decision making: Currents, connections, and controversies*:342.

Carifio, James, and Rocco J. Perla. 2007. "Ten Common Misunderstandings, Misconceptions, Persistent Myths and Urban Legends about Likert Scales and Likert Response Formats and Their Antidotes." *Journal of Social Sciences* 3 (3):106.

Caswell, Hal, and Esther Shyu. 2012. "Sensitivity Analysis of Periodic Matrix Population Models." *Theoretical population biology* 82 (4):329-39.

Center of Excellence in Wireless & Information Technology. 2013. *Center of Excellence in Wireless & Information Technology*. Stony Brook University 2013 [cited March 3 2013]. Available from http://cewit.org/html/index.html.

Chabot, Christian, Chris Stolte, and Pat Hanrahan. 2003. "Tableau Software." Tableau Software.

Chen, Chaomei. 2008. "An Information-Theoretic View of Visual Analytics." *Computer Graphics and Applications, IEEE* 28 (1):18-23.

Chen, Peter Y., and Autumn D. Krauss. 2003. "Reliability." In *Encyclopedia of Social Science Research Methods*. Thousand Oaks, CA: Sage Publications.

Christensen, Clayton M. 1997. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Cambridge, MA: Harvard Business Press.

Circos. 2013. *Application of Circos to Genomics* 2013 [cited February 24 2013]. Available from http://circos.ca/intro/genomic_data/.

Clark, Lee Anna, and David Watson. 1995. "Constructing Validity: Basic Issues in Objective Scale Development." *Psychological assessment* 7 (3):309.

Clarke, Harold D. 2003. *Trend Analysis. Encyclopedia of Social Science Research Methods*. Thousand Oaks, CA: Sage Publications.

Clemen, Robert T., and Robert L. Winkler. 1999. "Combining Probability Distributions from Experts in Risk Analysis." *Risk Analysis* 19 (2):187-203.

Coates, Joseph F. 1985. "Foresight in Federal Government Policy Making." *Futures Research Quarterly* 1 (2):29-53.

Code for America. 2015. *Code for America* 2014 [cited April 11 2015]. Available from https://www.codeforamerica.org/.

Committee on Forecasting Future Disruptive Technologies. 2009. "Persistent Forecasting of Disruptive Technologies." ed. National Research Council. Washington, DC: National Research Council.

———. 2010. "Persistent Forecasting of Disruptive Technologies: Report 2." ed. National Research Council. Washington, DC: National Research Council.

Committee on Prospering in the Global Economy of the 21st Century. 2007. "Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future." ed. National Academy of Sciences. Washington, DC: National Academy of Sciences, National Academy of Engineering, Institute of Medicine,.

Conceição, Pedro, Manuel V. Heitor, Giorgio Sirilli, and Robert Wilson. 2004. "The 'Swing of the Pendulum' from Public to Market Support for Science and Technology: Is the US Leading the Way?" *Technological Forecasting and Social Change* 71 (6):553-78.

Cornish, Edward. 2004. *Futuring: The Exploration of the Future*: World Future Society.

Cozzens, Susan, Sonia Gatchair, Jongseok Kang, Kyung-Sup Kim, Hyuck Jai Lee, Gonzalo Ordóñez, and Alan Porter. 2010. "Emerging Technologies: Quantitative Identification and Measurement." *Technology Analysis & Strategic Management* 22 (3):361-76.
Cozzens, Susan, and Dhanaraj Thakur. 2014. *Innovation and Inequality: Emerging Technologies in an Unequal World*. Cheltenham, United Kingdom: Edward Elgar Publishing.
Crano, William D., Marilynn B. Brewer, and Andrew Lac. 2014. *Principles and Methods of Social Research*. London, United Kingdom: Routledge.
Creswell, John W. 2003. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. 2nd ed. Thousand Oaks, CA: Sage Publications.
Daim, Tugrul U., Dundar F. Kocaoglu, and Timothy R. Anderson. 2009. "Knowledge Driven Planning Tools for Emerging and Converging Technologies." *Technological Forecasting and Social Change* 76 (1):1.
Daim, Tugrul U., Guillermo Rueda, Hilary Martin, and Pisek Gerdsri. 2006. "Forecasting Emerging Technologies: Use of Bibliometrics and Patent Analysis." *Technological Forecasting and Social Change* 73 (8):981-1012.
Dalkey, Norman Crolee, Bernice B. Brown, and Samuel Cochran. 1969. *The Delphi Method: An Experimental Study of Group Opinion*. Vol. 3. Santa Monica, CA: Rand Corporation.
Dawes, John G. 2008. "Do Data Characteristics Change According to the Number of Scale Points Used? An experiment using 5 point, 7 point, and 10 point scales." *International journal of market research* 51 (1).
Defense Advanced Research Projects Agency. 2013. *[Defense Advanced Research Projects Agency] (DARPA): Creating and Preventing Strategic Surprise* 2013 [cited March 3 2013]. Available from http://www.darpa.mil.
Della-Piana, Connie K. 2015. April 6, 2015.
Denzin, Norman K., and Yvonna S. Lincoln. 2008. *Strategies of Qualitative Inquiry*. Vol. 2. Thousand Oaks, CA: Sage Publications.
Desouza, Kevin C., and Akshay Bhagwatwar. 2012. "Leveraging Technologies in Public Agencies: The Case of the US Census Bureau and the 2010 Census." *Public Administration Review* 72 (4):605-14.
Dirk, Meissner, and Sokolov Leonid Gokhbelexander. 2013. *Science, Technology, and Innovation Policy for the Future*. 2013 ed. Germany: Springer Verlag.
Doan, AnHai, Jayant Madhavan, Pedro Domingos, and Alon Halevy. 2004. "Ontology Matching: A Machine Learning Approach." In *Handbook on Ontologies*. Dordrecht, The Netherlands: Springer.
Dreyer, Iana, and Gerald Stang. 2013. "Foresight in Governments - Practices and Trends around the World."
Ehrig, Marc, and York Sure. 2004. "Ontology Mapping–An Integrated Approach." In *The Semantic Web: Research and Applications*: Springer.
Eriksson, E. Anders, and K. Matthias Weber. 2008. "Adaptive Foresight: Navigating the Complex Landscape of Policy Strategies." *Technological Forecasting and Social Change* 75 (4):462-82.
European Commission. 2013. *Welcome to the FET [Future and Emerging Technologies] Flagship Initiatives*. Euoprean Commission 2013 [cited March 3 2013]. Available from http://cordis.europa.eu/fp7/ict/programme/fet/flagship/.

European Commission, Joint Research Centre. 2014. "Foreight and Horizon Scanning." European Commission.
European Commission, Joint Research Centre, Institute for Prospective Technological Studies. 2002. The Role of Foresight in the Selection of Research Policy Priorities. Paper read at Conference Proceedings, at Seville, Spain.
European Parliamentary Technology Assessment. 2014. *European Parliamentary Technology Assessment* 2014 [cited May 31 2014]. Available from http://www.eptanetwork.org/.
Euzenat, Jérôme. 2013. *Ontology Matching*. Edited by P. Shvaiko and SpringerLink. 2nd edition ed. Dordrecht, The Netherlands: Springer.
Executive Office of the President. 2011. "Executive Order 13563 – Improving Regulation and Regulatory Review." ed. Executive Office of the President. Washington, DC: Federal Register.
———. 2014a. "Circular No. A-11: Preparation, Submission, and Execution of the Budget." In *Circular No. A-11*, ed. Executive Office of the President. Washington, DC.
———. 2015. *Technology*. Executive Office of the President, 2014b [cited March 17 2015]. Available from https://www.whitehouse.gov/issues/technology.
———. 2015. *The All-of-the-Above Strategy*. Executive Office of the President 2015 [cited April 20 2015]. Available from https://www.whitehouse.gov/energy/securing-american-energy.
Executive Office of the President, Office of Management and Budget, and Office of Science and Technology Policy Executive Office of the President. 2012. "Science and Technology Priorities for the FY 2014 Budget." ed. Executive Office of the President. Washington, DC: Executive Office of the President,.
Executive Office of the President, Office of Science and Technology Policy. 2010. "Emerging technologies [Interagency Policy Coordination] IPC [Committee] Has Inaugural Meeting." ed. Executive Office of the President. Washington, DC: Executive Office of the President,.
Executive Office of the President, Office of the Press Secretary. 2009. "Memorandum for the Heads of Executive Departments and Agencies: Scientific Integrity." ed. Executive Office of the President. Washington, DC: Executive Office of the President,.
Executive Office of the President, President's Council of Advisors on Science and Technology. 2014c. "Report to the President and Congress on the Fifth Assessment of the National Nanotechnology Initiative." ed. Executive Office of the President. Washington, DC.
Fagerberg, J. 1987. "A Technology Gap Approach to Why Growth Rates Differ." *Research Policy* 16 (2):87-99.
———. 1994. "Technology and International Differences in Growth-Rates." *Journal of Economic Literature* 32 (3):1147-75.
Fey, William H. 2012. "Population Growth in Metro America Since 1980: Putting the Volatile 2000's in Perspective." ed. Brookings Institution. Washington, DC: Brookings Institution.
Fishkin, James. 2009. *When the People Speak: Deliberative Democracy and Public Consultation*. Oxford, United Kingdom: Oxford University Press.
Fleischer, Torsten, Michael Decker, and Ulrich Fiedeler. 2005. "Assessing Emerging Technologies—Methodological Challenges and the Case of Nanotechnologies." *Technological Forecasting and Social Change* 72 (9):1112-21.
Fowles, Jib, and Robert Brent Fowles. 1978. *Handbook of Futures Research*. Westport, CT: Greenwood Press.

French, Simon. 1983. *Group Consensus Probability Distributions: A Critical Survey*: University of Manchester, Department of Decision Theory.
Fuerth, Leon S. 2012. "Anticipatory Governance: Practical Upgrades." Washington, DC: The Project on Forward Engagement.
Gao, Huiji, Geoffrey Barbier, Rebecca Goolsby, and Daniel Zeng. 2011. "Harnessing the Crowdsourcing Power of Social Media for Disaster Relief." Defense Technical Information Center.
Gelfand, Alan E, Bani K Mallick, and Dipak K Dey. 1995. "Modeling Expert Opinion Arising as a Partial Probabilistic Specification." *Journal of the American Statistical Association* 90 (430):598-604.
Genest, Christian, and Kevin J McConway. 1990. "Allocating the Weights in the Linear Opinion Pool." *Journal of Forecasting* 9 (1):53-73.
George Mason University. 2015. *SciCast* 2015 [cited April 7 2015]. Available from https://scicast.org/ - !/.
George Washington University. 2015. *TechCast Global* 2015 [cited March 21 2015]. Available from http://www.techcastglobal.com.
Gephi. 2015. *Gephi* 2015 [cited March 27 2015]. Available from https://gephi.github.io/about/.
Gerdsri, Pisek, and Dundar Kocaoglu. 2009. *A Systematic Approach to Developing National Technology Policy and Strategy for Emerging Technologies: A Case Study of Nanotechnology for Thailand's Agriculture Industry*. Edited by D. F. Kocaoglu, T. R. Anderson, T. U. Daim, A. Jetter and C. M. Weber.
Gibson, Campbell. 1998. "Population of the 100 Largest Cities and Other Urban Areas in the United States: 1790 to 1990." ed. C. B. US Department of Commerce. Washington, DC: US Department of Commerce, Census Bureau.
Given, Lisa M., and Kristie Saumure. 2008. "Trustworthiness." In *The SAGE Encyclopedia of Qualitative Research Methods*. Thousand Oaks, CA: Sage Publications.
Global Business Network. *Global Business Network* 2013 [cited January 11, 2013. Available from http://www.gbn.com
Global Workplace Analytics. 2013. "Latest Telecommuting Statistics."
Goldberg, David Edward. 2002. *The Design of Innovation: Lessons from and for Competent Genetic Algorithms*. Vol. 7. Dordrecht, The Netherlands: Springer Science & Business Media.
Google, Inc. 2015. *Public Data Explorer* 2015 [cited March 27 2015]. Available from http://www.google.com/publicdata/directory.
Gordon, Adam. 2012. "Over to You Mr. Smart-Pants: How Would You Fix the World?" *Forbes.com*.
Assemblée Nationale. 1953. *Gouverner c'est prévoir, discourse d'investiture et réponses aux interpellateurs*. Pierre Mendès. 3 et 4 juin 1953.
Green, Kesten C., J. Scott Armstrong, and Andreas Graefe. 2007. "Methods to Elicit Forecasts from Groups: Delphi and Prediction Markets Compared."
Grimmer, Justin, and Brandon M. Stewart. 2013. "Text as Data: The Promise and Pitfalls of Automatic Content Analysis Methods for Political Texts." *Political Analysis*:mps028.
Grupp, Hariolf, and Harold A. Linstone. 1999. "National Technology Foresight Activities around the Globe: Resurrection and New Paradigms." *Technological Forecasting and Social Change* 60 (1):85-94.

Guba, Egon G., and Yvonna S. Lincoln. 1994. "Competing Paradigms in Qualitative Research." In *Handbook of Qualitative Research 2*, ed. E. G. Guba and Y. S. Lincoln.
Hackler, Darrene, and Gregory D. Saxton. 2007. "The Strategic Use of Information Technology by Nonprofit Organizations: Increasing Capacity and Untapped Potential." *Public Administration Review* 67 (3):474-87.
Halal, William E. 2013. "Forecasting the Technology Revolution: Results and learnings from the TechCast Project." *Technological Forecasting and Social Change* 80 (8):1635-43.
Halal, William E, Michael D Kull, and Ann Leffmann. 1997. "The GWU [George Washington University] Forecast of Emerging Technologies." *Technological Forecasting and Social Change (in press)*.
———. 1998. "The George Washington University Forecast of Emerging Technologies: A Continuous Assessment of the Technology Revolution." *Technological Forecasting and Social Change* 59 (1):89-110.
Hall, Bronwyn, and Stephen A. Merrill. 2005. "Research and Development Data Needs." ed. National Research Council. Washington, D.C.: National Research Council.
Hammersley, Martyn. 2003. "Objectivity." In *Encyclopedia of Social Science Research Methods*. Thousand Oaks, CA: Sage Publications.
Hinkin, Timothy R. 1995. "A Review of Scale Development Practices in the Study of Organizations." *Journal of Management* 21 (5):967-88.
Hora, Steven. 2007. "Eliciting Probabilities from Experts." *Advances in Decision Analysis: From Foundations to Applications*:129.
Horizon Scanning Center. 2008. "The Foresight Toolkit: Tools for strategic futures for policy-makers and analysts." ed. The Horizon Scanning Programme. London, England: Her Majesty's Government,.
Howe, Jeff. 2006. "The Rise of Crowdsourcing." *Wired magazine* 14 (6):1-4.
Huberman, A. Michael, and Matthew B. Miles. 2002. *The Qualitative Researcher's Companion*. Thousand Oaks, CA: Sage Publications.
2004. House Committee on Government Reform. *Identifying Federally Funded Research and Development on Information Technology*. July 7, 2004.
Imec. *Imec* 2013 [cited March 3, 2013. Available from www2.imec.be.
Institute for Alternative Futures. 2013. *Institute for Alternative Futures* 2013 [cited February 26 2013]. Available from http://www.altfutures.com.
Institute for the Future. 2015. *Signtific Lab: Game Platform & Report* 2009a [cited March 21 2015]. Available from http://www.iftf.org/our-work/people-technology/games/signtific-lab/.
———. 2009b. "Signtific Project: Year 1 Report Update." Palo Alta, CA: Institute for the Future.
———. 2015. *Engaged Foresight in Action* 2012 [cited April 8 2015]. Available from http://www.iftf.org/foresightengine/.
Intelligence Advanced Research Projects Activity. *[Intelligence Advanced Research Projects Activity] IARPA: Be the Future* 2013 [cited March 3, 2013. Available from http://www.iarpa.gov.
Intergovernmental Panel on Climate Change. 2000. "Summary for Policymakers: Emissions Scenarios." Intergovernmental Panel on Climate Change.

Jacobs, Robert A. 1995. "Methods for Combining Experts' Probability Assessments." *Neural computation* 7 (5):867-88.

James, Nalita. 2008. "Authenticity." In *The SAGE Encyclopedia of Qualitative Research Methods*. Thousand Oaks, CA: Sage Publications.

Jasanoff, Sheila, M. Lynch, C. Miller, B. Wynne, F. Buttel, F. Charvolin, P. Edwards, A. Elzinga, P. Haas, and C. Kwa. 1998. "Science and Decisionmaking."

Jick, Todd D. 1979. "Mixing Qualitative and Quantitative Methods: Triangulation in Action." *Administrative science quarterly* 24 (4):602-11.

Johnston, Erik. 2010. "Governance Infrastructures in 2020." *Public Administration Review* 70:S122-S8.

Kalil, Tom, and Chuck Thorpe. 2015. *Supporting the President's Naitonal Robotics Initiative* 2011 [cited April 6 2015]. Available from https://www.whitehouse.gov/blog/2011/08/03/supporting-president-s-national-robotics-initiative.

Kameoka, Akio, Yoshiko Yokoo, and Terutaka Kuwahara. 2004. "A Challenge of Integrating Technology Foresight and Assessment in Industrial Strategy Development and Policymaking." *Technological Forecasting and Social Change* 71 (6):579-98.

Kay, Luciano, Nils Newman, Jan Youtie, Alan L. Porter, and Ismael Rafols. 2014. "Patent Overlay Mapping: Visualizing Technological Distance." *Journal of the Association for Information Science and Technology*.

Keim, Daniel, Gennady Andrienko, Jean-Daniel Fekete, Carsten Görg, Jörn Kohlhammer, and Guy Melançon. 2008. *Visual Analytics: Definition, Process, and Challenges*. Dordrecht, The Netherlands: Springer.

Kelly, Kevin. 2010. *What Technology Wants*. New York, NY: Viking Press.

Kettl, Donald F. 2015. *Politics of the Administrative Process*. Edited by I. Sage Publications. Thousand Oaks, CA: Sage Publications.

Krippendorff, Klaus. 1980. "Content Analysis." ed. Sage Publications. Thousand Oaks, CA: Sage Publications.

———. 2013. "Content Analysis: An Introduction to Its Methodology." Thousand Oaks, CA: Sage Publications.

Krosnick, Jon A. 1999. "Survey Research." *Annual review of psychology* 50 (1):537-67.

Kurzweil, Ray. *Kurzweil Accelerating Intelligence* 2013 [cited March 3, 2013. Available from http://www.kurzweilai.net.

Lall, S. 1992. "Technological Capabilities and Industrialization." *World Development* 20 (2):165-86.

Lane, Julia. 2012. "Measuring the Results of Science Investments."

Lee, Hakyeon, Changyong Lee, Hyeonju Seol, and Yongtae Park. 2008. "On the R&D [Research & Development] Priority Setting in Technology Foresight: a DEA [Data Envelopment Analysis] and ANP [Analytic Network Process] Approach." *International Journal of Innovation and Technology Management* 5 (2):201-19.

Lehnert, Wendy G., and Martin H. Ringle. 1982. *Strategies for Natural Language Processing*. Abingdon, United Kingdom: Psychology Press.

Lewis-Beck, Michael, Alan E. Bryman, and Tim Futing Liao. 2003. *The Sage Encyclopedia of Social Science Research Methods*. Thousand Oaks, CA: Sage Publications.

Likert, Rensis. 1974. *A Method of Constructing an Attitude Scale*. Chicago, IL: Aldine.

Lima, Manual. 2011. *Visual Complexity: Mapping Patterns of Information*. New York: Princeton Architectural Press.
Liu, P., and A. Chetal. 2005. "Trust-Based Secure Information Sharing between Federal Government Agencies." *Journal of the American Society for Information Science and Technology* 56 (3):283-98.
Loia, Vincenzo, Witold Pedrycz, and Sabrina Senatore. 2007. "Semantic Web Content Analysis: A Study in Proximity-Based Collaborative Clustering." *IEEE Transactions on Fuzzy Systems* 15 (6):1294-312.
Lombard, Matthew, Jennifer Snyder-Duch, and Cheryl Campanella Bracken. 2002. "Content Analysis in Mass Communication: Assessment and Reporting of Intercoder Reliability." *Human communication research* 28 (4):587-604.
Mali, Franc. 2009. "Bringing Converging Technologies Closer to Civil Society. The Role of Precautionary Principles in Risk Technology Assessment." University of Ljubljana.
Marburger, John. 2005. "Wanted: Better Benchmarks." *Science* 308 (5725):1087.
Martin, Ben R, and John Irvine. 1989. *Research Foresight: Priority-Setting in Science*. London, United Kingdom: Pinter.
Massachusetts Institute of Technology. 2013. *Massachusetts Institute of Technology Technology Review* 2013 [cited February 27 2013]. Available from http://www.technologyreview.com.
Maxwell, Joseph A. 2004. *Qualitative Research Design: An Interactive Approach*. Thousand Oaks, CA: Sage Publications.
Maxwell, Joseph Alex. 1996. "Qualitative Research Design: An Interactive Approach." Thousand Oaks, CA: Sage Publications.
Mergel, Ines, and Kevin C. Desouza. 2013. "Implementing Open Innovation in the Public Sector: The Case of Challenge.gov." *Public Administration Review* 73 (6):882-90.
Meyer, Mary A., and Jane M. Booker. 2001. *Eliciting and Analyzing Expert Judgment: A Practical Guide*. Vol. 7: SIAM.
Minto, Barbara. 1996. *The Minto Pyramid Principle*. London, England: Minto International, Inc.
MIT [Massachusetts Institute of Technology] Technology Review, EmTech. 2013. *MIT Technology Review, EmTech* 2013 [cited March 3 2013]. Available from http://www2.technologyreview.com/emtech/12/.
Moore, Mark Harrison. 1995. *Creating Public Value: Strategic Management in Government*: Harvard University Press.
Morgeson, Forrest V., III, and Sunil Mithas. 2009. "Does E-Government Measure Up to E-Business? Comparing End User Perceptions of US Federal Government and E-Business Web Sites." *Public Administration Review* 69 (4):740-52.
Morgeson, Forrest V., III, David VanAmburg, and Sunil Mithas. 2011. "Misplaced Trust? Exploring the Structure of the E-Government-Citizen Trust Relationship." *Journal of Public Administration Research and Theory* 21 (2):257-83.
Mulgan, Geoff. 2002. "Governing in Time: Long-termism and the Role of Futures Thinking in the UK [United Kingdom] Government." In *The Role of Foresight in the Selection of Research Policy Priorities*. Seville, Spain: European Commission, Joint Research Centre, Institute for Prospective Technological Studies.
Mumpower, Jeryl L., and Thomas R. Stewart. 1996. "Expert Judgement and Expert Disagreement." *Thinking & Reasoning* 2 (2-3):191-212.

Naisbitt, John, and J. Cracknell. 1984. *Megatrends: Ten New Directions Transforming Our Lives*. New York, NY: Warner Books.
National Aeronautics and Space Administration. 2015. *National Robotics Initiative* 2011 [cited April 6 2015]. Available from http://www.nasa.gov/robotics/.
National Institutes of Health. *STAR METRICS* 2013 [cited February 27, 2013. Available from https://www.starmetrics.nih.gov.
———. 2015. *STAR METRICS: About STAR METRICS* 2015 [cited March 21 2015]. Available from https://www.starmetrics.nih.gov/Star/About.
National Institutes of Health, Office of Extramural Research. 2014. "STAR METRICS: Update and review of activities (2013 & 2014)." ed. National Institutes of Health. Bethesda, MD: National Institutes of Health,.
National Nanotechnology Initiative. 2015. *About the NNI [National Nanotechnology Initiative]*. United States National Nanotechnology Initiative 2015 [cited March 17 2015]. Available from http://www.nano.gov/about-nni.
National Network for Manufacturing Innovation. 2015. *NNMI: Snapshot* 2013 [cited April 17 2015]. Available from http://manufacturing.gov/nnmi.html.
National Robotics Initiative (NRI). 2015. *National Robotics Initiative (NRI)* 2015 [cited April 17 2015]. Available from http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503641&org=CISE.
National Science and Technology Council. 2008. "The Science of Science Policy: A Federal Research Roadmap." ed. B. a. E. S. Subcommittee on Social, Committee on Science, National Science and Technology Council, Office of Science and Technology Policy,. Washington, DC: National Science and Technology Council.
National Science Board. 2007. "Enhancing Support of Transformative Research at the National Science Foundation." ed. National Science Foundation. Washington, DC: National Science Foundation.
National Science Foundation. 2015. *Survey of Federal Funds for Research and Development*. National Science Foundation 2013a [cited March 17 2015]. Available from http://www.nsf.gov/statistics/srvyfedfunds/.
———. 2015. *Survey of Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions* 2013b [cited March 22 2015]. Available from http://www.nsf.gov/statistics/srvyfedsupport/.
———. 2015. *Most Recent Data Tables by Survey*. National Science Foundation 2014a [cited March 17 2015]. Available from http://www.nsf.gov/statistics/tables-by-survey.cfm.
———. 2015. *Partners: Collaboration with Other Federal Agencies*. National Science Foundation 2014b [cited March 17 2015]. Available from http://www.nsf.gov/about/partners/fedagencies.jsp.
Neuendorf, Kimberly A. 2002. *The Content Analysis Guidebook*. Vol. 300. Thousand Oaks, CA: Sage Publications.
———. 2011. "Content Analysis—A Methodological Primer for Gender Research." *Sex Roles* 64 (3-4):276-89.
Nordmann, Alfred. 2004. "Converging Technologies–Shaping the Future of European Societies." In *Interim report of the Scenarios Group, High Level Expert group*.
NVivo. 2014. "NVivo qualitative data analysis software." ed. L. QSR International Pty.

O'Reilly Media. *O'Reilly Emerging Technology Conference* 2013 [cited March 3, 2013. Available from http://blip.tv/oreilly-emerging-technology-conference.

Obama, Barack. 2015. *Remarks by the President at the Opening Session of the Forum on Modernizing Government* 2010 [cited February 26 2015]. Available from http://www.whitehouse.gov/the-press-office/remarks-president-opening-session-forum-modernizing-government

Ondercin, Heather L. 2003. "External Validity." In *Encyclopedia of Social Science Research Methods*. Thousand Oaks, CA: Sage Publications.

Onwuegbuzie, Anthony J., and Kathleen M. T. Collins. 2007. "A Typology of Mixed Methods Sampling Designs in Social Science Research." *Qualitative Report* 12 (2):281-316.

Oracle Corporation. 2015. *MySQL*.

Organisation for Economic Co-operation and Development. 1996. "The Knowledge-Based Economy." ed. Organisation for Economic Co-operation and Development. Paris, France: Organisation for Economic Co-operation and Development.

———. 2012. "Medium and Long-term Scenarios for Global Growth and Imbalances." In *OECD Economic Outlook*, ed. Organisation for Economic Co-operation and Development. Berlin, Germany: Organisation for Economic Co-operation and Development.

Otero-Cerdeira, Lorena, Francisco J. Rodríguez-Martínez, and Alma Gómez-Rodríguez. 2015. "Ontology Matching: A Literature Review." *Expert Systems with Applications* 42 (2):949-71.

Oxford Dictionaries. 2015. *Technology* 2015 [cited July 9 2015]. Available from http://www.oxforddictionaries.com/us/definition/american_english/technology.

Paradise, Jordan, Susan M. Wolf, Gurumurthy Ramachandran, and Efrosini Kokkoli. 2008. "Developing Oversight Frameworks for Nanobiotechnology." *Minnesota Journal of Law, Science and Technology* 9:399.

Pavitt, Keith. 1991. "What Makes Basic Research Economically Useful?" *Research Policy* 20:109-19.

QDA Miner. Provalis Research, Montreal, Canada.

Potter, W. J., and D. Levine-Donnerstein. 1999. "Rethinking Validity and Reliability in Content Analysis." *Journal of Applied Communication Research* 27 (3):258-84.

Ranard, Benjamin L., Yoonhee P. Ha, Zachary F. Meisel, David A. Asch, Shawndra S. Hill, Lance B. Becker, Anne K. Seymour, and Raina M. Merchant. 2014. "Crowdsourcing—Harnessing the Masses to Advance Health and Medicine, A Systematic Review." *Journal of general internal medicine* 29 (1):187-203.

RAND, Justice, Infrastructure, and Environment. 2015. *Selected Projects and Resources: RaDiUS* 2015 [cited March 21 2015]. Available from http://www.rand.org/jie/projects.html.

Rapley, Tim. 2007. *Doing Conversation, Discourse and Document Analysis*. Edited by U. Flick. Thousand Oaks, CA: Sage Publications.

Rasiel, Ethan M. 1999. *The McKinsey Way [electronic resource]: Using the Techniques of the World's Top Strategic Consultants to Help You and Your Business*: McGraw-Hill.

Reiss, Thomas, and Kate Millar. 2014. "Introduction to Special Section: Assessment of Emerging Science and Technology: Integration Opportunities and Challenges." *Science and Public Policy* 41 (3):269-71.

Roberts, Margaret E, Brandon M Stewart, Dustin Tingley, Christopher Lucas, Jetson Leder-Luis, Shana Kushner Gadarian, Bethany Albertson, and David G Rand. 2014. "Structural Topic Models for Open-Ended Survey Responses." *American Journal of Political Science* 58 (4):1064-82.

Roco, M. C., W. S. Bainbridge, B. Tonn, and G. Whitesides. 2013. *Convergence of Knowledge, Technology and Society: Beyond Convergence of Nano-Bio-Info-Cognitive Technologies*. Edited by M. C. Roco, W. S. Bainbridge, B. Tonn and G. Whitesides. Dordrecht: Springer.

Roco, Mihail C. 2007. "Possibilities for Global Governance of Converging Technologies." *Journal of Nanoparticle Research* 10 (1):11-29.

———. 2011a. *Opportunities for Global Governance of Emerging and Converging Technologies*. Sao Paolo, Brazil.

———. 2011b. "Technology Convergence." In *Leadership in Science and Technology: A Reference Handbook*, ed. W. S. Bainbridge. Thousand Oaks, CA: Sage Publications.

Roco, Mihail C., and William Sims Bainbridge. 2002. "Overview: Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology, and Cognitive Science (NBIC)." *Journal of Nanotechnology*:1-24.

———. 2003. "Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science." ed. National Science Foundation. Dordrecht, The Netherlands: Kluwer Academic Publishers (currently Springer).

Roco, Mihail C., Chad A. Mirkin, and Mark C. Hersam. 2011. "Nanotechnology Research Directions for Societal Needs in 2020: Summary of International Study." *Journal of Nanoparticle Research* 13 (3):897-919.

Rodriguez Bolivar, Manuel Pedro, Carmen Caba Perez, and Antonio M. Lopez Hernandez. 2007. "E-government and Public Financial Reporting - The Case of Spanish Regional Governments." *American Review of Public Administration* 37 (2):142-77.

Roelofsen, Anneloes, Jacqueline Broerse, Tjard de Cock Buning, and Joske Bunders. 2010. "Engaging with Future Technologies: How Potential Future Users Frame Ecogenomics." *Science and Public Policy* 37 (3):167-79.

Rohrbaugh, John. 1979. "Improving the Quality of Group Judgment: Social Judgment Analysis and the Delphi technique." *Organizational Behavior and Human Performance* 24 (1):73-92.

Rubin, Philip. 2013. Personal correspondence with Principal Assistant Director for the Office of Science and Technology Policy, Executive Office of the President Email, January 2013.

Samid, Amnon. 2009. "Implementation of New and Emerging Technologies in Israel." In *The Panel of the United Nations Commission on Science and Technology for Development*. Geneva, Switzerland.

Sanz-Menendez, L., C. Cabello, and C. E. Garcia. 2001. "Understanding Technology Foresight: The Relevance of its S & T [Science and Technology] Policy Context." *International Journal of Technology Management* 21 (7-8):661-79.

Sardar, Ziauddin. 2010. "The Namesake: Futures; Futures Studies; Futurology; Futuristic; Foresight—What's in a Name?" *Futures* 42 (3):177-84.

Sargent, John F., Jr. 2015. "Federal Research and Development Funding: FY2016." ed. Congressional Research Service. Washington, DC.

Sasuly, M. 1934. *Trend Analysis in Statistics: Theory and Technique*. Washington, DC: The Brookings Institution.
Satterfield, Terre, Joe Conti, Barbara Herr Harthorn, Nick Pidgeon, and Anton Pitts. 2013. "Understanding Shifting Perceptions of Nanotechnologies and Their Implications for Policy Dialogues about Emerging Technologies." *Science and Public Policy* 40 (2).
Schuppan, T. 2009. "Reassing Outsourcing in ICT-enabled Public Management: Examples from the UK." *Public Management Review* 11 (6):811-31.
Schwartz, Peter. 1996. *The Art of the Long View: Planning for the Future in an Uncertain World*. New York: Currency Doubleday.
Seelman, Katherine D. 2008. "Converging, Pervasive Technologies: Chronic and Emerging Issues and Policy Adequacy." *Assistive Technology* 20:126-37.
Senge, Peter M. 2014. *The Fifth Discipline Fieldbook: Strategies and Tools for Building a Learning Organization*. New York, NY: Crown Business.
Seoul National University. *Government-funded Research Centers* 2013 [cited March 3, 2013. Available from http://www.useoul.edu/research/government-funded-research-centers.
Shin, Juneseuk, and Chong Man Kim. 2013. "Risk-Adjusted Performance Forecasting of Future Key Technology." *Technology Analysis and Strategic Management* 25 (2):147-61.
Shively, W. Phillips. 2009. *The Craft of Political Research*. 7th ed. Upper Saddle River, New Jersey: Pearson Prentice Hall.
Stemler, Steve. 2001. "An Overview of Content Analysis." *Practical Assessment, Research and Evaluation* 7 (17):137-46.
Stiefel, Dorian. 2015. *The Foresight Challenge* 2015 [cited April 3 2015]. Available from http://www.foresightchallenge.org.
Stine, Deborah D. 2009. "Science and Technology Policymaking: A Primer." Washington, DC: Congressional Research Service.
Stone, Mervyn. 1961. "The Opinion Pool." *The Annals of Mathematical Statistics* 32 (4):1339-42.
Sunstein, Cass R. 2006. *Infotopia: How Many Minds Produce Knowledge*. Oxford, United Kingdom: Oxford University Press.
Swan, Melanie. 2012. "Crowdsourced Health Research Studies: An Important Emerging Complement to Clinical Trials in the Public Health Research Ecosystem." *Journal of medical Internet research* 14 (2).
Taleb, Nassim Nicholas. 2010. *The Black Swan: The impact of the Highly Improbable Fragility*. New York, NY: Random House.
Tashakkori, Abbas, and Charles Teddlie. 2010. *Sage Handbook of Mixed Methods in Social and Behavioral Research*. Thousand Oaks, CA: Sage Publications.
Thomas, James J., and Kristin A. Cook. 2006. "Visualization Viewpoints: A Visual Analytics Agenda." *IEEE Computer Graphics and Applications* January/February 2006:10-3.
Thomas, R., J. M. Gohlke, G. F. Stopper, F. M. Parham, and C. J. Portier. 2009. "Choosing the Right Path: Enhancement of Biologically Relevant Sets of Genes or Proteins Using Pathway Structure." *Genome Biol* 10 (4):R44.
Tinsley, H. E. A., and D. J. Weiss. 2000. "Interrater Reliability and Agreement." In *Handbook of Applied Multivariat Statistics and Mathematical Modeling*, ed. H. E. A. Tinsley and S. D. Brown. San Diego, CA: Academic Press.
Tonn, Bruce. 2010. "Global Trends and Forecasts: A List." Knoxville, TN.

Tonn, Bruce, and Dorian Stiefel. 2012. "The Future of Governance and the Use of Advanced Information Technologies." *Futures* 44 (9):812-22.
———. 2013. "Evaluating Methods for Estimating Existential Risks." *Risk Analysis* 33 (10):1772-87.
———. 2014. "Placing Global Catastrophic Risks in the Framework of Unintended Consequences." In *Annual Meeting of the Society for Risk Analysis*. Denver, CO: Society for Risk Analysis.
Twardy, Charles, Robin Hanson, Kathryn Laskey, Tods Levitt, Bruce D'Ambrosio, and Daniel Maxwell. 2014. "SciCast: Collective Forecasting of Innovation." *Collective Intelligence*.
Ughetto, Elisa. 2007. "Foresight as a Triple Helix of Industry, University and Government relations." *Foresight* 9 (5):14-22.
United Kingdom Government. 2015. *Horizon Scanning Programme Team* 2015 [cited March 21 2015]. Available from https://www.gov.uk/government/groups/horizon-scanning-programme-team.
United Kingdom Government, Department for Transport. 2004. "Scenario Planning Toolkit." ed. Department for Transport.
United Kingdom Government Office for Science. 2015. *Foresight Projects* 2013 [cited March 21 2015]. Available from https://www.gov.uk/government/collections/foresight-projects.
United Kingdom Government Office of Science. 2015. *Future of Ageing* 2014 [cited March 27 2015]. Available from https://www.gov.uk/government/collections/future-of-ageing.
———. 2015. *Future of Cities* 2015 [cited March 27 2015]. Available from https://www.gov.uk/government/collections/future-of-cities.
United Nations Environment Programme. *IE Training Manual - Module 6: 4.2 Medium-term regional and global scenarios - The UNEP GEO-3 and GEO-4 Scenarios* 2007 [cited March 3, 2013. Available from http://www.unep.org/ieacp/iea/training/manual/module6/1249.aspx.
United Nations Industrial Development Organization. 2002. *International Practice in Technology Foresight*. Edited by United Nations: United Nations.
US Census Bureau. 2013. *International Programs: International Database: World Population: 1950-2050* 2013 [cited February 26 2013]. Available from http://www.census.gov/population/international/data/idb/worldpopgraph.php
US Congress. 1993. "Government Performance and Results Act."
———. 2010. "Government Performance and Results Modernization Act."
US Congress, Office of Technology Assessment. 1982. *Global Models, World Futures, and Public Policy*. Edited by Office of Technology Assessment. Washington, DC: US Government Printing Office.
US Department of Commerce. 2010. "Notice of Determination." ed. United States Department of Commerce. Washington, D. C.: United States Department of Commerce, Emerging Technology and Research Advisory Committee.
———. 2011. "Strategic plan." ed. US Department of Commerce. Washington, DC: US Department of Commerce.
———. 2014. "America Is Open for Business: Strategic Plan: Fiscal Years 2014-2018." ed. US Department of Commerce. Washington, D. C.
———. 2015. *About Commerce* 2015a [cited April 17 2015]. Available from http://www.commerce.gov/page/about-commerce.

———. 2015b. "FY2016 Congressional Submission [Congressional Budget Justification]."
US Department of Energy. 2011a. "Report on the First Quadrennial Technology Review." ed. US Department of Energy. Washington, DC: US Department of Energy.
———. 2011b. "Strategic Plan." ed. US Department of Energy. Washington, DC: US Department of Energy.
———. 2012. "Report on the First Quadrennial Technology Review: Technology Assessments." ed. US Department of Energy. Washington, DC: US Department of Energy.
———. 2015. *Department of Energy Implementation Activities in the Case of a Lapse of Appropriations* 2013 [cited April 17 2015]. Available from http://energy.gov/articles/department-energy-implementation-activities-case-lapse-appropriations.
———. 2014. "Strategic Plan: 2014-2018." ed. US Department of Energy. Washington, DC: US Department of Energy.
———. 2015. "FY2016 Congressional Budget Request [Congressional Budget Justification]."
US General Accounting Office. 1996. "Executive Guide: Effectively Implementing the Government Performance and Results Act." ed. C. G. o. t. U. S. US General Accounting Office. Washington, DC: US General Accounting Office.
———. 1997. "Agencies' Strategic Plans Under GPRA: Key Questions to Facilitate Congressional Review." ed. G. G. D. US General Accounting Office. Washington, DC: US General Accounting Office.
US Government. 2015. *Data.gov* 2015 [cited March 27 2015]. Available from http://www.data.gov.
Vagias, Wade M. 2006. "Likert-type Scale Response Anchors." Clemson University: Clemson University.
Weber, Robert Philip. 1990. *Basic Content Analysis*. Vol. 49. Thousand Oaks, CA: Sage Publications.
Weiss, Robert Stuart. 1994. "Learning from Strangers: The Art and Method of Qualitative Interview Studies." New York, NY: Free Press.
Whitley, Darrell. 1994. "A Genetic Algorithm Tutorial." *Statistics and computing* 4 (2):65-85.
World Economic Forum. *Global Agenda Council on Emerging Technologies 2012* 2013 [cited March 3, 2013. Available from http://www.weforum.org/content/global-agenda-council-emerging-technologies-2012.
World Future Society. *The Futurist*. World Future Society 2013a [cited March 3, 2013. Available from http://www.wfs.org/futurist.
———. *World Future Review: A Journal of Strategic Foresight*. World Future Society 2013b [cited March 3, 2013. Available from http://www.wfs.org/wfr.
Yamaner, Michael. 2015. Electronic mail, March 18, 2015.
Yardley, Lucy. 2000. "Dilemmas in Qualitative Health Research." *Psychology and health* 15 (2):215-28.
Yoon, Janghyeok, and Kwangsoo Kim. 2012. "TrendPerceptor: A Property–Function Based Technology Intelligence System for Identifying Technology Trends from Patents." *Expert Systems with Applications* 39 (3):2927-38.
Zients, Jeffrey D., and John P. Holdren. 2012. "Memorandum for the Heads of Executive Departments and Agencies: Science and Technology Priorities for the FY 2014 Budget." ed. Executive Office of the President. Washington, DC.

Appendices

Appendix A. Tables

Table 1. Research Questions and Propositions Mapped to the Methodology

Phase	Step	**Research Question 1: Are ECT being used to fulfill agency strategic plans (current use)?**			**Research Question 2: Could ECT be used more extensively to fulfill agency strategic plans (potential use)?**		
		Approach 1: Content analysis involves culling information from documents (Krippendorff 1980; Weber 1990; Neuendorf 2002; Grimmer and Stewart 2013; Krippendorff 2013; Potter and Levine-Donnerstein 1999; Stemler 2001)	Approach 2: Technology assessment analysis captures expert opinions about the probability of technology use (Braun 1998; European Parliamentary Technology Assessment 2014; Fleischer et al. 2005; Kameoka et al. 2004)	Approach 3: Individual interviews involve open-ended discussion to explore and connect ideas (Weiss 1994; Denzin and Lincoln 2008; Maxwell 2004; Horizon Scanning Center 2008; Guba and Lincoln 1994)	Approach 3: Individual interviews [See column to the left]	Approach 4: Plausibility matrices involving expert opinions of probable, or priority, areas for focus (United Kingdom Government ; Horizon Scanning Center 2008; Green et al. 2007)	Approach 5: Crowd-sourced intelligence (folksonomies in futures research (Horizon Scanning Center 2008)) involves collecting expertise of individuals who volunteer their expertise (Howe 2006; Sunstein 2006; Briscoe et al. 2015)
Phase 1 / Develop Methodology Proposition 1	Define	Defined problem is to identify current and potential use of ECT agencies to fulfill agency strategies	[See column under Approach 1]	[See column under Approach 1]		[See column under Approach 1]	[See column under Approach 1]
Phase 2 / Apply Methodology Propositions 2a-2b	Collect	Government reports such as Agency Strategies, Congressional Budget Justifications, and Quadrennial Technology Reviews	Expert assessments on a survey matrix built from online articles and government reports	Government employee answers to open-ended questions		Expert assessments on a survey matrix build from online articles and government reports	Crowd-sourced website tool built from researched lists of agency strategies, ECT, platforms, trends/forecasts, potential futures, and societal benefits and risks

Table 1. Research Questions and Propositions Mapped to the Methodology (continued)

Phase	**Step**	**Research Question 1: Are ECT being used to fulfill agency strategic plans (current use)?**			**Research Question 2: Could ECT be used more extensively to fulfill agency strategic plans (potential use)?**		
Phase 2 / Apply Methodology Propositions 2a-2b (continued)	Organize	Loaded documents to QDA Miner with one record per report	Loaded probabilities of current use to Excel with one line per technology funded and one column per strategy	Typed interviews and loaded documents to QDA Miner with one record per interview subject		Loaded probabilities of potential use to Excel with one line per technology funded and one column per strategy	Loaded website answers, probabilities, and priorities to Excel with one line per answer, which were based on the researched data stored in MySQL™ and served on a website designed in PHP
	Analyze	▪ Established the process ▪ Developed the model ▪ Coded as human ▪ Coded as machine ▪ Calculated human/machine inter-rater reliability ▪ Validated the model ▪ Applied visual inspection and ran inter-coder reliability	▪ Established the process ▪ Aggregated the probabilities using the linear opinion pool method (Genest and McConway 1990; Stone 1961) ▪ Ran sensitivity analyses	▪ Established the process ▪ Developed the model based on the interview question categories, which were based on the methodology ▪ Coded as a human		▪ Established the process ▪ Coded as human ▪ Aggregated the probabilities using the linear opinion pool method (Genest and McConway 1990; Stone 1961) ▪ Ran sensitivity analyses	▪ Established the process ▪ Summarized the results

Table 1. Research Questions and Propositions Mapped to the Methodology (continued)

Phase	**Step**	**Research Question 1: Are ECT being used to fulfill agency strategic plans (current use)?**			**Research Question 2: Could ECT be used more extensively to fulfill agency strategic plans (potential use)?**		
Phase 2 / Apply Methodology Propositions 2a-2b (continued)	Synthesize	Table of findings	Table of results	Table of findings	Table of findings	Table of results	Table of findings
Phase 3 / Evaluate Methodology Proposition 3	Evaluate	▪ Reconsider defined problem and the resulting methodology ▪ Identify gaps in collection, organization, analysis, and synthesis ▪ Analyze gaps per Approach 6: Visual analytics (Börner 2010; Lima 2011; Thomas and Cook 2006; Keim et al. 2008; Chen 2008): o Established the process o Labeled and aligned the data o Ran visual analytic images					
Phase 4 / Disseminate Methodology Proposition 4	Disseminate	▪ Outreach with methodology and findings, results, and meta-inferences to researchers per best practices ▪ Outreach with methodology and findings, results, and meta-inferences to policymakers per best practices ▪ Outreach with methodology and findings, results, and meta-inferences to the general public per best practices					

Table 2. Overview of Key Methodologies

Role for Agency Strategies	Agency Current Use of Emerging and Converging Technologies	Agency Potential Use of Emerging and Converging Technologies		Any Organization's Potential Use of Emerging and Converging Technologies
Incorporates Agency Strategies	▪ None: Individuals at the White House Office of Science and Technology Policy (Rubin 2013) and the NSF (Yamaner 2015) confirm that there is no systematic collection of information about agency current use of ECT or technology-level investments in ECT	▪ Theoretical: Uses expert opinions about technology related to the nation's agricultural strategy. The applied case prioritized nanotechnology policies for agricultural development in Thailand (Gerdsri and Kocaoglu 2009)		▪ Applied: Sponsored by the US Government and run by George Mason University, SciCast.org uses a prediction market algorithm to forecast outcomes based on crowd-sourced answers (note the focus on any outcomes not just technologies) (Twardy et al. 2014; George Mason University 2015)
Does Not Incorporate Agency Strategies	▪ Applied: STAR METRICS[SM] captures voluntary information from federally-funded researchers about the research project and outcomes such as job creation and economic growth (National Institutes of Health 2013, 2015; National Institutes of Health 2014) ▪ Applied: RaDiUS was designed to track research conducted with grant money (RAND 2015) but is no longer funded and the data are no longer available (Della-Piana 2015)	▪ Theoretical: Based on decision-maker priorities, data are collected, analyzed, and automatically processed for expert and crowd-sourced analysis. Policymakers can allocate resources based on the resulting priorities (Committee on Forecasting Future Disruptive Technologies 2010, 2009) ▪ Applied (available intermittently): Foresight Engine grew out of Signtific (Institute for the Future 2009a, 2009b), which was designed to alert the government to concerns with ECT (United States). Foresight Engine is for any foresight about any issue and the games are offered intermittently (Gordon 2012; Institute for the Future 2012)		▪ Applied: TechCastGlobal.com provides continuous assessment of ECT via online Delphi cycles (Halal et al. 1998; Halal 2013) ▪ Theoretical: Grouping information about patents to predict technology trends (Yoon and Kim 2012) ▪ Theoretical: Based on patent citations for current emerging technologies, the proposed system fits a growth curve to patent cites and forecasts the growth path by technology, including risk and return (Shin and Kim 2013) ▪ Theoretical: Grouping patents by relationships between cited and citing patents allows a new visualization of technology areas (Kay et al. 2014)

Table 3. Methodology Design Criteria and Minimum Standard

Design Criteria	**Minimum Standard**
If qualitative: Trustworthiness in the form of credibility, transferability, dependability, and confirmability (Denzin and Lincoln 2008; Guba and Lincoln 1994)	High: the remaining criteria will not be considered by researchers or policymakers if this criterion is not met
If quantitative: External validity (generalizability), internal validity, reliability, and objectivity (Shively 2009; Ondercin 2003; Brewer 2003; Chen and Krauss 2003; Hammersley 2003)	High: the remaining criteria will not be considered by researchers or policymakers if these first two criteria are not met
Transparency and coherence of the inputs and outputs (Tonn and Stiefel 2013; Yardley 2000)	Medium: some approaches necessary for meeting the other criteria may impact transparency and coherence
Acceptability to the academic community (e.g., with respect to commitment and rigor) (Tonn and Stiefel 2013; Yardley 2000)	High: for the methodology and its results to be useful, they have to be accepted
Impact and importance (Yardley 2000): Utility of the approach to the research community and utility of the outputs to the policy community (Tonn and Stiefel 2013)	High: this is a subjective choice, though, and could vary by application of the methodology
Degree to which it integrates relevant stakeholders (Calof and Smith 2010)	Medium: this may or may not determine the utility of the outputs
Practicality of implementing and updating the approach (Tonn and Stiefel 2013)	Medium: others may or may not be willing to exert too much effort and time to produce the results
Ability to incorporate contexts, especially potential technologies, platforms, trends, and futures (Yardley 2000)	High: context can be decisive so capturing that surrounding information is necessary
Ability to address the defined problem (e.g., by characterizing current and potential agency use of ECT)	High: this is the purpose of the research and frames the two research questions

Table 4. Agency Strategies

Department of Commerce	Department of Energy
Department of Commerce FY 2014 - FY 2018 Goal 1, Trade and Investment: “Expand the US economy through increased exports and inward foreign investment that lead to more and better American jobs	**Department of Energy 2014 - 2018 Goal 1, Science and Energy:** “Advance foundational science, innovate energy technologies, and inform data driven policies that enhance US economic growth and job creation, energy security, and environmental quality, with emphasis on implementation of the President’s Climate Action Plan to mitigate the risks of and enhance resilience against climate change”
Department of Commerce FY 2014 - FY 2018 Goal 2, Innovation: “Foster a more innovative US economy—one that is better at inventing, improving, and commercializing products and technologies that lead to higher productivity and competitiveness”	**Department of Energy 2014 - 2018 Goal 2, Nuclear Security:** “Strengthen national security by maintaining and modernizing the nuclear stockpile and nuclear security infrastructure, reducing global nuclear threats, providing for nuclear propulsion, improving physical and cybersecurity, and strengthening key science, technology, and engineering capabilities”
Department of Commerce FY 2014 - FY 2018 Goal 3, Environment: “Ensure communities and businesses have the necessary information, products, and services to prepare for and prosper in a changing environment”	**Department of Energy 2014 - 2018 Goal 3, Management and Performance:** “Position the Department of Energy to meet the challenges of the 21st century and the nation’s Manhattan Project and Cold War legacy responsibilities by employing effective management and refining operational and support capabilities to pursue departmental missions”
Department of Commerce FY 2014 - FY 2018 Goal 4, Data: “Improve government, business, and community decisions and knowledge by transforming Department data capabilities and supporting a data-enabled economy”	
Department of Commerce FY 2014 - FY 2018 Goal 5, Operational Excellence: “Deliver better services, solutions, and outcomes that benefit the American people”	

Table 5. Evaluation of Design Criteria, Minimum Threshold, and Threshold Achieved

Design Criteria	**Minimum Threshold for the Methodology**	**Threshold Achieved for Content Analysis (Analysis Approach 1, qualitative)**	**Threshold Achieved for Technology Assessment (Analysis Approach 2, quantitative)**	**Threshold Achieved for Individual Interviews (Approach 3, qualitative)**	**Threshold Achieved for Plausibility Matrices (Approach 4, quantitative)**	**Threshold Achieved for Crowd-Sourced Intelligence (Approach 5, qualitative)**	**Threshold Achieved for Visual Analytics (Approach 6, qualitative)**
If qualitative: Trustworthiness in the form of credibility, transferability, dependability, and confirmability (Denzin and Lincoln 2008; Guba and Lincoln 1994)	High	High	[See next row, quantitative]	High	[See next row, quantitative]	High	High
If quantitative: External validity (generalizability), internal validity, reliability, and objectivity (Shively 2009)	High	[See previous row, qualitative]	Mixed, as noted	[See previous row, qualitative]	High	[See previous row, qualitative]	[See previous row, qualitative]
Transparency and coherence of the inputs and outputs (Tonn and Stiefel 2013; Yardley 2000);	Medium	High	Medium	High	Medium	High	High
Acceptability to the academic community (e.g., with respect to commitment and rigor) (Tonn and Stiefel 2013; Yardley 2000)	High	High	High	High	High	High	High

Table 5. Evaluation of Design Criteria, Minimum Threshold, and Threshold Achieved (continued)

Design Criteria	**Minimum Threshold for the Methodology**	**Threshold Achieved for Content Analysis (Analysis Approach 1, qualitative)**	**Threshold Achieved for Technology Assessment (Analysis Approach 2, quantitative)**	**Threshold Achieved for Individual Interviews (Approach 3, qualitative)**	**Threshold Achieved for Plausibility Matrices (Approach 4, quantitative)**	**Threshold Achieved for Crowd-Sourced Intelligence (Approach 5, qualitative)**	**Threshold Achieved for Visual Analytics (Approach 6, qualitative)**
Impact and importance (Yardley 2000): Utility of the approach to the research community and utility of the outputs to the policy community (Tonn and Stiefel 2013)	High	High	High	High	High	High	High
Degree to which it integrates relevant stakeholders (Calof and Smith 2010)	Medium	Medium as they wrote the source documents	High as they were expert respondents	High	High as they were expert respondents	High as they were website users	High
Practicality of implementing and updating the approach (Tonn and Stiefel 2013)	Medium	Medium as it is labor-intensive	Medium as it is difficult to secure expert respondents who meet the criteria	High	Medium as it is difficult to secure expert respondents who meet the criteria	High	High
Ability to incorporate contexts, especially potential technologies, platforms, trends, and futures (Yardley 2000)	High	High	High	High	High	High	High
Ability to characterize actual or potential agency use of ECT, as appropriate	High	High	Mixed	High	High	High	High

Table 6. Types of Interview Questions

Area of Inquiry	Question
These are background questions to establish the subject's level of knowledge and interest, especially as relates to technology and the agency's strategies	▪ Tell us more about your position description? ▪ What is your day-to-day work like? ▪ How do you know when you've been successful in your position? ▪ Do you engage with the agency's strategic plan for your day-to-day work? Are you accountable for particular sections of your agency's strategic plan? ▪ How do you use technology in your work to help meet the agency's strategic plan?
These are questions in support of Research Question 1, Are ECT being used to fulfill agency strategic plans (current use)?	▪ How do you find out about new technologies the agency is adopting or should adopt? ▪ What types of emerging technologies, technologies that are just now becoming available like [something relevant to their area], is the agency adopting or should it adopt? ▪ What types of converging technologies, technologies that are combining with other technologies like [something relevant to their area], is the agency adopting or should it adopt?
These are questions in support of Research Question 2, Could ECT be used more extensively to fulfill agency strategic plans (potential use)?	▪ Are there technologies you wish you were using for YOUR work? That you wish the agency was using? ▪ Are there emerging technologies you wish you were using? That you wish the agency was using? ▪ Are there converging technologies you wish you were using? That you wish the agency was using?
These are questions about the subject's search for new technologies; thoughts about the future; and the considerations that affect both search for and adoption of emerging technologies	▪ Regarding converging technologies—for example, the ability to read email on all of your devices or have your car read it to you—what are your opinions? ▪ What do you think the world will be like in 2050?

Table 7. Current Use of Emerging and Converging Technologies per Content Analysis of Strategic Plans (by Agency Strategy): Department of Commerce

Emerging and Converging Technology [Count of mentions in the strategic plan with a sample mention]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Artificial Intelligence	0	0	0	0	0
Biotechnology	0	0	0	0	0
Cognitive Science	0	0	0	0	0
Electronics	0	0	0	0	0
Energy Technology	0	0	1 "Boost exports of environmental and clean energy technologies (ITA [International Trade Administration])."	0	0
Geoengineering	0	0	0	0	0
Information Technology	0	2 "USPTO [United States Patent and Trademark Office] has made historic strides in reducing the backlog of applications in the past four years. The Department will continue the pace by engaging with stakeholders, developing new standards and tools, optimizing information technology (IT) capabilities, and hiring a nationwide workforce."	0	0	0

Table 7. Current Use of Emerging and Converging Technologies per Content Analysis of Strategic Plans (by Agency Strategy): Department of Commerce (continued)

Emerging and Converging Technology [Count of mentions in the strategic plan with a sample mention]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Interfaces	0	0	0	1 "Ensures that NOAA provides real time (or near real time) availability of critical satellite data and products without gaps."	0
Internet	0	9 "Objective 2.3. Strengthen the Nation's digital economy by championing policies that will maximize the potential of the Internet, expanding broadband capacity, and enhancing cybersecurity (NIST [National Institute of Standards and Technology], NTIA [National Telecommunications and Information Administration], USPTO)."	2 "Digital Coast is a web platform providing coastal geospatial information. The number of communities using Digital Coast is based on Census-designated places within coastal states, including all Census-defined cities, towns, townships, boroughs, and incorporated municipalities."	1 "Increase capacity to make data accessible, discoverable, and usable by the public (NIST, NOAA). The Department's Big Data vision will not be realized simply by making data available through conventional means. Through public-private partnerships, scientific data can be intelligently positioned in the cloud and be co-located with easy, affordable access to computing, storage, and advanced analytical capabilities."	0

Table 7. Current Use of Emerging and Converging Technologies per Content Analysis of Strategic Plans (by Agency Strategy): Department of Commerce (continued)

Emerging and Converging Technology [Count of mentions in the strategic plan with a sample mention]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Materials (Advanced)	0	0	1 "Develop standards and tools to assess green building technologies (NIST). NIST will develop measurement science that enables architects and developers to design buildings that produce as much energy as they consume and to use more durable materials."		0
Nanotechnology	0	0	0		0
Quantum (usually Computing)	0	0	0		0
Robotics	0	0	0		0
Sensors	0	0	0		0
Space (Outer)	0	0	1 "Ensures that NOAA provides real time (or near real time) availability of critical satellite data and products without gaps."		0
Ubiquitous Computing	0	0	0		0
Virtual Reality	0	0	0		0

Table 7. Current Use of Emerging and Converging Technologies per Content Analysis of Strategic Plans (by Agency Strategy): Department of Commerce (continued)

Emerging and Converging Technology [Count of mentions in the strategic plan with a sample mention]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Emerging and Converging Technologies (in General)	0	2 “Accelerate rate of lab-to-market commercialization (EDA [Economic Development Administration], NIST, USPTO). A wide range of life-changing commercial technologies were nurtured by federally funded R & D, from the Internet, to the global positioning system (GPS), to leading-edge vaccines. The federal R & D enterprise must continue to support fundamental research and diffuse this knowledge through open data and publications.”	0		0

Table 8. Current Use of Emerging and Converging Technologies per Content Analysis of Strategic Plans (by Agency Strategy): Department of Energy

Emerging and Converging Technology [Count of mentions in the strategic plan with a sample mention]	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Artificial Intelligence	0	0	0
Biotechnology	0	0	0
Cognitive Science	0	0	0
Electronics	0	0	0
Energy Technology	11 "Goal 1: Science and Energy. Advance foundational science, innovate energy technologies, and inform data driven policies that enhance US economic growth and job creation, energy security, and environmental quality, with emphasis on implementation of the President's Climate Action Plan to mitigate the risks of and enhance resilience against climate change."	0	"0
Geoengineering	0	0	0
Information Technology	0	0	4 "Management and Performance - DOE leads the largest cleanup effort in the world to remediate the environmental legacy of over six decades of nuclear weapons and nuclear research, development, and production. As DOE carries out its mission, it will strengthen effective and cost-efficient management, support an engaged workforce, and provide a modern, secure physical and information technology infrastructure."
Interfaces	0	0	0
Internet	0	0	0

Table 8. Current Use of Emerging and Converging Technologies per Content Analysis of Strategic Plans (by Agency Strategy): Department of Energy (continued)

Emerging and Converging Technology [Count of mentions in the strategic plan with a sample mention]	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Materials (Advanced)	3 "Conduct discovery-focused research to increase our understanding of matter, materials and their properties through partnerships with universities, national laboratories, and industry."	0	0
Nanotechnology	0	1 "Talented researchers, engineers, and technicians work across a range of national-level challenges and enhance their skills and expertise by working concurrently on stockpile stewardship and other national priority missions. For example, supercomputers are key to stockpile stewardship, but also have been used to provide foreign threat assessments and to open up the field of nanotechnology."	0
Quantum (usually Computing)	0	0	0
Robotics	0	0	0
Sensors	0	0	0
Space (Outer)	0	0	0
Ubiquitous Computing	0	0	0

Table 8. Current Use of Emerging and Converging Technologies per Content Analysis of Strategic Plans (by Agency Strategy): Department of Energy (continued)

Emerging and Converging Technology [Count of mentions in the strategic plan with a sample mention]	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Virtual Reality	0	1 "DOE will bolster the capabilities of the US government to address cyber and other related security threats through research and development, vulnerability analyses, testing at physical and virtual ranges, and modeling and simulation."	0
Emerging & Converging Technologies (General)	1 "National laboratories design, build, and operate unique scientific instrumentation and facilities that serve tens of thousands of scientists and engineers from academia, government, and industry collaborating on solutions to pressing and complex problems. These facilities, which are found nowhere else in the world, support open scientific research as well as classified work. They continually advance the state of the art through the development and use of next-generation tools and technologies. They enable fundamental scientific discoveries, ensure our national security, and assist industry (with new materials, improved manufacturing processes, and advanced product testing)."		

Table 9. Current Use of Emerging and Converging Technologies per Content Analysis (by Agency)

Emerging and Converging Technologies [Count from all strategy documents and sample content]	**Department of Commerce**	**Department of Energy**
Artificial Intelligence	2 mentions “Coupled with artificial-intelligence-based decision-support systems, tornado lead times could be increased from the current 13 minutes to over 20 minutes.”	0 mentions
Biotechnology	9 mentions “MML [Material Measurement Laboratory at NIST] serves a very broad range of industry sectors ranging from transportation to biotechnology by conducting research, and providing its output in the form of measurement services and measurement quality assurance tools to address problems of national importance, such as greenhouse gas emissions measurements; renewable energy; the Nation's aging infrastructure; environmental quality; food safety and nutrition; forensics and homeland security; healthcare measurements; and manufacturing ranging from advanced materials to photovoltaics to biologic drugs.”	5 mentions “Today, with its Genomic Sciences activity and the DOE Joint Genome Institute (JGI), BER [Biological and Environmental Research] researchers are using the powerful tools of plant and microbial systems biology to pursue fundamental breakthroughs needed to develop cost-effective cellulosic biofuels. The three DOE Bioenergy Research Centers lead the world in fundamental biofuels-relevant research.”
Cognitive Science	3 mentions “As noted above, the Economic Census is investing in an electronic -only mode of collection, which will require designing the Centurion system, another CEDCaP [Census Enterprise Data Collection and Processing] component, to accommodate the nation's largest companies with spreadsheet reporting, as well as a user -friendly self- response instrument to accommodate small business reporting needs. This involves doing extensive cognitive research with businesses, lots of prototyping of business scenarios, and development of requirements and specifications activities of which occur outside of the CEDCaP funding and are the responsibility of each of the programs.”	2 mentions “This philosophy extends further to the role of operator simulation environments as a platform for validation of the impact of the tools and techniques on decision-making processes. Decision support, cognitive task analysis, and visualization (i.e., human factors side of planning and operations) will be important to the effective implementation of new tools and models.”

Table 9. Current Use of Emerging and Converging Technologies per Content Analysis (by Agency) (continued)

Emerging and Converging Technologies [Count from all strategy documents and sample content]	**Department of Commerce**	**Department of Energy**
Electronics	35 mentions “Help the US electronics industry retain leadership in next-generation device realization by developing new measurement capabilities that combine atomic force microscopy with scanning tunneling microscopy to yield unprecedented, detailed, atomic scale electronic property information on a wide range of potential future electronic materials.”	68 mentions “Power electronics underpin the converters, controllers, and switches that regulate power flows on the grid. Advanced power electronics will ease renewable energy integration while improving stability as they can accommodate—and even counteract—voltage swings along circuits and dynamically reroute power in response to varying generation and system conditions. Transitioning to semiconductors with high operating temperatures (such as wide band-gap semiconductors) will allow for improved alternating current-direct current conversion, higher voltage operation, and improved efficiency. The cost and manufacturability of semiconductor materials tolerant of high voltage and temperature is a key challenge.”
Energy Technology	6 mentions “Boost exports of environmental and clean energy technologies (ITA). Governments around the world are creating regulations and policies to address the changing environment. ITA, with the Department of Energy and the Environmental Protection Agency, will lead interagency efforts to support and anticipate the needs of US exporters and foreign investors.”	216 mentions “DOE will give priority to those technologies most likely to have a significant impact on timescales commensurate with the urgency of national energy challenges. The Department will maintain a mix of analytic, assessment, and fundamental engineering research capabilities in a broad set of energy-technology areas without any expectation of DOE investment in demonstration or deployment activities. The mix will vary according to the status and significance of the technology, which can be judged by maturity, materiality, and market potential.”
Geoengineering	0 mentions	0 mentions
Information Technology	75 mentions “The foundations of smart city solutions lie in the convergence of information technology with manufactured products, engineered systems of products, and associated services that enable a new generation of ‘smart’ systems.”	70 mentions “The nation that succeeds in leading in HPC and large-scale data analysis for the long term will have a competitive advantage in a wide array of strategic sectors, including basic science, national defense, energy, advanced manufacturing, health care, space, transportation, education, and information technology.”

Table 9. Current Use of Emerging and Converging Technologies per Content Analysis (by Agency) (continued)

Emerging and Converging Technologies [Count from all strategy documents and sample content]	**Department of Commerce**	**Department of Energy**
Interfaces	18 mentions "NIST contributions to standards development in smart city data access, integration and analysis, application interfaces, and communication technologies and protocols."	36 mentions "Better understanding of how consumers respond to user interfaces and economic signals is needed, requiring integration of social science research with grid operation and planning."
Internet	142 mentions "Next Generation Internet Architectures: NIST released to the Internet industry, protocol specifications, rapid prototypes and measurement/monitoring systems for emerging secure inter-domain routing technologies. These are helping industry measure and characterize the completeness, correctness and robustness of emerging global information infrastructures for BGP security."	36 mentions "Funding supports development and deployment of a public web portal to track the inventory of STEM [Science, Technology, Engineering, and Mathematics] workforce internship and outreach activities and opportunities across the DOE laboratory complex."
Materials (Advanced)	235 mentions "Complementary expertise at NIST and partner consortium CHiMaD [Center for Hierarchical Materials Design] to address critical materials challenges in both "hard" (inorganic) and "soft" (organic) advanced materials in fields as diverse as self-assembled biomaterials, smart materials for self-assembled circuit designs, organic photovoltaic materials, advanced ceramics and metal alloys."	475 mentions "Challenges to the commercialization of these technologies include the stability of the materials against oxygen and water ingress, which could potentially be overcome by developing improved, cost-effective encapsulants. Alternatively, for organic solar cells, materials exist that are stable in air and can be deposited under a small vacuum or in a solution. Further R & D is needed to improve the efficiency of materials for these emerging technologies."
Nanotechnology	12 mentions "For example, NIST develops measurements focusing on the very small (e.g., nanotechnology devices) and the very large (e.g., skyscrapers), the physical (e.g., methods for characterizing strands of DNA for forensic testing) and the virtual (e.g., methodologies and best practices for securing cyberspace)."	4 mentions "Transformational developments in next-generation manufacturing concepts can enable revolutionary advances in energy efficiency and carbon abatement. This includes innovating the next generation of processes and materials with lower embodied energy and lifecycle costs for all manufactured products. Innovative enabling technologies for energy-efficient and low CO2-equivalent emission products and processes can take advantage of developments in sensors and controls, catalysis, nanotechnology, micro-manufacturing, and reducing the GWP of industrial gases."

Table 9. Current Use of Emerging and Converging Technologies per Content Analysis (by Agency) (continued)

Emerging and Converging Technologies [Count from all strategy documents and sample content]	**Department of Commerce**	**Department of Energy**
Quantum (usually Computing)	40 mentions "To conduct research into quantum resistant cryptography, usable security, privacy enabling encryption, constrained encryption and formal proofs for cryptography."	21 mentions "Quantum chemical calculations were used for the first time to obtain molecular reaction rates for surrogate biodiesel in combustion reactions. The results revealed that by including tunneling reactions in high-fidelity engine models, predicted engine performance was noticeably impacted. Such calculations significantly improve the fidelity of engine modeling and will assist in the design and optimization of compression-ignition engines."
Robotics	7 mentions "Robotic Systems for Smart Manufacturing: To safely increase the versatility, autonomy, and agile re-tasking of collaborative robot systems with humans-in-the-loop for next-generation smart manufacturing systems."	2 mentions "Continue development of robotics and smart tooling systems that are needed to facilitate characterization, equipment removal, and dismantlement under complex, unsafe or inaccessible conditions for human entry. This initiative focuses on development of next generation remote and robotic platforms and smart tooling systems to improve the efficiency of decontamination and demolition efforts."
Sensors	58 mentions "Communication technologies and protocols that provide for flexible and agile interconnection of sensors, systems, and infrastructures."	63 mentions "The Department's whole-building R & D portfolio will focus on gaining a better under- standing of how buildings operate as a system, including the development of sensors, controls, and validated building energy models. This will guide R & D in component and envelope technologies, as well as the development of the next generation of model codes and building labels."
Space (Outer)	112 mentions "NOS [National Ocean Service] conducts geodesy and height modernization activities in all 50 states and many US territories. NOS' s geodesy products provide the foundational data layer for transportation, mapping and charting, and a multitude of other scientific and engineering applications."	3 mentions "Continues required engineering development work and satellite interface coordination to support payload design update for subsequent satellite blocks for GBDs [Global Burst Detector] and treaty monitoring focused payloads."

Table 9. Current Use of Emerging and Converging Technologies per Content Analysis (by Agency) (continued)

Emerging and Converging Technologies [Count from all strategy documents and sample content]	**Department of Commerce**	**Department of Energy**
Ubiquitous Computing	4 mentions "NIST will provide measurement science and standards to support the development of distributed and ubiquitous devices that can be integrated everywhere by consumers and manufacturers, to meet diverse needs."	9 mentions "IA [International Affairs] will explore and pursue international collaborations, building on extensive relationships with international stakeholders in recognition that the energy-water nexus is a global issue with ubiquitous data, modeling and analysis; technology RDD&D [Research, Development, Demonstration, and Deployment]; and policy analysis interests."
Virtual Reality	11 mentions "Piloted a Virtual Desktop Infrastructure to allow NIST business and scientific users to access their data and applications anytime, anywhere, from any device, so that ideas, collaboration, and innovation aren't limited to business hours or office buildings."	24 mentions "Establish a virtual collaborative environment for conducting real-time advanced digital forensics analysis."
Emerging and Converging Technologies (in General)	93 mentions "lnteroperability - Critical emerging technologies such as the Smart Grid and National healthcare information systems have the potential to transform our society and revitalize the US economy. NIST programs are helping to accelerate the development of standards needed to ensure that the many interconnected components in these systems can fully function and exchange information seamlessly across systems."	100 mentions "Emerging Technology (IM-51): Funding will provide analysis on the impact of emerging technologies and solutions on current strategies, and develop a vision of the technological future of the organization. Work products will include, but are not limited to: partner engagement framework, partner engagement catalogue, strategic vendor reports, targeted market validation, and the DOE Technology Roadmap."

Table 10. Current Use of Emerging and Converging Technologies per Technology Assessment Analysis (by Agency Strategy): Department of Commerce

Emerging and Converging Technologies Legend: ■Are using (probability ≥ 50%) ■Are not using (probability < 50% [Linear opinion pool calculated without weightings, percent probability]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Artificial Intelligence	13%	50%	13%	56%	31%
Biotechnology	69%	88%	31%	6%	13%
Cognitive Science	50%	50%	25%	44%	25%
Electronics	81%	88%	75%	56%	63%
Energy Technology	56%	75%	75%	38%	38%
Geoengineering	25%	31%	31%	38%	38%
Information Technology	75%	88%	75%	75%	75%
Interfaces	38%	50%	63%	56%	44%
Internet	56%	75%	75%	75%	63%
Materials (Advanced)	69%	81%	56%	25%	31%
Nanotechnology	81%	81%	50%	25%	25%
Quantum (usually Computing)	50%	56%	38%	25%	38%
Robotics	63%	88%	56%	25%	25%
Sensors	50%	63%	50%	44%	44%
Space (Outer)	56%	50%	31%	25%	25%
Ubiquitous Computing	56%	69%	44%	25%	38%
Virtual Reality	33%	17%	17%	17%	8%

Table 11. Current Use of Emerging and Converging Technologies per Technology Assessment Analysis (Sensitivity Analysis): Department of Commerce

Emerging and Converging Technologies Legend: ■ ECT moves ≥ 50% probability if average score increased absolutely by 25% ■ ECT moves <50% probability if average score decreased absolutely by 25%	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Artificial Intelligence		25%		31%	56%
Biotechnology	44%		56%		
Cognitive Science	25%	25%	50%	69%	50%
Electronics				31%	38%
Energy Technology	31%			63%	63%
Geoengineering	50%	56%	56%	63%	63%
Information Technology					
Interfaces	63%	25%	38%	31%	69%
Internet	31%				38%
Materials (Advanced)	44%		31%	50%	56%
Nanotechnology			25%	50%	50%
Quantum (usually Computing)	25%	31%	63%	50%	63%
Robotics	38%		31%	50%	50%
Sensors	25%	38%	25%	69%	69%
Space (Outer)	31%	25%	56%	50%	50%
Ubiquitous Computing	31%	44%	69%	50%	63%
Virtual Reality	58%				

Table 12. Current Use of Emerging and Converging Technologies per Technology Assessment Analysis (by Agency Strategy): Department of Energy

Emerging and Converging Technologies Legend: ■Are using (probability ≥ 50%) ■Are not using (probability < 50% [Linear opinion pool calculated without weightings, percent probability]	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Artificial Intelligence	38%	69%	6%
Biotechnology	56%	19%	25%
Cognitive Science	38%	13%	6%
Electronics	81%	88%	44%
Energy Technology	63%	38%	13%
Geoengineering	50%	13%	13%
Information Technology	88%	81%	50%
Interfaces	56%	69%	44%
Internet	75%	88%	25%
Materials (Advanced)	56%	75%	38%
Nanotechnology	56%	88%	50%
Quantum (usually Computing)	50%	63%	25%
Robotics	25%	81%	38%
Sensors	75%	75%	50%
Space (Outer)	25%	38%	0%
Ubiquitous Computing	50%	44%	25%
Virtual Reality	8%	33%	25%

Table 13. Current Use of Emerging and Converging Technologies per Technology Assessment Analysis (Sensitivity Analysis): Department of Energy

Emerging and Converging Technologies Legend: ■ ECT moves ≥ 50% probability if average score increased absolutely by 25% ■ ECT moves <50% probability if average score decreased absolutely by 25%	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Artificial Intelligence	63%	44%	
Biotechnology	31%		50%
Cognitive Science	63%		
Electronics			69%
Energy Technology	38%	63%	
Geoengineering	25%		
Information Technology			25%
Interfaces	31%	44%	69%
Internet			50%
Materials (Advanced)	31%		63%
Nanotechnology	31%		13%
Quantum (usually Computing)	25%	38%	50%
Robotics	50%		63%
Sensors			25%
Space (Outer)	50%	63%	
Ubiquitous Computing	25%	69%	50%
Virtual Reality		58%	50%

Table 14. Current and Potential Use of Emerging and Converging Technologies per Individual Interviews (by Agency)

Interview Questions and Agency [Respondent codes noted in parentheses where: DOC# = Respondent from DOC DOE# = Respondent from DOE]	**Department of Commerce**	**Department of Energy**
Research Question 1: Are ECT being used to fulfill agency strategic plans (current use)?	Focused on information technology for doing the daily work (DOC2, DOC5), for capturing data (DOC2, DOC4, DOC5), and for cyber-security (DOC5). Sensors also came up (DOC3, DOC4), especially when thinking about how to get information about natural phenomena.	Respondents tended to discuss current technology use as something assigned to them (DOE1), or as something to be analyzed (DOE2, DOE3). Many conversations were about energy technologies (DOE2, DOE4) and information technology hardware and software (DOE1, DOE4, DOE5).
Research Question 2: Could ECT be used more extensively to fulfill agency strategic plans (potential use)?	Respondents tended to think more about existing information technology capabilities (DOC1, DOC2, DOC3, DOC4, DOC5) and how use them more for collecting individual opinions (DOC1, DOC2); information analysis and modeling for risk management (DOC3); and privacy (DOC5). Also related to information technology, one respondent balanced potential technology use with concerns about government versus private sector leadership.	Respondents tended to think about considerations (see below), especially lack of technology choice (DOE1), time (DOE2), and agenda choice (DOE3). Some conversations were about potential energy technologies (DOE3, DOE4, DO5), materials (advanced) DOE4), and nanotechnology (DOE5).
Specific Mentions of Emerging and Converging Technologies	Information technology for decision support systems (DOC3, DOC4) and paperless workflow (DOC3); Internet for cyber-security and privacy (DOC1, DOC4, DOC5), ubiquitous computing (DOC1). Even when prompted with examples, interviewees did not mention other ECT.	Energy technologies (DOE3, DOE4, DOE5); information technology (DOE1, DOE2, DOE3, DOE4, DOE5), materials (advanced; DOE4), and nanotechnologies (DOE5) were mentioned. Other than that, even when prompted with examples, no other ECT were mentioned. Specific technologies are not the conversation. It is more about choosing a technology based on the desired outcome and funding only the things that industry is not getting to (DOE3).
Details about Search for Emerging and Converging Technologies	Some consider emerging technologies based on cultural conversations within the agency (e.g., to build or buy an information technology product (DOC1) and funding studies (DOC3). Some do not search at all because there is enough current technology to incorporate (DOC4).	Search for ECT is based on cultural conversation about building or buying (DOE1), a short-term horizon (DOE1), and, in some cases, workshops (DOE4) or peer-review (DOE5).

Table 14. Current and Potential Use of Emerging and Converging Technologies per Individual Interviews (by Agency) (continued)

Interview Questions and Agency [Respondent codes noted in parentheses where: DOC# = Respondent from DOC DOE# = Respondent from DOE]	**Department of Commerce**	**Department of Energy**
Considerations	Fall behind the private sector because of congressional appropriator strategy failure to understand what is needed and when (DOC3, DOC4), but also have to consider opportunities for private sector leadership (DOC5) and privacy considerations (DOC4). Note again the focus on information technology.	Respondents tended to mention considerations, especially lack of technology choice (DOE1), time (DOE2, DOE5), agenda choice (DOE3), and incentives (DOE4). Insufficient public and congressional technical literacy and numeracy (DOE4). Strategy failure and insufficient funding (DOE2, DOE4, DOE5).
Imagined Future	Most respondents imagined a future with more input and progress from industry (DOC1). Three thought ahead to an increased use of wearables and drones (DOC1) or internalized devices (DOC4, DOC5). Most thought about extensions of their current work (e.g., improved forecasts, sensors, handhelds) (DOC2, DOC3, DOC4).	Imagined future involves massive increases in data and technology use (DOE1), but not in creation or design (DOE2). Smaller scale nanotechnologies will emerge (DOE5).

Table 15. Potential Use of Emerging and Converging Technologies per Plausibility Matrix Analysis (by Agency Strategy): Department of Commerce

Emerging and Converging Technologies Legend: ■ Could be using (probability ≥ 50%) ■ Could be using (probability < 50% [Linear opinion pool calculated without weightings, percent probability]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Artificial Intelligence	55%	58%	60%	80%	53%
Biotechnology	68%	70%	40%	18%	25%
Cognitive Science	45%	65%	58%	58%	50%
Electronics	88%	78%	60%	58%	60%
Energy Technology	68%	68%	48%	50%	53%
Geoengineering	40%	53%	50%	23%	20%
Information Technology	80%	75%	83%	89%	70%
Interfaces	60%	83%	83%	70%	68%
Internet	95%	75%	83%	85%	75%
Materials (Advanced)	73%	68%	40%	33%	35%
Nanotechnology	73%	68%	35%	38%	33%
Quantum (usually Computing)	50%	63%	44%	50%	31%
Robotics	75%	73%	48%	40%	43%
Sensors	75%	73%	60%	63%	40%
Space (Outer)	43%	45%	25%	23%	28%
Ubiquitous Computing	65%	73%	60%	50%	45%
Virtual Reality	53%	70%	40%	53%	45%

Table 16. Potential Use of Emerging and Converging Technologies per Plausibility Matrix Analysis (Sensitivity Analysis): Department of Commerce

Emerging and Converging Technologies Legend: ■ ECT moves ≥ 50% probability if average score increased absolutely by 25% ■ ECT moves <50% probability if average score decreased absolutely by 25%	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Artificial Intelligence	30%	33%	35%		28%
Biotechnology	43%	45%	65%		50%
Cognitive Science	70%	40%	33%	33%	25%
Electronics			35%	33%	35%
Energy Technology	43%	43%	73%	25%	28%
Geoengineering	65%	28%	25%		
Information Technology					45%
Interfaces	35%			45%	43%
Internet					
Materials (Advanced)	48%	43%	65%	58%	60%
Nanotechnology	48%	43%	60%	63%	58%
Quantum (usually Computing)	25%	38%	69%	25%	56%
Robotics		48%	73%	65%	68%
Sensors		48%	35%	38%	65%
Space (Outer)	68%	70%	50%		53%
Ubiquitous Computing	40%	48%	35%	25%	75%
Virtual Reality	28%	45%	65%	28%	70%

Table 17. Potential Use of Emerging and Converging Technologies per Plausibility Matrix Analysis (by Agency Strategy): Department of Energy

Emerging and Converging Technologies Legend: ■Could be using (probability ≥ 50%) ■Could be using (probability < 50% [Linear opinion pool calculated without weightings, percent probability]	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Artificial Intelligence	75%	70%	70%
Biotechnology	55%	35%	48%
Cognitive Science	45%	45%	50%
Electronics	65%	80%	68%
Energy Technology	65%	75%	50%
Geoengineering	53%	28%	35%
Information Technology	70%	78%	73%
Interfaces	65%	70%	63%
Internet	73%	73%	68%
Materials (Advanced)	45%	53%	53%
Nanotechnology	50%	55%	48%
Quantum (usually Computing)	47%	67%	50%
Robotics	40%	73%	43%
Sensors	68%	68%	55%
Space (Outer)	50%	33%	23%
Ubiquitous Computing	43%	50%	40%
Virtual Reality	45%	55%	38%

Table 18. Potential Use of Emerging and Converging Technologies per Plausibility Matrix Analysis (Sensitivity Analysis): Department of Energy

Emerging and Converging Technologies Legend: ■ ECT moves ≥ 50% probability if average score increased absolutely by 25% ■ ECT moves <50% probability if average score decreased absolutely by 25%	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Artificial Intelligence		45%	45%
Biotechnology	30%	60%	73%
Cognitive Science	70%	70%	25%
Electronics	40%		43%
Energy Technology	40%		25%
Geoengineering	28%	53%	60%
Information Technology	45%		48%
Interfaces	40%	45%	38%
Internet	48%	48%	43%
Materials (Advanced)	70%	28%	28%
Nanotechnology	25%	30%	73%
Quantum (usually Computing)	72%	42%	25%
Robotics	65%	48%	68%
Sensors	43%	43%	30%
Space (Outer)	25%	58%	
Ubiquitous Computing	68%	25%	65%
Virtual Reality	70%	30%	63%

Table 19. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Commerce

Emerging and Converging Technologies [Averaged across all answers for a goal. Includes sample answers for illustration purposes (Probability, Priority)]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Artificial Intelligence	Converging building artificial intelligence into smartphones with converting light energy into mechanical work: "Converting light energy into mechanical work (the second emerging technology) could make it easier and cheaper to build artificial intelligence into smartphones (the first emerging technology), making a product that would be a popular export (the agency strategy)." (100%, 4)	Converging making IBM's artificial-intelligence engine, Watson, smarter with developing new self-healing materials: "It would seem that fostering a more innovative US economy in the future requires radical rethinking of the strategy for public education. How do you foster innovative thinking at all levels of society? Perhaps there are innovative teaching approaches that incorporate Watson technology, or expose students to it at a young age, in ways that foster curiosity and a deeper desire for learning?" (25%, 1)	Converging developing deep learning with making self-driving cars without steering wheels, brakes, or accelerators: "Use the improved artificial intelligence in self-driving cars to deliver capacity-building services. Count on market pressures and competition to drive the quality and price of the technologies and the capacity-building services." (100%, 4)	Converging building artificial intelligence into smartphones and developing molten glass for thermal storage: "Truly 'Smart' Phones having some level of AI could assist in the decision making and data sharing between departments and other agencies. The AI could coordinate meetings and availability. This might lead to an increase in public opinion of government." (25%, 2)	

Table 19. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Commerce (continued)

Emerging and Converging Technologies [Averaged across all answers for a goal. Includes sample answers for illustration purposes (Probability, Priority)]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Biotechnology		Converging describing a potential meat production process from stem cells with developing utility-scale silicon carbide power transistors: "Developing the utility-scale silicon carbide power transistors (the second emerging technology) could power the meat production process (the first emerging technology). Both, together and separately, drive higher productivity and competitiveness (the agency strategy) and support sustainability (the potential future)." (100%, 4)	Converging developing enhanced carbon concentration in camelina with developing an exascale supercomputer: "Faster supercomputers allow for better modeling. This might include modeling of fuel future fuel needs or CO2 emissions and their effect on the environment. This information might help communities and companies make better decisions for the future." (100%, 4)		

Table 19. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Commerce (continued)

Emerging and Converging Technologies [Averaged across all answers for a goal. Includes sample answers for illustration purposes (Probability, Priority)]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Cognitive Science	Converging developing knowledge through social learning networks with revealing reflected faces in pupils: "Learning more through social learning networks (the first emerging technology) and from others' faces (the second emerging technology) could be commercialized (the platform) and then exported or financed through foreign investment (the agency strategy)….." (100%, 3)	Converging improving neuron modeling to see more patterns with making a material with surface area and water adsorption abilities: "If neuron modeling could be used to visualize other non-neurological technologies such as traffic or logistics routing, this would definitely enhance productivity and competitiveness." (50%, 4)	Converging mimicking the brain in real time and observing excitons in action: "Mimicking the Brain in Real Time sounds compelling, but artificial intelligence attempts in the past have been far to slow and use far too much computing power to be competitive." (0%, 1)		

Table 19. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Commerce (continued)

Emerging and Converging Technologies [Averaged across all answers for a goal. Includes sample answers for illustration purposes (Probability, Priority)]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Electronics	Converging triggering rain and lightening with a laser with developing quantum cryptography: "Better Cryptography if applied correctly could help prevent industrial espionage by foreign governments and entities." (100%, 5)				

Table 19. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Commerce (continued)

Emerging and Converging Technologies [Averaged across all answers for a goal. Includes sample answers for illustration purposes (Probability, Priority)]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Energy Technology	Converging developing a renewable energy positioning system with developing a liquid filter with plasmonic nanoparticles: “More efficient manufacture of alternate Fuel would further the global trend of decreasing Petroleum imports, which in turn could further the potential future by making clean fuels more cost effective/abundant. If enough fuel could be synthesized, it could become a global export for local companies” (75%, 5)	Converging discovering a synthetic pathway for methanol conversion with converging algae to crude oil in minutes: “It would seem that either of these technologies would have many applications in industry that would necessitate the creation of new jobs.” (50%, 5)	Converging using 3D graphene in solar cells with imaging individual atoms: “Getting buildings off the grid is a priority for disaster mitigation, especially in storm-prone regions. Any technology that makes solar more affordable, more available to at-risk communities, and more commonplace would have positive ramifications.” (0%, 5)	Converging breaking the record for cadmium telluride solar modules with leveraging Einstein to produce an ultra-secure Internet: “Improving the security of the Internet (the second emerging technology) will make it safer for the Department of Commerce to share data within the agency and with other agencies (the agency strategy). Rapid economic growth and more efficient technologies (the potential future) would enable this progress.” (100%, 5)	
Geoengineering					

Table 19. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Commerce (continued)

Emerging and Converging Technologies [Averaged across all answers for a goal. Includes sample answers for illustration purposes (Probability, Priority)]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Information Technology	Developing crash-proof code: "Spaceships to explore outside our solar system would benefit greatly from a Crash-Proof Computer control system. It is likely that a crash in critical systems could cause catastrophic failures. This effort is enormous and possibly financially lucrative. It is likely that if this were a private company developing these spaceships, that foreign investors would be attracted to the opportunity." (50%, 4)	Converging developing universal authentication with developing cognitive radio: "As Internet sales increase and the potential market of potential buyers increases worldwide, a Secure Universal Authentication would make a big difference in the online commercialization of new products. This would be a driver in building public and private inventions and improvements to existing products." (100%, 4)	Converging developing cognitive radio with leveraging offshore wind farms: "Developing cognitive radios (the first emerging technology) can improve communication before and during a weather event (the agency strategy) and can improve the communication of data from offshore wind farms (the second emerging strategy). Both support Earth (the platform) and increased urbanization (the global trend), especially in a future where markets drive everything (the potential future)." (100%, 3)	Converging developing an autonomous, decentralized grid architecture with using mind-controlled robots: "Just as computing evolved from centralized to distributive machinery, decentralized grid architecture could allow decision making possible at the most appropriate points and then share the benefits with all." (100%, 3)	

Table 19. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Commerce (continued)

Emerging and Converging Technologies [Averaged across all answers for a goal. Includes sample answers for illustration purposes (Probability, Priority)]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Interfaces		Enhancing technology for education: "The link between improved education and increased innovation is certain. By enhancing technology for education one cannot help but succeed in fostering a more innovative US economy." (100%, 5)			
Internet			Converging contemplating the Internet of Things with connecting renewables directly to the grid: "Neither of these are [*sic*] likely to advance understanding or prediction." (0%, 1)		

Table 19. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Commerce (continued)

Emerging and Converging Technologies [Averaged across all answers for a goal. Includes sample answers for illustration purposes (Probability, Priority)]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Materials (Advanced)		Microscale 3D printing: "High-value, yes. Job-creating, probably not as much as traditional manufacturing processes. This type of multi-material microscale printing would align with the goals of agility and high-value outputs." (100%, 5)		Converging exploring the 3D structure of objects with building artificial intelligence into smartphones: "Building artificial intelligence into smartphones (the second emerging technology) would support Department data capabilities (the agency strategy), both in data calculations, data presentation, and communication of results/implications. In a world with a service economy and fewer materials (the potential future), this development might be especially important." (100%, 5)	

Table 19. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Commerce (continued)

Emerging and Converging Technologies [Averaged across all answers for a goal. Includes sample answers for illustration purposes (Probability, Priority)]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Nanotechnology	Converging discovering a new class of industrial polymers with developing a chip-scale power conversion for LED lighting: "Offering financial incentives to foreign firms that specialize in these types of technologies to continue development or manufacturing in the US" (50%, 4)	Converging using grapheme to absorb radio waves with developing a flexible display made of paper: "A desk with using the flexible display technology desk could be located in an enclosure that screens all Radio wave transmissions for privacy or to prevent the user from transmitting sensitive information from inside the enclosure." (75%, 3)	Converging making a small but powerful magnet with using eye-tracking instead of passwords: "Information is burgeoning; products are increasingly personalized. Just to get where something can happens takes time and effort. Let's simplify the gateways." (100%, 2)	Improving "plastic" semiconductors: "Combine better semiconductors (first emerging technology) with synbio to extend the forecast of reviving recently extinct species (global trend). Together, these could support better data products and services to customers (agency strategy) for a variety of issues and all of it could be done locally (potential future)." (100%, 4)	

Table 19. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Commerce (continued)

Emerging and Converging Technologies [Averaged across all answers for a goal. Includes sample answers for illustration purposes (Probability, Priority)]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Quantum (usually Computing)	Converging linking LEDs and superconductors to get entangled protons with developing cloud programming: "The interconnectivity of data in the future will require an easier programming environment." (100%, 3)			Converging achieving fault-tolerant quantum computing with discovering a hidden code in DNA: "By encouraging quantum computing the ability of private enterprise to solve existing problems and tackle new ones would be immense. Perhaps the biggest connection would be the use of the technology to speed up the internet. The U.S already has so.me of the most reliable, and robust networks in the world. How can we make them faster? More widespread?...." (50%, 3)	

Table 19. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Commerce (continued)

Emerging and Converging Technologies [Averaged across all answers for a goal. Includes sample answers for illustration purposes (Probability, Priority)]	**DOC Goal 1, Trade and Investment**	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**
Robotics			Converging turning robots into "Adaptive, Learning Beings" with developing solid state batteries: "I'll go with developing solid state batteries. The robot thing is pretty far out." (50%, 2)		
Sensors					
Space (Outer)					
Ubiquitous Computing					
Virtual Reality					

Table 20. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Energy

Emerging and Converging Technologies [Averaged across all answers for a particular goal. Includes answers to goals and sub-goals for illustration purposes (Probability, Priority)]	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Artificial Intelligence	Converging building artificial intelligence into smartphones with refueling with space robots: "Advances in AI (smartphone or otherwise) could get us closer to effective smart grids for more optimized strategies of minimizing energy consumption and actually maximizing energy production by end users and sharing that energy in effective ways. AI could also be linked to better software for operating buildings in more resource-efficient ways based on better predictions of occupant behavior in different scenarios." (50%, 5)		

Table 20. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Energy (continued)

Emerging and Converging Technologies [Averaged across all answers for a particular goal. Includes answers to goals and sub-goals for illustration purposes (Probability, Priority)]	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Biotechnology		Converging creating spontaneous "cell" division in artificial cell models with speculating about former life on Mars: "Far-fetched: If Mars is habitable for humans (extension of the second emerging technology), then global nuclear security threats (the agency strategy) would be reduced for the humans who move to Mars. This fits with a potential future in which local identities are preserved because the Mars colony would be likely to develop a local identity." (25%, 2)	
Cognitive Science			
Electronics			

Table 20. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Energy (continued)

Emerging and Converging Technologies [Averaged across all answers for a particular goal. Includes answers to goals and sub-goals for illustration purposes (Probability, Priority)]	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Energy Technology	Converging developing distributed power flow control with testing detectability of dark matter: "Improving power flow control (the emerging technology) and incorporating artificial intelligence (the platform) will improve transmission efficiency, which is part of reducing cumulative carbon pollution (the agency strategy). Improving transmission efficiency should reduce electricity costs, which would decrease expenses for everyone, especially individuals living in poverty (the global trend)." (100%, 5)		Converging developing biofuels from bacteria, electricity, and CO2 with improving interactions between humans and robots: "By improving interactions between humans and robots, it will become ever more possible to offload undesirable or boring tasks to automated workers. With such tasks out of the way the remaining job descriptions will be more interesting and challenging, a condition that will attract the best workforce." (75%, 5)
Geoengineering			
Information Technology	Converging designing a replacement to flash memory and developing an accelerator on a chip: "Both the replacement to flash memory and the accelerator on a chip could improve modeling for climate change mitigation and consumer choices." (50%, 4)		
Interfaces			
Internet			

Table 20. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Energy (continued)

Emerging and Converging Technologies [Averaged across all answers for a particular goal. Includes answers to goals and sub-goals for illustration purposes (Probability, Priority)]	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Materials (Advanced)	Converging converting light energy into mechanical work with turning graphite into diamond: "This technology could have applications in smart facades or smart roofs to help reduce overall energy consumption and the subsequent carbon pollution / greenhouse gas emissions associated with operating buildings. In cooling-determinate climates, surfaces oriented to the sun could be developed with a material that subtly changes shape at times of day when the incident solar energy is too intense. This could be a kind of screen that morphs at sunniest or hottest times of the day to provide incremental shading when needed most." (50%, 1)		
Nanotechnology		Converging improving "Plastic" semiconductors with developing a biological teleportation device: "WOW this idea of plastic semiconductors is exciting. Military could use it. "Agents" could use it. Diplomats could use it. Who wouldn't want this?" (100%, 4)	

Table 20. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Energy (continued)

Emerging and Converging Technologies [Averaged across all answers for a particular goal. Includes answers to goals and sub-goals for illustration purposes (Probability, Priority)]	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Quantum (usually Computing)	Converging inventing the optical analog of a transistor with attaching molecules to gold nanoparticles: "Optical analog of transistor will increase computer and computer interconnections, this will help improve the management and control of the energy infrastructure." (75%, 3)		

Table 20. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Energy (continued)

Emerging and Converging Technologies [Averaged across all answers for a particular goal. Includes answers to goals and sub-goals for illustration purposes (Probability, Priority)]	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Robotics	Developing robots like us: "Much of the US energy infrastructure is, at the moment, built and maintained by humans. Enhancing desirable characteristics will, in large part, be accomplished by improving or increasing the frequency of existing human-based tasks. By developing Robots Like Us we will be more easily able to 1:1 substitute automated workers for existing human-based tasks. This enables the realization of the benefits of automation without suffering the necessity of redesigning/developing all existing infrastructure-related tasks in order to automate them. It is also worth noting that energy infrastructure work is mostly done at the fleet level, which can simplify the rolling out of changes such as the introduction of new technologies such as Robots Like Us….." (75%, 5)		

Table 20. Potential Use of Emerging and Converging Technologies per Crowd-sourced Intelligence (by Agency Strategy and Probabilities): Department of Energy (continued)

Emerging and Converging Technologies [Averaged across all answers for a particular goal. Includes answers to goals and sub-goals for illustration purposes (Probability, Priority)]	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Sensors	Converging considering the “Internet of Cars” with developing crop models to better forecast food production: “Internet of Cars is already ‘sort of’ happening as sensors watch cars creeping into blind spots. The sensors are fundamental science and implemented into auto technology.” (100%, 4)		
Space (Outer)			
Ubiquitous Computing			Assisting real-time drawing and developing compact inexpensive reformers for natural gas: “I don't see either emerging technology helping with project management, financial assistance agreements, contracts or contractor performance.” (0%, 1)
Virtual Reality			

Table 21. Summary of Current and Potential Use of Emerging and Converging Technologies (by Agency and Analysis Approach)

Emerging and Converging Technologies [Findings and results for each analysis approach: 1. Content Analysis (mentions in the strategic documents) 2. Technology Assessment Analysis (see the note below the table) 3. Individual Interviews 4. Plausibility Matrix Analysis 5. Crowd-sourced intelligence (sample feasibility and priority)]		**Department of Commerce**					**Department of Energy**		
		DOC Goal 1, Trade and Investment	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Artificial intelligence	1.	2 mentions					0 mentions		
	2.	13%	50%	13%	56%	31%	38%	69%	6%
	3.	0 mentions					0 mentions		
	4.	55%	58%	60%	80%	53%	75%	70%	70%
	5.	A feasibility, priority: 65%, 2.8					A feasibility, priority: 50%, 5.0		
Biotechnology	1.	9 mentions					5 mentions		
	2.	69%	88%	31%	6%	13%	56%	19%	25%
	3.	0 mentions					0 mentions		
	4.	68%	70%	40%	18%	25%	55%	35%	48%
	5.	A feasibility, priority: 57%, 2.9					A feasibility, priority: 25%, 2.0		
Cognitive Science	1.	3 mentions					2 mentions		
	2.	50%	50%	25%	44%	25%	38%	13%	6%
	3.	0 mentions					0 mentions		
	4.	45%	65%	58%	58%	50%	45%	45%	50%
	5.	A feasibility, priority: 50%, 2.5					No examples		
Electronics	1.	35 mentions					68 mentions		
	2.	81%	88%	75%	56%	63%	81%	88%	44%
	3.	0 mentions					0 mentions		
	4.	88%	78%	60%	58%	60%	65%	80%	68%
	5.	A feasibility, priority: 100%, 3.0					No examples		
Energy Technology	1.	6 mentions					216 mentions		
	2.	56%	75%	75%	38%	38%	63%	38%	13%
	3.	0 mentions					Current and potential use		
	4.	68%	68%	48%	50%	53%	65%	75%	50%
	5.	A feasibility, priority: 64%, 4.6					A feasibility, priority: 88%, 4.8		
Geoengineering	1.	0 mentions					0 mentions		
	2.	25%	31%	31%	38%	38%	50%	13%	13%
	3.	0 mentions					0 mentions		
	4.	40%	53%	50%	23%	20%	53%	28%	35%
	5.	No examples					No examples		

Table 21. Summary of Current and Potential Use of Emerging and Converging Technologies (by Agency and Analysis Approach) (continued)

Emerging and Converging Technologies [Findings and results for each analysis approach: 1. Content Analysis (mentions in the strategic documents) 2. Technology Assessment Analysis (see the note below the table) 3. Individual Interviews 4. Plausibility Matrix Analysis 5. Crowd-sourced intelligence (sample feasibility and priority)]		**Department of Commerce**					**Department of Energy**		
		DOC Goal 1, Trade and Investment	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Information Technology	1.	75 mentions					70 mentions		
	2.	75%	88%	75%	75%	75%	88%	81%	50%
	3.	Current and potential use					Current and potential use		
	4.	80%	75%	83%	89%	70%	70%	78%	73%
	5.	A feasibility, priority: 90%, 3.7					A feasibility, priority: 50%, 4.0		
Interfaces	1.	18 mentions					36 mentions		
	2.	38%	50%	63%	56%	44%	56%	69%	44%
	3.	0 mentions					0 mentions		
	4.	60%	83%	83%	70%	68%	65%	70%	63%
	5.	A feasibility, priority: 100%, 5					No examples		
Internet	1.	142 mentions					36 mentions		
	2.	56%	75%	75%	75%	63%	75%	88%	25%
	3.	Current use					Current and potential use		
	4.	95%	75%	83%	85%	75%	73%	73%	68%
	5.	A feasibility, priority: 42%, 1.7					No examples		
Materials (Advanced)	1.	235 mentions					475 mentions		
	2.	69%	81%	56%	25%	31%	56%	75%	38%
	3.	0 mentions					Potential use		
	4.	73%	68%	40%	33%	35%	45%	53%	53%
	5.	A feasibility, priority: 94%, 4.5					A feasibility, priority: 42%, 2.0		
Nanotechnology	1.	12 mentions					4 mentions		
	2.	81%	81%	50%	25%	25%	56%	88%	50%
	3.	0 mentions					Potential use		
	4.	73%	68%	35%	38%	33%	50%	55%	48%
	5.	A feasibility, priority: 75%, 3.6					A feasibility, priority: 100%, 4.0		
Quantum (usually Computing)	1.	40 mentions					21 mentions		
	2.	50%	56%	38%	25%	38%	50%	63%	25%
	3.	0 mentions					0 mentions		
	4.	50%	63%	44%	50%	31%	47%	67%	50%
	5.	A feasibility, priority: 50%, 3.7					A feasibility, priority: 75%, 3.0		

Table 21. Summary of Current and Potential Use of Emerging and Converging Technologies (by Agency and Analysis Approach) (continued)

Emerging and Converging Technologies [Findings and results for each analysis approach: 1. Content Analysis (mentions in the strategic documents) 2. Technology Assessment Analysis (see the note below the table) 3. Individual Interviews 4. Plausibility Matrix Analysis 5. Crowd-sourced intelligence (sample feasibility and priority)]		**Department of Commerce**					**Department of Energy**		
		DOC Goal 1, Trade and Investment	**DOC Goal 2, Innovation**	**DOC Goal 3, Environment**	**DOC Goal 4, Data**	**DOC Goal 5, Operational Excellence**	**DOE Goal 1, Science and Energy**	**DOE Goal 2, Nuclear Security**	**DOE Goal 3, Management and Performance**
Robotics	1.	7 mentions					2 mentions		
	2.	63%	88%	56%	25%	25%	25%	81%	38%
	3.	0 mentions					0 mentions		
	4.	75%	73%	48%	40%	43%	40%	73%	43%
	5.	A feasibility, priority: 50%, 2.0					A feasibility, priority: 75%, 5.0		
Sensors	1.	58 mentions					63 mentions		
	2.	50%	63%	50%	44%	44%	75%	75%	50%
	3.	Current and potential use							
	4.	75%	73%	60%	63%	40%	68%	68%	55%
	5.	No examples					A feasibility, priority: 100%, 4.0		
Space (Outer)	1.	112 mentions					3 mentions		
	2.	56%	50%	31%	25%	25%	25%	38%	0%
	3.	0 mentions					0 mentions		
	4.	43%	45%	25%	23%	28%	50%	33%	23%
	5.	No examples					No examples		
Ubiquitous Computing	1.	4 mentions					9 mentions		
	2.	56%	69%	44%	25%	38%	50%	44%	25%
	3.	Potential use					0 mentions		
	4.	65%	73%	60%	50%	45%	43%	50%	40%
	5.	No examples					A feasibility, priority: 0%, 1.0		
Virtual Reality	1.	11 mentions					24 mentions		
	2.	33%	17%	17%	17%	8%	8%	33%	25%
	3.	0 mentions					0 mentions		
	4.	53%	70%	40%	53%	45%	45%	55%	38%
	5.	No examples					No examples		

Table 22. Disposition of the Propositions

Proposition	Disposition
Proposition 1: Develop a Methodology. Developing a methodology depends upon identifying design criteria and noting efficiencies and deficiencies in related methodologies. Thus, a methodology can be developed by identifying design criteria and using effective elements of related methodologies to meet the criteria.	Supported. See the set of criteria and a methodology that met the criteria.
Proposition 2a: Apply to Characterize Current Use. The viewpoints of federal agencies are summarized in strategic documents and Congressional Budget Justifications, as required by the Executive Office of the President and the Government Performance and Results Act, and are known by people familiar with the agencies and government employees. Thus, agency actual present use of technology can be characterized based on strategic documents, expert knowledge, and government employee knowledge.	Supported. See the findings and results from the content analysis (Analysis Approach 1), technology assessment analysis (Analysis Approach 2), and individual interviews (Analysis Approach 3).
Proposition 2b: Apply to Characterize Potential Use. Potential use can be defined as a function of ECT, agency strategies, global trends, potential futures, and agency strategies. Thus, agency potential present use of technology can be characterized based on government employee knowledge, expert knowledge, and crowd-sourced knowledge.	Supported. See the findings and results from the individual interviews (Analysis Approach 3), plausibility matrix analysis (Analysis Approach 4), and crowd-sourced intelligence (Analysis Approach 5).
Proposition 3: Evaluate a Methodology. Evaluating a methodology requires a standard to evaluate against or use of a different analysis approach to see if it produces the same results. Thus, my methodology can be evaluated against a standard set of criteria and using a different analysis approach.	Supported. See the comparison of the methodology application to the original criteria and the visual analytics (Analysis Approach 6).
Proposition 4: Disseminate a Methodology. Disseminating a methodology requires sharing it with a variety of audiences using a variety of media. Thus, the methodology and results can be disseminated by distributing them to members of academia, government employees, and the general public via websites.	Supported. See the summary of the distribution of data, results, and executive summary.

Appendix B. Figures

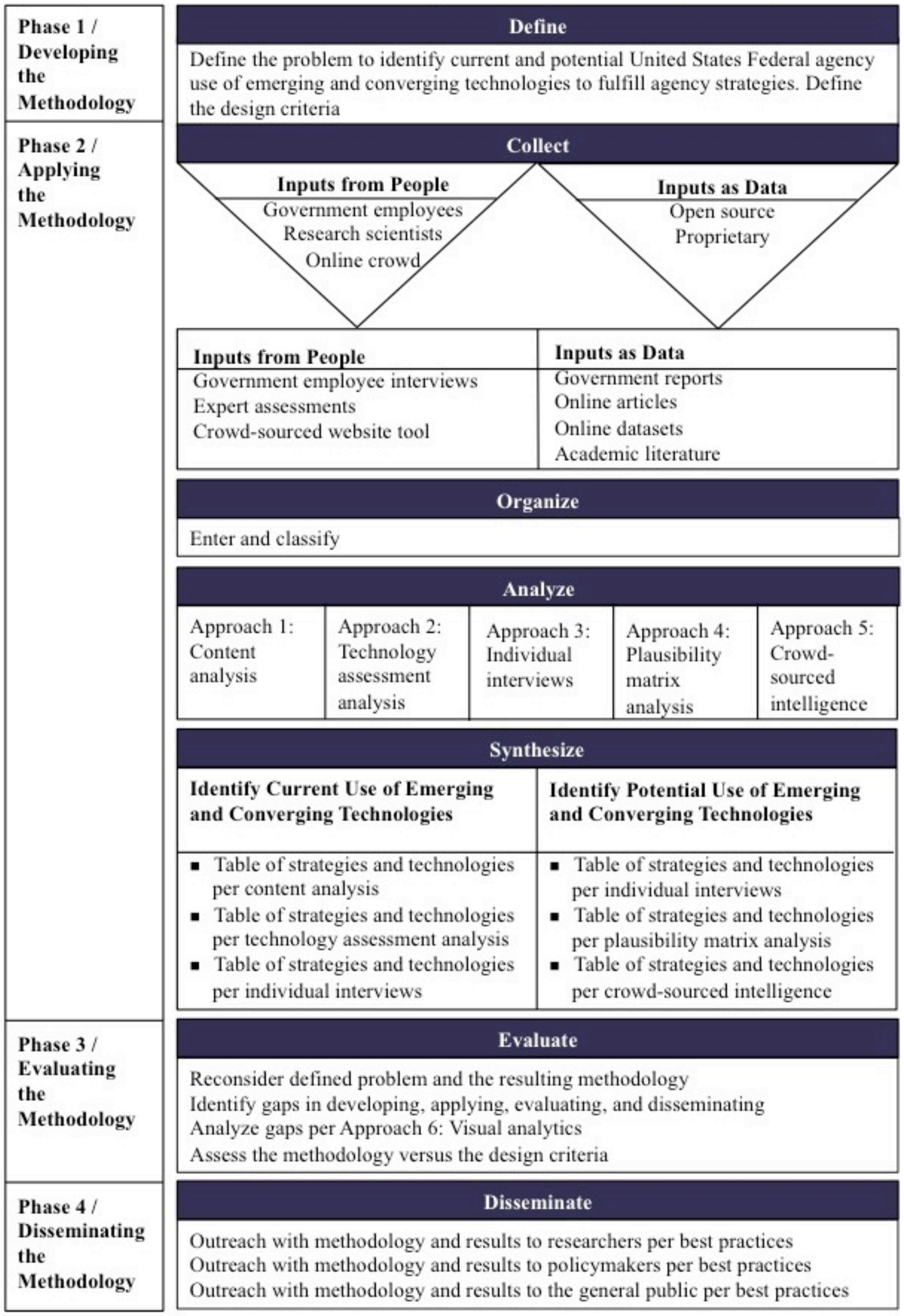


Figure 1. Developed Methodology with Phases [inspired by “Conceptual Process Flow for the Persistent Forecasting System” (Committee on Forecasting Future Disruptive Technologies 2009, 59)]

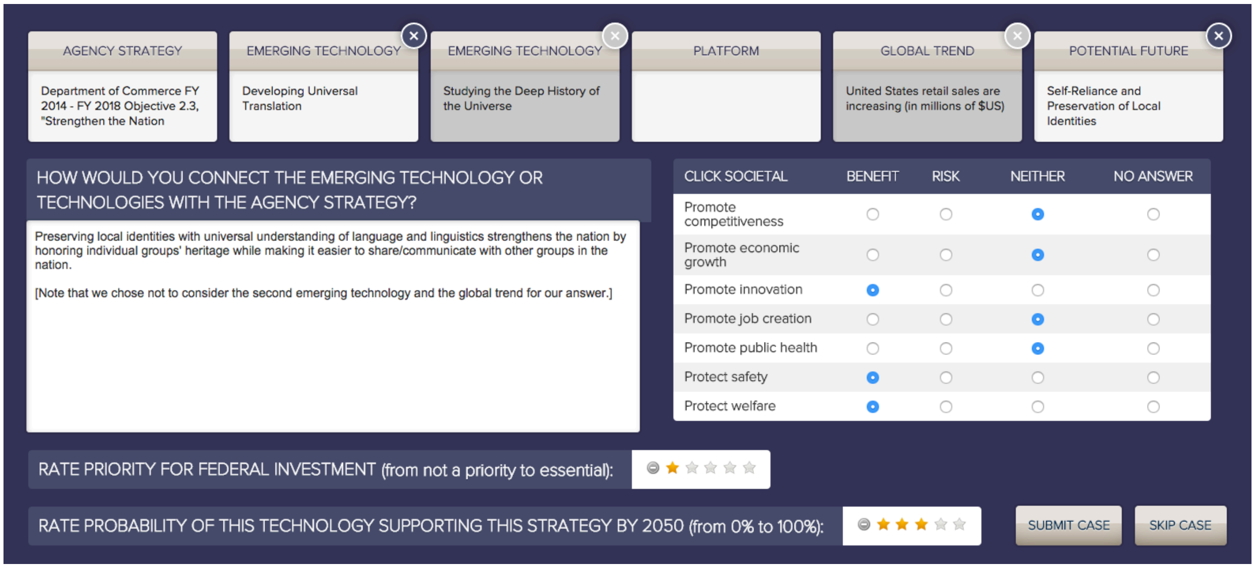


Figure 2. “Connect Technologies” Example from The Foresight Challenge

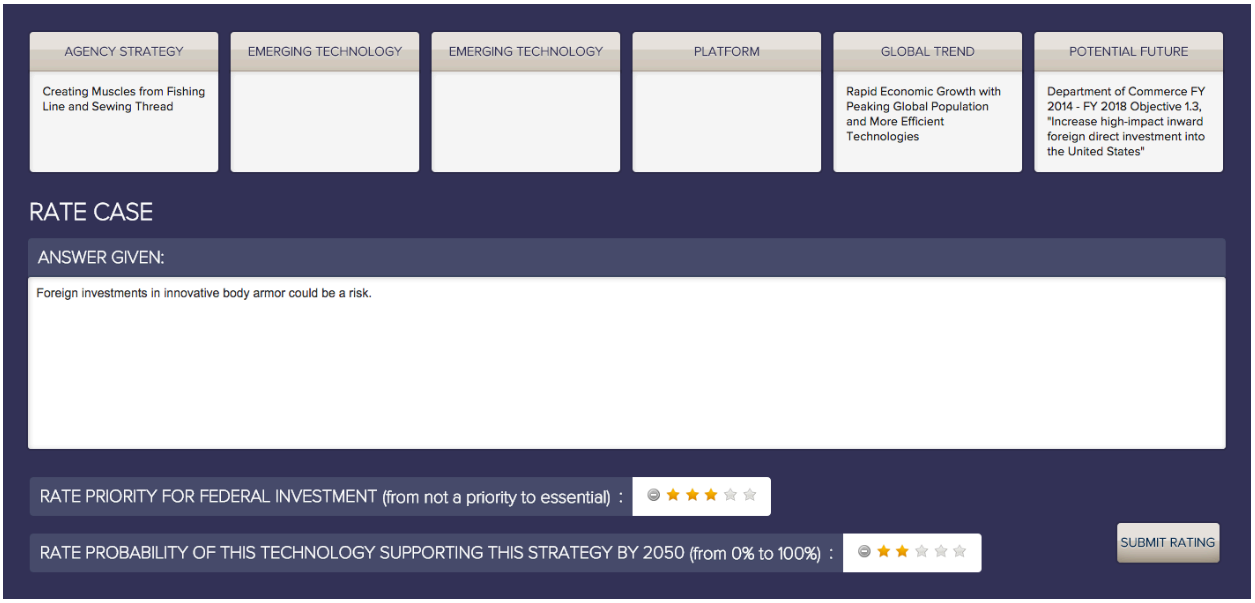


Figure 3. “Rate Other Answers” Example from The Foresight Challenge

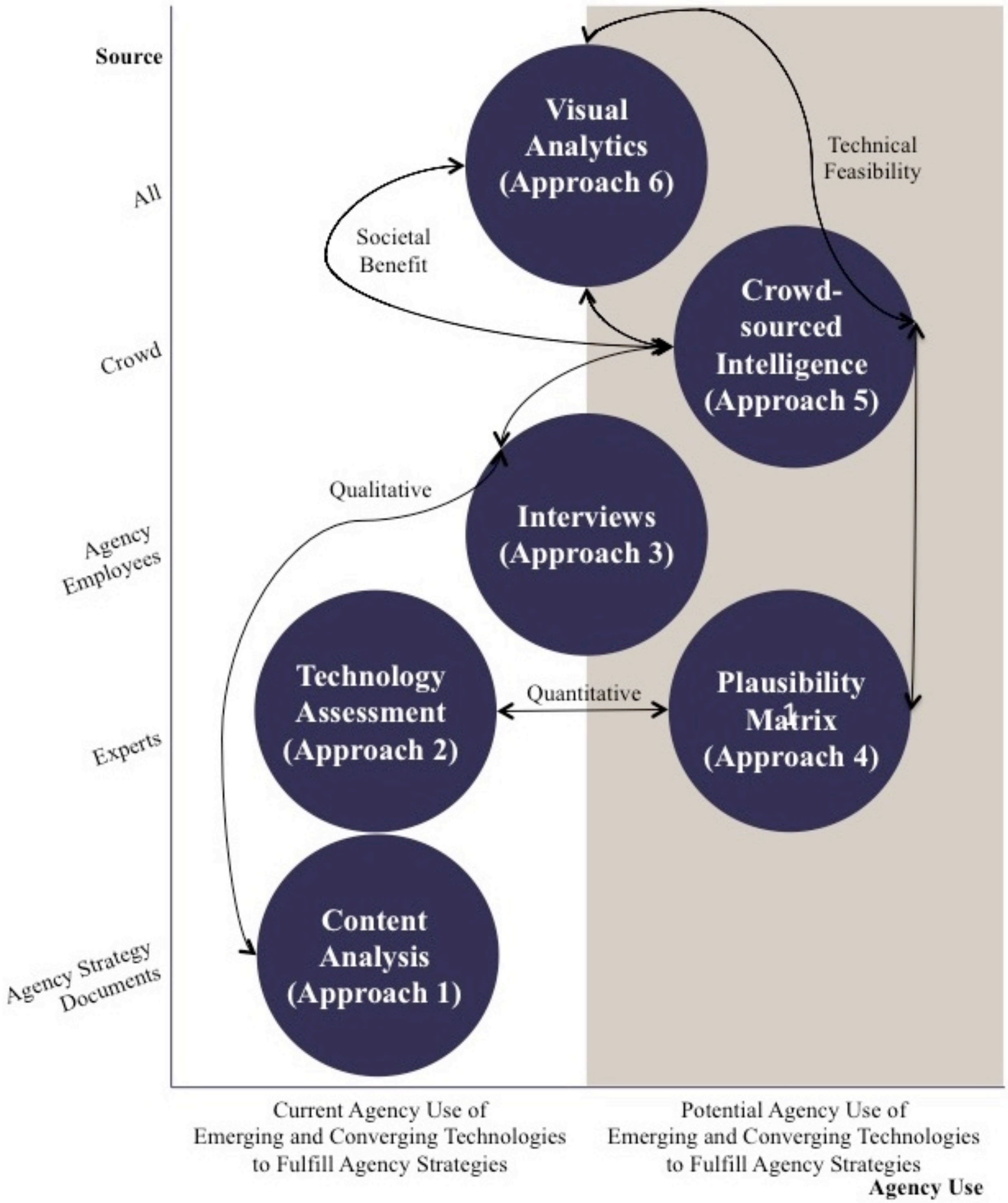


Figure 4. Integrating the Approaches

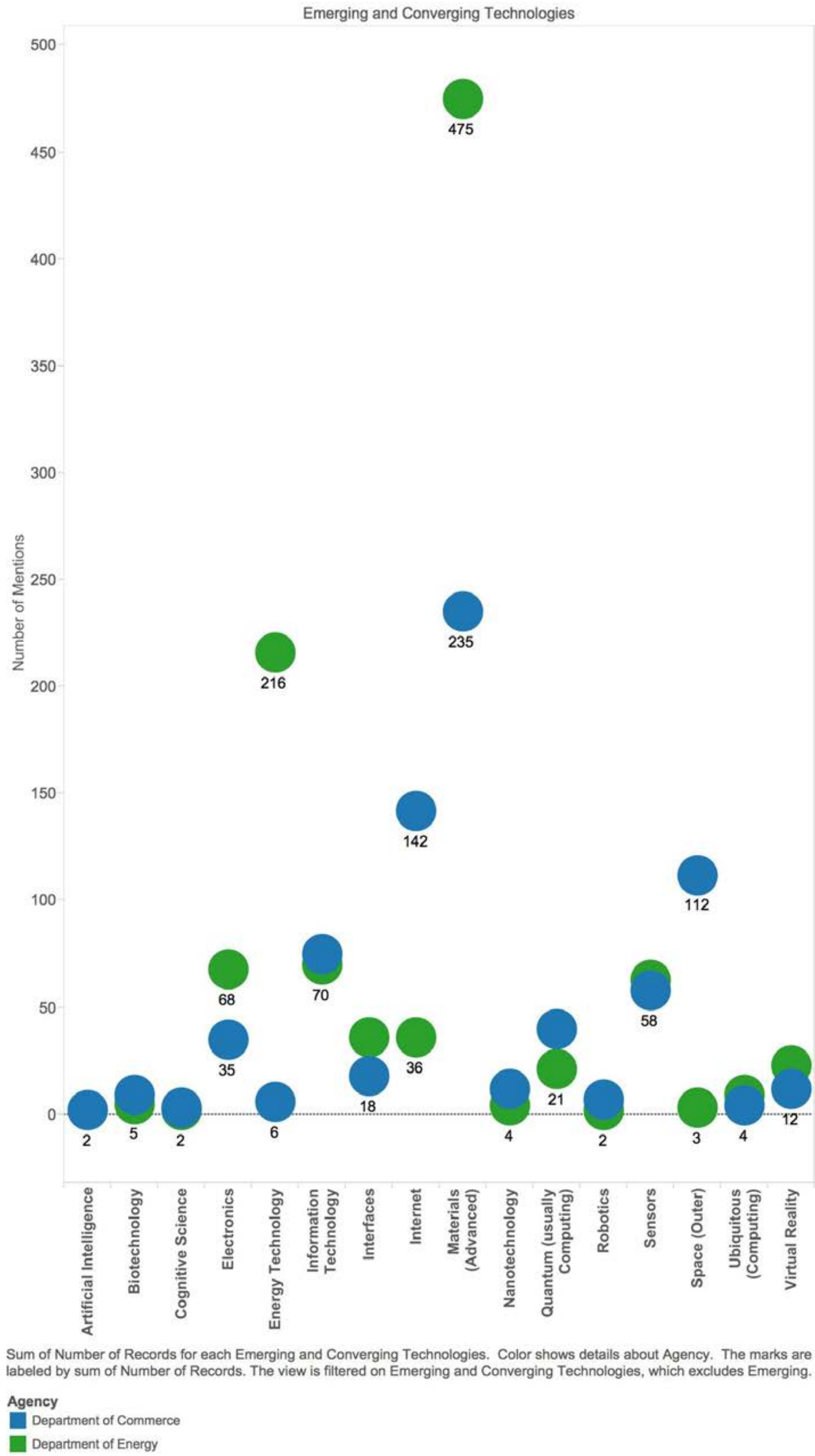


Figure 5. Visual Analytics of Content Analysis (Approach 1)

	Agency / Agency Strategy Code							
	Department of Commerce					**Department of Energy**		
Emerging and Converging Technologies	DOC1.0	DOC2.0	DOC3.0	DOC4.0	DOC5.0	DOE1.0	DOE2.0	DOE3.0
Artificial Intelligence	0.1250	0.5000	0.1250	0.5625	0.3125	0.3750	0.6875	0.0625
Biotechnology	0.6875	0.8750	0.3125	0.0625	0.1250	0.5625	0.1875	0.2500
Cognitive Science	0.5000	0.5000	0.2500	0.4375	0.2500	0.3750	0.1250	0.0625
Electronics	0.8125	0.8750	0.7500	0.5625	0.6250	0.8125	0.8750	0.4375
Energy Technology	0.5625	0.7500	0.7500	0.3750	0.3750	0.6250	0.3750	0.1250
Geoengineering	0.2500	0.3125	0.3125	0.3750	0.3750	0.5000	0.1250	0.1250
Information Technology	0.7500	0.8750	0.7500	0.7500	0.7500	0.8750	0.8125	0.5000
Interfaces	0.3750	0.5000	0.6250	0.5625	0.4375	0.5625	0.6875	0.4375
Internet	0.5625	0.7500	0.7500	0.7500	0.6250	0.7500	0.8750	0.2500
Materials (Advanced)	0.6875	0.8125	0.5625	0.2500	0.3125	0.5625	0.7500	0.3750
Nanotechnology	0.8125	0.8125	0.5000	0.2500	0.2500	0.5625	0.8750	0.5000
Quantum (usually Computing)	0.5000	0.5625	0.3750	0.2500	0.3750	0.5000	0.6250	0.2500
Robotics	0.6250	0.8750	0.5625	0.2500	0.2500	0.2500	0.8125	0.3750
Sensors	0.5000	0.6250	0.5000	0.4375	0.4375	0.7500	0.7500	0.5000
Space (Outer)	0.5625	0.5000	0.3125	0.2500	0.2500	0.2500	0.3750	0.0000
Ubiquitous Computing	0.5625	0.6875	0.4375	0.2500	0.3750	0.5000	0.4375	0.2500
Virtual Reality	0.3333	0.1667	0.1667	0.1667	0.0833	0.0833	0.3333	0.2500

Probability (Current) (color) broken down by Agency and Agency Strategy Code vs. Emerging and Converging Technologies. The view is filtered on Agency Strategy Code, which keeps 8 of 50 members.

Measure Values

0.0000 0.8750

Figure 6. Visual Analytics of Technology Assessment Analysis (Approach 2)

Emerging and Converging Technologies	Department of Commerce					Department of Energy		
	DOC1.0	DOC2.0	DOC3.0	DOC4.0	DOC5.0	DOE1.0	DOE2.0	DOE3.0
Artificial Intelligence	0.5500	0.5750	0.6000	0.8000	0.5250	0.7500	0.7000	0.7000
Biotechnology	0.6750	0.7000	0.4000	0.1750	0.2500	0.5500	0.3500	0.4750
Cognitive Science	0.4500	0.6500	0.5750	0.5750	0.5000	0.4500	0.4500	0.5000
Electronics	0.8750	0.7750	0.6000	0.5750	0.6000	0.6500	0.8000	0.6750
Energy Technology	0.6750	0.6750	0.4750	0.5000	0.5250	0.6500	0.7500	0.5000
Geoengineering	0.4000	0.5250	0.5000	0.2250	0.2000	0.5250	0.2750	0.3500
Information Technology	0.8000	0.7500	0.8250	0.8889	0.7000	0.7000	0.7750	0.7250
Interfaces	0.6000	0.8250	0.8250	0.7000	0.6750	0.6500	0.7000	0.6250
Internet	0.9500	0.7500	0.8250	0.8500	0.7500	0.7250	0.7250	0.6750
Materials (Advanced)	0.7250	0.6750	0.4000	0.3250	0.3500	0.4500	0.5250	0.5250
Nanotechnology	0.7250	0.6750	0.3500	0.3750	0.3250	0.5000	0.5500	0.4750
Quantum (usually Computing)	0.5000	0.6250	0.4444	0.5000	0.3056	0.4722	0.6667	0.5000
Robotics	0.7500	0.7250	0.4750	0.4000	0.4250	0.4000	0.7250	0.4250
Sensors	0.7500	0.7250	0.6000	0.6250	0.4000	0.6750	0.6750	0.5500
Space (Outer)	0.4250	0.4500	0.2500	0.2250	0.2750	0.5000	0.3250	0.2250
Ubiquitous Computing	0.6500	0.7250	0.6000	0.5000	0.4500	0.4250	0.5000	0.4000
Virtual Reality	0.5250	0.7000	0.4000	0.5250	0.4500	0.4500	0.5500	0.3750

Agency / Agency Strategy Code

Probability (Potential) as an attribute (color) broken down by Agency and Agency Strategy Code vs. Emerging and Converging Technologies. The view is filtered on Agency Strategy Code, which has multiple members selected.

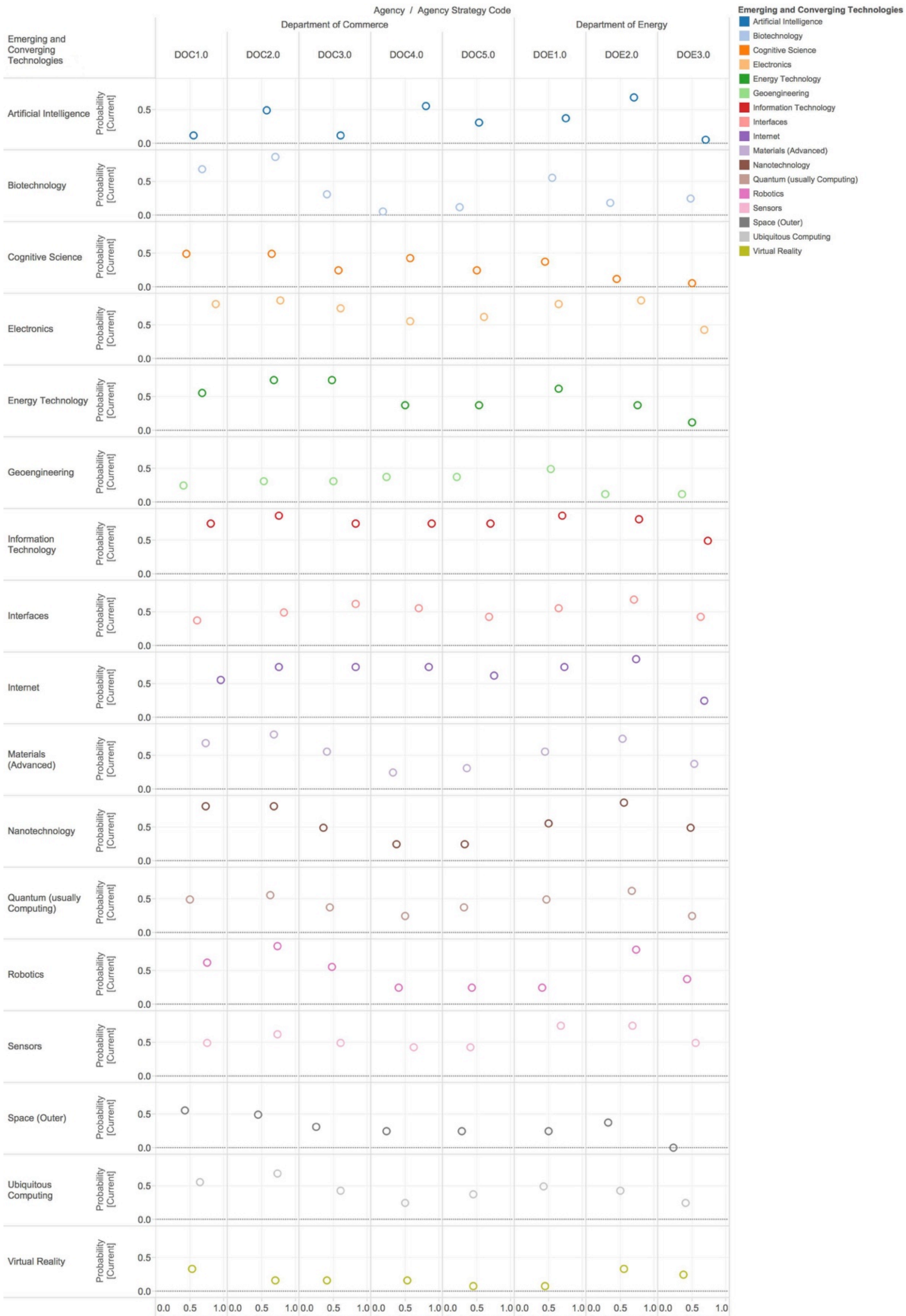
Probability (Potential)

0.1750 — 0.9500

Figure 7. Visual Analytics of Plausibility Matrix Analysis (Approach 4)

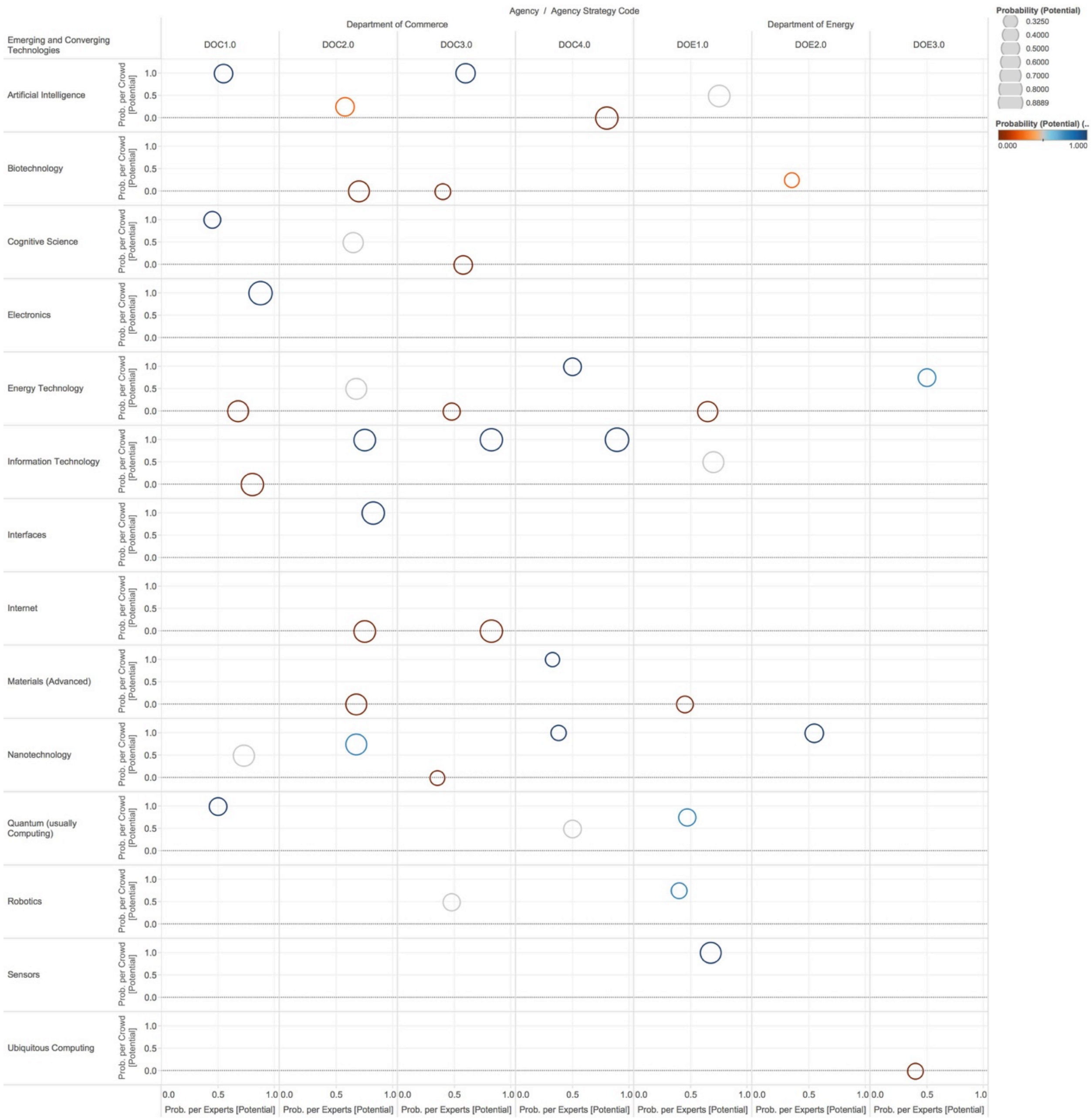
Probability (Potential) as an attribute vs. Priority as an attribute broken down by Agency and Agency Strategy Code vs. Emerging and Converging Technologies. Color shows details about Agency Strategy Code. Size shows details about Probability (Potential). The view is filtered on Agency Strategy Code, which excludes DOC.P1 and DOC.P5.

Figure 8. Visual Analytics of Crowd-sourced Intelligence Probabilities and Priorities (Approach 5)



Probability (Potential) as an attribute vs. Probability (Current) as an attribute broken down by Agency and Agency Strategy Code vs. Emerging and Converging Technologies (4. Probability Matrix). Color shows details about Emerging and Converging Technologies. The view is filtered on Agency Strategy Code, which keeps 8 members.

Figure 9. Visual Analytics of Technology Assessment and Plausibility Matrix (Approaches 2 and 4)



Probability (Potential) as an attribute vs. Probability (Potential) (5a. Crowd-sourced (Connect)) as an attribute broken down by Agency and Agency Strategy Code vs. Emerging and Converging Technologies. Color shows Probability (Potential) (5a. Crowd-sourced (Connect)) as an attribute. Size shows Probability (Potential) as an attribute. The view is filtered on Agency Strategy Code, which keeps 8 members.

Figure 10. Visual Analytics of Plausibility Matrix and Crowd-sourced Intelligence Probabilities (Approaches 4 and 5)

Appendix C. Data Management Plan

My data management plan addresses the data generated and related standards; policies for accessing and sharing data; policies for re-using, redistributing, and production of derivatives; plan for managing and archiving the data; and past performance.

C.1 Data Generated and Standards Used

My research generated data and metadata (e.g., methodological protocols, code for the web portal), which is now managed via the Institute for Quantitative Social Science's (IQSS) Dataverse Network at Harvard. Code for the website tool and the visual analytics tool is proprietary so individuals requesting access will have to request permission from those content owners.

Developing and applying the methodology generated several data sets. These data are available in Excel™ via the Dataverse Network. Evaluating the methodology via visual analytics generated visual images in Tableau™ files, which also are available via the Dataverse Network. Disseminating the methodology required publicly-available email and mailing addresses for Members of Congress and their staffs and federal agency employees and posting materials on www.foresightchallenge.org.

C.2 Policies for Accessing and Sharing Data

Anyone is free to access or share my data within the parameters specified here and on the websites on which the data are posted.

C.3 Policies for Re-using, Redistributing, and Production of Derivatives

Anyone is free to re-use and redistribute my materials and to produce any derivatives they wish.

C.4 Plan for Managing and Archiving the Data

All of the data sets are posted to the Institute for Quantitative Social Science's (IQSS) Dataverse Network at Harvard.

Appendix D. Status of Certificate of Exemption for Human Subjects Research

The University of Tennessee-Knoxville's Institutional Review Board (IRB) has certified my research as exempt from IRB review under 45 CFR 46.101(b)(4). Certification was granted January 28, 2013; the institution's federal-wide Assurance Number is FWA00006629.

I proposed the following information for consent on my Form A: "The purpose of this research is to share ideas about how federal agencies, in this case the Department of Commerce and Department of Energy, can use technologies to fulfill their strategies. The procedure is for participants to use the website in three ways: 1) The website will serve up a preset combination of technologies, platforms, global trends, potential futures, and agency strategies and the user will enter an approach to fulfilling the provided Agency strategy, if possible; 2) Users will come with their own inventions and tag their data as they add it to the website; and 3) Users will rate ideas by searching for them or by getting a random set to rate and comment upon. I understand and agree to the preceding purposes and procedures, as well as the following:

- I am benefiting society by sharing ratings and ways that federal agencies can use technologies to fulfill their strategies and serve society.
- I am not required to participate in on this website.
- I have the right to confidentiality. I am not required to provide identifying information, and I am discouraged from providing it.
- I can participate as much or as little as I would like.
- I can withdraw at any time.
- I will not be paid for participating.
- All information will be hosted on a secure server.
- I am over the age of 18.
- I agree to participate professionally and respectfully.
- I release all rights to the material I post here.
- I promise to provide only peaceful solutions.
- I can reach Dori Stiefel with concerns, suggestions, or questions, dori@websiteURL.org
- I choose to participate."

Vita

Dorian (Dori) Akerman Stiefel's doctoral research on United States federal agency use of emerging and converging technologies to fulfill agency strategies entailed developing a methodology to characterize current and potential uses by agencies. She also has conducted extensive co-authored research on climate change adaptation, sustainability, human existential risk reduction, and unintended consequences, which is published in journals as varied as *Sustainability* and *Risk Analysis*. Before returning to academia, Dori provided consulting services to executives in federal agencies and the private sector. She graduated with a Doctor of Philosophy degree in Political Science from the University of Tennessee in August 2015. Dori also holds a Bachelor of Arts in Mathematics earned from Mary Baldwin College in 1992 (Program for the Exceptionally Gifted; Staunton, Virginia) and a Masters in Accounting earned from the University of Virginia in 1994 (McIntire School of Commerce; Charlottesville, Virginia).