Energy Innovation Policy and Climate Change: A Synthesis

Supporting Document

Consortium for Science, Policy and Outcomes

Clean Air Task Force

1. Introduction

This online document is a supplement to **Four Innovation Principles for Energy Innovation and Climate Change: A Synthesis**, published in June 2010 by the Consortium for Science, Policy and Outcomes and the Clean Air Task Force (CSPO/CATF). This report examined recent publications from ten research groups examining energy innovation policy, identifying key principles for how innovation works and can be encouraged. This supplemental document contains a more detailed discussion of those reports, which may help provide some additional context for understanding the principles.

First, the reports will be briefly listed. Then, the different perspectives used by each of these reports takes will be clarified. Finally, additional summaries of some of the reports will be presented.

2. Reports Used in the Synthesis.

America's Energy Problem (and How to Fix it), by Richard Lester, from the Massachusetts Institute of Technology (MIT) and its Industrial Performance Center. This report examines the magnitude of the energy-climate challenge and the current context surrounding energy innovation while advocating for a better "system of innovation institutions." Funded by the Doris Duke Charitable Foundation (DDCF). 2009.

Structuring an Energy Technology Revolution, by Charles Weiss and William Bonvillian. Written by experts on innovation policy, this book presents a framework for innovation policy, seeking to create appropriate policies for different technologies and to overcome institutional hurdles. (MIT Press). 2009

Innovation Policy for Climate Change, by Arizona State University's Consortium for Science and Policy Outcomes and the Clean Air Task Force (CSPO/CATF). This report relied on expert analysis from three workshops for obstacles to innovation for three different energy technologies. Provides a framework for improving Federal energy innovation policy. Funded by the National Commission on Energy Policy and led by Dan Sarewitz and Armond Cohen. 2009

"Technology Policy and Global Warming," by David Mowery, Richard Nelson and Ben Martin. This overview paper examines what the best metaphor for energy innovation should be. Examines key historical episodes of innovation in the US and UK, including agriculture and information technology. Funded by the National Endowment for Science, Technology and the Arts (NESTA). 2009.

An Energy Future Transformed, by Xan Alexander. From the Climate Policy Center of Clean Air Cool Planet. This report provides recommendations and an analytical framework for the new Advanced Research Projects Agency for Energy (ARPA-E). The author is a former manager in the Defense ARPA and provides a one year operating plan for ARPA-E. Funded by DDCF. 2009.

Coal without Carbon, by the Clean Air Task Force (CATF). Used groups of expert authors to develop research, development and demonstration road maps for critical clean coal and geologic sequestration technologies. Introduces the idea of a First Project Demonstration Fund to support demonstration projects. Supported by DDCF and led by Joe Chaisson. 2009.

Energy Discovery-Innovation Institutes, by Duderstadt et al. From the Metropolitan Policy Program at the Brookings Institution. This report advocates for creating regionally focused innovation hubs which would connect academic and federal researchers with private industry, oriented around on particular innovation tracks. Congress has since funded three energy hubs, following the EDII concept. 2009.

Clean Energy Technology Pathways, by the National Commission on Energy Policy (NCEP), which is part of the Bipartisan Policy Center. Using a system-level framework, this report draws on models of future energy technology 'mixes' and the effect that each technology will have on one another. Examines cross-cutting challenges to energy technology development. 2009.

Various publications by the **Energy Research, Development, Demonstration and Deployment** (ERD3) Policy Project, which is part of the Energy Technology Innovation Program at Harvard University. These reports Provides budgetary recommendations for federal energy programs. Funded by DDCF and led by Matthew Bunn and Venkatesh Narayanamurti. 2009-2010.

Accelerating Energy Innovation, by researchers from the National Bureau of Economic Research (NBER). These publications examine the history of innovation in the life science, chemistry, agriculture, and information technology industries, examining insights for accelerating innovation in energy technologies. They will be part of a book edited by Rebecca Henderson and Richard Newell.

3. Viewing Innovation from Many Perspectives

Collectively, the ten reports approach the problem of innovation from a variety of different perspectives. While it is impossible to fully distinguish between each of the different dimensions of energy innovation, some of these research groups focus more on some perspectives than on others. Table 1 lists the main perspectives each report used to examine the energy system.

Table 1: The different perspectives used in the different reports.

Establishing the tools of Innovation Policy	History of Innovation	Technology Specific Approaches	System Level Focus	Institutional Challenges	Experience in Managing Innovation
MIT Harvard ERD3	NESTA NBER CSPO/CATF	Weiss and Bonvillian CSPO/CATF CATF	MIT NCEP	Brookings Harvard ERD3 CSPO/CATF	Clean Air Cool Planet

Establishing the tools of Innovation Policy (Industrial Performance Center; CSPO CATF; ERD3)

Several of the reports describe the tools that innovation policy can utilize, many of which are listed in Figure 1 and in Table 2. In the figure from the Harvard Energy Research, Development, Demonstration and Deployment Project, technology policies are divided into supply level "technology push" tools as well as demand side "market pull" tools, and general conditions for innovation. Other report authors refer to the demand side tools as 'back end' policies, and supply side tools as 'technology push' or front end policies. No one policy tool is sufficient to encourage the growth of a new technology. In the case of technology-push support, several authors argue that assistance at the intermediate development stage can be critical, particularly in supporting the demonstration of new technologies at scale. In terms of market pull support, several authors, including Richard Lester from the Industrial Performance Center, argue that government procurement can be important for establishing new markets and encouraging innovation.

Figure 1. Front end and back end innovation policy tools. (Anadon and Holdren 2009, p. 104).

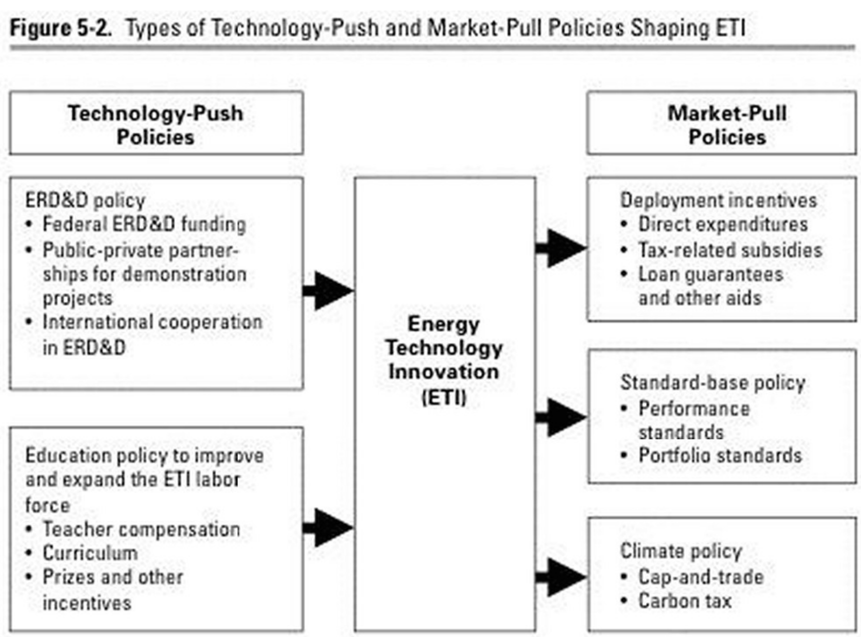

Table 2: Description of Innovation Tools from the Consortium for Science, Policy and Outcomes and Clean Air Task Force report.

Table 2. Technology and Innovation Policies [a]

	POLICY	COMMENTS
I. DIRECT GOVERNMENT FUNDING OF KNOWLEDGE GENERATION	1. R&D contracts with private firms (fully funded or cost shared).	Normally support government missions, such as defense.
	2. R&D contracts and grants with nonprofits.	Mostly universities, mostly basic research.
	3. Intramural R&D in government laboratories.	Wide range of activities, depending on agency. Some laboratories much more capable than others.
	4. R&D contracts with consortia or collaborations.	Proprietary interests of participating organizations may limit R&D to generic, pre-competitive work.
II. DIRECT OR INDIRECT SUPPORT FOR COMMERCIALIZATION AND PRODUCTION	5. R&D tax credits.	Unlikely to alter firms' risk/reward assessments. Difficult or impossible to target.
	6. Patents.	The stronger the protection, the weaker the incentives for diffusion through imitation or circumvention.
	7. Tax credits or production subsidies for firms bringing new technologies to market.	Tend to push technologies into the marketplace from supply side.
	8. Tax credits, rebates, or payments for purchasers/users of new technologies.	Create demand pull, in contrast to technology push (above).
	9. Procurement.	Powerful stimulus when government sales a substantial fraction of the total.
	10. Demonstration projects.	Intended to validate technologies viewed as too risky for private investment.
	11. Monetary prizes.	Administratively simple, once rules have been set.
III. DIFFUSION AND LEARNING	12. Education and training.	Many established channels slow acting (e.g., university degree programs).
	13. Codification and diffusion of technical knowledge (e.g., screening, interpretation, and validation of R&D results, support for databases).	Usually must await acceptance as valid, useful (e.g., information and knowledge generated through demonstration projects).
	14. Technical standards.	Depends on consensus; compromises among competing interests may lock-in inferior technologies.
	15. Technology/industry extension.	Time consuming, costly to reach large numbers of firms, individuals.
	16. Publicity, persuasion, consumer information.	Competing interests may attenuate, perhaps distort, the message.

[a] For further discussion of the policy classification and entries, see "Energy Innovation from the Bottom Up: Project Background Paper," CSPO/CATF, March 2009, <www.cspo.org/projects/eisbu/ >.

One way to affect technological innovation is by adjusting the Federal budget's direct support for innovation. The Harvard ERD3 group also examines the Federal energy budget, making recommendations on priorities and research funding1. Research is just one part of the broader spectrum of innovation policy and, as discussed below, the ERD3 group examines institutional changes that can accelerate innovation.

A thorough discussion of the innovation policy toolbox does not take place here. For more innovation about the tools of innovation policy, see the online CSPO/CATF background document[1].

History of Innovation (NESTA; NBER; CSPO/CATF):

Every technology is different, but there are often important similarities among the different ways

1 http://www.cspo.org/php/getfile.php?file=231&section=lib

that technologies develop. All of the reports examined historical cases of past innovation, but Mowery, Nelson and Martin's National Endowment for Science, Technology and the Arts (NESTA) report and the National Bureau of Economic Research (NBER) reports have the most explicitly historical focus. Mowery, Nelson and Martin examine historical case studies to offer better analogies for thinking about energy innovation than the often-cited Apollo and Manhattan Projects. Unlike with those famous projects, energy technologies face an exceptional challenge: they must replace existing technologies that currently benefit from incremental innovations that come from being deployed by industry, they must be produced at mass scale rather than limited scale, and they typically do not have effectively unlimited government financial support. Mowery et al. examine several cases of government innovation in the US, highlighting institutional keys to success, such as how competition among government research programs was key to the successful development of the internet. Mowery et al also examine more focused issues, such as the role that openness in intellectual property can play in helping an entire industry advance more quickly, and the need for long term stability within innovation policies.

The NBER cases examine the history of innovation in the life sciences, chemical, agricultural, and information technology industries. In each field, government support of the technology was both large as well as pivotal in enabling development. For example, some researchers examine the development of the information technology industry, and illustrate the powerful effect that government procurement of early computer hardware had on enabling innovation, a theme which was also important in other cases. This theme represents how the federal government can serve as an initial 'first mover' for developing a technology, shouldering the innovation burden while progressively encouraging private industry to innovate on its own. While the different cases discuss different lessons learned about the history of innovation, overall there is a strong emphasis about the importance of using diverse technological pathways and of catalyzing connections between industry, academia and government. While the NBER researchers offer few policy recommendations, they place the government's prospective role in energy innovation within a long tradition of government-influenced technological innovation.

Historical examples can help guide future action, partially grounding them in experience. The Consortium for Science, Policy and Outcomes and Clean Air Task Force (CSPO/CATF) report argues that the US innovation system during the Cold War is an appropriate historical analogy for energy innovation today. The Cold War brought about a massive transformation of military technologies that was proportionate to the perceived threat of the Soviet Union (and, by analogy, perhaps proportionate to the perceived threat of energy security and climate change). Government encouraged continuous and rapid innovation in many different industries, including aerospace, information technology, and chemistry, much of which subsequently transformed civilian life. Energy innovation today, CSPO/CATF argue, requires systematic changes that are on par with changes induced by the Cold War, and such changes may not occur without similar government organization and involvement. Beyond its description of the scale of the energy challenge, the Cold War analogy suggests other useful policies. As summarized in Table 3, the US government's procurement policies, in addition to competition amongst government agencies for development of technologies, were essential parts of an accelerated innovation system.

	POLICY	OBSERVATIONS AND OUTCOMES
I. DIRECT GOVERNMENT FUNDING OF KNOWLEDGE GENERATION	1. R&D contracts with private firms (fully funded or cost shared).	DoD R&D funds flow predominately to engineering design and development of weapons systems. Some contractors also maintain research laboratories that contribute more generic forms of knowledge to the technology base.
	2. R&D contracts and grants with nonprofits.	Universities get more than half of DoD basic research dollars, but basic research comprises only about 2 percent of DoD R&D. Not-for-profit FFRDCs (federally-funded research and development centers) sometimes take on system integration tasks for the services and intelligence agencies.
	3. Intramural R&D in government laboratories.	The armed forces operate dozens of R&D laboratories of their own. Most of these conduct relatively applied work, such as extending academic research or verifying technical methods. DoD engineers and scientists sometimes work directly with contractors or at front-line military bases.
	4. R&D contracts with consortia or collaborations.	Little activity, although Congress gave the Defense Advanced Research Projects Agency oversight of the pioneering R&D consortium, Sematech, at the time it approved cost-shared federal funding.
II. DIRECT OR INDIRECT SUPPORT FOR COMMERCIALIZATION AND PRODUCTION	5. R&D tax credits.	Rarely significant in defense.
	6. Patents.	DoD generally favored open rather than proprietary technologies, as illustrated by its insistence on multiple sourcing of semiconductor devices, which requires technology sharing, and open protocols for wide-area computer networks culminating in the Internet.
	7. Tax credits or production subsidies for firms bringing new technologies to market.	Not applicable, since DoD is the customer.
	8. Tax credits, rebates, or payments for purchasers/users of new technologies.	Not applicable.
	9. Procurement.	Powerful stimulus for dual-use innovations in microelectronics, computer languages, jet engines, avionics (e.g., fly-by-wire), and materials (fiber-reinforced composites).
	10. Demonstration projects.	In DoD's seven-tiered R&D budget classification, category 6.5, "system development and demonstration," accounts for about one-quarter of all R&D, around $20 billion in recent years.
	11. Monetary prizes.	Not applicable (although contractors may view procurement contracts as the reward for successful R&D).
III. DIFFUSION AND LEARNING	12. Education and training.	Defense officials recognized after World War II that national security depended on a highly capable technical workforce, able to innovate as scientists and engineers had innovated during the Manhattan Project. DoD has supported graduate students through fellowships and research and also sponsored programs that place engineering and science faculty in military laboratories for temporary assignments, along with "summer schools" focused on particular problems.
	13. Codification and diffusion of technical knowledge (e.g., screening, interpretation, and validation of R&D results, support for databases).	DoD engineers and scientists participate in and sometimes organize programs to validate and test new technical methods (computerized finite-element analysis, test procedures for fiber-composite materials).
	14. Technical standards.	Defense agencies have been active participants in standards-setting. In some cases, military standards have provided a basis for civilian standards; the Federal Aviation Administration, for example, based its airworthiness requirements for structural design on those of the Air Force.
	15. Technology/industry extension.	DoD sometimes provides technical assistance to suppliers, especially smaller firms, to ensure they use required methods or simply best commercial practices.
	16. Publicity, persuasion, consumer information.	DoD officials and major contractors often (not always) join in statements on, for example, education and training of engineers and scientists.

Table 3. The Cold War Innovation Policy Portfolio

Table 3: Assessing the Cold War Innovation System

Technology specific approaches: (Weiss and Bonvillian; CSPO/CATF; CATF)

Several of the reports focused on the challenges that will confront specific technologies, thus encouraging policies that are suited for each individual technology. The following reports also provide a framework to create technology-specific innovation policies.

Charles Weiss and William Bonvillian's book divides energy technologies into different categories, based on their readiness and the nature of the challenge that these technologies will face when they enter the market. Weiss and Bonvillian, both respected experts on innovation policy with considerable practical experience (Weiss at the World Bank, Bonvillian in Congress), list support tools for each category of technology, including front-end 'technology-push' support, which aids not only research and development but also prototyping and demonstration; and back-end support, which can be based on market incentives, which lower costs, and mandates which require adoption. As described in the next text box, they tailor their policy recommendations based on the role that a technology will play in the energy system (primary or secondary), the maturity of a technology, as well as the potential of technology to disrupt the existing energy system.

Types of Technologies based on readiness, function and challenges to market launch (Weiss and Bonvillian, W&B)

Experimental technologies are possible technologies that are so speculative that R&D is the only suggested policy priority. W&B look at the example of hydrogen fuel cells (which are not close to development but could provide significant benefits to society).

Potentially disruptive technologies, are more near-term technologies which have the potential to change the sociotechnical system. W&B give two examples of disruptive technologies: Light Emitting Diodes (LEDs), which could reshape the electricity market, and solar power technologies, which already exist but have the potential to create new off-grid electricity sources which would alter the nature of the energy system. Because of their potential disruptiveness, existing firms and interest groups may try to prevent the development of the technology, W&B recommend extra front-end support to develop these technologies in small-scale niches, where the technology can be developed sufficiently that the technology can eventually compete on a broader market.

Secondary technologies (uncontested launch): Secondary technologies are components of the larger energy system that can be added individually and without a large-scale reorganization of the energy system. Wind and geothermal technologies are considered to be secondary technologies, because they can be connected to the energy grid easily, thus making them components in the larger system. If secondary technologies are not attempting to replace technologies supported by entrenched political interests, then their potential development is considered to be uncontested. To develop, uncontested technologies still have to be cost-competitive and of high quality. Their development can be speeded through back-end government policies, but these technologies may not need innovation policy support.

Secondary technologies (contested launch): Secondary technologies that will face political or economic opposition from moment of launch are considered to be contested. For example, carbon capture and sequestration technologies for coal plants are an additional component to be added to coal power plants, but the coal industry does not want to utilize these technologies because they provide no market value absent any sort of carbon pricing mechanism. Similarly, the development of new non-corn-based biofuels may be seen as a contested lauch primarily due to the staunch opposition of the corn industry to the creation of biofuels based on non-corn products. Because of their opposition, these technologies may require market and technology-push policy support in order to grow.

Incremental innovations in conservation and end-use efficiency: Beyond energy generating technologies, energy efficiency and conservation are important goals for government support. To examine how incremental innovations can be important, W&B look at the internal combustion engine. To examine how to encourage better building efficiency, W&B look to energy intensity in buildings. For any of this kind of technology, W&B would assess if the technology could develop without policy support, and then would encourage market or technology-push support as necessary.

Improvements in manufacturing technologies and processes: The ability to improve manufacturing technologies and processes is one of the most important ways to make energy technologies cost competitive. W&B review challenges to their development and list policies that may be necessary to develop these technologies.

CSPO/CATF based their discussion of innovation on the results of three workshops, which assembled experts on solar photovoltaics, post-combustion carbon capture for coal plants, and direct air capture of carbon dioxide. None of these workshops identified the need for more research as the major obstacle to further innovation. The largest challenges were consistently found to be specific institutional challenges, including a need for better support of demonstration projects and competition within government.

More than any other report, the Clean Air Task Force (CATF) "Coal without Carbon" report focuses on technology-specific policies, examining policies for clean coal technologies. Relying on authors who are experts in the relevant technologies, the report creates road maps for the development of several groups of technologies that can enable the use of coal without creating carbon dioxide emissions. The technology groups that they examine are listed in the appendix. CATF reviews four technology types: two of them can use coal to create energy in a way that allows carbon dioxide emissions to be easily captured and sequestered; one technology type that can be useful for directly capturing carbon dioxide emissions from coal plants; and a final set of technologies that store captured carbon dioxide underground.

Understanding Innovation at the Systems Level: (Industrial Performance Center, NCEP)

Two reports looked at energy innovation from a systems level perspective.

Richard Lester is professor of nuclear engineering at the Massachusetts Institute of Technology and is the director of the Industrial Performance Center. Lester encourages the development of a diversity of energy innovation approaches that pursue multiple innovation pathways. Just as no one technology can solve the climate problem, Lester argues that no one institution or institutional approach is capable of solving the problem either. Lester thus calls for a "system of innovation institutions" that will pursue innovation at different scales, with different goals, both within government and within private industry. Lester lists six characteristics for a successful system of institutions including:

- Diversity

- Openness/ability to self-correct
- Specialization
- Capacity to conduct large-scale demonstrations
- Capacity to fill the post-demonstration financing gap
- Political viability

In terms of general recommendations, Lester calls for more involvement amongst a broader group of federal agencies so as to create increased competition amongst the federal agencies (45-46).

The National Commission on Energy Policy (NCEP) report explicitly takes a systems-level approach to understanding energy innovation, in particular focusing on model predictions of possible future combinations of different energy technologies. The first half of the report focuses on understanding the impact that individual technologies will have on the overall energy mix. Relying on models from the Pacific Northwest National Lab, NCEP examines the likely energy mix that would result from innovation policies favoring specific energy technologies such as nuclear or renewables, contrasting them to a reference scenario assuming business as usual technological innovation, and an all-of-the-above innovation policy approach. The second half of the report focuses on cross-cutting challenges that apply to each technology, such as siting difficulties and financing.

Focus on institutional connections (ERD3, Brookings)

The institutional dimension of technological change can be more important than research done in a laboratory. Two research groups focus on different but complementary dimensions of institutional connections.

The Harvard ERD3 group has looked at institutional challenges surrounding the management of innovation. In a recent article in Issues in Science and Technology3, ERD3 authors argue that current institutional approaches to energy innovation will not work to enact the magnitude of needed change in energy innovation. The authors review key principles to guide government management of innovation, which include a goal of finding a balance between competition and collaboration amongst research institutions. They also call for establishing better metrics and indicators for evaluating research programs, and for better connecting research programs with programs that try to deploy technologies in the field.

The Brookings report exclusively focused on the creation of energy innovation hubs, which are motivated by the challenge of use-oriented research. In the report, the authors call for the creation of a network of Energy Discovery Innovation Institutes (EDIIs), composed of a few dozen institutes funded at levels around 200 million dollars per year. Key to the EDII approach is bringing together industry, academia, federal national labs employees, investors and entrepreneurs in geographical "clusters," all focused on "cutting edge, applications oriented" research that will tackle specific energy themes. By making the energy hubs focus on local projects and by linking research to private industry needs, the EDIIs are designed to encourage fruitful institutional connections. The focus on local partners and outcomes is thus a way to encourage innovation, not just to attempt to benefit and involve local communities. Since the report's writing, Congress has since authorized three energy innovation hubs, largely embodying many of the ideas expressed in the report (albeit with different funding allotments).

Experience from managing major R&D centers (Clean Air Cool Planet)

The Clean Air Cool Planet report written by Xan Alexander, a former manager in the Defense Advanced Research Projects Agency, goes into detail in designing a framework for how an Advanced Research Projects Agency for energy (ARPA-E) should work. The report includes step by step guidelines for the first year of the ARPA-E and practical advice on the hiring of an ARPA-E director and of program managers. The author highlights that ARPA-E can be valuable, but that other parts of the innovation system, including demonstration and deployment, are both important as well.

The report's greatest insight comes from its view about what the ARPA agencies' goals for a portfolio should be, which highlights the role of transformative research within the larger innovation system. Alexander recommends that 80-85% be focused on “overcoming key technical barriers to industry investment” (51). This can include focusing on specific technologies or it can focus on a system-level implementation. 5-10% of the research budget is recommended for “programs evaluating and creating potential payoffs for immature technologies” (50), which involves research that is similar to what is traditionally known as basic science. The difference with APRA-E’s basic research is its selection of potentially transformative projects, with a focus on developing them later on. The last 5-10% recommendation is for projects “enabling a different future” (51). Such projects could focus on ideas that are currently incapable of competing commercially but that could aid in pursuing a positive societal outcome if conditions were to change.

4. *Summaries of selected reports*

Structuring an Energy Technology Revolution. By Charles Weiss and William Bonvillian

Weiss and Bonvillian’s book shows how to structure an energy revolution in a thorough treatment of how energy technology policy can be structured. The book’s final recommendations do differ from the status quo, with important recommendations.

With respect to ARPA-E, which has now been enacted, Weiss and Bonvillian sketch several institutional gaps the new agency needs to help overcome. Beyond simply doing transformational research, they suggest ARPA-E help motivate industry consortia to mobilize on improving manufacturing processes, and to provide research support to stated industry problems. Also, the authors caution that housing ARPA-E within the DOE presents some risks of drowning the new organization in a culture that historically fails to encourage innovation (163), due either do differing priorities or due to bureaucratic lethargy.

Weiss and Bonvillian also call for the creation of a government sponsored company that would help with financing of energy technology projects. The first major goal for this organization would be demonstration support, to address the gap when commercial scale demonstration projects go unfunded, crippling the development of a new technology. Weiss and Bonvillian recommend a government owned and sponsored corporation, which would be more flexible, more independent from Congressional manipulation, and better able to involve the private sector in its work. Weiss and Bonvillian examine the 1980s Synthetic Fuels Corporation, citing Deutch 2005, and argue that its flexibility might provide a good role model for a new demonstration company, particular as indirect financing incentives that encourage the private sector to do their own demonstration projects can be more effective than government-run projects which may not have private sector buy-in. Weiss and Bonvillian caution that, while the SFC is a good example, any new government corporation needs to be more flexible in responding to a changing price environment than was the SFC, which collapsed when oil prices declined.

In order to address larger gaps in financing for infrastructure, manfucturing scale-up and process innovation, the same government sponsored corporation would also provide financing assistance (171). Weiss and Bonvillian suggest that this corporation should be self-financing.

In addition to creating these three institutions, Weiss and Bonvillian suggested creating an energy industry consortium focused on enhancing manufacturing technologies for energy development, similar to SEMETECH, which was a DARPA funded consortia for the energy industry. They argue that ARPA-E should support this new consortia, either by helping to organize it or by providing focused R&D to aid the proclaimed needs that an industry consortium would identify.

Weiss and Bonvillian also call for enhanced road-mapping, through both the consortia and ARPA-E, and potentially within a new energy council to be created by the President. Further, Weiss and Bonvillian call for better linkage of educational processes and universities with the innovation process, as well as a reorganization of many of the back-end incentives that affect market demand for energy technologies.

Weiss and Bonvillian's basic framework:

Weiss and Bonvillian divide energy technologies into different categories, based on the nature of the challenge that these technologies will face when they enter the market. The support tools for each of these technologies can be addressed by front-end support, which aids not only research and development but also prototyping and demonstration; and by back-end support, which can be based on incentives, which lower costs, and mandates which require adoption. The above discussion details the different categories of technologies that Weiss and Bonvillian discuss.

An Energy Future Transformed: The Advanced Research Projects Agency for Energy (ARPA-E) – R&D Pathways to a Low Carbon Future. By Xan Alexander. Clean Air Cool Planet. Funded by DDCF.

This report, written by a former manager in the Defense Advanced Research Projects Agency, goes into the weeds in designing a framework for how ARPA-like agencies should work. The report has significant value for the management and creation of the ARPA agency, including step by step guidelines for the first year of the ARPA agency and practical advice on the hiring of an ARPA-E director and of program managers.

Given that it is so focused on the procedures of ARPA, it focuses less on general principles of innovation, and as such only has a few recommendations of relevance for our report. The report's greatest insight comes from its view about what the ARPA agencies' goals for a portfolio should be. Alexander recommends that 80-85% of all research is focused on "overcoming key technical barriers to industry investment" (51). This can include focusing on specific technologies or it can focus on a system-level implementation. 5-10% of the research budget is recommended for "programs evaluating and creating potential payoffs for immature technologies" (50), which involves research that is similar to what is traditionally known as basic science. The difference with APRA-E's basic research is its selection of potentially transformative projects, with a focus on developing them later on. The last 5-10% recommendation is for projects “enabling a different future” (51). Such projects could focus on ideas that are currently incapable of competing commercially but that could aid in pursuing a positive societal outcome if conditions were to change. As examples, Alexand discusses technologies that might enable a ten-fold increase in fuel emissions standards or that could diminish industry emissions by 90%, or mitigation programs for CCS.

Also, the report makes an important point that ARPA-like agencies are not equipped to handle demonstration projects (9, 54). Given that development of many full-sized power plant technologies will required to complete the development of many energy technologies, ARPAE as a result has to work with an outside group, such as DOE’s Applied Programs, to ensure that demonstration projects will be a natural continuation of the proposed work.

Other key ideas focus on management, and how the ARPA-E director and program officers should do their jobs.

With respect to intellectual property, Alexander recommends APRA encourage intellectual property (IP) strategies that are acceptable for a target industry (ergo, if an industry is focused on trade secrets, then ensure that research will support that, etc). This is key to ensuring industry buy-in, but IP strategies also need to have a ‘creative tension’ to ensure that public good can best be attained.

The stated mission in the founding legislation for ARPA is to reduce energy imports; reduce GHG emissions; increase efficiency; and ensure American competitiveness. The specific tasks that are assigned are to 1) identif and promote revolutionary advances in basic science; 2) translate scientific discovery into innovation; and 3) to accelerate technological advance.

DARPA is discussed in some detail, showing how they do not do demonstration, nor do they try to solve all problems with a particular technology; rather, they develop a given technology or system to the point where it is reliable enough to be carried on by the next developer. DARPA will often identify potential military applications for particular technologies and then go about trying to make those applications a reality. Oftentimes they will pursue dual use technologies because the cost of developing it (and the labor of developing it) are too great for the DOD to do on their own, and instead require the private industry to see their own profit motivation so that they can do the majority of the work.

Coal without Carbon: an Investment Plan for Federal Action. A Clean Air Task Force report. Funded by DDCF.

More than any other report, the Clean Air Task Force “Coal without Carbon” report focuses on technology-specific policies. Using authors who are experts on the technologies examined, the report creates road maps for the development of several groups of technologies that can enable the use of coal without creating carbon dioxide emissions. The technology groups that they examine are listed in the text box below. CATF reviews four technology types: two of them can use coal to create energy in a way that allows carbon dioxide emissions to be easily captured and sequestered; one technology type that can be useful for directly capturing carbon dioxide emissions from coal plants; and a final set of technologies that store captured carbon dioxide underground.

One of the most significant ideas in the CATF report is the idea of a First Project Demonstration Fund, which can apply to all energy technologies. Demonstrating a new technology is a crucial part of technological development. The massive costs involved in demonstrating a technology at commercial scale can be significant, and the financial and technological risks of failure can be too much for most financial lenders to take on. As a result, obtaining financial capital for a first demonstration project can be difficult, and government support may be needed.

The existing policy tools to fund demonstrations may not be enough. The federal government currently uses federal loan guarantees to enable major technology projects, such as nuclear power plants, to receive financing from banks. These loan guarantees assure banks that the federal government will pay if a particular project goes bankrupt. The CATF report finds two faults with reliance on loan guarantees: first, the process of applying for a loan guarantee can be quite burdensome and may prevent some worthwhile technologies from receiving funding; and second, the federal loan guarantee budget might be overwhelmed with loan guarantees for nuclear and renewable energy, thus leaving insufficient funds for coal-related loan guarantees.

To enable demonstrations, CATF calls for the creation of a First Project Demonstration Fund, which would likely be formed as a Public Private Partnership (PPP). The Fund would use loan guarantees, direct investment, or capital structuring to provide the financing for private companies to carry out demonstration projects. The Fund would need its own technology assessment capabilities to evaluate projects, and would attract its own investors in order to have substantial private capital. As a PPP, the Fund should have members of government as part of its governing board, and should have transparent evaluation criteria.

The Fund would remain sustain its own funding in two ways. First, it would charge a fee for its financial support and, second, it would take become entitled to some share of the profits of the potential technology, either through an equity stake or some other mechanism. This second mechanism potentially would enable the government to make money from the Fund's investments. The CATF report wants to prevent first project funding from replacing private capital, and would seek to have money serve as a 'keystone' to push a technology's development forward.

Text box: Types of technologies examined in the "Coal without Carbon" report

Next Generation Coal Gasification:

Gasification is a process that uses gases and chemicals to remove carbon from coal, using the resulting gas product as an energy source. Dating back to century-old technology, US research into gasification during the 1970s and 1980s has lead to a variety of next generation gasification techniques, none of which are commercially ready. The authors profiled seven different companies that have next generation gasification technologies, identifying obstacles and potential for improvement. To ensure future development of this technology, the authors suggest research pathways for future progress. However, the authors argue that the financing hurdle involved in demonstrating these technologies at a commercial scale needs to be resolved. The First Projects Demonstration Fund, described above, is their recommendation for solving this problem.

Underground Coal Gasification (UCG):

By pumping steam and oxidants into underground coal deposits, UCG can convert many different coal types into synthetic gas through gasification. The resulting gas then can be pumped up to a surface station and used as an energy source. If successful, UCG could be done cheaply and allow for the containment of carbon dioxide emissions. UCG may be particularly useful for countries like India, which have extensive low-quality coal deposits, which normally are not conducive to mining but which might be appropriate for UCG. As recommendations, the UCG author lists research problems that need to be addressed, suggests a US field demonstration program, and suggests investing more human capital in the technology's development.

Post-Combustion Capture of Carbon Dioxide from Coal Plants:

Existing coal power plants are going to emit carbon dioxide. To significantly reduce global CO2 emissions, directly capturing coal plant CO2 emissions through post combustion capture (PCC) may be necessary. The authors review the current state of PCC technologies and list six technologies that could greatly improve PCC capabilities. The authors propose a combination of research, proof of concept efforts, pilot plants as well as full-scale commercial demonstrations.

Deployment of Geological Sequestration:

One of the most publicly scrutinized aspects of carbon capture and sequestration is the ability to safely store carbon dioxide for long periods of time. Geological carbon sequestration techniques would store CO2 in underground saline aquifers which, if successful, could contain CO2 safely. The authors call for research on the sequestration process and its safety and efficacy. They recommend demonstration projects and planning for the transfer of these technologies to developing countries.

Clean Energy Technology Pathways: An Assessment of the Critical Barriers to Achieving a Low-Carbon Energy Future. National Commission on Energy Policy.

Relying on models from the Pacific Northwest National Lab, they examine the likely energy mix that would result from policies favoring specific energy technologies such as nuclear or renewables, to a reference scenario assuming business as usual technological capacity, and an all-of-the-above technology approach. By examining the effect that one energy technology can have upon the potential for other energy technologies, the report provides a richer background for identifying institutional and technical challenges that face a variety of energy technologies.

The National Committee on Energy Policy report examines possible future combinations of different energy technologies and cross-cutting challenges to their development. The development of technologies to combat climate change will depend on many complex institutional and technoligcal issues. No one technology will be able to solve the climate problem on its own: a combination will be needed, and the reliance on or lack of one specific technology can have a strong impact on the development of other technologies and on the overall cost of responding to climate change.

The first half of the report focuses on understanding the impact that individual technologies will have on the overall energy mix. Relying on models from the Pacific Northwest National Lab, they examine the likely energy mix that would result from policies favoring specific energy technologies such as nuclear or renewables, to a reference scenario assuming business as usual technological capacity, and an all-of-the-above technology approach.

In all scenarios, the NCEP authors assumed the existence of a carbon price, implemented through either a direct tax or a carbon emissions program. They also predicted the price needed to achieve 70% electricity reduction by 2050 for the reference technology scenario (where the costs and capabilities of non-carbon technologies develop at current rates) and the All of the above scenario (where comprehensive programs to enhance all of the technologies listed in Table XX are listed. It was estimated that the direct cost for CO2 in the above all case would be much lower than the reference case. By examining the effect that one energy technology can have upon the potential for other energy technologies, the report provides a richer background for identifying institutional and technical challenges that face a variety of energy technologies.

The second half of the report examined cross-cutting challenges to energy technology development. The first challenge is the issue of siting, which involves not only issues of public acceptance but also issues of government authority, federal state interactions, and financial costs. The second theme focused on transmission barriers, which will be a particular problem for renewable energy technologies, which may require both long range transmission capabilities but also conversion capability in a more intelligent grid in order to resolve problems of voltage variability. The third issue was difficulties in financing, especially learning how to create useful information for lenders about technological, market, and regulatory uncertainties. In terms of recommendations on financing, the NCEP authors suggest enhancing DOE's federal loan program, implementing a new public private investment fund, and implementing new styles of 'PACE' loans, or property assessed clean energy loans. The last cross cutting challenge is the energy industry's workforce, which lacks sufficient training capacity and has many members who are on the verge of retirement.

Contained in the appendix of their report, NCEP gives detailed analysis of potential challenges and solutions for CCS, Bioenergy, Advanced Nuclear Power, Wind and Solar, and Building and Transport Efficiency. These reports were in part based on NCEP workshops that brought in experts on the topics as well as from a review of the energy policy literature on challenges to each specific technology's development. NCEP reviewed several policy tools for dealing with this challenge including incentives, mandates, and government investment.

America's Energy Innovation Problem (and How to Fix it). By Richard Lester

Industrial Performance Center, Massachusetts Institute of Technology. Funded by DDCF

Written by Richard Lester, the director of the Industrial Performance Center at the Massachusetts Institute of Technology, this report examines the scale of innovation necessary in order to combat climate change, and provides a variety of recommendations about how to address the problem.

The first half of the report examines the general political context surrounding energy innovation policy. Lester thinks that Obama's emphasis on funding energy technologies, including more than 80 billion dollars in stimulus funding, should be recognized at the global level by participants at Copenhagen. Lester argues that current policy proposals will be insufficient to meet President Obama's goal of an 80% reduction in US CO2 emissions by 2050.

As an alternative, Lester argues that energy policy needs to first address the massive scale of the problem. Unlike in other past government programs like the Manhattan or Apollo projects, the government is not the main consumer of energy technologies, which makes the need to reduce technology costs important.

Lester examines 10 'inconvenient truths' about energy innovation, addressing several themes including: the need for fast action; the massive scale of the problem; technology breakthroughs will not be available to act in the short timeframe needed for action; breakthroughs in energy storage, biofuels and solar technologies may play an important role in the second half of the 21st century; accelerating the rate of decarbonization of the economy will require a greater emphasis on electricity, as vehicles will likely need to be powered by low CO2 emitting electricity sources; removing nuclear or post combustion capture of CO2 for coal plants would make 80% reductions by 2050 impossible; the public does not strongly support action on climate change; the potential for energy job creation may be oversold; from the view of innovation studies, energy technologies are more difficult than information technology; the international dimension of energy technology is important, with competition and collaboration each serving important roles.

Lester's analysis about the international dimension of energy systems change is revealing, especially with its focus on China. Lester argued that technology transfer to China could yield benefits to the US in terms of cheaper costs. Second, China might be able to more quickly engage of 'first of its kind' development and demonstration activities from which US firms might be able to greatly benefit. Lastly, Lester notes that many US companies are now doing research and manufacturing abroad in China. Lester suggests that this might lead to a loss of US jobs. This type of competition is essential in order to reach the scale of innovation needed to protect against climate change.

Lester examines the different tools that the government uses to encourage innovation, through either market pull and technology push approaches. With respect to climate change, the government has a role to play because low CO2 technologies are not likely to be adopted and developed until they are cost effective. While market incentives are important, Lester argues that a price on carbon, in part because it will likely be established through political compromises that hedge its effectiveness, will not be enough to encourage innovation.

As a result of this, Lester advocates for stronger government roles at both the early R&D level (a role in which everyone acknowledges the government should be) but also at the intermediate and late stages of the development process. Lester acknowledges that many past government demonstration projects have failed to meet their goals for success, but he argues that the potential benefit to the public justifies the government's involvement in late state development. This use of the public good (p.33) as a justification for the public's involvement in R&D is a key principle in our synthesis report.

To avoid the failures of the past, Lester examines some of the key reasons why technology demonstration projects have failed in the past. Citing Cohen and Noll 1991, he cites: a tendency by DOE to underestimate costs; failure to anticipate future variability in fuel costs; congressional interference; a lack of consistent policy, in part as a result of electoral changes.

Lester cites a recent issues article by Ogden, Podesta and Deutch to say that government agencies are not well equipped to meet this kind of demonstration challenge. Among several possible options, Lester cites the Ogden et al proposal to use an energy technology company that would be a quasi-public organization devoted to financing demonstration projects. He also cites recent congressional legislation calling for a clean energy deployment administration and for a demonstration funding company for carbon capture and sequestration.

In terms of creating institutions that can handle the intermediate stage development challenges, Lester suggests the use of a hybrid public private institution or the use of regulations to give a private corporation enhanced abilities to pursue innovation.

Lastly, just as no one technology can solve the climate problem, Lester argues that no one institution is capable of solving the problem either. Lester thus calls for a "system of innovation institutions" that will pursue innovation at different scales, within government and within private industry as well. Lester lists 6 characteristics for a successful system of institutions including:

- Diversity
- Openness/ability to self-correct
- Specialization
- Capacity to conduct large-scale demonstrations
- Capacity to fill the post-demonstration financing gap
- Political viability

In terms of general recommendations, Lester calls for more involvement amongst a broader group of federal agencies so as to create increased competition amongst the federal agencies (45-46). Further, he calls for enhancing local and state involvement in energy innovation, discussing the notion of energy innovation hubs that were also discussed in the Brookings report.

Energy Discovery Innovation Institutes: a Step Toward America's Energy Sustainability. Brookings Institution.

Metropolitan Policy Program. James Duderstadt, Gary Was, Robert McGrath, Mark Muro, Michael Corradini, Linda atehi, Ric Shandgraw, and Andrew Sarzynski

To meet the challenges of economic recovery, energy security and climate change, the authors call for the creation of a network of Energy Discovery Innovation Institutes (EDIIs), composed of a few dozen institutes funded at levels around 200 million dollars per year. Key to the EDII approach is bringing together industry, academia, federal national labs employees, investors and entrepreneurs in geographical "clusters," all focused on "cutting edge, applications oriented" research that will tackle specific energy themes. The report examines the motivation for EDII institutes, the new research paradigm that it represents, and how the concept could be deployed as part of a federal network. Since the report's writing, Congress has since authorized three energy innovation hubs, largely articulating many of the ideas expressed in the report.

The authors argue that the scale of energy transformation need to accomplish national goals requires a far greater level of effort than the federal government is now committing. Specifically, they recommend a 20-30 billion dollar federal investment in energy research, with 6 billion of that amount being spent on EDIIs. The authors argue for the need for government support of energy research and development primarily because private industry is not likely to achieve the necessary level of investment in energy innovation. The authors provide several reasons why private investment alone will be insufficient, with factors such as technological and market uncertainty, the inability for companies' to capture the benefits of their research, corporate biases toward applied R&D all precluding companies from making the types of R&D investments needed (16-23). Further, the authors suggest that potential prices on carbon will not be high enough to encourage energy innovation alone (17). In order to attain the public good benefits of energy R&D, the government needs to provide the additional financing. The problem, however, is not exclusively one of research funding: they argue that "several problems exist with the current federal energy research paradigm" (30). The authors are critical of DOE, arguing that their current research paradigm is too focused on fossil fuels research focusing on particular problems and technologies as opposed to broad and integrative work that addresses the creation, use and transmission of electicity in a sustainable and systems-level way. Given the DOE's focus on the National Labs system, the authors argue that the NLs are ill suited for the kinds of energy innovation needed because they lack the mission and capabilities to create and maintain energy infrastructure, and because the NLs do not create human capital, which is essential for creating the workforce needed for lasting energy innovation (30).

As guidelines for government intervention in the energy innovation system, the authors propose four principles. First, they do believe that the government should set a price on carbon, which will greatly encourage innovation. Second, government should subsidize research and development, especially focused on 1) high risk, high impact research; 2) strategic research to overcome particular technological barriers; and 3) when appropriate, funding demonstration projects for new technologies (p. 12).

As part of a new federal research paradigm, the authors call for the creation of energy discovery innovation institutes. The cluster of networks would be created outside of the Department of Energy, thus better allowing for the creation of a new research culture. The authors provide six guidelines for how the EDIIs should be made:

1. The EDIIs need to be structured around particular energy themes, such as carbon capture and sequestration, renewable energy, or biofuels. A focus helps provide tractability.
2. The EDIIs need to create partnerships with a variety of actors, each of which will serve valuable roles. Industry is needed to help provide problems, development of technologies, and to provide valuable market knowledge. Research universities provide faculty, staff and students can further provide frameworks for technology transfer, intellectual propery rights and financial management, and for education. States and local governments can provide resources, in addition to National Labs providing both talent and infrastructural support. Lastly, entrepreneurs and the investment community are needed to help understand how to create new businesses to develop work from the hubs, as well as to license technological developments.
3. The EDIIs need to serve as hubs, in the sense that they must genuinely encourage collaboration. The authors describe possible exchanges of participants, regular meetings, and shared cyberinfrastucture as

ways in which discussion can occur. The geographical proximity of different actors will also aid in enhancing innovation.

4. There should be a strategic goal of commercializing all developments. The involvement of private industry to provide a use-inspired focus to research will be critical.

5. The institutional structure should encourage transfer of new technologies into the marketplace. The authors discuss several possible models for issues such as intellectual property rights, and argue that overmanagement of such issues should be avoided and if possible be worked out in advance so as not to hinder collaboration.

6. An express goal for the project should be to encourage regional economic development, in large part as a means to ensure that research will be useful and practical. This will have an additional benefit of creating jobs that will be difficult to outsource because they will be regionally oriented in focus.

7. The EDIIs need to expand knowledge and train a large number of future workers. The ability for educational training is essential as massive change to the energy system may be impossible without a greatly expanded workforce.

8. The EDIIs need to expand the scope of possible activities, such as by enabling cutting edge work that neither private industry, academia, nor government could achieve individually on their own.

The authors show how some of the EDII concept ideas are already being implanted both in foreign countries and within different parts of the United States (Sections VIII and IX). They also argue that other proposed programs such as ARPA-E, an In-Q-Tel for energy, or the Energy Frontier Research Centers will not be of sufficient scope to transform the energy system. Of interest, the authors argue that the EFRCs may be limited due to DOE's institutional fragmentation and lack of purpose. They argue that ARPA E previously proposed (and now actualized) levels of funding would be insufficient to enact necessary change, and its range of projects would be too narrow.

The later sections of the report give guidelines about how the EDIIs should be created and managed. They propose three types of EDIIs, one university based, one based in National Labs, and several satellite EDIIs, scoped to and funded at levels similar to the Energy Frontier Research Center concepts. The network should be funded through an interagency effort, and should be kept separate from the national labs system (56). They advocate for a phased in solicitation and creation cycle for the EDIIs, so as to allow for later EDIIs to learn from the experiences of early EDIIs. In terms of management structure, they advocate that each hub should have an institutional and management structure that is independent from its host institution, be it university or national lab. They should have external advisory boards including representatives from industry, state and local government, nonprofits, entrepreneurs and investment. The authors hope that new and potentially valuable research organizational structures may be created as a result of the EDII proposal process (59).

Lastly, having previously said that the Apollo and Manhattan projects are imperfect models for the current energy challenge, the authors instead look to an older analogy. As the best analogy for the EDII system, they point to the 1887 Hatch amendment, which created a series of agricultural experiment stations throughout that country which involved partnerships with universities, industry, and state and local governments. The scope and scale of this change parallels the current energy challenge, and the success of the agricultural experiment stations as hubs for regional development highlights the potential for the EDII framework.

Various publications from Energy Research, Development, Demonstration and Deployment (ERD3) group at Harvard University. Energy Technology Innovation Policy group

As part of the Harvard Energy Technology and Innovation Policy group, the Energy Research, Development, Demonstration and Deployment (ERD3) Project has published several papers in energy innovation technology in the past year. The following articles represent some of the key ideas, but are mentioned while recognizing that ERD3 will be publishing new research soon.

1. Narayanamurti, V., Anadon, L.D., and Sagar, A.D. "Transforming Energy Innovation." Issues in Science & Technology, Fall 2009, pp. 57–64

After arguing that current institutional approaches to energy innovation will not work to enact the magnitude of needed change in energy innovation, the authors review key principles to guide government management of innovation. They cite Ogden, Deutch and Podesta's argument in favor of creating an Energy Technology Corporation to choose and fund commercial-scale demonstration projects. They also cite the Brookings' institutions report on energy discovery innovation institutes. There are several reasons why energy innovation is complex:

-Limited and uncertain market signals create need for help.

-Large scale of coal or nuclear necessitates long time frames.

-There is a lot of variety amongst energy technologies

-Competition with a locked-in market system.

The principles that the research group cites include:

"A clearly-defined mission that is informed by, and linked to, a larger systems perspective"

"Leadership that has proven scientific and managerial excellence, has a vision of the role of the institution or enterprise in the overall energy system, and is capable of acting as an integrator of processes"

"Entrepreneurial culture that promotes competition but also collaboration and interaction among researchers"

"Management procedures and organizational structures that promote independence, and yet give primacy to performance accountability"

"Stable and predictable funding that allows a thorogh and sustained exploration of technical opportunities and system-integration questions"

In a text box, the authors discuss the National Labs, and note that the mission of the labs to aid energy innovation is not optimally in line with their organizational structure.

2. Anadon, Laura, Matthew Bunn, Charles Jones, and Venkatesh Narayanamurti, “U.S. Public Energy Innovation Institutions and Mechanisms: Status & Deficiencies.” Cambridge, Mass.: Policy Memo from the Science, Technology and Public Policy Program, Belfer Center for Science and International Affairs, Harvard Kennedy School, 14 January 2010

In this brief policy brief, the authors recommend:

a. Collecting metrics and indicators for assessing progress.

b. Aligning RD&D and deployment programs. This notes the disconnect between Congress, which establishes deployment strategies, and the DOE, which establishes RD&D strategies.

c. Improving the structure and management of energy innovation institutions

They discuss institutional challenges for the National Lab, the proposed energy hub concept, and for ARPA E. They also strongly advocate for the suggestion of an Energy Technology Corporation (Odgen, Podesta and Deutch).

3. Laura Diaz Anadon, Kelly Sims Gallagher, Matt hew Bunn, and Charles Jones, Tackling U.S. Energy Challenges and Opportunities: Preliminary Policy Recommendations for Enhancing Energy Innovation in the United States, (Cambridge, Mass: Energy Research, Development, Demonstration & Deployment Policy Project, Energy Technology Innovation Policy Group, Harvard University, February 2009)

In addition to the issues raised above, they discuss the budget amounts for different energy technologies.